RELATING YARN TENACITY TO FIBER STRENGTH IN FOUR COTTON CULTIVARS

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Abstract

There have been considerable interests of aiming to evaluate yarn tenacity property from available cotton fiber quality data acquired by various means, including HVI test that is a primary and routine measurement of providing fiber properties to cotton researchers. The purpose of this study was to characterize the fiber HVI strength and yarn skein tenacity of four cotton cultivars harvested from three locations in three crop years. Instead of developing linear regression models from acquired HVI fiber qualities to predict yarn tenacity, this study examined the effects of five HVI fiber quality components (micronaire, +b, UHML, SFI, and UI) on correlations between corrected fiber strength and yarn tenacity. The results indicate that SFI could have more significant effect on the correlation between corrected yarn tenacity and corrected fiber HVI strength than micronaire, +b, UHML, and UI.

Introduction

Cotton fiber, as a raw and starting material, is commonly processed into yarns. The tenacity (or strength) property of a spun yarn is an important quality index, as it directly affects the winding and knitting efficiency as well as warp and weft breakages during weaving. The knowledge of correlating the yarn tenacity property with raw cotton fibers is beneficial to cotton researchers in the areas of next-generation genotype development and crop field management and also to fiber spinners during mill preparation. In general, two approaches (theoretical vs. statistical) were explored to predict yarn tenacity and other yarn properties, from collected properties of cotton fibers (Cai et al., 2013; Faulkner et al., 2012; Frydrych, 1992; Kelly & Hequet, 2013; Kelly et al., 2013; Long et al., 2013; Pan et al., 2001; Ramey et al., 1977; Thibodeaux et al., 2008; Üreyen & Kadoglu, 2006). The theoretical approach is based on certain assumptions and the models provide good information about interactions among different fiber properties and yarn characteristics (Frydrych, 1992; Pan et al., 2001), while the statistical approach establishes a relationship between yarn and fiber quality characteristics through multiple linear regression methods (Cai et al., 2013; Faulkner et al., 2012; Kelly & Hequet, 2013; Kelly et al., 2013; Long et al., 2013; Ramey et al., 1977; Thibodeaux et al., 2008; Üreyen & Kadoglu, 2006). The latter approach has gained the interest as voluminous fiber quality attributes are available from routine, standard, and improved fiber quality measurements, including high volume instrument (HVI), advanced fiber information system (AFIS), Favimat, Fineness Maturity Tester (FMT), and fiber cross-sectional image analysis.

In an earlier investigation, Thibodeaux et al. (2008) examined the effect of short fiber content in raw cotton on the yarn quality and found that the yarn strength model developed using the four basic HVI properties (strength, micronaire, short fiber content, and uniformity index) alone was nearly as good as those using all 23 fiber properties from the AFIS, HVI, and Suter-Webb (SW) Array method. Later on, Cai et al. (2013) analyzed the impacts of fiber length parameters on yarn properties and reported the effectiveness of these length parameters and their combinations in predicting yarn properties such as strength and irregularity. Long et al. (2013) assessed alternative cotton fiber quality attributes and their relationship with yarn strength, and revealed that the substitution of alternative fiber fineness variables for micronaire or single fiber strength for bundle strength improved the prediction of yarn strength in their models. Hequet and collaborators (Faulkner et al., 2012; Kelly & Hequet, 2013; Kelly et al., 2013) have taken great attention to predict yarn quality from combined HVI and AFIS data, along with the consideration of harvest method and cultivar information.

The main objective of this study was not to develop a set of universal equations to predict yarn tenacity; rather, it was intended to examine the relationship between cotton fiber strength and yarn tenacity after their modifications by five different HVI fiber qualities, namely, micronaire, short fiber index (SFI), yellowness (+b), upper-half mean length (UHML), and uniformity index (UI). The goal was to explore a relatively simple and semi-qualitative screening method for a rapid comparison of yarn tenacity performance either within or between the cultivars.

Materials and Methods

Cotton Fibers

During 2011, 2012, and 2014 crop years, four commercial cultivars (DP 393, FM 958, Phytogen 72, and UA 48), together with other breeding lines, were grown in four replicated field tests at the Clemson University Pee Dee Research and Education Center near Florence, SC (Florence), the Clemson University Edisto Research and Education Center near Blackville, SC (Blackville), and the North Carolina State University Sandhills Research Station near Jackson Springs, NC (Sandhills). It is a Norfolk loamy sand soil in Florence, a Barnwell loamy sand soil in Blackville, and a Candor sand soil in Sandhills. Each trial was arranged in a randomized complete block design with four replications. Each entry was planted in a two-row plot of 10.7 m long with 96.5 cm spacing between rows. Plots were managed conventionally and followed the established local practices.

From each plot, 50 bolls were hand harvested and then ginned on a 10-saw laboratory gin. Collected cotton fibers were conditioned at a constant relative humidity of 65 ± 2% and temperature of 21 ± 1 ºC for at least 24 hours, prior to subsequent fiber and yarn quality measurement. Table 1 summarizes the fiber distributions of each cotton cultivar grown at three locations over three crop years. Some trials were not scheduled at specific locations or crop years.

Table 1. Fiber distributions of four cotton cultivars grown at three locations and three crop years.

		Florence	Blackville	Sandhills
DP 393 (total: 32)	2011	4	4	4
	2012		4	4
	2014	4	4	4
FM 958 (total: 20)	2011	4	4	4
	2012		4	4
	2014			
Phytogen 72 (total: 31)	2011	4	4	4
	2012		3	4
	2014	4	4	4
UA 48 (total: 32)	2011	4	4	4
	2012		4	4
	2014	4	4	4

Fiber Quality Measurement

An Uster® HVI™ 1000 system (Uster Technologies Inc., Knoxville, TN) was used to acquire a number of quality components of cotton fibers from five replicates on each sample. All measurements were performed at the Southern Regional Research Center of USDA's Agricultural Research Service (USDA-ARS-SRRC). The same instrument was utilized for all fibers throughout the study.

Yarn Quality Measurement

With the limited quantity of lint sample available, 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 sliver 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. Additionally, 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.

Results and Discussion

Fiber HVI and Yarn Quality Characteristics

The selected fiber properties in this study were HVI micronaire, UHML, strength, SFI, UI, and +b, while fiber spinning performance from conventional tensile procedures was determined as yarn tenacity from the skein test. Table 2 summarizes the range, mean, and standard deviation (SD) of selected fiber and yarn qualities for the four cultivars in three growing locations over three crop years.

Table 2. Range, mean, and standard deviation of selected fiber and yarn qualities for four cultivars.

		DP 393	FM 958	Phytogen 72	UA 48
Micronaire (units)	Range	3.73-5.46	3.60-5.68	3.81-5.14	4.07-5.60
	Mean	4.84	4.63	4.63	4.99
	SD	0.48	0.60	0.35	0.42
Strength (gm/tex)	Range	27.46-32.75	27.19-33.36	29.60-35.91	30.30-37.96
	Mean	30.60	30.99	32.76	34.07
	SD	1.25	1.60	1.91	1.96
UHML (inch)	Range	1.04-1.27	1.02-1.27	1.05-1.25	1.08-1.33
	Mean	1.13	1.15	1.17	1.21
	SD	0.06	0.07	0.05	0.07
UI (%)	Range	81.44-85.56	81.20-86.52	82.24-85.97	82.48-88.45
	Mean	83.75	83.86	84.00	84.71
	SD	1.16	1.51	0.97	1.52
SFI (%)	Range	4.56-8.70	3.91-10.95	4.52-8.92	2.57-8.52
	Mean	6.70	6.53	6.58	6.00
	SD	1.25	1.92	1.02	1.78
+b	Range	6.51-8.68	6.11-7.70	6.52-8.81	5.64-8.33
	Mean	7.60	7.10	7.41	7.02
	SD	0.58	0.36	0.50	0.54
Tenacity (g/tex)	Range	33.71-54.17	36.27-50.24	42.54-56.94	36.39-58.48
	Mean	44.24	45.45	49.29	48.77
	SD	5.09	3.64	3.56	5.58

In general, the mean fiber micronaire of FM 958 and Phytogen 72 were relatively identical (4.63 vs. 4.63), both were lower than those from DP 393 and UA 48 cultivars that had respective micronaire of 4.84 and 4.99.

There was evident difference in fiber HVI strength increasing from 30.60, 30.99, 32.76 to 34.07 gm/tex for respective DP 393, FM 958, Phytogen 72, and UA 48 cultivars. Coincident or not with strength across the cultivars, UHML increased from 1.13 to 1.21 inches, UI increased from 83.75 to 84.71 %, SFI decreased from 6.70 to 6.00 %, and yarn tenacity increased from 44.24 to 48.77 g/tex.

The DP 393 cottons showed the most +b or yellowness (7.60), followed by Phytogen 72 (7.41), FM 958 (7.10), and UA 48 (7.02).

Relationship between Fiber HVI Strength and Yarn Skein Tenacity

The plot of yarn tenacity against fiber strength for four commercial cultivars is given in Figure 1. Considering all data combined across cultivars and years, a reasonable trend with a scattered pattern is apparent (correlation coefficient, $R^2 = 0.14$). When both fiber strength and yarn tenacity values were modified by corresponding fiber micronaire, resultant plot in Figure 2 suggests a much strong linear correlation for the same data set as in Figure 1.

Furthermore, both fiber strength and yarn tenacity values were corrected by fiber micronaire at elevating powers or exponents (i.e., HVI_{str} / HVI_{mic}^n or $Skein_{ten} / HVI_{mic}^n$, n = 1, 2, 3, 4, 5), and the plot of correlation coefficients against the power n is depicted in Figure 3. Along with n = 0 to 5, R^2 increases expectedly from 0.14 to 0.97, implying the sensitivity of fiber / yarn mechanic property to the inherent fiber maturity and fineness attributes that determine fiber HVI micronaire (Lord, 1956).

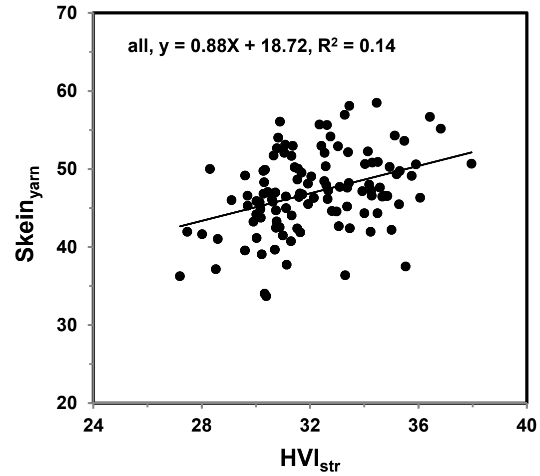

Figure 1. Plot of fiber HVI strength against yarn skein tenacity for 4 cultivars grown in 3 crop years.

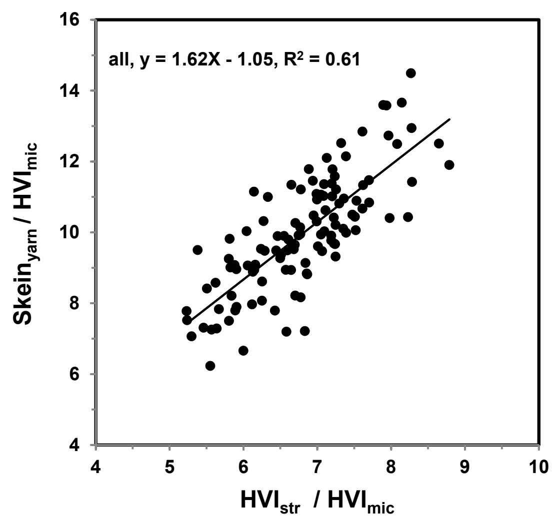

Figure 2. Plot of HVI micronaire corrected yarn tenacity against fiber strength for 4 cultivars in 3 crop years.

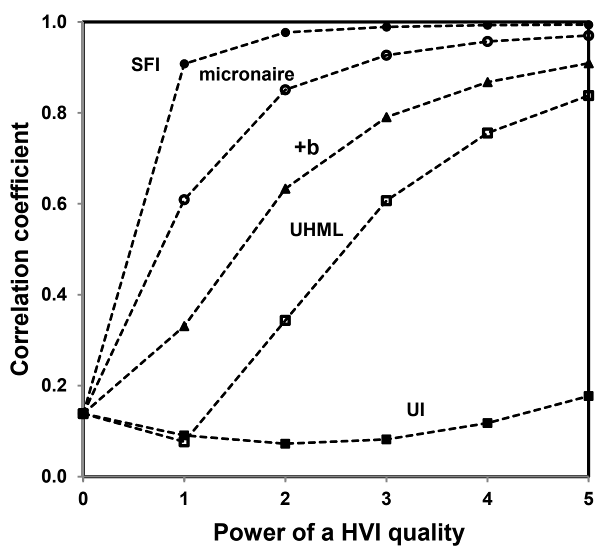

Figure 3. Correlation coefficient vs. power of either one of five HVI qualities.

To examine whether other HVI fiber components have the similar effects on corrected properties as micronaire, additional four HVI qualities (UHML, UI, SFI, and +b) were attempted in the same procedure and the results are also compiled in Figure 3. Scale of R^2 test indicates that, in general, SFI has the most impact on the correlations between modified fiber strength and yarn tenacity, followed by micronaire, +b, UHML, and UI.

With the increase of power n from 0 to 5, R^2 raises in nearly identical pattern but differing increment among SFI, micronaire and +b properties, R^2 decreases initially prior to a quick ascent for UHML, R^2 shows minimum variation for UI. Likely, it suggests more significant effects of SFI, micronaire, +b, and UHML on modified strength property than that of UI.

R^2 easily reaches to 0.90 when power n =1 for SFI (Figure 3 and 4), while it needs a power of 3 to yield a 0.90 for micronaire variable and a power of more than 5 for +b, UHML, and UI.

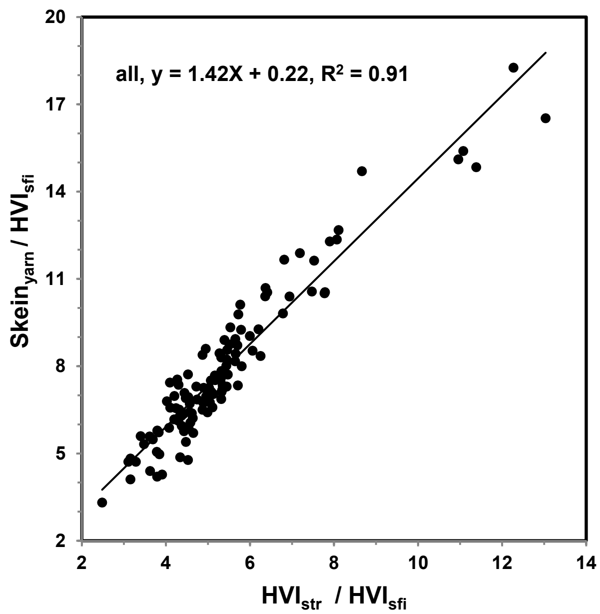

Figure 4. Plot of HVI SFI corrected yarn tenacity against corrected fiber strength for 4 cultivars in 3 crop years.

Summary

A number of fiber quality parameters are accessible from routine and standard fiber testing procedures, including HVI measurement. Focus of this investigation was to characterize the relationship between fiber strength and yarn tenacity on four cotton cultivars grown in three locations and three crop years. Instead of developing linear regression models from available HVI fiber qualities to predict yarn tenacity, this study examined the effects of five HVI fiber quality components on correlations between corrected fiber strength and yarn tenacity. The results indicate that SFI could have more significant effect on the correlation between corrected yarn tenacity and corrected fiber HVI strength than micronaire, +b, UHML, and UI. The observation suggests the feasibility of applying fiber SFI and strength properties, as a semi-quantitative and fast tool, to compare cultivar performance for yarn tenacity.

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Disclaimer

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