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Variation and relationship of quality and near infrared spectral characteristics of cotton fibers collected from multi-location field performance trials

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Abstract

Standardized instrument for testing of cotton (SITC) and advanced fiber information system (AFIS) measurements are increasingly being utilized as primary and routine means of acquiring fiber quality data by cotton breeders and fiber processors. A significant amount of information regarding fiber and yarn qualities is present, but little information exists about the compositional and chemical structure difference of cotton fibers harvested at different locations. Such information could prove useful in attempts to understand the variety selection of cotton cultivars. The purpose of this study was to characterize the fiber SITC and AFIS quality and also yarn skein strength of cottons harvested from various locations, and also to unravel the near infrared (NIR) spectral response to these differential environments. Moderate positive or negative relationships among fiber properties were observed. However, these relationships varied across experimental locations and years. Further, the analysis of variance tests indicated substantial variations among genotypes for most fiber properties, but less detectable variation among genotypes for yarn tenacity. Interestingly, principal component analysis of NIR spectra enhanced the similarity or dissimilarity of cotton fibers harvested at differing locations, implying the feasibility of the NIR technique for site selection in future cotton variety trials.

Keywords

cotton fiber, fiber quality, yarn quality, standardized instrument for testing of cotton, advanced fiber information system, growing environment, near infrared, principal component analysis

Cotton is one of the most important agricultural commodities in the world, and its production is determined by at least three main factors and interactions among them. These include genotype, environment, and production practices. These three factors and their interactions influence both yield and fiber quality potential and ultimately determine the growers' and processors' profitability.[1] Thus, the desired cotton cultivars for both cotton growers and fiber/fabric processors would be high fiber yield and good fiber quality.

Relating the genotype and environment to fiber quality could assist cultivar development and selection for targeted cotton production areas. Over the years, various techniques and systems, including optical, physical, and chemical methods, have been developed to measure a number of cotton fiber properties and also processed yarn qualities.[2–7] Among them, high volume instrumentation (HVI™) and advanced fiber information system (AFIS) measurements are being utilized as primary and routine tools of acquiring fiber quality properties by cotton breeders and fiber processors.

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The United States Department of Agriculture's (USDA's) Agricultural Marketing Service (AMS) has relied on the automation-based HVI™ procedure, as a universal testing method and official classification system, to measure the fiber color, leaf grade, and such physical properties as micronaire, strength, length, and uniformity. The International Cotton Advisory Committee has proposed the HVI™ as a standardized instrument for testing of cotton (SITC) that is now used in place of HVI™ . This system uses automated sampling techniques and evaluates multiple fiber characteristics at a relatively high speed. Unlike or complementary to the SITC, the AFIS reports up to 14 cotton fiber properties from a 0.5 g fiber sliver containing 3000–5000 fibers simultaneously, including the fiber maturity ratio, fineness, length distributions, trash content, and neps.

Although the SITC and AFIS methods determine a number of cotton fiber properties, there is no chemical/molecular structure information on these cottons available from such physical tests. Hence, it will be of interest to obtain structural data from additional measurements. Such measurements include mid-infrared (mid-IR),[8] near infrared (NIR),[9] and Raman spectroscopy,[10] as well as x-ray diffraction.[11] Due to the speed, ease of use, minimum sample preparation, and potential on-line/off-line implementations, NIR spectroscopy was performed in this study. Not only has it been used to characterize the distinctive NIR spectral difference between white and naturally colored cottons,[12] but it can also be used to perform the qualitative classification and quantitative prediction of interested cotton quality properties, such as micronaire.[13–15]

With unique absorptions in the region from 750 to 2500 nm (or from 13,300 to 4000 cm^{-1}), NIR spectra represent the overtones and combination bands of the fundamental absorbances observed in the mid-IR spectral regions of cotton fiber cellulose.[9] It is likely that NIR spectra might detect subtle differences between two sets of cotton fibers that exhibit similar fiber qualities but were harvested at different locations, with the aid of multivariate data analysis, namely principal component analysis (PCA). PCA is a very effective variable reduction technique for spectroscopic data from n variables (2780 in this study) to a fewer number of dimensions.[16] It decomposes a set of spectra into mathematical spectra (called loading vectors, factors, principal components (PCs), etc.) that represent the most common variations to all spectral data. The correlations among samples (or spectra) are indicated by their scores (or projections) on new PCs. Similar samples tend to group together in the score–score plot and, in turn, atypical samples could be easily detected by the simple visualization.

Although genotypic and environmental contributions to fiber quality have been studied considerably in the cotton industry for a long period,[17–19] little published information exists regarding the variation of both fiber and yarn spinning quality of cottons harvested from different locations. The main objectives of the current study were (1) to compare cotton fiber and yarn qualities for a range of field evaluation trials in South and North Carolina over a two-year period, (2) to relate these parameters with entry lines and growing environments, and (3) to characterize the NIR spectral response to cotton fibers grown at various environments. Observation of spectral similarity or difference among cottons at different environments/locations might allow for more effective selection of growing sites in field evaluation trials.

Materials and methods

Cotton samples

In 2011 and 2012, a total of 20 entries (16 elite breeding lines and 4 commercial cultivars) were evaluated in replicated field tests at the Clemson University Pee Dee Research and Education Center near Florence, South Carolina (Florence), the Clemson University Edisto Research and Education Center near Blackville, South Carolina (Blackville), and the North Carolina State University Sandhills Research Station near Jackson Springs, North Carolina (Sandhills). In Florence, trials were evaluated on a Norfolk loamy sand soil (fine-loamy, kaolinitic, thermic Typic Kandiudults). In Blackville, trials were evaluated on a Barnwell loamy sand soil (fine-loamy, kaolinitic, thermic Typic Kanhapludults). In Jackson Springs, trials were evaluated on a Candor sand soil (sandy, kaolinitic, thermic Grossarenic Kandiudults). Each trial was arranged in a randomized complete block design with four replications. Each entry was grown in a two-row plot 10.7 m long with 96.5 cm spacing between rows. Plots were managed conventionally and followed the established local practices.

For each trial, 50 bolls were hand harvested from each plot. Boll samples were subsequently ginned on a 10-saw laboratory gin and lint fibers were collected. Cotton lint fibers were conditioned at a constant relative humidity of $65 \pm 2\%$ and temperature of 21 ± 2 °C for at least 24 hours, prior to subsequent fiber and yarn quality measurement as well as visible/NIR spectral acquisition.

Fiber quality measurement

Average micronaire, upper-half mean length (UHML), and strength values were obtained from five replicates on each sample by a SITC system (Uster® HVI™ 900 A, Uster Technologies Inc., Knoxville, TN). AFIS fineness was determined from five repeats by an Uster® AFIS-Pro (Uster Technologies Inc., Knoxville, TN). All measurements were performed at the Southern Regional Research Center of USDA's Agricultural Research Service (USDA-ARS-SRRC). The same instruments were used for all samples during experiments. Both instruments were calibrated throughout the study following the manufacturer's recommendations.

Yarn quality measurement

With the available sample amount in the range of 70–90 g, a mini-spinning protocol was applied by carding approximately 60 g per sample on a modified Saco Lowell Model 100 card. The carded web was drawn into slivers on a modified Saco Lowell DF 11 draw frame. Two bobbins of ring spun yarn were spun to a nominal count of Ne 30/1 per sample. A 54.9 m (or 109.8 m for the 2012 cottons) mini-skein was produced from each bobbin and tested on an Instron tensile tester.[20] In addition, each bobbin was tested for 1 min at 91.4 m/min on an Uster Tester 4 (UT4) and 20 single-end breaks on an Uster Tensorapid 4. The skein strength was reported in single-end tenacity equivalent (g/tex), which is a normalization process to account for yarn size variations.

Fiber and yarn quality data analysis

For each individual growing environment in 2011 and 2012, fiber and yarn quality data were subjected to an analysis of variance (ANOVA) by SAS to test if differences exist among the 20 breeding lines (PROC GLM, Version 9.2, SAS Institute Inc, Cary, NC). Also, homogeneity of variance tests was conducted to determine if data could be combined across environments in a single year. Data could not be combined across two-crop years because 2011 and 2012 trials did not contain all of the same breeding lines. Following validation of homogeneous variances, data were combined across environments and subjected to a mixed model ANOVA. Environments, replicates within environments, and entry × environment were considered random effects, while entries were considered fixed effects. The PROC GLM module of SAS (with the RANDOM statement) was used to perform the mixed model ANOVA.

Acquisition of visible/NIR reflectance spectra of cotton fibers

Visible/NIR reflectance spectra were acquired on a Foss XDS rapid content analyzer (Foss NIRSystems Inc., Laurel, MD). Approximately 10 g of cotton fibers were pressed into a Foss coarse granular cell (3.8-cm wide × 15.2-cm long × 4.8-cm deep). Background was recorded with the use of an internal ceramic reference tile before scanning the samples. The log (1/Reflectance) readings were acquired over the 400–2500 nm wavelength range at 0.5 nm interval and 32 scans. Two spectra were collected for each of the cotton samples by repacking and the mean spectrum was obtained.

All spectra were imported into GRAMS IQ application in Grams/AI (Version 9.1, Thermo Fisher Scientific, Waltham, MA), and subsequent PCA characterization was performed in the 1105–2495 nm NIR region with mean centering (MC) and Savitzky–Golay first-derivative (2 degrees and 13 points) spectral pretreatment. The data set was defined by n variables or data points (in this study, $n = 2780$ wavenumbers in the 1105–2495 nm region with 0.5 nm intervals) and m samples (in this study, $m = 99$). PCA models the maximum directions of variations in this spectral set by projecting the objects (or spectra) as a cluster of points in a space defined by PCs. Each PC is a linear function of a number of original variables, resulting in a reduction of the original number of variables. PCs describe the most variations among the spectra in a decreasing order, and each PC can be interpreted independently, since they are calculated to be orthogonal to one another. Simply, PCs describing this decomposition are presented as

$$PC_i = a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{in}X_n$$

where i is the PC number used ($i < n$), a is the loading vectors or eigenvectors, n is the number of variables, and X is the original spectral intensity.

In brief, both quality properties and spectral data were obtained on each plot in each trial (four reps per entry in each trial) and then the mean in each trial was used for analysis.

Results and discussion

Fiber and yarn quality characteristics

Quality results from this study included fiber analysis from routine SITC and AFIS protocols, and yarn characteristics from conventional tensile procedures. The selected fiber properties were SITC micronaire, UHML, and strength as well as AFIS fineness. Fiber spinning performance was determined as yarn tenacity from the skein test. Table 1 summarizes the range, mean, and standard deviation (SD) of selected fiber and yarn qualities for the 20 genotypes in three growing locations over two consecutive years.

Table 1. Range, mean, and standard deviation of selected fiber and yarn qualities in three growing locations and two crop years

		2011 crop year			2012 crop year	
		Blackville	Florence	Sandhills	Blackville	Sandhills
Micronaire (Units)	Range	4.50–4.99	4.74–5.37	4.80–5.61	3.68–4.25	3.94–4.57
	Mean	4.71	5.09	5.22	4.00	4.23
	SD	0.13	0.18	0.18	0.13	0.18
Strength (gm/tex)	Range	30.07–34.13	26.76–33.20	27.97–36.32	29.77–33.91	29.80–34.15
	Mean	31.78	29.77	31.18	31.41	31.59
	SD	0.96	1.80	1.69	1.11	1.23
UHML (mm)	Range	30.0–31.5	26.4–29.2	26.9–29.7	30.0–33.5	29.5–32.2
	Mean	30.7	27.4	27.9	31.2	30.5
	SD	0.51	0.76	0.76	1.02	1.02
Fineness (mtex)	Range	171.4–186.2	173.2–194.8	179.2–204.6	165.7–178.8	156.2–177.0
	Mean	181.4	186.0	192.0	171.4	165.8
	SD	3.85	5.48	5.20	3.84	5.93
Tenacity (g/tex)	Range	44.32–54.16	39.66–53.23	43.86–54.84	44.30–50.99	43.71–52.00
	Mean	49.27	46.36	47.58	47.17	47.22
	SD	2.37	4.10	2.89	2.03	2.14

UHML: upper-half mean length.

Among the 2011-year cottons, the mean fiber micronaire of 20 entries at Blackville was lower (4.71) than those from identical entries at Florence and Sandhills that had respective micronaire values of 5.09 and 5.22. For the 2012-year cottons from two locations (Blackville and Sandhills), micronaire values were relatively close (4.00 versus 4.23). Cotton fineness showed nearly the same pattern as micronaire, which is expected as micronaire is determined by both maturity (degree of secondary cell wall development) and fineness (weight per unit length) of the fibers.[21]

Cotton fibers were assigned into "Discount Range," "Base Range," and "Premium Range" classes according to the established criterion,[22] which represent the micronaire values in the respective range of <3.5 or >5.0, 3.5–3.6 or 4.3–4.9, and 3.7–4.2. In this regard, the 2012-year cottons from both Blackville and Sandhills areas could be considered as high grade or premium cottons in terms of micronaire.

There were evident differences in UHML among locations ranging from 27.4 to 30.7 mm within 2011-year cottons and 30.5 to 31.2 mm between the 2012-year cottons.

The 2011-year fibers from two locations (Blackville and Sandhills) were stronger than those from Florence (~31.5 versus 29.8 gm/tex), and yarn tenacity suggested the same trend. In contrast for the 2012-year cottons, fiber strength and year tenacity did not differ among two growing locations.

Table 2. Univariate correlation coefficients for five fiber and yarn qualities[a]

Micronaire	UHML	Strength	Fineness	Tenacity
Micronaire	–0.76			
UHML	–0.17	0.60		
Strength	0.92	–0.64	–0.12	
Fineness	0.01	0.19	0.46	0.01
Tenacity				

[a]Absolute values greater than 0.50 were objectively considered to have significant correlation, the values between 0.50–0.20 to have moderate correlation, and the values less than 0.20 to have insignificant correlation.
UHML: upper-half mean length.

In general, from the 2011-year to 2012-year cottons, micronaire and fineness decreased, UHML increased, and fiber strength and yarn tenacity were nearly unchanged.

Univariate correlation coefficients

The univariate correlation coefficients (or Pearson correlations) between two of the five fiber and yarn quality indices are shown in Table 2. As anticipated, micronaire had positive and significant correlation with fineness, and negative and strong correlation with UHML. Also, it showed insignificant correlations with fiber strength and yarn tenacity. This observation agrees well with a previous report that cottons with the same micronaire values can have different yarn strengths.[23]

UHML had strong correlations with strength and fineness, positively with strength but negatively with fineness. Interestingly, UHML did not correlate with yarn tenacity in the same manner as fiber strength. Probably, the yarn size and ''relatively high'' fiber length for most of the samples mask the classic fiber length to yarn tenacity relationship that is normally observed for ring spun yarns.

Moderate and positive correlation was observed between fiber strength and yarn tenacity, and both indices were not found to have clear relationships with fiber fineness and micronaire.

Correlation of quality indices and growing locations

Although Tables 1 and 2 provide an overall view of fiber and yarn qualities, they might lack the specific details of whether environment could influence one or more quality characteristics. As one example, Figure 1 shows the plot of AFIS fineness against SITC micronaire. Within the line of expectation, AFIS fiber fineness increased linearly with SITC micronaire for both individual and all trial locations generally. Careful examination revealed that the slopes from the regression (or relationship) between fiber fineness and micronaire were 24.8, 28.6, and 24.5 for 2011 Blackville cottons, 2011 Florence cottons, and 2011 Sandhills cottons, and 19.5 and 29.7 for 2012 Blackville cottons and 2012 Sandhills cottons, respectively. As a comparison, the slope was 19.9 for all fibers in Figure 1. Since either the 2011-year or 2012-year cottons were processed and tested simultaneously, such concerns as experimental and instrumental fluctuation could be excluded from the consideration when looking into these variations. Most likely, differences in growing environments (soil, nutrition, water, and weather) might be attributed to the varying degree of fiber maturity, as indicated by fiber micronaire and fineness that varied greatly with both growing locations and crop years.

Another example is the relationship between SITC micronaire and strength (Figure 2). Overall, fiber strength did not change along with fiber micronaire or environment, but it did increase with micronaire, apparently within the 2011 Blackville cottons only. This finding may imply that growing environment impacts the relationship between fiber strength and micronaire (or maturity).

Figure 3 relates SITC strength to fiber length. Although SITC strength increased with SITC UHML generally among all fibers, as characterized by the positive slope of 13.8, there were notable distinctions in the

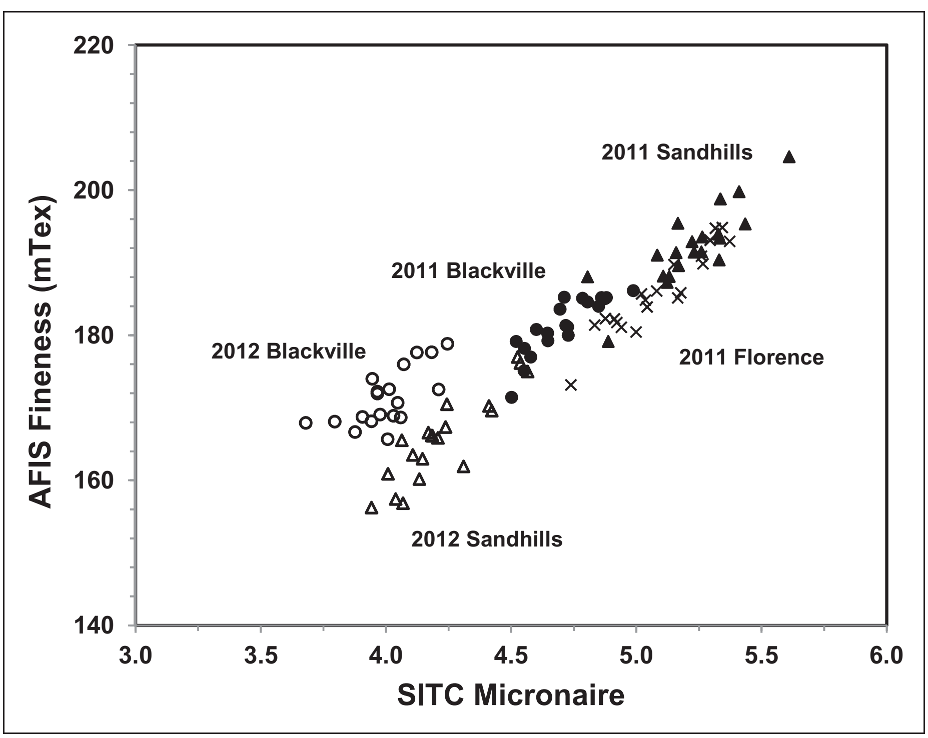

Figure 1. Plot of advanced fiber information system (AFIS) fineness against standardized instrument for testing of cotton (SITC) micronaire (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

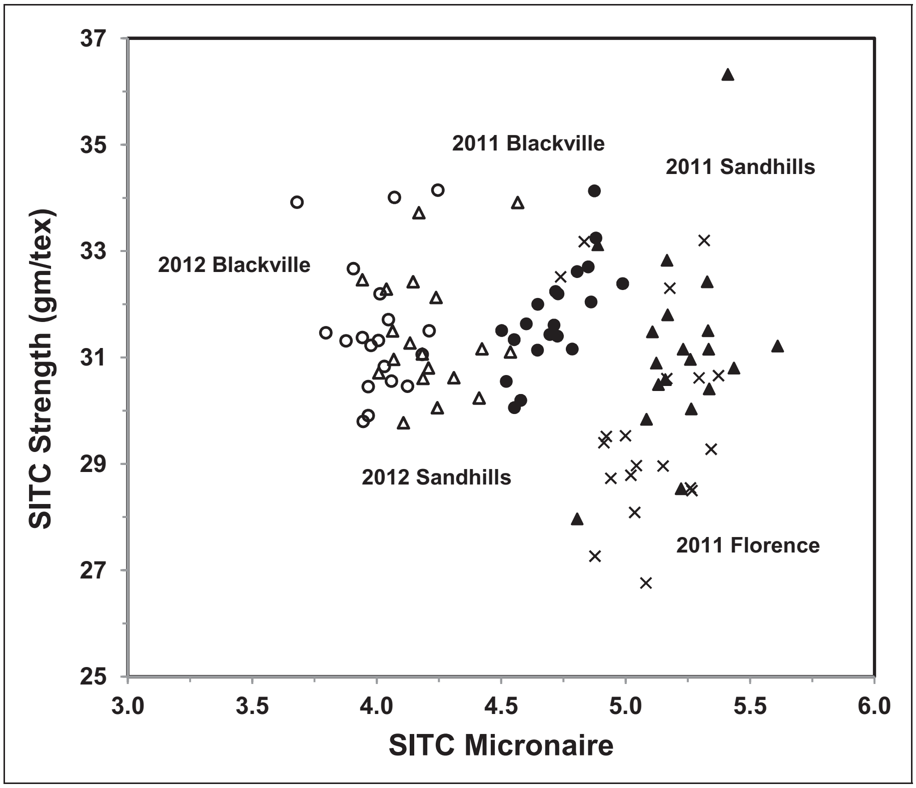

Figure 2. Plot of standardized instrument for testing of cotton (SITC) strength against SITC micronaire (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

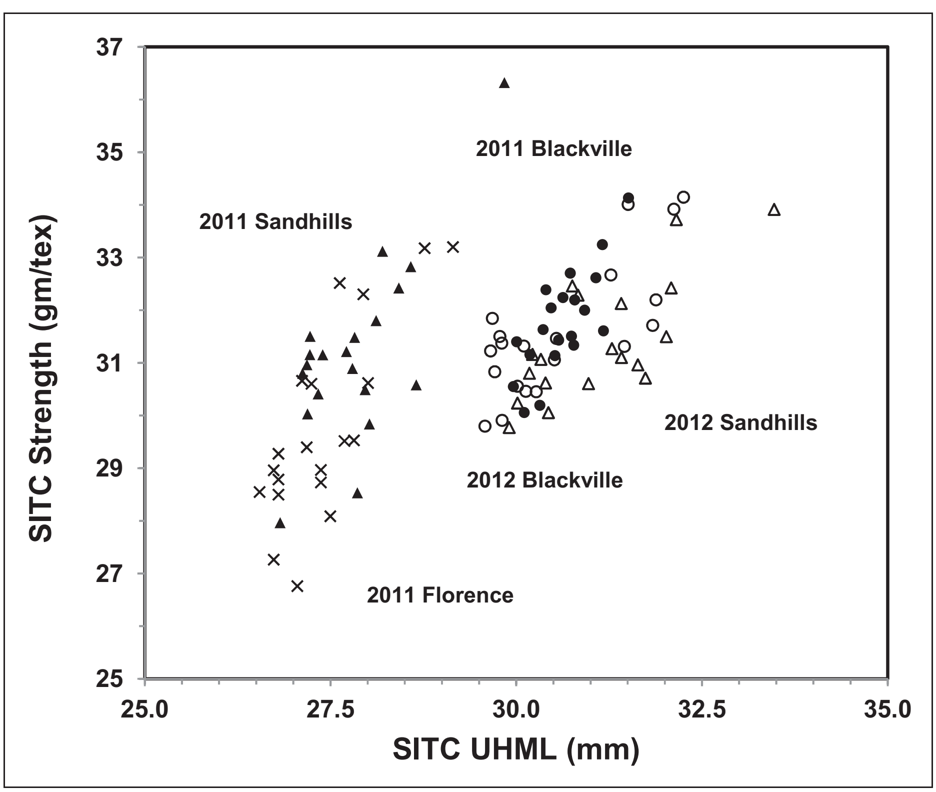

Figure 3. Plot of standardized instrument for testing of cotton (SITC) strength against SITC upper-half mean length (UHML) (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

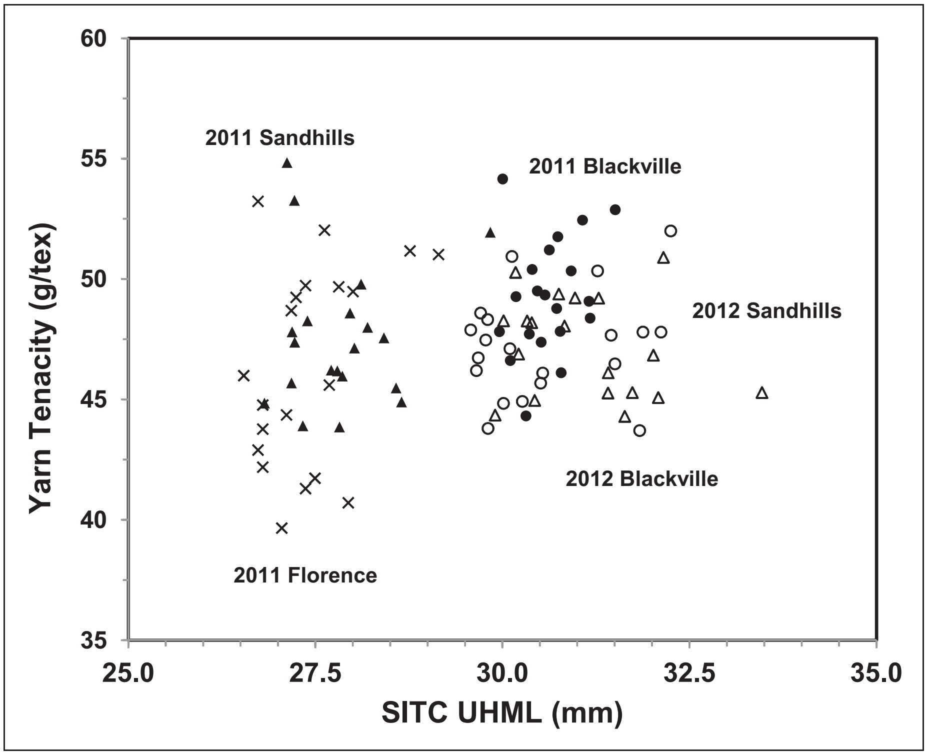

Figure 4. Plot of yarn tenacity against standardized instrument for testing of cotton (SITC) upper-half mean length (UHML) (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

slopes between the 2011-year and 2012-year cottons. The former crops represented the slope range of 45.4–53.0 (45.4 for Sandhills cottons, 53.0 for Florence cottons, and 46.0 for Blackville cottons), and the latter crops exhibited the range of 23.2–26.0 for respective 2012 Sandhills and Blackville cottons.

Unlike the tendency in Figure 3, yarn tenacity was not impacted by fiber UHML index for either individual or combined growing locations (Figure 4).

The plot of yarn tenacity against fiber strength indicated a reasonable trend but with a scattered pattern (Figure 5), which is not surprising. This indicates that likely SITC fiber strength and yarn tenacity measurements represent different fiber breaking mechanisms and need to be explored further. Meanwhile, the results could be limited by the fact that only 60 g of fiber was spun onto only two bobbins and limited reps were tested.

Variation of quality indices among genotypes

Table 3 summarizes the ANOVA tests performed on 2011 data. For each of the fiber characteristics measured, highly significant differences were detected among genotypes or entries. Genotypes displayed significant differences in each of the three individual environments as well as combined across the three environments. Yarn tenacity was only significant among genotypes in the Florence environment and combined across all environments. Among the traits measured, entry × environment interactions were significant for UHML and strength only. This indicated that for micronaire, fineness, and yarn tenacity, entries performed similarly across environments.

Table 4 summarizes the ANOVA tests performed on 2012 data. Similar to the results of 2011 data, significant differences were detected among genotypes or entries for fiber quality characteristics in both individual environments and combined across environments. Yarn tenacity was not different among genotypes in each individual environment or combined across the two environments. Among the traits measured, entry × environment interactions were significant for yarn tenacity only. This indicated that for micronaire, UHML, strength, and fineness, entries performed similarly across environments.

In total, ANOVA tests indicated substantive variations among genotypes for fiber quality characteristics. However, these tests also indicate less detectable variation among genotypes for yarn tenacity. ANOVA tests also indicate more environmental variation among testing sites in 2011 as compared to 2012. In 2011, significant differences among environments were detected for all traits, while only being detected for micronaire

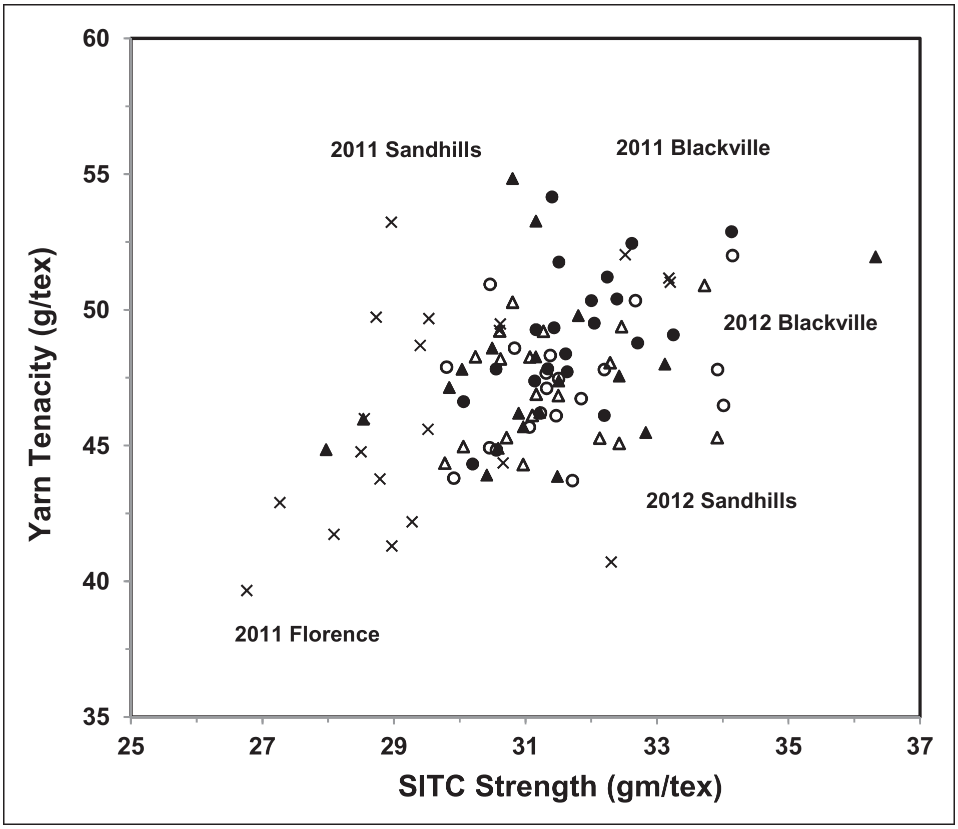

Figure 5. Plot of yarn tenacity against fiber standardized instrument for testing of cotton (SITC) strength (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

Table 3. Analysis of variance for fiber micronaire, upper-half mean length (UHML), strength, fineness, and yarn tenacity for 20 elite breeding lines evaluated in three field trials conducted during the 2011 year

			Mean squares				
Environment	Source of variation	df	Micronaire	UHML	Strength	Fineness	Tenacity
Blackville	Replicate	3	0.069	0.0032	5.4	35	26.1
	Entry	19	0.130**	0.0030**	8.0**	107.0**	24.8
	Error	57	0.026	0.0003	0.9	22.5	16.5
Florence	Replicate	3	0.005	0.0029	8.6	77.2	6.5
	Entry	19	0.137**	0.0029**	13.6**	126.3**	71.0**
	Error	57	0.03	0.0006	1.5	20.1	33.6
Sandhills	Replicate	3	0.005	0.0009	2.1	12.3	10.7
	Entry	19	0.132**	0.0031**	12.0**	113.7**	36.9
	Error	57	0.010	0.0002	0.5	9.5	29.7
Combined	Environment	2	5.70**	0.3749**	82.7**	2398.2**	164.5*
	Replicate (environment)	9	0.026	0.0023	5.4	41.5	14.4
	Entry	19	0.344**	0.0066**	23.4**	314.6**	81.6**
	Entry × environment	38	0.029	0.0012**	5.1**	16.2	25.5
	Error	171	0.022	0.0004	9.6	17.4	26.6

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.

Table 4. Analysis of variance for fiber micronaire, upper-half mean length (UHML), strength, fineness, and yarn tenacity for 20 elite breeding lines evaluated in three field trials conducted during the 2012 year

			Mean squares				
Environment	Source of variation	df	Micronaire	UHML	Strength	Fineness	Tenacity
Blackville	Replicate	3	0.279	0.0016	1.8	142.9	5.7
	Entry	18	0.076*	0.0043**	4.2**	60.5*	13.9
	Error	47	0.041	0.0004	0.6	28.4	9.7
Sandhills	Replicate	3	0.203	0.0032	1.1	103.2	5.7
	Entry	19	0.133**	0.0055**	6.4**	148.0**	19.2
	Error	57	0.026	0.0005	0.5	27.2	12.2
Combined	Environment	1	1.357*	0.0101	0.7	1264.2*	0.2
	Replicate (Environment)	6	0.241	0.0024	1.4*	123.0	5.7
	Entry	19	0.166**	0.0085**	8.3**	164.1**	10.5
	Entry x environment	18	0.040	0.0007	1.6**	42.2	21.5*
	Error	104	0.033	0.0005	0.6	27.7	11.1

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.

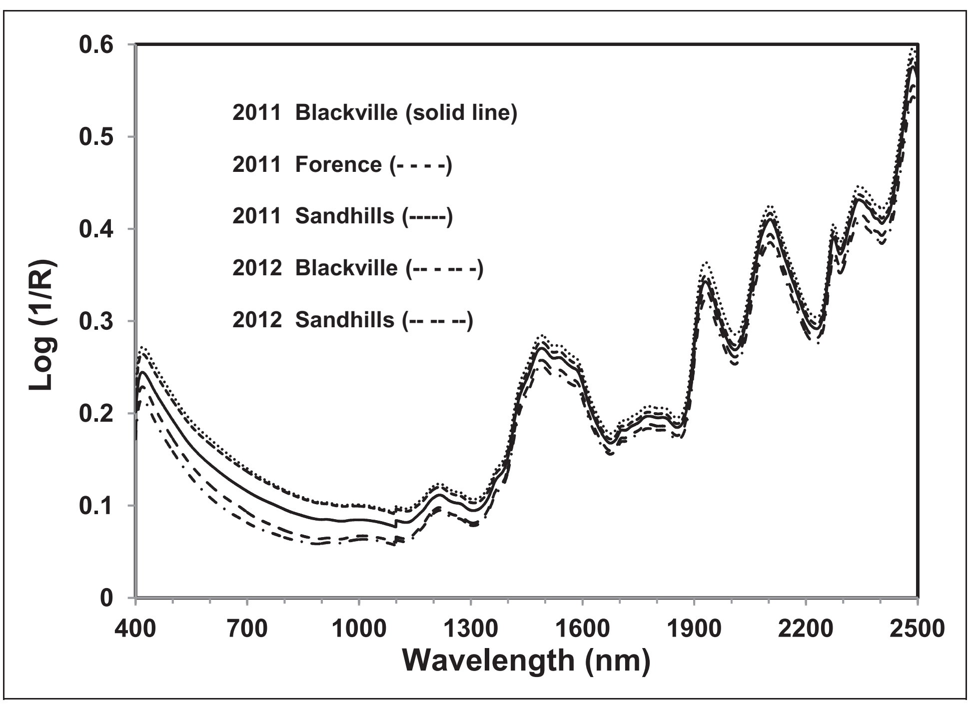

Figure 6. Average log (1/R) spectra of cotton fibers with varying locations and crop years.

and fineness in 2012. These results are consistent with previous studies that suggest greater environmental influences on micronaire and fineness as compared to UHML and strength.[24] Although the total number of environments evaluated in this study is limited, the detection of minimal entry $\times$ environment interactions for fiber quality characteristics is also consistent with previous studies.[24,25]

NIR spectra of cotton fibers

Figure 6 shows the average log (1/R) spectra in the 400–2500 nm region of cotton fibers representing three locations and two crop years. Spectral intensity variations suggested color, physical, and chemical differences among these fibers. There are at least five intense and broad bands with one (<600 nm) in the visible region

(400–750 nm) and four (1490, 1935, 2105, and 2340 nm) in the NIR region (750–2500 nm). In this study, cotton fibers were processed at a small scale; thus, the interferences from cotton plant parts could be presented. In general, the visible region of 400–750 nm contains the color information and represents a mixture of contributions from the pigmentations in cotton fibers, for example, flavonoids,[26] degraded products between a reducing sugar and an amino acid,[27] and also chlorophyll and its degradation derivatives in cotton plants.[28] Whereas the origins of NIR bands differ from those in the visible region, they are mainly due to the (first and second) overtones and combinations of OH and CH stretching vibrations of cotton fiber cellulose.[9] The broad absorptions between 1150 and 1300 nm are from the second overtones of CH stretching modes and their first overtones appear in the 1675–1860 nm region. Features in the 1300–1400 nm region are ascribed to combination bands of the CH vibrations. Broad and intense bands in the 1400–1675 nm region are due to the overlap of the first overtones of the OH stretching modes in hydrogen bonded forms. The strong bands at 1935 and 2105 are most likely attributed to the combination of OH stretching and deformation mode and the combination of OH and CO stretching vibrations in cellulose, respectively.

PCA of NIR spectra

As one approach to interpret the spectral intensity variation, all spectra were subjected to PCA characterization in the 1105–2495 nm region with the full cross-validation method. The first two PCs accounted for 95.5% of the total variation, with the first PC (PC1) and the second PC (PC2) explaining 87.4% and 8.1% of the spectral variation, respectively. As shown in Figure 7, the plot of PC2 versus PC1 scores provided a better visualization of separation among the five environments than such a combination as PC1 versus other PCs. It reveals that the fibers could be distinguished at some degree by the magnitude of fiber micronaire with the use of a sole PC1 score (horizontal axis), which is in good agreement with Table 1. This finding is expected, as NIR spectral intensity fluctuations reflect the chemical, physical, and structural variations among cottons and are associated with the fiber's fineness and maturity.[29] Further, NIR models have been demonstrated to be successful in predicting micronaire quality with high and promising accuracy.[13,15]

PC2 scores along the vertical axis differentiated the Sandhills cottons from the Blackville (and Florence) cottons in respective crop years. The separation

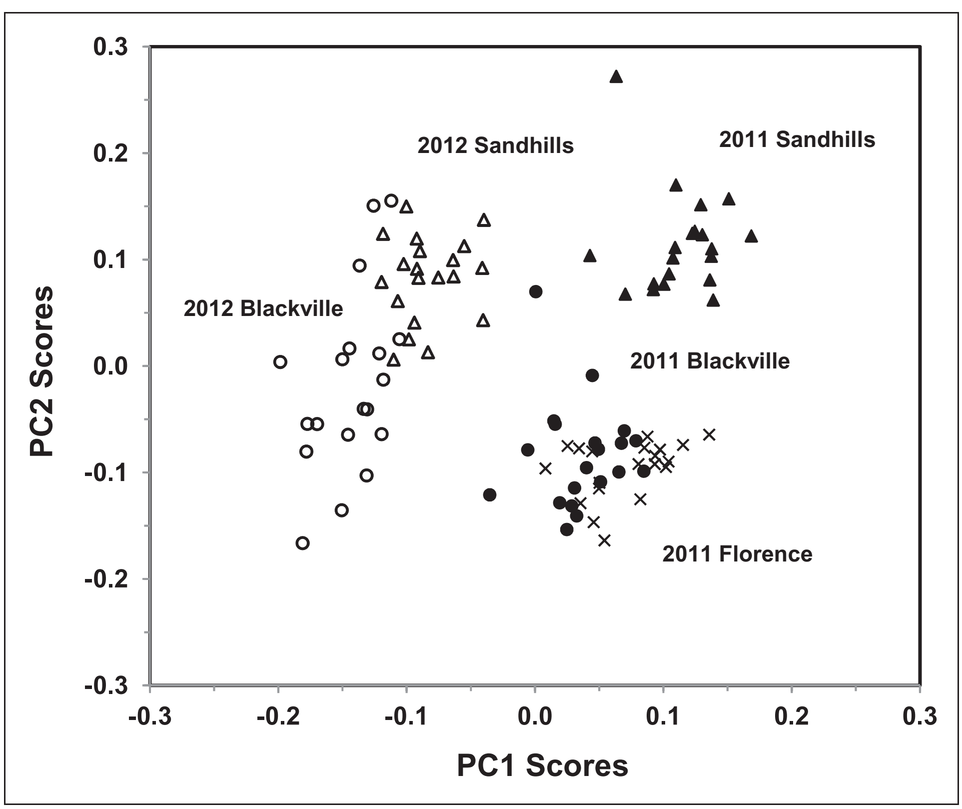

Figure 7. PC1 versus PC2 score–score plot of cotton fibers from three growing locations and two crop years (2011 Blackville: •; 2011 Florence: X; 2011 Sandhills: ▲; 2012 Blackville: ○; 2012 Sandhills: △).

between the Sandhills cottons and the Blackville (and Florence) cottons might address the significance of growing environments in cotton fiber physical and chemical development. This separation is not surprising, as Sandhills contains a uniformly deep, Candor soil that has less water holding capacity than Florence and Blackville soils. Hence, the difference in soil type between these locations likely contributes to this separation. Such a subtle difference could not be detected or measured by routine SITC and AFIS tests. On the other hand, close distribution between the 2011 Blackville and Florence cottons might imply whether only one of two locations should be chosen for the trials, despite there being differences in fiber and yarn qualities between the two locations, as given in Table 1. Clearly, more fiber samples from additional crop years are desired to validate the findings.

Conclusions

Analysis of both fiber/yarn qualities and NIR spectral characteristics of cotton fibers was performed on 20 cotton genotypes evaluated in three growing locations over two crop years. Comparison of fiber and yarn qualities revealed several significant/moderate correlations. For example, fiber micronaire had much greater correlations with fiber UHML and fineness than fiber strength and yarn tenacity, and fiber strength had moderate correlation with yarn tenacity. Apparently, the relations between two qualities were influenced by growing locations and years. For instance, SITC strength was found to increase with micronaire only for the 2011 Blackville cottons, and a large discrepancy in slopes of relating SITC strength to fiber length was observed between the 2011 and 2012-year cottons. The ANOVA results also suggested substantive variations among genotypes for fiber quality characteristics, but insignificant variation among genotypes for yarn tenacity. Complementary to these physical parameters, compositional and chemical structural information from PCA on corresponding NIR spectra suggested the similarity of the 2011 cotton fibers harvested at two locations (Florence and Blackville), and also dissimilarity of cotton fibers between these locations. This suggested the potential of the NIR technique as a screening tool in the site selection of future cotton variety trials. Future research should examine the possibility of improving cotton breeding for improved fiber quality by combining NIR results in addition to or in combination with AFIS, SITC, spinning, and yarn test results.

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