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BREEDING AND GENETICS

Relationships of Plant Trichomes to Yield and Fiber Quality Parameters in Upland Cotton

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ABSTRACT

Botanically, the hair on leaves, stems and bracts, as well as the fibers on seed are plant trichomes. Reducing trichomes on cotton leaves, stems and bracts can reduce trash in ginned cotton lint, but might negatively impact fibers on seed and other parameters. Our objective was to determine the impact of reducing trichomes on leaves, stems and bracts on number and density of fibers on seed and on other agronomic and fiber quality parameters. Trichome (leaf, stem and bract), agronomic (9 parameters) and fiber quality (6 parameters) data were extracted from the Keiser location of the Advanced and New Strain Tests (2006-2015) and the Main and 1st year Variety Test (2007-2015) in Arkansas. All agronomic and fiber quality data were analyzed using PROC GLM and a linear mixed model (PROC MIXED in SAS) with leaf pubescence, stem pubescence and bract trichomes as independent variables. Trends for trichome measures in Strain Tests differed from trends in Variety Tests. Leaf and stem pubescence influenced more parameters than bract trichome density. Increased leaf pubescence was related to higher yields in each test and with higher fibers seed^{-1} and fiber density in the Strain (but not the Variety) Tests. Bract trichome density did not affect any parameter (except fiber strength) in the University of Arkansas (UA) Cotton Breeding Program. Compared to leaf and stem pubescence, bract trichome density appears to have fewer adverse relationships with yield and quality parameters. Reducing bract trichome density should be the optimum method to lower plant hairiness in Upland cotton.

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Trichomes are hair-like protrusions that may occur on abaxial and adaxial surfaces of leaves and bracts, as well as on stems and seed of cotton (*Gossypium hirsutum* L.) plants. On seed, the epidermal trichomes are better known as cotton fibers. Extensive breeding efforts have been made to reduce trichomes on leaves, and some attention has been made to reduce trichomes on stems and bracts. There is concern that these efforts might have unintended negative effects on number of fibers produced on the seed and on other agronomic parameters.

Trichomes on cotton leaves have been investigated more thoroughly than trichomes on bracts and stems. Reduced leaf pubescence (i.e. lower trichome density) has been associated with enhanced cleaning efficiency of seed cotton and improved grades of ginned cotton (Anthony and Rayburn, 1989; Novick et al., 1991; Boykin et al., 2013). Breeding for reduced trichomes on cotton leaves has led to the development of “smooth-leaf” (glaborous) and “semi-smooth leaf” (intermediate pubescent) cultivars. In their summary of the response of insects to several cotton morphological traits, Jenkins and Wilson (1996) also included effects of the leaf pubescence on agronomic parameters. They indicated that that glabrous and pubescence traits tended to be neutral with respect to most yield and agronomic parameters, while the pilose characteristic tended to be negative. Several studies have noted lower lint percentage associated with some glaborous genes (Lee, 1984; Meredith et al., 1996; Jones et al., 1971, 1977, and 1978).

The possible negative association between glabrous leaves and lint percentage elicits concern of whether reducing trichomes on leaves, stems, and bracts might produce a reduction in number of fibers produced on the seed. Lewis et al. (2000) proposed that lint yield of cotton could be simply modelled as number of seed produced area^{-1} times weight of fiber seed^{-1}. They suggested that yield stability could be enhanced by placing a greater reliance on weight of fiber seed^{-1} rather than number of seed area^{-1}. Weight of fiber seed^{-1} is a function of number of fibers seed^{-1} times the average weight fiber^{-1}.

Although most trichome research has focused on leaves, a large source of trash in harvested cotton lint is bract tissue (Morey et al., 1976). With effective defoliation (i.e., removal of nearly all leaves) and timely harvest, leaf tissue originating from true leaves in harvested seed cotton should be minimal. Defoliation does not remove bracts, and thus bract tissue forms much of the trash in seed cotton. Intuitively, trash in seed cotton and lint should be effectively lowered by reducing number of marginal bract trichomes since the trichomes would cause the bract tissue to cling to the cotton fibers. Boykin et al. (2013) found trichome density on leaves and bracts to be highly correlated in the lines they studied. They concluded that trash content in ginned cotton could be lowered by reducing trichome density on leaves or bracts.

Bourland and Hornbeck (2007) indicated that density of marginal bract trichomes tended to be greater on younger bracts and on genotypes with greater leaf trichome density. However, they did not find any Upland cotton genotype to have glabrous bracts. Marginal bract trichome density varied among smooth leaf, semi-smooth, and hairy leaf genotypes. Additionally, trichome density on bract margins was positively related to trichome density on abaxial leaves, leaf margins, and stems. The low magnitude of these correlations (ranged from 0.29 to 0.41) indicated that the traits were not pleiotropic, and could likely be modified independently. However, selection for reduced trichomes on one plant part might be associated with lower trichome density on other plant parts, including fibers on seed.

Hornbeck and Bourland (2007) showed that trichomes on leaves, stems and bracts can be effectively characterized with visual ratings, but visual rating of bracts was difficult. Except for the comparison of trichomes on abaxial surfaces and margins of leaves, they found trichomes on all plant parts (leaves, stems and bracts) to be correlated, but the low coefficients suggested that the traits have some degree of independence. Thus, it may be possible to genetically reduce the degree of marginal bract pubescence of genotypes, while retaining higher degrees of pubescence on leaves and stems.

The objective of this research was to determine if trichome density on leaves, bracts and stems influences the number and density of trichomes (fibers) on seed, and other agronomic and fiber quality parameters.

MATERIALS AND METHODS

Data were extracted from 2007 through 2015 Arkansas Cotton Variety Tests and the 2006 through 2015 Advanced and New Strain Tests of the University of Arkansas (UA) Cotton Breeding Program. All data were from tests at the Northeast Research and Extension Center at Keiser. The plots were on a Sharkey clay (Veryfine, smectitic, thermic Chromic Epiaquerts) soil and were furrow-irrigated. Plots were two rows, 12 to 15 m long, on 1 m centers and planted in a randomized complete block (RCB) design with four replications. The Variety and Strain Tests were located in the same field and managed similarly each year. As outlined in annual reports, available at www.ArkansasVarietyTesting.com, standard management practices were employed throughout the season for all of the tests each year.

The number of entries in the annual Variety Tests ranged from 34 to 75 entries in the 2007 through 2015 tests. Typically, about one-half of the cultivars in the annual Variety Tests were evaluated in the previous year's test with some cultivars remaining in the test from two to five years. The cultivars were evaluated in two adjacent tests in 2007 through 2012 with entries returning from the previous year in the Main Variety Test and first year entries in second test (designated as 1st-year Variety Test). A total of 424 entries were evaluated from 2007 through 2015; 90% of these were transgenic genotypes. The Main and 1st year Variety Tests were randomly placed into each replication in the field. With fewer entries, all cultivars were evaluated in one test in 2013 through 2015. Reports from these annual tests are available at www.ArkansasVarietyTesting.com.

Within the Arkansas Cotton Breeding Program, cotton strains (all conventional) are evaluated annually in four Preliminary Strain Tests, one New Strain Test, and one Advanced Strain Test (Bourland, 2004, 2013). Each test includes 18 strains and two check cultivars. Annually, 18 superior strains from the Preliminary Strain Tests are promoted to the New Strain Test the following year. Similarly, about one-half of New Strains are promoted and evaluated in the Advanced Strain Test for up to two years.

In Arkansas, trichome measurements are restricted to the Keiser location because pubescence ratings of cotton lines are highly correlated over locations (Bourland et al., 2003). Also, Bourland and Hornbeck (2007) indicated that bract trichome density could be effectively characterized by taking samples from one irrigated (non-stressed) location of the tests. Therefore, only data from the Keiser location were used in this study. The current data sets were initiated with the 2006 Strain Tests and 2007 Variety Tests because all three trichome measurements were not available from earlier years. Data for lint percentage, seed index, lint index, fibers seed^{-1}, fiber density and fiber quality parameters were collected from two replications of each test. All other parameters (including trichome measurements) were determined for four replications. Parameters measured for each test included:

1. Trichome measurements:
   - Leaf pubescence: As plants approached physiological cutout, leaf pubescence of a full-sized leaf, about five to seven nodes from plant apex, was rated for six plants plot^{-1} using a scale of 1 (smooth leaf) to 9 (pilose) described by Bourland et al. (2003).
   - Stem pubescence: After harvest, stem pubescence on the highest fully expanded internode from the plant apex was visually rated for six plants plot^{-1} using a scale of 1 (smooth leaf) to 9 (pilose).
   - Bract trichomes: After physiological cutout, a bract from a mid-canopy, first-position boll was taken from six random plants plot^{-1} using sampling procedures developed by Bourland and Hornbeck (2007). Bracts from a plot were stapled together with a plot label and frozen. Prior to evaluation, frozen bracts were allowed to thaw on wetted germination paper until they became pliable. A standard hole-punch (0.65 cm diameter) was made in an index card and placed over the sampled tissue. Using a viewing microscope, number of trichomes exposed through the hole was then counted. Marginal bract trichome density was determined by counting marginal trichomes on two representative marginal areas of the center tooth of each bract, then converting to number cm^{-1}. Each branch of stellate trichomes was counted as an individual trichome.
2. Yield and maturity parameters:
   - Plant height: After harvest was completed, plant heights were determined by measuring from the soil surface to the terminal of one average-sized plant in each of the two rows. Plot means (average of the two measurements) were evaluated.
   - Open bolls percentage: Percentage of open bolls was estimated after application of defoliants. Estimates were made from the front and back of each plot then averaged for each plot. Due to late maturity associated with delayed planting dates, open boll estimates were not made in 2013 and 2015.
   - Lint yield: After converting weight of seed cotton harvested plot^{-1} to yield ha^{-1}, lint yield was determined by multiplying seed cotton yield ha^{-1} by lint percentage (averaged by location and entry within each test).
3. Basic yield component variables:
   - Seed ha^{-1}: The number of seed produced was determined by multiplying seed cotton yield (kg ha^{-1}) times the average seed percentage (the percentage of seed weight to seed cotton weight in ginned samples, averaged by entry over replications), then dividing by average seed weight (average seed index by entry over replications divided by 100).
   - Lint index: Weight of lint from 100 seed was determined from boll sample data by dividing lint weight of ginned sample by the number of seed sample^{-1} (seed weight of sample divided by average seed weight) then multiplying by 100.
4. Variables related to basic yield components:
   - Lint percentage: the percentage of lint weight to seed cotton weight in each sample.
   - Seed index: Two sets of 50 fuzzy seed from the ginned seed of each boll sample were counted and weighed. Seed index (weight of 100 seed) was calculated by summing two consistent weights of 50 seed.
   - Fibers seed^{-1}: Fibers seed^{-1} was calculated by dividing lint index by estimated weight per fiber where, Weight of a fiber = fiber length ×length uniformity ×(micronaire ÷1,000,000).
   - Fiber density: Fiber density is an estimate of the number of fibers mm^{-2} of seed surface area and was calculated by dividing fibers per seed by seed surface area (SSA), where SSA was estimated by the regression equation suggested by Groves and Bourland (2010):
5. Fiber quality traits (determined by HVI):
   - Micronaire: Fiber fineness is estimated by the relative degree of restriction to air flow caused with a standard weight of fiber.
   - Fiber length: The upper half mean length (mm) of a beard of cotton fibers.

- ○ Length uniformity index: The degree of fiber length uniformity in a sample is expressed as ((mean length of fibers / upper half mean length × 100).
- ○ Strength: The force (kN m kg^{-1}) required to break a bundle of fibers equivalent to 1,000 meters of fiber.
- ○ Elongation: Elongation measures the percentage change in gauge length up on rupture of a bundle of fibers with respect to the original gauge length.
- ○ Q-score: Q-score is a weighted fiber quality index as described by Bourland et al. (2010). Parameters (and weightings) included in Q-score were fiber length (50%), micronaire (25%), length uniformity index (15%), and strength (10%).

These 18 variables were analyzed as a randomized complete block (RCB) with four replications in each test using the PROC GLM procedure in SAS Version 9.1 (SAS Institute, Cary, NC). The data were also analyzed using a linear mixed model (PROC MIXED in SAS) assuming normally distributed responses with year, test, entries (i.e., strains and cultivars), and reps as random effects. The initial regression model had leaf pubescence, stem pubescence and bract trichomes as potential independent variables. Nonsignificant independent variables were eliminated one at a time based on the largest p-value until either (1) all remaining independent variables were significant at the 10% level or (2) none of the three original independent variables were significant individually.

RESULTS AND DISCUSSION

Trichome variables: Variation in leaf and stem pubescence between years may be associated with environmental effects causing variation in trichome development or may simply be due to variation in the subjective ratings of pubescence. In particular, both visual ratings and counts of trichomes on leaves of the same genotype may vary over locations and years, but relative differences between genotypes tend to be consistent (Bourland et al., 2003; Hornbeck and Bourland, 2007; Morgan et al, 2016). Since bract trichomes were counted (rather than visually rated), they should be less subjective than the visual ratings of leaf and stem pubescence, and should accurately assess the variation over years.

Leaf, stem and bract trichome data used in this study were only collected at one location each year because previous studies indicated that location by genotype interaction were not present - as long as highly stressed (e.g. non-irrigated) locations were excluded (Bourland et al., 2003; Bourland and Hornbeck, 2007). For convenience to our laboratory, we chose the Keiser location over other Arkansas locations for collecting the data. Also, we have observed that trichomes appear to be longer and easier to visually rate at Keiser than at more southern locations. This visual variation in trichome length has been consistent over years between test locations within Arkansas. We seek to reduce variation in visual ratings of leaf and stem pubescence over and within years by establishing leaf and stem pubescence standards that are used for reference when ratings are being made.

Differences in leaf pubescence, stem pubescence and bract trichome density were found among genotypes in each year and in each test (PROC GLM procedure, data not shown). When evaluated over all years by trait and test, none of the slopes was significant (0.05 probability level). The highest (most hairy) leaf pubescence means were found in the 2011 Advanced Strain Test and the 2015 Main Variety Test (Fig. 1 and 2). Averages of leaf pubescence ratings have remained relatively constant over years in the Strain Tests (Fig. 1). Leaf pubescence means in the Main and 1st year Variety Tests were relatively constant from 2007 through 2012, but leaf pubescence means in the Main Variety Test have trended upwards since 2012 (Fig. 2). In the past, cotton breeders have preferred smooth-leaf over hairy leaf genotypes. The relative leaf pubescence values in 2013 through 2015 in the Main Variety Test suggest that this preference has weakened.

Stem pubescence ratings were lowest in 2011 through 2014 of each test (Fig. 1 and 2). Similar declines in stem pubescence ratings were found in the Advanced Strain and New Strain Tests (Fig. 1) and in the Main Variety Test (Fig. 2), but ratings have trended upward since 2013. The slope in the 1st year Variety Test verifies the strong downward trend from 2007 through 2013. Since little selection preference for stem pubescence is being applied by United States (U.S.) cotton breeders, the recent upward trend may be indirectly related to the increase in leaf pubescence, or it may be due to a subtle shift in the standard used for visual ratings.

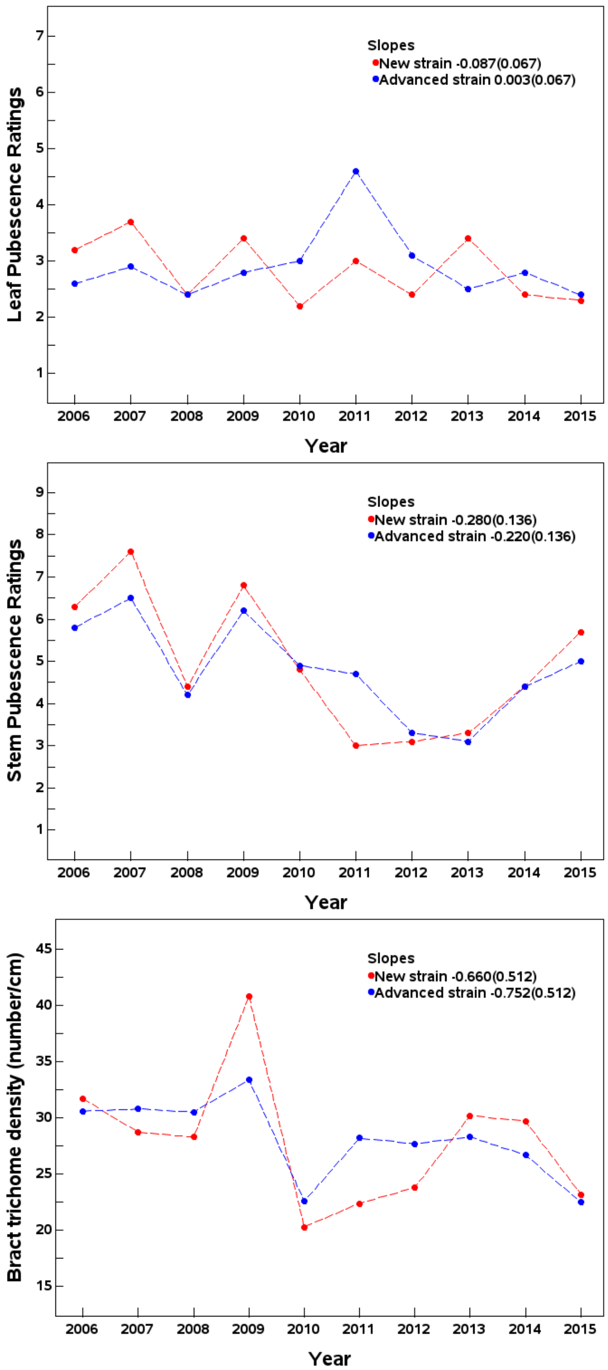

Figure 1. Leaf and stem pubescence ratings and bract trichome density for genotypes in the Advanced and New Strain Tests (2006 through 2015) of University of Arkansas Cotton Breeding Program. (Slopes estimated standard errors associated with each are indicated in legend.)

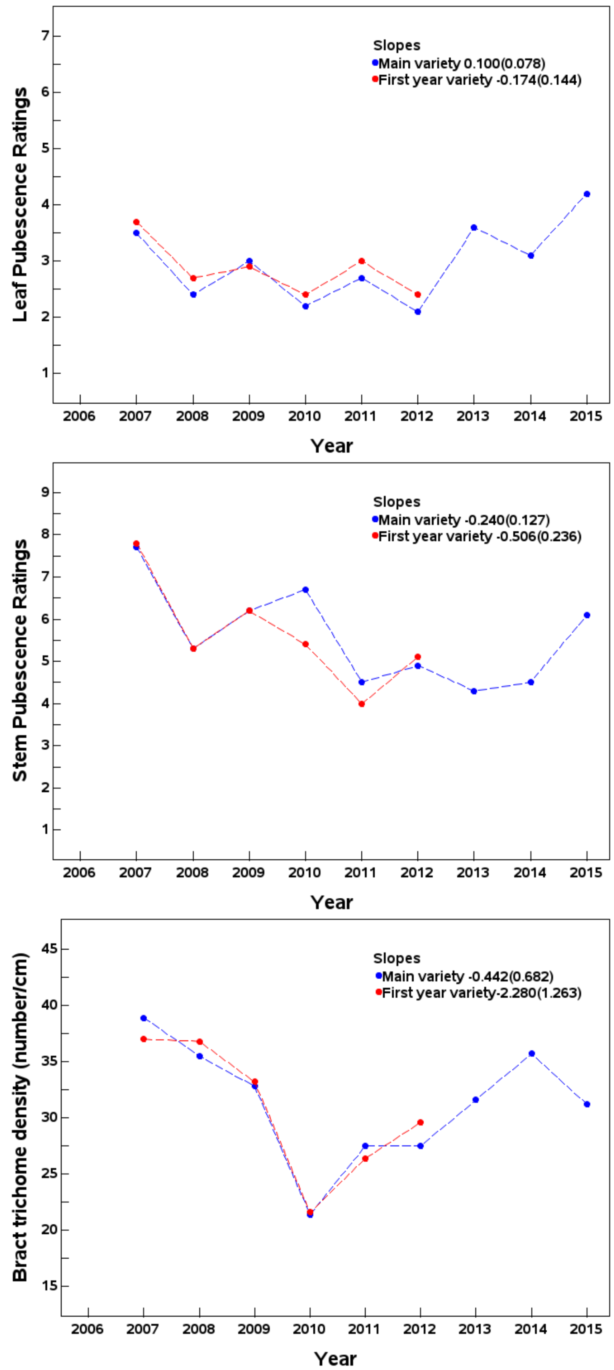

Figure 2. Leaf and stem pubescence ratings and bract trichome density for genotypes in the Main Variety Test (2007 through 2015) and 1st year Variety Test (2007 through 2012) of Arkansas Cotton Variety Tests. (Slopes estimated standard errors associated with each are indicated in legend.)

Except for 2009, bract trichome density tended to decline at similar rates over years in both the Advanced and New Strain Test (Fig. 1). Values in the New Strain Test appeared to have greater annual variation than the Advanced Strain Test. Bract trichome densities in the Main and 1st year Variety Tests were equal from 2007 through 2012 (Fig. 2). Bract trichome density in the Main Variety Test trended downward until 2010 and trended upward from 2011 through 2015.

From 2007 through 2015, leaf pubescence in the Strain Tests and in the Variety Tests were equal, each having an average rating of 2.9. Compared to the Strain Tests over the same period, entries in Variety Tests averaged 19% higher stem pubescence (ratings of 5.6 vs. 4.7) and 12% higher bract trichome density (31.1 vs. 27.7 trichomes cm^{-1}). These averages suggest that plant trichomes on stems and bracts are being lowered in the UA Cotton Breeding Program. The program rarely makes direct selection of plant trichomes, but more pubescent lines are discarded when other critical factors are similar (Bourland, 2013).

Genotypic differences in lint yield, lint percentage, lint index, fiber length, and fiber strength were found in every test each year (data not shown). Length uniformity index had the lowest percentage of years (65%) with genotypic differences over all four tests. Excluding length uniformity index, the other nine variables had significant genotypic variation in 93% of the tests. These differences indicate that the genotypes evaluated in these tests represented a wide range of genetic variation with regard to these parameters.

Relationships of trichome variables to other variables: In the linear mixed model regression analyses, leaf pubescence was more frequently associated with the 15 dependent variables than the other two independent variables. Leaf pubescence was significantly used in eight and nine of the dependent variables in the Strain and Variety Tests, respectively (Tables 1 and 2). Stem pubescence was the second most frequently used independent variable and bract trichome density was the least frequently used independent variable.

Table 1. Relation of trichome and pubescence measurements on bracts, leaves, and stems to yield, maturity, yield-component, and fiber quality parameters in the 2006 through 2015 Advanced and New Cotton Strain Tests at Keiser, AR[z]

Dependent variable[y]	Intercept (s.e.)	Leaf pubes. rating (s.e.)	Stem pubes. rating (s.e.)	Bract trichome density (s.e.)
Lint yield	1061.0 (106.1)	13.36 (3.29)***	-	-
Maturity:				
Plant height	97.475 (1.854)	-	-0.258 (0.172) ns	-
Open boll %	57.122 (4.902)	-	-0.426 (0.188)*	-
Yield-component:				
Seed ha^{-1}	14.877 (1.425)	0.136 (0.047)**	-	-
Lint index	7.118 (0.118)	0.033 (0.015)*	-	-
Lint percentage	38.675 (0.302)	-	0.105 (0.036)**	-
Seed index	11.042 (0.202)	-	-0.027 (0.021)ns	-
Fibers $seed^{-1}$	14884 (313)	129 (35)***	-	-
Fiber density	134.74 (3.60)	1.26 (0.33)***	0.79 (0.33)*	-
Fiber quality:				
Q-score	63.77 (1.04)	-0.96 (0.28)***	-	-
Fiber length	30.48 (0.23)	-0.102 (0.025)***	-	-
Fiber micronaire	4.754 (0.075)	-0.014 (0.009)	-	-
Fiber strength	328.00 (5.28)	-	-	-0.186 (0.088)+
Length uniformity	85.176 (0.216)	-0.074 (0.027)**	-	-
Fiber elongation	6.856 (0.668)	0.043 (0.020)*	0.061 (0.20)**	-

+, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 probability levels, respectively.

[z] Data taken from 2 replications of tests (800 observations over 10 years).

[y] None of the trichome measurements had significant effects on plant height, seed index, or fiber micronaire. A dash (“-“) indicates that the respective independent variable was not chosen to explain variation in the dependent variable.

Table 2. Relation of trichome and pubescence measurements on bracts, leaves, and stems to yield, maturity, yield-component, and fiber quality parameters in the 2007 through 2015 Arkansas Cotton Variety Tests at Keiser[z]

Dependent variable[y]	Intercept (s.e.)	Leaf pubes. rating (s.e.)	Stem pubes. rating (s.e.)	Bract trichome density (s.e.)
Lint yield	1033.2 (141.7)	15.06 (3.19) ***	-	2.17 (0.69) ns
Maturity:				
Plant height	98.398 (4.580)	-	-0.715 (0.191) ***	-
Open boll %	53.952 (3.959)	-	0.395 (0.184) *	-
Yield-component:				
Seed ha^{-1}	14.669 (1.981)	0.247 (0.052)***	-	0.042 (0.052) ***
Lint index-run 1	6.925 (0.121)	-0.025 (0.015) +	-	-
Lint index-run 2	7.014 (0.146)	-	-0.030 (0.016) +	-
Lint percentage	40.446 (0.389)	-	0.039 (0.040) ns	-
Seed index-run 1	10.044 (0.199)	-	-0.055 (0.022) *	-
Seed index-run 2	9.896 (0.160)	-0.048 (0.020) *	-	-
Seed index-run 3	10.113 (0.190)	-0.038 (0.020) +	-0.045 (0.022) *	-
Fibers $seed^{-1}$	16426 (455)	-	-124 (49) *	-
Fiber density	161.26 (4.60)	-	-0.62 (0.48) ns	-
Fiber quality:				
Q-score	63.108 (1.280)	-0.250 (0.296) ns	-	-
Fiber length	29.972 (0.229)	-0.033 (0.020) +	-	-
Fiber micronaire	4.355 (0.131)	-	0.013 (0.011) ns	-
Fiber strength	310.97 (6.58)	0.902 (0.412) *	-	-
Length uniformity	84.355 (0.237)	-	0.012 (0.028) ns	-
Fiber elongation	7.716 (0.588)	0.067 (0.022) **	-	-

+, *, **, * Significant at the 0.10, 0.05, 0.01, and 0.001 probability levels, respectively.**

[z] Data taken from 2 replications of tests (860 observations over 9 years).

[y] None of the trichome measurements had significant effects on lint percentage, fiber density, micronaire, uniformity index or Q-score. . A dash (“-“) indicates that the respective independent variable was not chosen to explain variation in the dependent variable.

Leaf pubescence positively influenced lint yield, seed ha^{-1}, and fiber elongation and negatively influenced fiber length in both Strain and Variety Tests (Tables 1 and 2). The only other variable that leaf pubescence influenced in both Strain and Variety Tests was lint index, but the direction of the influence differed between the two sets of tests. Variables influenced by leaf pubescence in only one set of tests included seed index (negatively in Variety Tests), fibers $seed^{-1}$ (positively in Strain Tests), fiber density (positively in Strain Tests), Q-score (negatively in Strain Tests), fiber strength (positively in Variety Tests) and length uniformity index (negatively in Strain Tests). Consistent relationships over the both Strain and Variety Tests suggest more important effects. Positive influences of increased leaf pubescence on lint yield and seed ha^{-1} may be related to pest or environment tolerance associated with increased trichomes on the plant (Jenkins and Wilson, 1996).

Leaf pubescence did not influence lint percentage in either the Strain or Variety Tests (Tables 1 and 2). The absence of positive relationship between leaf pubescence and lint percentage in this study differs from earlier findings (Lee, 1984; Meredith et al., 1996; Jones et al., 1971, 1977, and 1978). This relationship may have been neutralized with breeding efforts to increase lint percentage on glabrous genotypes in 1990's and early 2000's.

Leaf pubescence positively influenced both fibers seed^{-1} and fiber density in the Strain Tests, but not in the Variety Tests (Tables 1 and 2). This suggests that trichomes on leaves and on seed (lint fibers) may be related. These relationships cause some concern in the UA Cotton Breeding Program in that selection for lower leaf hairiness may tend to lower both lint yield and these components of yield.

As indicated earlier, selection preference for smooth-leaf genotypes has eased in recent years, and leaf pubescence has trended upward in the Variety Tests (Fig. 2). Rayburn (1986) proposed a three-class leaf hairiness index that was based on the density of trichomes. At that time, he indicated that all cultivars included in the "smooth" and "hairy" classes, but none in "moderately hairy" class, were adapted to the Mississippi River Delta region. The majority of current cultivars possess intermediate (rather than smooth-leaf or very hairy) values of leaf pubescence. Of the 45 entries in the 2016 Arkansas Cotton Test, only six were rated as smooth-leaf (average leaf pubescence ratings less than 2.0) and three were rated as hairy/very hairy (ratings over 4.0) (Bourland et al., 2017). Favoring of moderately hairy cultivars may combine the positive yield relationship to leaf pubescence shown in this study with the avoidance much of the trash discounts associated with very hairy cultivars (Boykin et al., 2013).

Stem pubescence did not influence lint yield, seed ha^{-1}, Q-score, fiber length, fiber micronaire, fiber strength, or length uniformity index in either the Strain or Variety Tests (Tables 1 and 2). The only variable that stem pubescence influenced in both sets of tests was open boll percentage, but its influence was negative in the Strain Tests and positive in the Variety Tests. The only other influences of stem pubescence were on plant height (negatively in Variety Tests), lint index (positively in Variety Tests), lint percentage (positively in Strain Tests), seed index (negatively in Variety Tests), fibers seed^{-1} (negatively in Variety Tests), fiber density (positively in Strain Tests), and fiber elongation (positively in Strain Tests).

Both leaf and stem pubescence had positive influences on fiber density and elongation in the Strain Tests, but not in the Variety Tests. The relation of both leaf and stem pubescence on fiber density in the Strain Test is concerning since breeders often select for lower trichomes on leaves and stems. In some genetic materials, this selection pressure might be related to lower fiber density.

Bract trichome density had a negative influence on fiber strength in the Strain Tests and a positive influence on lint yield and seed ha^{-1} in the Variety Tests (Tables 1 and 2). The lack of influence on lint index, lint percentage, fibers seed^{-1}, fiber density, and most fiber quality parameters suggest that trichomes on bracts are independent of seed trichomes (lint fibers), and may be reduced without negatively affecting these yield component and fiber quality parameters.

The only parameter influenced by both bract trichome density and leaf pubescence rating was seed ha^{-1} in the Variety Tests (Tables 1 and 2). These relationships suggest that trichomes on leaves and bracts may influence seed and fiber production, and causes concern if breeders seek to lower hairiness of leaves and bracts. Bract trichome density is routinely measured in the UA Cotton Breeding Program, and lines having lower density are favored. The absence of influence of bract trichome density on all variables (expect fiber strength) in the Strain Tests suggest that this selection pressure has not negatively impacted lint yield, seed ha^{-1}, yield-related components, or most fiber quality parameters.

CONCLUSIONS

Trichome density on leaves, stems and bracts have varied greatly among cotton genotypes in the 2007 through 2015 Arkansas Cotton Variety Tests and the 2006 through 2015 UA Cotton Breeding Strain Tests. In the Main Variety Test, trichomes on leaves, stems and bract margins have trended downward in the earlier years, but upward since 2012. In contrast, leaf pubescence ratings have been relatively constant and marginal bract trichomes have generally declined in the Strain Tests. Selection pressure for lower leaf and stem pubescence has been relaxed in favor of higher pressure for reduced bract trichome density in the UA Cotton Breeding Program.

Increased leaf pubescence in both the Variety and Strain Tests was associated with increased lint yield. In the past, cotton breeders placed a high preference for smooth-leaf over hairy-leaf genotypes. Selection pressure for smooth-leaf genotypes appears to have been relaxed, which has resulted in moderately hairy and possibly higher yielding genotypes.

Seed ha^{-1} was the only yield component variable that was influenced by leaf pubescence ratings in both the Variety and Strain Tests. Groves et al. (2016) showed that seed ha^{-1} and lint yield were highly related. The absence of consistent effects of any of the other yield component variable suggests that plant trichomes are mostly independent of these yield component variables. However, both leaf and stem pubescence influenced fiber $seed^{-1}$ and fiber density in either the Variety or Strain Tests. These possible influences might be avoided by focusing selection on bract trichome density rather than leaf and stem pubescence.

Bract trichome density and stem pubescence had no consistent effects on any of the fiber quality parameters. However, leaf pubescence was negatively related to fiber length and positively related to fiber elongation. Therefore, selection associated with bract trichome density and stem pubescence would less likely affect fiber quality parameters than selection related to leaf pubescence. Leaf pubescence influenced more fiber quality parameters than did stem pubescence or bract trichome density. This suggests that trichomes on leaves are more closely associated with fiber development than are trichomes bracts or stems.

Genotypes that have less bract trichome density, regardless of their leaf and stem pubescence, have been preferentially selected in the UA Cotton Breeding Program. These data indicate that bract trichomes can be reduced in this program without adversely affecting any agronomic or fiber quality parameter (except fiber strength). Reducing hairiness of cotton genotypes by selecting lower bract trichome density should have fewer negative effects than selecting for reduced pubescence on leaves or stems in most cotton breeding programs.

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REFERENCES

Anthony, W.S., and S.T. Rayburn. 1989. Cleanability of smooth- and hairy-leaf cottons – quality effects. T. ASABE 32:1127-1130.

Bourland, F. M. 2004. Overview of the University of Arkansas Cotton Breeding Program. pp. 1093-1097. In Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 5 9 Jan. 2004. National Cotton Council, Memphis, TN.

Bourland, F.M. 2013. Novel approaches used in the University of Arkansas cotton breeding program. pp. 409-418. In Proc., Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 7-10 Jan. Nat'l, Cotton Counc. Am., Memphis, TN.

Bourland, F., W. Barnett, C. Kennedy, L. Martin, A. Rouse, and B. Robertson. 2017. Arkansas cotton variety test 2016. Arkansas Agric. Exp. Stn. Research Series 641.

Bourland, F.M., R. Hogan, D.C. Jones, and E. Barnes. 2010. Development and utility of Q-score for characterizing cotton fiber quality. J. Cotton Sci. 14:53-63.

Bourland, F.M. and J.M. Hornbeck. 2007. Variation in marginal bract trichomes on Upland cotton. J. Cotton Sci. 11:242-251. Available at http://www.cotton.org/jounal/2007/11/4/242.cfm

Bourland, F.M., J.M. Hornbeck, A.B. McFall, and S.D. Calhoun. 2003. A rating system for leaf pubescence of cotton. J. Cotton Sci. 7:8-15.

Boykin, J.C., F. Bourland, and D.M. Dobbs. 2013. Relationship of leaf and bract trichomes to trash content of ginned lint. pp. 774-782. In Proc., Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 7-10 Jan. Nat'l, Cotton Counc. Am., Memphis, TN.

Groves, F.E., and F.M. Bourland. 2010. Estimating seed surface area of cottonseed. J. Cotton Sci. 14:74-81.

Groves, F.E., F.M. Bourland, and D.C. Jones. 2016. Relationships of yield component variables to yield and fiber quality parameters. J. Cotton Sci. 20:320-329.

Hornbeck, J.M., and F.M. Bourland. 2007. Visual ratings and relationships of trichomes on bracts, leaves, and stems of Upland cotton. J. Cotton Sci. 11:252-258.

Jenkins, J.N., and F.D. Wilson. 1996. Host Plant Resistance. In King, Phillips, and Coleman (Eds.), Cotton Insects and Mites: Characterization and Management. Memphis, TN: The Cotton Foundation.

Jones, J.E., D.F. Clower, B.R. Williams, J.W. Brand, K.L. Quebedeaux, and M.R. Milam. 1977. Isogenic evaluation of different sources of glabrousness for agronomic performance and pest resistance. Proc. Beltwide Cotton Prod. Res. Conf., Atlanta, GA. 10-12 Jan. 1977. Natl. Cotton Counc. Am., Memphis, TN.

Jones, J.E., L.W. Sloane, and A.J. Major, Jr. 1971. Isogenic studies of D2 smoothness in Upland cotton. Proc. Beltwide Cotton Prod. Res. Conf., Atlanta, GA. 12-13 Jan. 1971. Natl. Cotton Counc. Am., Memphis, TN.

Jones, J.E., B.R. Williams, J.W. Brand, D.F. Clower, and D.T. Bowman. 1978. Interacting effects of the okra leaf, frego bract and glabrous traits on pest resistance and agronomic characteristics. Proc. Beltwide Cotton Prod. Res. Conf., Dallas, TX. 9-11 Jan. 1978. Natl. Cotton Counc. Am., Memphis, TN.

Lee, J.A. 1984. Effects of plant smoothness on agronomic traits of Upland cotton - lint percentage. Crop Sci. 24:583-587.

Lewis, H., L. May, and F. Bourland. 2000. Cotton yield components and yield stability. pp. 532 536. In Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 4 8 Jan. 2000. National Cotton Council, Memphis, TN.

Meredith, W.R. Jr., W.T. Pettigrew, and J.J. Heitholt. 1996. Sub-okra, semi-smoothness, and nectariless effect on cotton lint yield. Crop Sci. 36:22-25.

Morey, P.R., P.E. Sasser, R.M. Bethea, and M.T. Kopetzky. 1976. Variation in trash composition in raw cottons. Am. Ind. Hyg. Assoc. J. 37:407-412.

Morgan, G., F. Bourland, J. Dever, D. Fromme, J. Gassett, S. Assango, and E. Barnes. 2016. Developing an industry-wide standard for leaf hairiness. pp. 63-66. In Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 5-7 Jan. 2016. National Cotton Council, Memphis, TN.

Novick, R.G., J.E. Jones, W.S. Anthony, W. Aguillard, and J.I. Dickson. 1991. Genetic trait effects on nonlint trash of cotton. Crop Sci. 31:1029-1034.

Rayburn, S.T., Jr. 1986. A leaf hairiness index for nine cotton cultivars. p. 434. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 4-9 Jan. 1986. Natl. Cotton Counc. Am., Memphis, TN.