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Inheritance of fiber quality and lint yield in a chemically mutated population of cotton

Andy D. Herring¹, Dick L. Auld,^{2,*} M. Dean Ethridge³, Eric F. Hequet³, E. Bechere², Cary J. Green² & Roy G. Cantrell⁴

¹Department of Animal Science, Texas A&M University, College Station, TX 77843; ²Department of Plant and Soil Science, Texas Tech University, Lubbock, TX 79409; ³Textile Research Center, Texas Tech University, Lubbock, TX 79409; ⁴Cotton Incorporated, Carry, NC 27513; (*author for correspondence; e-mail: dick.auld@ttu.edu)

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Summary

The narrow germplasm base of the upland cotton (*Gossypium hirsutum* L.), grown on the Texas high plains historically, has limited improvement of fiber quality. Chemical mutagenesis and subsequent selection have helped the development of lines with improved fiber quality in cultivars adapted to this region. This study was conducted to determine the inheritance of improvements in fiber quality. M₃ lines with divergent fiber properties of micronaire, length, and strength were selected from a population of Paymaster HS 200 treated with 3% v/v ethyl methanesulfonate (EMS) for two hours. The 115 selected lines of M₄ and M₅ generation were evaluated for fiber quality and lint yield. Regression of the M₄ and M₅ on the M₃ generation, as well as the M₅ on the M₄ was used to generate narrow sense heritability coefficients. Significant variations were observed between the mutant lines in all generations except for lint yield in the M₅ (1997). The highest heritability estimates were found in fiber length ($h^2 = 0.29^{**}$ to 0.46^{**}). Micronaire and strength showed intermediate heritability estimates of $h^2 = 0.14$ to 0.19 , while lint yield had a very low heritability estimate of $h^2 = 0.03$. Fiber length and strength were correlated ($r = 0.58^{**}$ to 0.46^{**}) in all the three generations. The mutants identified in these studies have the potential to improve fiber quality of upland cotton without introducing alien genes that may reduce adaptation to short growing season production regions.

Introduction

Nearly 20% of the US total cotton production (three million bales) occurs on the high plains of Texas (Cotton Incorporated, 2000). Because of the relatively poor fiber quality of the cultivars adapted to this region having a short growing season, this cotton has been sold to low value markets historically. The cotton cultivars adapted to this region, unlike commercial upland cotton, has a narrow germplasm base that has limited the success of breeding programs attempting to improve fiber quality using conventional breeding techniques (Bowman et al., 1996).

Chemical mutagenesis has not been utilized extensively to create new genetic variation in cotton (Naivar, 1996). Low rates of monoethanolamine (MEA) were shown to create variation for lint yield and fiber quality

in Egyptian cotton (Raffat, 1998a). Earlier work had shown that gamma irradiation in cotton could also induce genetic variation (Raffat, 1995). Studies at Texas Tech University indicated that successful mutagenesis in cotton would require exposing germinating embryos to high rates (3X to 5X of the predetermined LD₅₀ dose) of ethyl methanesulfonate (EMS) (Auld et al., 1998).

The objective of this study was to evaluate the effectiveness of chemical mutagenesis in improving fiber quality in cotton.

Materials and methods

On June 6, 1993, a 10 kg-lot of the cultivar Paymaster HS 200 was treated with 3% v/v of ethyl

methanesulfonate (EMS) for two hours (Auld et al., 1998). During the fall of 1993, one boll was harvested from each M_1 plant, and the seed bulked to produce M_2 seed. The M_2 seed were increased during the 1994 growing season, and one boll each was harvested from approximately 5000 M_2 plants to obtain M_3 seeds. The M_3 seeds were planted at the Texas Tech University (TTU) campus at Lubbock, TX in 1995. Four bolls were individually harvested from each of the 1997 randomly selected M_5 plants and the fiber were analyzed using a standard High-Volume Instrument (HVI) analyses at the TTU-International Textile Center.

A total of 115 M_3 putative mutant lines with extreme measurements in fiber length, strength, and micronaire selected in 1995 were evaluated during the seasons of 1996 and 1997 for lint yield and fiber properties. Two commercial cultivars, Paymaster HS 26 and Paymaster HS 200, were used as check cultivars in these studies. Each plot consisted of a single row, 5.1 m $\times$ 1 m, with three replications. Plots were seeded on May 29, 1996 and May 24, 1997. Plots were furrow-irrigated with 320 mm water, applied to supplement 305 mm precipitation in 1996, and 387 mm water applied to supplement 480 mm precipitation in 1997. In early June, during both the years 1996 and 1997, 67.2 kg ha⁻¹ of nitrogen (in the form of ammonium nitrate) and 44.8 kg ha⁻¹ of phosphorus (in the form of P₂O₅) were applied to the plots. Plots were sprayed six times in 1996 and seven times in 1997 to control insects. The insecticides used were Centric 40 WG, Fury, Steward and Intruder for controlling lygus, bollworm, beet armyworm and aphids at the rates of 2, 3.8, 8.5, and 6 ounces per acre, respectively. At maturity, seed cotton from 1 m length of each plot (row) was hand harvested and ginned to obtain estimates of per cent lint and lint yield. Approximately 40 g lint from each plot was analyzed for fiber quality using HVI analyses. Data were subjected to analyses of variance and means were separated with Fisher's Protected Least Significant Difference test.

Analyses of covariance were performed using the general linear model procedure in SAS (1992) for fiber micronaire, length, uniformity, strength, and elongation of the M_3 , M_4 , and M_5 generations, and additionally per cent fiber and fiber yield in the M_4 and M_5 generations. Adjustment of the regression coefficients for level of inbreeding to estimate heritability was performed as recommended by Nyquist (1991). Under this approach, the narrow sense heritability is estimated as $h^2 = b/[1 + F_1(1 - b)]$, where b is the coefficient of regression of the offspring observation on the parental observation, and F_1 is the inbreeding coefficient of the

generation of line derived. Since for this experiment, single plants in the M_3 generation were used to establish the M_4 generation, an estimated F_1 of 0.75 was used. Consequently, the two coefficients, b and $b=$, should serve as boundaries to contain the true narrow sense heritability.

The regression of the performance of the M_5 generation on the M_3 generation also was conducted, although the interpretation of this relationship is not as concise as parent-offspring regression. Additionally, Pearson correlation coefficients were calculated through SAS (1992) to study relationships among the measured traits within each generation.

Results and discussion

High Volume Instrument (HVI) analyses of 1,997 M_3 plants derived from Paymaster HS 200 treated with EMS showed a broad range of variation for all fiber traits evaluated (Figure 1). There was significant variation for micronaire (range of 2.8 to 5.8; S.D. = 0.40), length (range of 24.6 to 35.1 mm, S.D. = 1.3 mm), and strength (range of 23 to 41 g tex⁻¹; S.D. = 2.3 g tex⁻¹). Based on these phenotypic evaluations, 115 M_3 lines with divergent HVI values for micronaire, length, and strength were selected for evaluation of fiber traits, lint percent, and lint yield in the M_4 and M_5 generations.

Significant differences among the selected 115 lines were found in both the M_4 and M_5 generations for micronaire, length, and strength (Figures 2, 3, 4). The average micronaire values of the M_5 lines grown in 1997 were lower than the M_4 lines grown in 1996 (Figure 2). However, the range in the micronaire values observed among the 115 M_3 plants initially selected in 1995 was as much as that observed in both the subsequent years when the M_4 and M_5 generations were evaluated. Average fiber length was higher in 1996 than in 1997, but again the initially selected M_3 lines grown in 1995 had an equivalent range in variation as that observed in the subsequent test years (Figure 3). The average fiber strength was greater in 1997 than in 1996, but again the initial range of the 115 M_3 plants in 1995 was as much as that observed in the subsequent test years (Figure 4). Correlation and regression were used to determine the consistency of these traits across generations and test years.

Average lint yields of the 115 selected mutant lines and the two check cultivars were higher in 1996 and 1997 (Figure 5). Lint yields ranged from 1,170 to 2,087 kg ha⁻¹ in 1996 and from 925 to 1,632 kg ha⁻¹ in 1997.

Figure 1. Distribution of high volume index fiber micronaire (a), length (b), and strength (c) of 1997 M₃ plants of Paymaster HS 200 grown at Lubbock, Texas in 1995.

The lines included in these trials did not have significant differences in lint yield in 1997. These wide ranges of variation in lint yield had not been expected in a chemically mutated population derived from a commercial cultivar such as Paymaster HS 200. This could be indicative of a fairly high range of initial genetic variation in Paymaster HS 200 even before the mutagen treatment.

Figure 2. High volume index micronaire values of 115 M₃, M₄, and M₅ lines and two cultivars of cotton grown at Lubbock, Texas in 1995 (a), 1996 (b), and 1997 (c).

In studying the relationship between the M₄ and M₃ generations, fiber length showed the highest heritability ($h^2 = 0.29$) followed by micronaire and strength ($h^2 = 0.14$) (Table 1). However, the relationship between the M₅ and M₄ generations showed a different ranking in heritabilities. Length showed the highest heritability ($h^2 = 0.46$) followed by percent lint ($h^2 = 0.22$) (not shown in Table 1), micronaire ($h^2 = 0.19$), strength ($h^2 = 0.17$), and lint yield ($h^2 = 0.03$) (Table 1).

Figure 3. High volume index fiber length of 115 M₃, M₄, and M₅ lines and two cultivars of cotton grown at Lubbock, Texas in 1995 (a), 1996 (b), and 1997 (c).

Gibson (1996) stated that *b* required no adjustment for inbreeding when the intent was to predict permanent gain from selection. Consequently, fiber micronaire, length, strength, elongation, and percent lint all show significant potential of improvement from selection in this population of chemically mutated cotton. Measurement of fiber traits using HVI analyses provides higher heritability estimates than those obtained from conventional fiber quality techniques, and HVI has been seen to be suitable for improvement of fiber quality traits

Figure 4. High volume index fiber strength of 115 M₃, M₄, and M₅ lines and two cultivars of cotton grown at Lubbock, Texas in 1995 (a), 1996 (b), and 1997 (c).

in cotton (Latimer et al., 1996). However, HVI estimates of fiber strength have not been correlated with estimates of yarn strength, indicating that final selection for fiber strength should be done on a stelometer (Green and Culp, 1988).

The extremely low heritability estimates obtained by regressing lint yield of the M₄ on the M₅ in this study ($h^2 = 0.03$) was much lower than narrow sense heritability values reported by earlier researchers (Meredith, 1984; Simongulyan and Kosba, 1975; Konoplya et al., 1974; Table 1). Raffat (1998a) reported narrow sense heritabilities of $h^2 = 0.52$ for the control,

Table 1. Heritability coefficients and standard errors estimated from regression of offspring generations on parental generations of a chemically mutated population of cotton grown at Lubbock, TX in 1995, 1996, and 1997

Generations	HVI fiber traits			Lint yield
	Micronaire	Length	Strength	
	h^2 (Std. Errors)			
M ₄ vs. M ₃	0.14 (0.03) [†]	0.29 (0.03)	0.14 (0.04)	—
M ₅ vs. M ₄	0.19 (0.06)	0.46 (0.04)	0.17 (0.06)	0.03 (0.05)

[†] Values were adjusted for level of inbreeding.

Figure 5. Lint yield of 115 M₄ and M₅ lines and two cultivars of cotton grown at Lubbock, Texas in 1996 (a) and 1997 (b).

and $h^2 = 0.32$ for M₁ populations created by exposing the P₁, F₁, F₂, BC₁, BC₂, and P₂ of *G. barbadense* to monoethanolamine (MEA). However, in a separate study of two intervarietal crosses of *G. barbadense*, Raffat (1998b) reported narrow sense heritabilities for

lint yield not differing from zero. In our study, the h^2 for lint percent ($h^2 = 0.22$) was similar to values reported by Keim and Quisenberry (1983), Konoplya et al. (1974), and Raffat (1998a and 1998b), but lower than historic values reported by Meredith (1984). Chemical mutagens such as EMS has been used extensively to create point mutations in *Arabidopsis* (Somerville and Browse, 1991). Consequently, development of significant genetic variation for multigenic traits, such as lint yield, were not expected.

Heritability estimates obtained for fiber traits in this study using parent/progeny regression of plants selected in a chemically mutated population were generally equivalent to those obtained from segregating populations obtained by sexual hybridization. Micronaire in our study had $h^2 = 0.14$ and 0.19 compared to values ranging from $h^2 = 0.0$ to 0.15 obtained by May and Jividen (1999) who compared the efficiency of HVI with single instrument fiber analyses (Table 1). The heritabilities for fiber length in this study were equivalent to values reported by May and Jividen (1999), Simongulyan and Kosba (1975), and Konoplya et al., (1974), but were slightly lower than historic values summarized by Meredith (1984). The narrow sense heritabilities for fiber strength in this study ($h^2 = 0.14$ and 0.17) were lower than those reported by Meredith (1984), May and Jividen (1999), Cantrell and Escabado (1997), and Simongulyan and Kosba (1975). However, Raffat (1998a) reported an exceptionally high narrow sense heritability for fiber strength ($h^2 = 0.82$) in M₁ populations exposed to the mutagen, MEA.

The fiber traits, length and strength, were moderately correlated in all the three generations ($r = 0.46^{**}$ to $r = 0.58^{**}$) (Table 2). The correlation between micronaire and length was $r = -0.11^*$ in the M₃ generation; $r = -0.43^{**}$ in the M₄, and $r = -0.15^{**}$ in the M₅ generation (Table 2). These were the only pairs of traits that exhibited similar correlations in all the three generations. In the M₄ generation, no other trait was significantly correlated to lint yield, but in the M₅ generation, micronaire showed a correlation of $r = 0.33^{**}$ to yield. The variation in correlation coefficients between pairs of traits in the later generations indicates that gene combinations influencing these relationships may be still segregating. Also, the environmental influences between years may cause phenotypic correlations to change when the actual genetic correlations are not changing.

In this mutagenized population, lint yield was not consistently correlated with micronaire, length, or

Table 2. Correlation coefficients among fiber traits and lint yield measured in the M₃, M₄, and M₅ generations at Lubbock, TX during the 1995, 1996, and 1997 growing seasons

	HVI fiber traits		
HVI fiber traits	Length	Strength	Lint Yield
	<i>r</i> values		
Micronaire			
M ₃	-0.11*	-0.22**	—
M ₄	-0.43**	-0.46**	-0.02 ns
M ₅	-0.15**	-0.09 ns	0.33**
Length			
M ₃	—	0.58**	—
M ₄	—	0.47**	0.05 ns
M ₅	—	0.46**	-0.09 ns

*, **, ns = Significant at the 0.05 and 0.01 level of probability, and non-significant respectively.

strength as has been previously reported (Green and Culp, 1988). Similar associations have been reported in segregating populations derived by sexual hybridization (Smith and Coyle, 1997; Basal and Smith, 1997). Increased fiber length was consistently associated with increased fiber strength in our study and also by Basal and Smith (1997) and Kloth (1998). This would indicate that it should be possible to simultaneously select for both fiber strength and length in this mutant population similar to what is possible in conventional segregating populations. Other associations between individual fiber traits were not consistent over all three generations evaluated in this study or supported by references in the literature.

Several individual lines selected from this mutagenesis program have provided valuable germplasm in short season cotton. Two elite mutant lines (TTU 202-1107B and TTU 271-2155C) released as germplasm lines have been used as parents in both public and private cotton breeding programs across the U.S. (Auld et al., 2000). These lines have HVI upper half mean fiber lengths 8 to 9% greater than that of the original cultivar, Paymaster HS 200.

Approximately, 200 microsatellites or simple sequence repeat (SSR) markers were used to determine if unique genetic markers were associated with these mutants. Compared with Paymaster HS 200, TTU 202-1107B has unique loci for the markers BNL 2257, BNL3408-1, and BNL 3649 (Null), while TTU 271-2155C has a unique locus for CML 43. This limited molecular analysis suggests that these lines are genetically different from the original cultivar, Paymas-

ter HS 200 (Auld et al., 2000). Both these lines have been grown as commercial cultivars for cotton markets where fiber quality is at a premium. Based on the results of these trials on inducing heritable variation for fiber quality in cotton, additional populations have since been mutagenized.

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