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Comparison of Artificial and Natural Selection in American Pima Cotton under Different Environments[1]

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ABSTRACT

The effectiveness of artificial vs. natural selection for improving lint yield and other traits in American Pima cotton (*Gossypium barbadense* L.) when grown in predictable environments was evaluated at low and high elevations. A cross was made between 'Pima S-3,' adapted to the less fertile soils at high elevations, and 'Pima S-4,' adapted to low elevations and to the more fertile soils at high elevations. F_2 through F_8 populations from this cross were grown at one low-elevation and two high-elevation locations. These populations were subjected to natural selection by bulking all plants to form the next generation, or to artificial selection by bulking only selected plants to form the next generation. Phenotypic differences for lint yield, plant height, and fruiting height among plants within the succeeding generations were greatest at Phoenix, next greatest at Safford, and least at El Paso. Therefore, selection of genotypically productive plants was most effective at Phoenix, somewhat less effective at Safford, and the least effective at El Paso.

Artificial- vs. natural-selection cycles 0 (F_2), 3, and 6 from each of the three locations were evaluated at all locations. The populations developed by artificial selection at a given location tended to yield more than naturally selected populations at that location, with the greatest advantage at Phoenix, next greatest at Safford, and no advantage at El Paso. Likewise, among locations, natural selection had the most influence on yield potential at Phoenix. In some years, the artificially selected populations from one location tended to yield well at the other locations, but no population yielded well at all three locations in both years. Selection for improvement of traits such as lint yield in the environment where the selected population will be utilized was effective. However, if the Pima improvement program were confined to one location, Phoenix appears to be the best of the three locations. At Phoenix, the magnified expression of productivity, and fruiting- and plant-height differences would permit the selection of genotypes that would be productive at each elevation of the American Pima Belt.

Additional index words: *Gossypium barbadense* L., Correlations, Breeding sites, Cultivar improvement, Genotype-environment interactions, Morphological traits, Fiber properties.

THE Pima cotton (*Gossypium barbadense* L.) improvement program includes breeding efforts at low elevations (up to 450 m) and high elevations (750 m and above) to develop cultivars adapted to those predictable environments as related to elevation (1). During the fruiting period of the crop, the lower elevations are characterized by high day and night temperatures, 43+ C and 27+ C, respectively. At the higher elevations, day temperatures are relatively high (38± C) and night temperatures are moderate (21± C). Adaptation of a cultivar to low elevations depends largely upon its tolerance to high night temperatures during fruiting. Excessive boll shedding commonly occurs in those cultivars lacking heat tolerance. However, heat tolerance is not a requirement at elevations above 750 m.

Our experience indicates that genetically superior strains developed at low elevations also are superior in yield at high elevations except under conditions when bolls are set so low on the plant and so rapidly that plant growth is limited and plant structure is inadequate for maximum yield (2). In contrast, we have not found that productive strains developed at high elevations are adapted for low elevations. Presumably, strains developed at high elevations are not subjected to high-temperature selection pressures during development and thus lack the heat tolerance which is essential for adaptation at low elevations.

The objective of this study was to evaluate the effectiveness of natural- vs. artificial-selection pressures in our American Pima cotton cultivar development programs at three locations with predictably different environments.

MATERIALS AND METHODS

A cross was made between two cultivars which differed in adaptation to environments in which Pima cotton is grown. One parent, 'Pima S-4,' matures early, has tolerance to high night temperatures, and is adapted to low elevations where it begins fruiting low on the plant and continues fruiting throughout the growing season (2). It also is adapted at high elevations on the more fertile soils where plant growth is adequate for maximum yield. The other parent, 'Pima S-3,' is adapted only at the higher elevations on soils of below average fertility; where, compared to Pima S-4, it begins fruiting at a higher, more desirable height on the plant and produces plant growth more suitable for maximum yield. Pima S-3 tends to be vegetative under conditions that favor Pima S-4 at high elevations. Pima S-3 is unadapted at low elevations because it lacks the heat tolerance required to set bolls in early- and mid-season; and it matures late, is unproductive, and has excessive plant growth.

In 1969, F_2 (Cycle $_0$ or C_0) seed were planted in two areas of about 0.04 ha each (approximately 1,300 plants) at Phoenix, Ariz. (elevation 350 m), Safford, Ariz. (885 m), and El Paso, Texas (1,200 m). In one area at each location all plants were harvested; thus, providing natural selection in that block. In the other area, only the more productive plants were harvested and bulked; thus, providing artificial selection in the second

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Table 1. Lint yield of Pima S-3 vs. Pima S-4 cotton at three locations for 2 years.

	Phoenix		Safford		El Paso	
Cultivar	1976	1977	1976	1977	1976	1977
	kg/ha					
Pima S-3	782 b*	543 b	685 a	895 a	614 a	905 a
Pima S-4	1,161 a	784 a	719 a	977 a	470 a	774 b
	%					
Pima S-3/Pima S-4	67	69	95	92	131	117

* Means in a column followed by the same letter were not significantly different at the 0.05 level of probability.

block. The natural vs. artificial selection of the respective areas were continued from year to year through the C_8 (F_8). The number of plants selected in the artificial-selection experiments ranged from 48 to 77 at Phoenix, 55 to 120 at Safford, and 61 to 93 at El Paso, depending upon growing conditions. Some environments magnified phenotypic expression, and fewer selections were required to assure inclusion of the more productive plants. Feaster and Turcotte made the selections at Phoenix and Safford, and Young made the selections at El Paso. Remnant seed from each area for each year-location were held in reserve. In 1975, a portion of the reserve C_0 seed and seed from natural- vs. artificial-selection C_3 and C_6 populations were increased at the location where they were developed. This seed, advanced one generation and exposed to an additional cycle of natural selection, was used to plant performance tests. For convenience in discussion, the populations are designated C_0, C_3 and C_6, the cycle designations prior to the cycle of seed increase for the performance tests. Tests included the above five populations from each location (15 populations) and the original parents, Pima S-3 and Pima S-4. The tests were grown at Phoenix, Safford, and El Paso in 1976 and 1977 in a randomized complete block design with six replications. Plots were four rows 1 m apart and ranged in length from 10 to 20 m, with data collected from the center two rows.

The following characteristics were measured: *lint yield* (kg/ha); *fruiting height* (height in cm at which the bulk of the bolls began to set); *plant height* (cm); *boll size* (g/boll); *percent lint* (percentage of seed-cotton that is lint); *fiber length* (2.5% span length in mm); *fiber strength* (mN/tex, measured on a stelometer with jaws 3.18 mm apart); *fiber fineness* (micronaire units, measured on the micronaire; higher readings indicate coarser fiber). Linear phenotypic correlations of fruiting and plant height with yield were based on the 15 populations grown at the three locations.

RESULTS AND DISCUSSION

The relative lint yields of Pima S-3 and Pima S-4 were used to characterize the test environments in this study (Table 1). At the low elevation (Phoenix), Pima S-4 had significantly higher yields than Pima S-3 in both years. At the higher elevations (Safford and El Paso), the yields of Pima S-3 and Pima S-4 were not significantly different in three of the four tests. Differences between years were observed at each location; however, the two cultivars performed as expected relativ to one another from long-term comparisons (2). In 1976 at Phoenix, temperatures during the fruiting period were lower than normal and more favorable for greater boll set. Genotypes which began fruiting lowest on the plant yielded less than expected over the entire season because bolls set so low on the plant that growth was restricted and flowering ceased before the end of the normal fruiting period. The 1977 fruiting season was more typical at Phoenix. In 1976 at Safford, the test followed alfalfa, and vegetative growth was excessive. Growth in 1977 was more typical for that elevation. At El Paso, the plants were grown on a less fertile soil in 1976 than in 1977. Thus, yields were lower in 1976.

Table 2. Percentage change in lint yield, fruiting height, and plant height for four cotton populations developed at three locations by natural vs. artificial selection for six cycles and measured at the respective location for 2 years.

		Phoenix		Safford		El Paso	
Selection	Selection cycle	1976	1977	1976	1977	1976	1977
		Percentage change from C_0					
		Lint yield					
Natural	C_3	6	33	14	6	18	6
	C_6	18	50	9	4	8	15
Artificial	C_3	17	60	18	8	14	13
	C_6	32	115	45	20	19	11
L.S.D. (0.05)*		13	26	20	10	27	10
		Fruiting height					
Natural	C_3	−21	−7	−6	−1	3	42
	C_6	−26	−18	−4	−4	6	26
Artificial	C_3	−35	−30	−15	−13	10	33
	C_6	−68	−60	−33	−39	10	31
L.S.D. (0.05)		23	19	26	30	17	19
		Plant height					
Natural	C_3	−6	8	−4	−5	16	22
	C_6	−6	0	0	−4	16	26
Artificial	C_3	−13	−7	−2	−4	18	30
	C_6	−27	−28	−10	−25	10	17
L.S.D. (0.05)		7	14	7	10	8	9

* The L.S.D. (0.05) is appropriate for comparing the three- and six-cycle periods, the two selection pressures, or any cycle-selection combination.

The effectiveness of natural selection vs. artificial selection for lint yield, fruiting height, and plant height was expressed as percentage change in C_3 and C_6 from C_0 (Table 2). These values show the total change from C_0 to C_3 and from C_0 to C_6. Rates of change per cycle can be calculated from the values in Table 2 by dividing the total change by the number of cycles involved. For example, the rate of change for lint yield at Phoenix in 1977 under artificial selection from C_0 to C_3 was 20% (60/3) per cycle, and from C_0 to C_6 it was 19.2% (115/6) per cycle. However, statistical comparisons of these two rates of change are invalid due to different number of cycles. Statistical significance can be established only when comparing rates of change involving the same number of cycles.

The populations developed at Phoenix and tested there in 1976 showed significant increases in yield from the C_0 to the C_6 under natural selection and to the C_3 and C_6 under artificial selection (Table 2). In 1977 (the more typical year for Phoenix), the advanced cycles developed under both types of selection were significantly more productive than the C_0. At Phoenix, C_0 was generally unproductive with excessive vegetative growth and with the majority of plants showing a lack of heat tolerance typical of the unadapted parent, Pima S-3. During development, the segregates with heat tolerance were more productive and contributed a higher proportion of seed in the bulk harvest. Artificial selection by bulking selected plants resulted in even greater selection for the more heat-tolerant, productive segregates than did natural selection. In three of the four possible comparisons between natural- vs. artificial-selection populations at Phoenix, yields of artificial-selection populations were significantly higher than yields of corresponding cycles under natural selection. The fourth comparison approached

Table 3. Linear phenotypic correlations (r) of lint yield with fruiting height and plant height for 15 cotton populations under six environments.

Year	Location	Lint yield vs. Fruiting height	Lint yield vs. Plant height
1976	Phoenix	−0.79**	−0.73**
	Safford	−0.84**	−0.82**
	El Paso	−0.13	−0.23
1977	Phoenix	−0.95**	−0.91**
	Safford	−0.78**	−0.66**
	El Paso	0.35	0.38

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

significance at the 0.05 probability level. Perhaps yield advances would have been even greater if the competitive effects of relatively unproductive, taller plants had not been so pronounced.

At Safford, only artificial selection for six cycles resulted in a significant increase in yield over C_0 for either year (Table 2).

At El Paso, none of the four advanced populations was significantly more productive than the C_0 in 1976 (Table 2). In the 1977 test, three of the four advanced populations were more productive than C_0, but there were no significant differences between natural vs. artificial selection for either C_3 or C_6.

At low elevations, the yield of Pima cotton is highly correlated with fruiting height response (1). The most productive plants set bolls relatively low on the plant. Fruiting height at Phoenix was lower with each advancing cycle from both types of selection, though differences were not significant in 1977 between C_3 and C_6 developed by natural selection (Table 2). Bolls were set lowest on the artificially selected C_6 population which yielded the most lint. In three of the four possible comparisons between natural vs. artificial selection at Phoenix, fruiting height was significantly lower in the artificially selected populations. The fourth comparison showed the same trend.

At Safford, the fruiting height trend was similar to that observed at Phoenix, except that only artificial selection for six cycles resulted in significantly lower fruiting height than for C_0 in either year (Table 2).

At El Paso, fruiting height response showed no significant differences in 1976 (Table 2). All advanced cycles fruited higher than C_0 in 1977, but no trends were evident among generations.

Under artificial selection, plants tended to become significantly shorter with advancing cycles at Phoenix and Safford (Table 2). C_6 plants were significantly shorter than C_0 plants at both locations in both years; the C_3 plants were significantly shorter in 1976 at Phoenix. At El Paso, all four advanced populations were significantly taller than C_0 in both years, but no significant trends were evident among cycles or between types of selection.

Fruiting height and plant height were negatively and significantly correlated with lint yield at Phoenix and Safford but not at El Paso (Table 3). The highest correlations of fruiting and plant heights with yield were obtained at Phoenix in 1977. Growth at El Paso typically was restricted in both years, and all populations differed little in fruiting height and plant height. Lower fruiting on the plant and shorter plants were

Table 4. Performances under six environments of three cotton populations each developed by artificial selection through C_6 at Phoenix, Safford, and El Paso.

Population source	Phoenix 1976	Phoenix 1977	Safford 1976	Safford 1977	El Paso 1976	El Paso 1977
	Lint yield (kg/ha)					
Phoenix	1,078 ab*	1,035 a	1,047 a	1,126 b	578 b	838 b
Safford	1,193 a	877 b	1,004 a	1,349 a	716 a	1,055 a
El Paso	952 b	572 c	764 b	1,084 b	724 a	1,013 a
	Fruiting height (cm)					
Phoenix	20 c	25 b	20 b	13 b	14 b	17 b
Safford	33 b	37 b	36 ab	19 b	17 ab	18 b
El Paso	53 a	66 a	48 a	36 a	21 a	23 a
	Plant height (cm)					
Phoenix	120 c	133 b	108 b	83 b	57 c	50 b
Safford	136 b	154 b	124 a	90 b	66 b	55 b
El Paso	164 a	199 a	137 a	113 a	72 a	67 a
	Boll size (g)					
Phoenix	3.39 b	3.06 a	4.07 a	3.54 a	3.48 a	3.07 b
Safford	3.59 a	2.92 ab	4.09 a	3.59 a	3.67 a	3.38 a
El Paso	3.57 a	2.81 b	4.01 a	3.68 a	3.64 a	3.14 ab
	% Lint					
Phoenix	34.3 b	32.2 a	34.6 b	34.5 b	36.2 a	37.1 b
Safford	34.9 a	32.8 a	35.7 a	36.5 a	37.8 a	38.8 a
El Paso	32.6 c	30.0 b	34.2 b	34.5 b	36.4 a	37.3 b
	2.5% span fiber length (mm)					
Phoenix	33.5 c	35.1 b	34.5 b	34.3 b	34.3 b	33.3 b
Safford	34.5 b	35.1 b	34.8 b	34.8 b	34.3 b	33.8 b
El Paso	36.3 a	36.3 a	36.6 a	36.3 a	36.3 a	35.6 a
	T_1 fiber strength (mN/tex)					
Phoenix	295 a	301 a	282 a	291 a	286 a	284 a
Safford	291 a	284 b	274 b	291 a	275 a	280 ab
El Paso	283 b	286 b	265 c	286 a	278 a	273 b
	Micronaire (units)					
Phoenix	4.02 a	3.70 b	3.76 b	3.64 b	3.78 b	3.66 b
Safford	4.10 a	3.87 a	3.92 a	3.82 a	4.11 a	3.91 a
El Paso	3.89 b	3.50 c	3.64 c	3.59 b	3.76 b	3.74 b

* Means in a column for each trait followed by the same letter were not significantly different at the 0.05 level of probability.

associated with higher lint yields at Phoenix and Safford, but not at El Paso.

Of the four advanced populations in this study, the C_6 from artificial selection theoretically should be the most productive population from each location. Table 4 shows the performances for eight traits of the artificially selected C_6 populations developed at each location when grown at that and the other two locations for 2 years.

At Phoenix, the Phoenix and Safford source populations were not significantly different in lint yield in 1976, but the Phoenix source population was significantly more productive in 1977 (Table 4). The relatively high yield at Phoenix for the Safford source population in 1976 probably was due to the cooler-than-normal fruiting period. Under those conditions, the Phoenix source population ceased flowering before the end of the normal fruiting period, but the Safford source, which began fruiting higher on the plant, continued fruiting. At Safford in 1976, the Phoenix and Safford source populations did not differ significantly in yield. In that environment, plant growth was taller than average for the location. In 1977, the

Safford source population was significantly more productive than either the Phoenix or El Paso source populations. At El Paso, yields of the Safford and El Paso source populations were not significantly different, and both were significantly more productive than the Phoenix source population. The C_6 population developed by artificial selection at a given location tended to yield higher at that location. In some years, it tended to yield well at the other locations, but no population yielded well at all three locations both years.

The populations developed at Phoenix had significantly lower fruiting height and plant height than those developed at El Paso regardless of test environment (Table 4). The Safford source population gave the next lowest fruiting and plant heights, though its fruiting height was significantly different from the fruiting height of the Phoenix population in only one instance (Phoenix, 1976) and its plant heights in three of the six comparisons (all three locations in 1976). The El Paso source population gave the highest numerical values for both traits in each test. It was significantly different from the Safford population in fruiting height in four of the six comparisons and in plant height in five of the six comparisons. The Phoenix source plants fruited too low on the plant and were too short for maximum yield on the less fertile soils at high elevations because of restricted numbers of boll positions. The El Paso source grown at El Paso was tall enough to provide a good vegetative-fruiting balance for optimum yield. The El Paso source population grown at Phoenix was very tall and unproductive.

Boll size did not appear to be closely associated with population source. Trends in boll size at Phoenix in 1976 were reversed in 1977 (Table 4). No significant differences were detected at Safford in either year or at El Paso in 1976. At El Paso in 1977, the Safford population had significantly larger bolls than that from Phoenix, but the El Paso population was not different from the other two sources. The Safford population had significantly higher lint percentages than did the Phoenix source in four of the six tests, and it was significantly higher than the El Paso population in five of six comparisons. The El Paso population had significantly longer fiber than the other populations in all tests. Only at Phoenix in 1976 did the Safford population appear to have longer fiber than the Phoenix population. The Phoenix source population had stronger fiber than the Safford population in two of the six comparisons and than the El Paso population in four of the six. The Safford population showed stronger fiber than that from the El Paso population in two of six tests. The Safford population had significantly coarser fiber in five of the six comparisons. The Phoenix population had coarser fiber than El Paso in three of six tests.

During the development of the populations shown in Table 2, phenotypic differences for production among plants within the succeeding populations were greatest at Phoenix, next greatest at Safford, and least at El Paso. Therefore, selection of genotypically productive plants was most effective at Phoenix, somewhat less effective at Safford, and least effective at El Paso. The high correlations of lint yield with plant height and with fruiting height at Phoenix and Safford provided additional criteria for identifying productiveness of single plants at these locations. Identification of superior genotypes was difficult at high elevations because genotypic differences relating to yield were not expressed as obviously by phenotype. This suggests that, at high elevations, bulking during early segregating generations followed by selections designed to obtain relatively pure lines might be an effective breeding technique requiring minimum effort. Quisenberry et al. (3) have reported that natural selection in a bulked hybrid population of Upland cotton (*G. hirsutum* L.) increased yield under semi-arid conditions on the Texas High Plains. Quisenberry et al. (4) also found that selecting in a less stressed environment was more effective due to the lack of genotype-environment interactions.

Our results indicate that selection for improvement of traits such as lint yield in the environment where the selected population will be utilized was effective. However, if the Pima improvement program were to be confined to one location, Phoenix appears to be the best of the three locations. At Phoenix, genotypes that perform well at each elevation can be identified readily on the basis of productivity, fruiting height, and plant height. The productive segregates that begin fruiting relatively low on the plant should be utilized to develop cultivars for the low elevations and the taller segregates that begin fruiting higher on the plant to develop cultivars for the high elevations. The genotypes that begin fruiting relatively low on the plant have heat tolerance required for adaptability at low elevations, and the genotypes that begin fruiting higher on the plant provide an efficient fruiting-to-vegetative ratio for high elevation. At Safford and El Paso, fruiting and plant heights within segregating populations differ less than at Phoenix, and it is more difficult to identify plant types adapted to the various environments of the American Pima Belt. Also, at Safford and El Paso, there is little, if any, environmental pressure for selecting heat tolerant genotypes.

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