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Breeding Cottons with Higher Yarn Tenacity

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ABSTRACT

Stronger cotton yarns are needed by the textile industry as knit and woven fabric manufacturing speeds increase, thus placing greater strain on cotton yarns. We compare fiber properties as selection criteria for the genetic improvement of yarn tenacity in a breeding population consisting of twenty-five cotton germplasm lines grown for two years at two locations near Florence, SC. Fiber properties measured with the fibrograph, Stelometer, fibronaire, and Arealometer are obtained on lint from each experimental line in this population, along with ring spun yarn with a tenacity of 27 tex (22 Ne). Among individual fiber properties, selection for 50% fiber span length results in the greatest gain in yarn tenacity. Simultaneous selection for low Micronaire reading, long 50% fiber span length, and high fiber tenacity improve yarn tenacity more so than selection for individual fiber properties. Selecting for fiber properties measured with the Arealometer generally results in lower gains in yarn tenacity. We show individual and combinations of fiber properties that are useful as selection criteria for yarn tenacity improvement.

Developing cotton germplasm with higher yarn tenacity is a priority of the cooperative USDA/ARS and Clemson University cotton genetics program. Over its history, this program has developed numerous high yielding germplasm lines with improved fiber and yarn quality [4, 5]. Private breeding firms have used this publicly developed germplasm to produce commercial cultivars with better fiber quality [3]. Stronger cotton yarns are needed to sustain productivity increases in knit and woven fabric manufacture [6] and also to counteract the reduction in fabric strength from chemical treatments applied to achieve wrinkle resistant 100% cotton fabric [9].

Yarn tenacity is an expensive trait for breeders to measure, currently costing about $30 per sample. Because of the high cost of measurements and the large populations that breeders generally work with, yarn tenacity can be directly selected for only in advanced stages of breeding. Indirect selection for higher yarn tenacity by selecting individual fiber properties such as fiber tenacity is practiced normally in early generations such as the F_2 or F_3 following population synthesis [4, 5]. Selection on the basis of fiber tenacity, however, may not always result in progeny with better yarn tenacity [13]. In contrast to the high cost of yarn tenacity measurements, standard fiber properties consisting of Micronaire reading, 2.5 and 50% span length, elongation, and fiber tenacity can be obtained for about $2 to $4 per sample using the high volume instrument, Stelometer, or fibrograph.

Yarn manufacturers use combinations of various fiber properties to assemble cotton bale mixes to predict yarn performance [17]. The challenge breeders face is to exploit individual fiber properties in early generations of breeding, which will result in germplasm with improved yarn tenacity. A successful breeding scheme relies on identifying those common fiber properties genetically correlated [2] with yarn tenacity. The existence of a genetic correlation between two traits such as fiber tenacity and yarn tenacity implies that selecting for either trait will result in a corresponding change in the trait not selected for. No study that we could find has compared in a breeding population the response of yarn tenacity to selection for individual or combinations of fiber properties.

The Arealometer is another instrument that breeders may use to evaluate the fiber properties of their experimental cottons [10]. The Arealometer measures resistance to airflow at low and high compression volumes of a constant weight of fibers. From these two airflow measurements, it is possible to calculate other fiber parameters such as perimeter and maturity. The advantage of the Arealometer over the Micronaire instrument is that both maturity and fineness can be calculated.

These properties may be measured for a relatively cost efficient \$5 per sample. In genetic studies, the Arealometer instrument has received little attention as a tool to select for improved yarn tenacity. Meredith *et al.* [15] reported that perimeters measured with an Arealometer explain 50% of the variation in yarn tenacity for nineteen cotton cultivars, suggesting the use of fiber perimeter as a possible additional selection criteria for improved yarn tenacity. Other studies relating fiber properties to variations in yarn tenacity among cultivars have found some Arealometer properties associated with yarn tenacity [7, 18].

Our objective in this study is to compare fiber properties as selection criteria for genetically improved yarn tenacity.

Methodology

For two years, we evaluated 25 experimental cotton lines from the ARS/Clemson cotton breeding program at two locations on the Pee Dee Research and Education Center, Florence, SC. We used a randomized complete block design with four replicates for each test. Cotton was produced using Clemson University Cooperative Extension Service recommended cultural practices.

We determined fiber and yarn properties on each genotype from twenty-five hand-picked bolls from each replicate. Prior to ginning, boll samples were combined from two replicates (1 + 2, 3 + 4) to yield sufficient lint for the desired testing. The boll samples were ginned on a ten-saw laboratory gin. All fiber and yarn tests were performed by Starlab, Knoxville, TN. Fiber length as 2.5% and 50% span lengths was determined with a fibrograph, along with fiber tenacity (T_1, 3.2 mm gauge) and elongation (E_1) by the Stelometer. Micronaire values were recorded with a fibronaire instrument. We obtained Arealometer values *AH* and *AL*, resistance to airflow in the Arealometer instrument, from which we calculated the following fiber properties [19]: *D* value, difference between *AH* and *AL* values; maturity % (*Mat*); weight fineness (*FINE*), mass per unit length of fiber; wall thickness (*THIC*), fiber cell wall thickness in microns; and perimeter (*PER*), distance around the outside of the fiber. Finally, we determined the yarn tenacity of 27 tex (22 Ne) ring spun yarn with yarn spinning methods appropriate for small fiber samples [11, 12].

We subjected each fiber property and yarn tenacity to analysis of variance (ANOVA) across years and locations. We computed the heritability of each trait from the genotypic variance divided by the appropriate phenotypic variance, where these estimates were derived from the ANOVA across years and locations. We assessed the utility of each fiber property as a selection criterion to improve yarn tenacity as follows: we computed simple correlations between each fiber property with yarn tenacity from genotypic means calculated across years and locations. We then used the direction of the correlation between yarn tenacity and each putative selection criterion to select the best five (*e.g.*, highest or lowest, depending on sign of the correlation) out of twenty-five genotypes based on location means in 1992, and observed their yarn tenacity in 1993, also using means across locations. We then expressed observed improvement in yarn tenacity as the mean of the selected five genotypes minus the mean of all twenty-five genotypes.

We accomplished selection for more than one fiber property by using a selection index [8], which allows a set of genotypes to be ranked based on combinations of two or more fiber traits. The index computes a single value for each experimental genotype based on combinations of two or more fiber properties. For example, to rank the twenty-five genotypes simultaneously for T_1 and *FINE*, assuming that it is desirable to increase T_1 while simultaneously decreasing *FINE* so that a gain in yarn tenacity may be realized in the next generation, we used the following formula to compute a composite value for each experimental cotton:

$$[X_i - \text{minimum } T_1 \text{ value of 25 lines}] \times [(-1 \times FINE)_i + \text{maximum } FINE \text{ value of 25 lines}] \quad ,$$

where X_i and i refer to the T_1 and *FINE* data, respectively, for the ith experimental genotype. These twenty-five index values were then the basis for ranking the genotypes for this combination of traits. We calculated the index values from 1992 genotypic means across replicates and locations, and the response of yarn tenacity to index selection in the same manner as described for response to selection for a single fiber property. Many of the fiber properties measured by the Arealometer are highly correlated with each other, since they are defined in terms of *AH*, *AL*, or quantities derived mathematically from *AH* and *AL* [19]. Therefore, in choosing traits to include in the selection index, we avoided combinations of highly correlated traits.

Results and Discussion

We observed significant genotypic variation for all fiber properties except *PER*, along with yarn tenacity (Table I). Although there exist some significant ($P < 0.05$) genotype $\times$ location $\times$ year interactions, the

TABLE I. Variance estimates for genotype and the interactions of genotypes with years and locations for fiber properties and yarn tenacity.

Source of variation	Trait[a]												
	MIC	2.5% *SL*	50% *SL*	E_1	T_1	*YT*	*AH*	*AL*	*D*	*MAT*	*FINE*	*THIC*	*PER*
Genotype	0.021**	0.0003**	0.00005**	0.048**	0.115*	9.36*	139.56**	92.0**	5.33**	3.29**	0.0094**	0.0081**	0.23
Genotype × yr	0[b]	0[b]	0[b]	0.002	0.015	0.24	19.98	7.5	2.00	1.24	0[b]	0.0020	0.03
Genotype × loc	0[b]	0.000031	0.000023	0.001	0[b]	1.65	0[b]	4.5	0[b]	0[b]	0.0018	0[b]	0[b]
Genotype × yr × loc	0.0023	0[b]	0[b]	0.037*	0.191	2.25	73.9*	38.7	5.08*	2.97	0[b]	0.0058*	0.14

[a] *MIC* = Micronaire reading, 2.5% *SL* = 2.5% span length, 50% *SL* = 50% span length, E_1 = elongation, T_1 = fiber tenacity, *YT* = yarn tenacity, *AH* and *AL* = Arealometer resistance to airflow at high and low pressures, respectively, *D* = difference between *AH* and *AL*, *MAT* = % maturity, *FINE* = weight fineness, *THIC* = fiber cell wall thickness, and *PER* = fiber perimeter. * and ** indicate variance is significantly greater than zero at 5 and 1% probability levels, respectively. [b] Negative estimate for which most reasonable value is zero.

variation due to genetic differences among the lines was generally large relative to the interaction components. Only for T_1 was the genotype × location × year variance larger than genetic variation, though it was not significant. For these fiber properties, with the exception of *MIC* in a few instances, other studies have found that interactions of genotypes with environments are generally small relative to genetic variation [7, 14, 15]. The high heritability estimates for most of the fiber properties support this contention (Table II). Heritability is the ratio of genetic variation and observed, or phenotypic, variation. Phenotypic, or observed, variation is composed of genetic and environmental variation along with their interaction. Heritability takes a value between 0 and 100% and indicates the extent to which observed variation among a set of genotypes is due to genetic effects. Heritability values are thus suggestive of the progress expected from selections made by the breeder. The presence of significant differences among cotton lines combined with no previous selection for fiber or yarn properties provides an opportunity to assess each fiber property as a means to improve yarn tenacity.

TABLE II. Heritability values for fiber properties.

Trait[a]	Heritability
MIC	0.85**
2.5% *SL*	0.91**
50% *SL*	0.58**
E_1	0.76**
T_1	0.57*
YT	0.91**
AL	0.79**
AH	0.78**
D	0.66**
MAT	0.65**
FINE	0.61**
THIC	0.75**
PER	0.29

[a] Abbreviations the same as for Table I. * and ** indicate heritability estimate is greater than zero at 5 and 1% probability levels, respectively.

Based on selection for a single fiber property, 50% span length provided the greatest improvement in yarn tenacity (Table III), suggesting a strong positive genetic correlation between these traits. Selecting for long 50% span length also identified two of the five genotypes in 1993 with the best yarn tenacity. This finding contrasts with studies reporting that fiber tenacity is the chief fiber trait associated with yarn tenacity variation [7, 15].

TABLE III. Response of yarn tenacity to selection for fiber properties.

Selection criteria[a]	Response of yarn tenacity, Mn/tex
Low *MIC*	1.14
Long 2.5% *SL*	1.84
Long 50% *SL*	2.39
High E_1	0.37
High T_1	1.74
High *AL*	1.14
High *AH*	1.14
High *D*	0.50
Low *MAT*	0.49
Low *FINE*	0.34
Low *THIC*	1.44
Low *PER*[b]	–
Low *MIC*, long 50% *SL*, high T_1	2.49
Low *MIC*, long 2.5% *SL*, high T_1	2.24
Low *FINE*, long 50% *SL*, high T_1	2.49

[a] Abbreviations the same as for Table I. [b] Not determined since genotypic variation was not significant.

The influence of a longer 50% span length on yarn tenacity is not well defined but could reflect the better overall length uniformity considered beneficial for ring spinning performance [4]. After 50% span length, selection for 2.5% span length and fiber tenacity resulted in the next largest gain in yarn tenacity (Table III). Of course, the fiber properties are correlated with each other, particularly 2.5 and 50% span lengths (Table IV). Consequently, in selecting for a single fiber trait, we are simultaneously selecting other fiber properties that are correlated genetically with the primary trait.

Selecting for high E_1 provided the least improvement in yarn tenacity, which we did not expect based on a report that elongation is an important predictor of yarn tenacity from bale cotton [1]. This finding suggests a low genetic correlation between E_1 and yarn tenacity. Another possible reason we observed little improvement in yarn tenacity with selection for E_1 could be the significant genotype × location × year interaction. Examination of the nature of the interaction indicates it is due to several complete changes in rank of genotypes across locations and years (data not shown). Rank changes confound the response to selection because genotypes selected as the best types at a particular location or year may not be superior in the next generation of testing.

Of the properties measured with Arealometer, selection for low *THIC* resulted in the most improved yarn tenacity. This level of improvement was not as great as that for 2.5 and 50% span length or T_1, but it was greater than that due to *MIC* despite the high correlation between *MIC* and *THIC* (Table IV). These data indicate that individually, the fiber properties measured with Arealometer are not as valuable as selection criteria for improved yarn tenacity as several of the standard fiber properties. Generally, the magnitude of improvement in yarn tenacity in this population is small yet consistent with the response to selection for traits conditioned by a large number of genes [14].

Maximizing genetic progress towards higher yarn tenacity may have to include concurrent selection for two or more fiber properties. Meredith *et al.* [15] alluded to this in a study relating variation in yarn tenacity to various fiber properties in a diverse set of advanced breeding lines and cultivars. In that study, T_1 was the chief individual fiber property explaining variation in yarn tenacity, but the interaction of span length, T_1, and fineness was also important. In our study, we selected genotypes based on multiple traits using a selection index [8], which is a statistical tool that allows a breeder to rank a set of genotypes for multiple traits. From two or more traits, the index computes a composite value for each genotype, which the breeder then uses to select genotypes to advance for the next generation of evaluation. This process is analogous to the methods yarn manufacturers employ in selecting cotton bales to make yarn based on measures of fiber length, fiber tenacity, and fineness [17]. In our study, selecting for the combination of low *MIC*, long 50% span length, and high T_1 resulted in more yarn tenacity gain than selecting for any single fiber property [Table IV]. Other studies have found T_1, measures of fiber fineness, and 2.5% fiber length to be important predictors of yarn tenacity when evaluating advanced generation breeding lines or cultivars [15]. Simultaneously selecting for low *MIC*, long 2.5% span length, and high T_1 resulted in slightly less yarn tenacity improvement than selecting for *MIC*, T_1, and 50% span length [Table IV].

We wanted to determine if the fiber properties measured by the Arealometer could be combined with common fiber traits such as length and strength, thus offering breeders additional selection criteria for improved yarn tenacity. Data in Table IV indicate that many of the Arealometer measured properties are highly correlated with the other fiber properties. Since *MIC*, *AH*, and *AL* are all measures of resistance to airflow, it follows that these traits are highly correlated and thus measure similar fiber properties in this cotton population. Consequently, in choosing combinations of fiber traits to include in the selection index, we avoided combining traits with correlations similar in magnitude to

TABLE IV. Simple correlations among fiber properties.[a]

	MIC	*50% SL*	*2.5% SL*	E_1	T_1	*YT*	*AL*	*AH*	*D*	*MAT*	*FINE*	*THIC*
50% SL	−0.17											
2.5% SL	−0.28	0.83**										
E_1	−0.13	0.01	−0.09									
T_1	0.12	0.31	0.07	−0.35								
YT	−0.44**	0.64**	0.44*	0.09	0.50*							
AL	−0.94**	0.26	0.37	0.14	−0.09	0.54**						
AH	−0.93**	0.26	0.39	0.19	−0.13	0.52**	0.99**					
D	−0.80**	0.24	0.42*	0.36	−0.27	0.39	0.88**	0.92**				
MAT	0.79**	−0.25	−0.44*	−0.37	0.27	−0.40*	−0.87**	−0.92**	−0.99**			
PER	−0.21	0.10	0.33	0.53*	−0.39	0.01	0.28	0.38	0.71**	−0.72**		
FINE	0.75**	−0.19	−0.15	0.23	−0.16	−0.50*	−0.77**	−0.70**	−0.37	0.36	0.39	
THIC	0.91**	−0.29	−0.44*	−0.21	0.13	−0.53**	−0.99**	−0.99**	−0.93**	0.93**	−0.41*	0.67**

[a] Abbreviations the same as for Table I. * and ** indicate that correlation is different from zero at 5 and 1% probability levels, respectively.

those among *AH*, *AL*, and *MIC*. One such combination is that of *FINE*, T_1, and 50% span length. Although the correlation between *MIC* and *FINE* was high [$r = 0.75$], it was not of a magnitude to indicate that *FINE* and *MIC* are redundant properties. Simultaneous selection for low *FINE*, long 50% span length, and high T_1 resulted in more gain in yarn tenacity than selection for any single trait [Table IV]. The magnitude of gain was, however, the same as selecting for low *MIC*, long 50% span length, and high T_1.

Another fiber property measured by the Arealometer that has been used to explain variation in yarn tenacity is *PER* [15]. In our study, there was no significant genotypic variation in *PER*, and so we could not assess it as a selection criterion to improve yarn tenacity. We would expect cotton fibers with smaller perimeters, high maturity, and T_1 to produce stronger yarns relative to coarser fibers with similar maturity and T_1 [6]. Considering the cost of obtaining Arealometer measurements in addition to that of the standard fiber properties, their use as selection criteria to improve yarn tenacity is not warranted in this cotton population.

While the Arealometer measured fiber properties were of little value as criteria to improve yarn tenacity, breeders may soon exploit new instruments to measure cotton fiber properties. The advanced fiber information system [AFIS] provides properties not measured by the Arealometer, Stelometer, Micronaire, or fibrograph instruments [16]. Several of the AFIS measured fiber properties, including fiber area and diameter, explain a large portion of the variability in yarn tenacity in a set of cotton germplasm lines and cultivars [16]. An important finding is that the AFIS properties estimate a larger genetic component relative to environmental variation when compared with the Arealometer [16]. These properties deserve further study as selection criteria to improve yarn tenacity. Another recent finding that may provide breeders and yarn manufacturers with fiber information to predict yarn tenacity is the contribution of fiber waxes and lubricants. Taylor [20] reported that cotton from bales with the highest amounts of wax and lubricants processed into the strongest yarns and fabrics. Additionally, total wax and lubricant was estimated by a simple near-infrared measurement without costly laboratory analysis. The contribution of genetics to variation in wax content of cultivars has yet to be investigated.

Conclusions

We have accomplished maximum improvement in yarn tenacity in a breeding population by selecting for the combination of low *MIC*, long 50% span length, and high T_1. We have found that 50% span length is a useful single fiber property with which to select for higher yarn tenacity. The 50% span length is cost-efficient and easily obtained during all phases of breeding. Compared with fiber tenacity or length measurements, fiber properties measured with the Arealometer are not as useful as selection criteria to improve yarn tenacity.

Literature Cited

1. Backe, E. E., The Importance of Cotton Fiber Elongation on Yarn Quality and Weaving Performance, in "Proc. 9th Annual EFS System Conference," Research Triangle Park, NC, 1996, in press.
2. Becker, W. A., Prediction of Correlated Responses, in "Manual of Quantitative Genetics," 5th ed., Academic Enterprises, Pullman, WA, 1992, pp. 27–28.
3. Bowman, D. T., May, O. L., and Calhoun, D. S., Genetic Base of Upland Cotton Cultivars Released Between 1970 and 1990, *Crop Sci.* **36** (3), 577–581 (1996).
4. Culp, T. W., and Harrell, D. C., Breeding Quality Cotton at the Pee Dee Experiment Station, Florence, SC, USDA Publ. ARS S-30, U.S. Gov. Print. Office., Washington, D.C., 1974, pp. 1–12.
5. Culp, T. W., Moore, R. F., and Pitner, J. B., Simultaneous Improvement of Lint Yield and Fiber Strength in Cotton, *S. C. Agric. Exp. Stn. Tech. Bull.* **1090,** 1–10 (1985).
6. Deussen, H., Improved Cotton Fiber Properties—The Textile Industry's Key to Success in Global Competition, in "Cotton Fiber Cellulose: Structure, Function, and Utilization Conf.," National Cotton Council, Cotton Inc., USDA, ARS, Savannah, GA, 1992, pp. 43–63.
7. El-Sourady, A. S., Worley, S. Jr., and Stith, L. S., The Relative Contribution of Fiber Properties to Variations in Yarn Strength in Upland Cotton, *Gossypium hirsutum L.*, *Textile Res. J.* **44** (4), 301–306 (1974).
8. Elston, R. C., A Weight-Free Index for the Purpose of Ranking or Selection with Respect to Several Traits at a Time, *Biometrics* **19,** 85–97 (1963).
9. Faerber, C., Future Demands on Cotton Fiber Quality in the Textile Industry: Technology—Quality—Cost, in "Proc. Beltwide Cotton Production Research Conference," National Cotton Council, San Antonio, TX, 1995, pp. 1449–1454.
10. Hertel, K. L., and Craven, C. J., Cotton Fineness and Immaturity as Measured by the Arealometer, *Textile Res. J.* **21** (11), 765–774 (1951).
11. Landstreet, C. B., Ewald, P. R., and Hutchens, H., The 50-gram Spinning Test: Its Development and Use in Cotton Quality Evaluation, *Textile Res. J.* **32,** 655–669 (1962).
12. Landstreet, C. B., Ewald, P. R., and Kerr, T., A Miniature Spinning Test for Cotton, *Textile Res. J.* **29,** 701–706 (1959).

13. May, O. Lloyd, and Green, C. C., Genetic Variation for Fiber Properties in Elite Pee Dee Cotton Populations, *Crop Sci.* **34,** 684–690 (1994).
14. Meredith, W. R. Jr., Quantitative Genetics, in ''Cotton,'' R. J. Kohel and C. F. Lewis, Eds., American Society of Agronomy, Madison, WI, 1984.
15. Meredith, William R. Jr., Culp, T. W., Robert, K. Q., Ruppenicker, G. F., Anthony, W. S., and Williford, J. R., Determining Future Cotton Variety Fiber Quality Objectives, *Textile Res. J.* **61** (12), 715–720 (1991).
16. Meredith, W. R. Jr., Sasser, P. E., and Rayburn, S. T., Regional High Quality Fiber Properties as Measured by Conventional and AFIS Methods, in ''Proc. Beltwide Cotton Prod. Res. Conference,'' National Cotton Council, Nashville, TN, 1996, pp. 1681–1684.
17. Relationship of Fiber Strength to Yarn Strength, *Textile Top.* **15** (12) (1987).
18. Ramey, H. H. Jr., Lawson, R., and Worley, S. Jr., Relationship of Cotton Fiber Properties to Yarn Tenacity, *Textile Res. J.* **47** (10), 685–691 (1977).
19. Rayburn, S. T., Regional Cotton Variety Tests, USDA, ARS, Stoneville, MS, 1993, pp. 5–6.
20. Taylor, R. A., Predicting Denim Fabric Strength from Fiber Measurements, in ''Proc. 9th Annual EFS System Conference,'' Research Triangle Park, NC, 1996, pp. 54–67.

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