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Comparative Relationship of Fiber Strength and Yarn Tenacity in Four Cotton Cultivars

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Abstract

High volume instrumentation (HVI^{TM}) measurement is a primary and routine tool of providing fiber properties to cotton researchers. There have been considerable studies designed to derive yarn quality from acquired fiber quality data by various means, including HVI. There is also of desired information about the comparison of yarn quality within a cotton cultivar or among the cultivars, as such knowledge could be informative in attempts to understand the selection of cotton cultivars. The purpose of this preliminary study was to characterize the fiber HVI strength and yarn skein tenacity of four cotton cultivar harvested from three locations in different crop years. Instead of developing linear regression models from acquired fiber property parameters to predict yarn tenacity, this study applied a simple ratio method (i.e., correct fiber strength or yarn tenacity with fiber micronaire component) to relate fiber strength with yarn tenacity. The results indicate that three cultivars (DP 393, Phytogen 72, and FM 958) show stronger correlation between micronaire corrected yarn tenacity and micronaire corrected fiber HVI strength. It implies the feasibility of utilizing HVI fiber micronaire and strength property data, as a semi-quantitative and fast tool, to compare the yarn tenacity performance within a cotton cultivar or between cultivars.

Keywords: cotton fiber, fiber quality, yarn quality, HVI, cotton cultivar

1. Introduction

Cotton is one of the most important and widely grown crops in the world. It is a well-traded agricultural commodity mostly for textile fiber purpose, but it also yields a high grade vegetable oil from cottonseed for human consumption as well as multiple cellulosic byproducts and whole seeds used as a primary source of fiber and protein in animal feed (Wakelyn & Chaudhry, 2010).

Cotton production is determined by at least three main factors and the 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 (Bradow & Davidonis, 2000). Thus, the desired cotton cultivars would provide high fiber yield, good fiber quality, and efficient processing at the ginning site and textile mill.

Cotton fiber, as a raw and starting material, could impact its intermediate yarn production and quality. Since yarn manufacturing requires specific equipment and uses a large amount of cotton fibers, substantial research has been done to optimize the methods of predicting yarn properties, such as tenacity (strength), uniformity, hairiness, and elongation, from available properties of raw 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). In general, two approaches (theoretical vs. statistical) were explored in these studies. The theoretical approach is based on certain assumptions and the generated models provide good information about interactions among different fiber properties and yarn characteristics (Frydrych, 1992; Pan et al., 2001). The statistical approach, being preferred more frequently, bridges 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).

This approach has become more preferred as a result of voluminous fiber quality attributes available from routine, standard, and improved fiber quality measurements, including high volume instrument (HVI^{TM}), advanced fiber information system (AFIS), Favimat, Fineness Maturity Tester (FMT), and fiber cross-sectional image analysis.

The tenacity property of a spun yarn is an important index in determining the quality of the yarn, as it directly affects the winding and knitting efficiency as well as warp and weft breakages during weaving. Therefore, understanding the yarn tenacity potential from raw cotton fibers directly is advantageous to fiber researchers in the periods of next-generation genotype development and crop field management and also to fiber spinners during mill preparation. As such, great efforts have been made to estimate yarn tenacity from diversified fiber properties (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). Üreyen and Kadoglu (2006) observed a high positive correlation between fiber and yarn strength and also found that fiber strength was the most important parameter for yarn tenacity, while fiber elongation, fiber length, uniformity index, fiber fineness, yarn count, yarn twist, roving count and unevenness of roving are other parameters that can have a significant influence on yarn tenacity. 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. By analyzing the impacts of fiber length parameters on yarn properties, Cai et al. (2013) reported the effectiveness of these length parameters and their combinations in predicting yarn properties such as strength and irregularity. In a more recent investigation, 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.

As a different strategy of better understanding the relationship between cotton fiber strength and yarn tenacity, we present the concept of dividing fiber HVI strength and yarn skein tenacity by fiber HVI micronaire component, instead of modeling yarn tenacity from a number fiber properties using multiple linear regression. The main objective of this study was not to develop a set of universal equations to predict yarn tenacity; rather, it was intended to provide a relatively simple and semi-qualitative screening method for a rapid comparison of yarn tenacity performance either within or between the cultivars.

2. Method

2.1 Cotton Samples

In crop years of 2011, 2012, and 2014, four commercial cultivars Deltapine 393 (DP 393, PVP #200400206), Fibermax 958 (FM 958, PVP #200100208), Phytogen 72 (PVP #200100115), and UA 48 (PVP #201100041), along with additional elite 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 10.7 m long with 96.5 cm spacing between rows. Plots were managed conventionally and followed the established local practices.

From each plot in each trial, 50 bolls were picked by hand. These 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 ± 2% and temperature of 21 ± 1 ºC for at least 24 hours, prior to routine fiber and yarn quality measurement. Table 1 summarizes the fiber distributions of each cotton cultivars grown at three locations over three crop years.

2.2 Fiber Quality Measurement

Average micronaire and strength values were obtained from five replicates on each sample by an Uster® HVI^{TM} 900A (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 instrument was used for all fibers throughout the study.

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

2.3 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 (ASTM, 2012). 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.

3. Results and Discussion

3.1 Relationship between Fiber HVI Strength and Micronaire

Figure 1 shows the plot of HVI strength against micronaire for a total of 115 cotton fibers from 4 known varieties grown in 3 crop years. HVI fiber micronaire is determined by both maturity (degree of secondary cell wall development) and fineness (weight per unit length) of the fibers (Lord, 1956), while HVI strength reflects the normalized external force required to break a bundle of parallel fibers. Overall, fiber HVI strength did not change along with fiber micronaire, although the scatter becomes more apparent as micronaire elevates. As anticipated, Pearson correlation or univariate correlation coefficient (r) between HVI strength and micronaire within these samples was extremely low ($r = 0.12$). In this work, we generally considered a significant correlation between two variables when absolute r value is greater than 0.50, a moderate correlation between two variables when absolute r value is between 0.20-0.50, and an insignificant correlation between two variables when absolute r value is less than 0.20. In Figure 1, mean HVI strengths were 30.2, 31.0, 31.5, and 33.6 gm/tex for DP 393, FM 958, Phytogen 72, and UA 48, corresponding to respective micronaire units of 4.84, 4.63, 4.61, and 4.99.

Characteristics of regression lines for individual varieties are also inserted in Figure 1. Regardless of growing locations and crop years, HVI strengths among DP 393 fibers showed no correlation with fiber micronaire ($r = -0.08$), strengths in FM 958 fibers had negative and moderate correlation with micronaire ($r = -0.46$), while those within Phytogen 72 and UA 48 fibers showed positive and moderate correlations with micronaire ($r = 0.44$ and 0.21, respectively).

In a previous study (Liu et al., 2011), fiber HVI strength readings were corrected by respective micronaire values in both quotient (HVI_{str} / HVI_{mic}) and product ($HVI_{str} * HVI_{mic}$) forms. Following, the effect of modified HVI strength indices on NIR model performance were examined through partial least squares (PLS) regression using large data sets. Two modified strength indices were observed to have better correlations than raw HVI strength index with NIR spectra, and the use of the quotient form resulted in an improved model performance than that of the product one. When plotting micronaire corrected HVI strength against HVI micronaire for those samples in Figure 1, significant and linear relationships were expected for each cultivar (Figure 2). Relatively lower correlation ($r = 0.72$) among Phytogen 72 fibers than the other three cultivars ($r > 0.85$) suggests either great differences in strength readings for fibers having the similar micronaire values or great variations in micronaire readings for samples having the similar strength values.

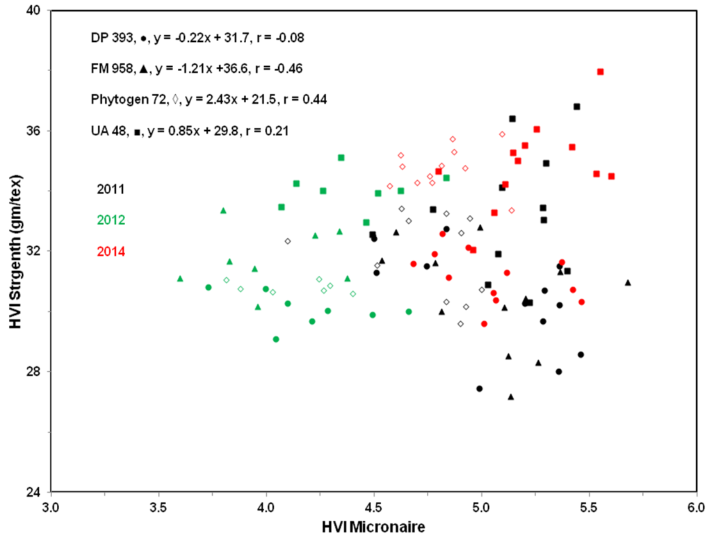

Figure 1. Plot of fiber HVI strength against HVI micronaire for four commercial cultivars grown in crop years of 2011, 2012, and 2014. Regressions for each cultivar were inserted for comparison. Pearson correlation r was 0.12 among all samples

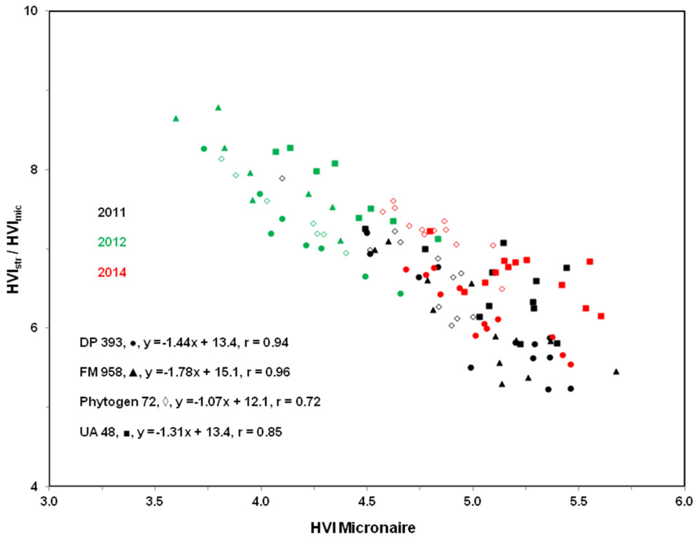

Figure 2. Plot of corrected fiber HVI strength against HVI micronaire for four commercial cultivars grown in crop years of 2011, 2012, and 2014. Regressions for each cultivar were inserted for comparison. Pearson correlation r was 0.84 among all samples

The difference in magnitude of slopes in Figure 2 might reflect differing response of HVI_{str} / HVI_{mic} ratio to HVI micronaire parameter among the four cultivars. An example of both calculated HVI_{str} / HVI_{mic} ratio from regression lines in Figure 2 and converted HVI strength is tabulated in Table 2, given the fiber micronaire (HVI_{mic}) = 4.0 and 5.0, respectively. From low to high micronaire, the four cultivars showed a decrease in modified strength. Also, variations in either HVI_{str} / HVI_{mic} ratio or HVI strength among 4 cultivars within lower micronaire fibers were smaller than those among higher micronaire fibers.

Table 2. Comparison of calculated HVI_{str}/HVI_{mic} from regression lines in Figure 2. Converted HVI strength was included in parentheses

Cultivar	HVI_{mic} = 4.0	HVI_{mic} = 5.0
DP 393	7.7 (30.8)	6.2 (31.0)
FM 958	8.0 (32.0)	6.2 (31.0)
Phytogen 72	7.8 (31.2)	6.7 (33.5)
UA 48	8.2 (32.8)	6.9 (34.5)

3.2 Relationship between Fiber HVI Strength and Yarn Skein Tenacity

The plots of yarn tenacity against fiber strength for four commercial cultivars are given in Figure 3. Considering data combined across cultivars and years, a reasonable trend with a scattered pattern was evident (r = 0.55). The average fiber strength and yarn tenacity were 30.2 gm/tex and 45.7 g/tex for DP 393 fibers, 31.0 gm/tex and 45.4 g/tex for FM 958 fibers, 31.5 gm/tex and 50.1 g/tex for Phytogen 72 fibers, and 33.6 gm/tex and 50.6 g/tex for UA 48 fibers. Overall, yarn tenacity displayed a strong relationship with fiber strength for DP 393 fibers (r = 0.60), followed by moderate correlations for FM 958 (r = 0.49), Phytogen 72 (r = 0.47), and UA 48 fibers (r = 0.24). Meanwhile, the slope decreased in the order of DP 393, Phytogen 72, FM 958, and UA48 cultivars. Both higher r and slope values reflected stronger correlation between fiber strength and yarn tenacity for DP 393 as opposed to FM 958 and Phytogen 72. The lowest correlation between fiber strength and yarn tenacity was found for UA 48 fibers.

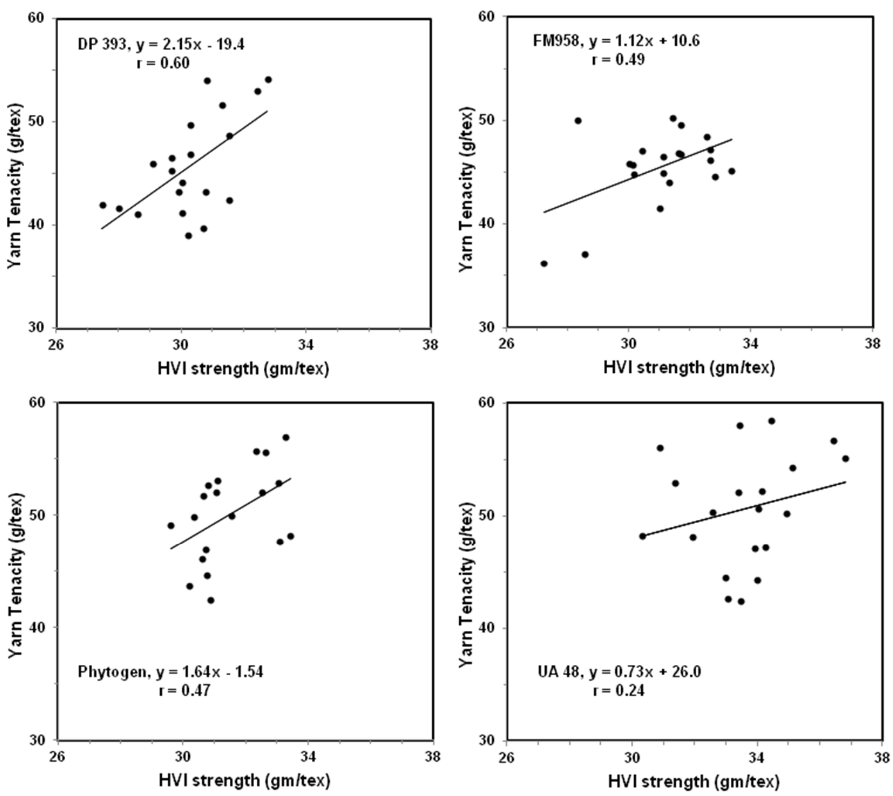

Figure 3. Plot of yarn tenacity against fiber strength for four commercial cultivar grown in crop years of 2011 and 2012 (Yarn data for 2014 was not available this time). Regressions for each cultivar were inserted for comparison. Pearson correlation r was 0.55 among all samples

When both fiber strength and yarn tenacity values were modified by fiber micronaire, the resulting plot in Figure 4 suggests a much stronger linear correlation for each cotton cultivar. Improvement of r from the 0.24 to 0.60 range in Figure 3 to the 0.54 to 0.93 range in Figure 4 implies the sensitivity of fiber / yarn breaking property to the inherent fiber chemical and physical structure. Especially, DP 393, Phytogen 72, and FM 958 fibers showed a larger r (> 0.85) than UA 48 fibers (~0.54), indicating that micronaire corrected yarn tenacities could be strongly related with micronaire corrected fiber HVI strength for these three cultivars. Meanwhile, the slope in Figure 4 decreased in the order of Phytogen 72 (2.10), DP 393 (1.99), FM 958 (1.50) and UA 48 (0.71) fibers. Concurrently, the UA 48 fibers displayed the lowest fiber strength-yarn tenacity correlation in Figure 3.

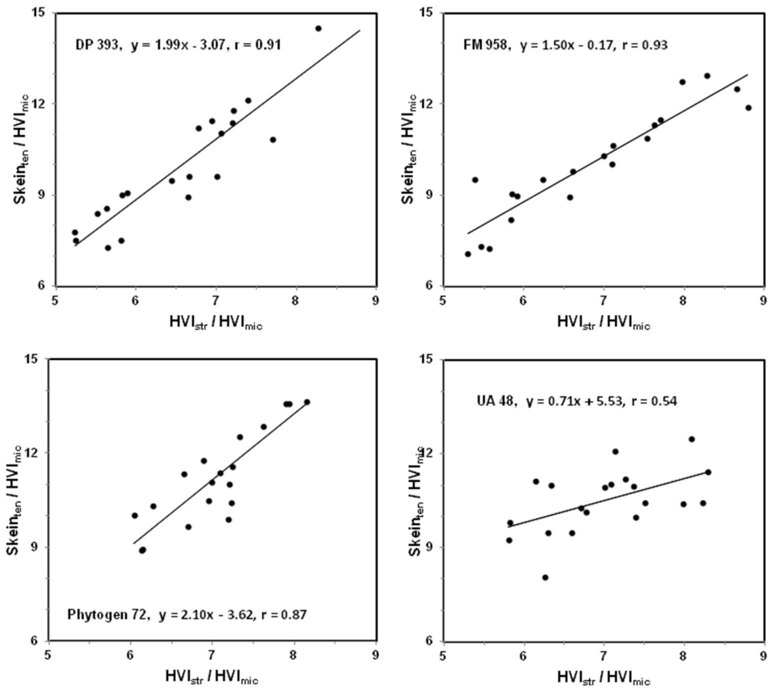

Figure 4. Plot of corrected yarn tenacity against corrected fiber strength for four commercial cultivars grown in crop years of 2011 and 2012. Regressions for each cultivar were inserted for comparison

Potentially, relationships in Figure 4 could be utilized to compare the yarn tenacity property either between the same or differing cultivars on the basis of HVI micronaire and strength data only. For instance, Table 3 presents the predicted $Skein_{ten}/HVI_{mic}$ values from the regressions in Figure 4, assuming the HVI_{str} / HVI_{mic} = 6.0 and 8.0, respectively. Interestingly, DP 393, FM 958, and Phytogen 72 cultivars had a close $Skein_{ten}/HVI_{mic}$ when HVI_{str} / HVI_{mic} = 6.0, and the difference between any two of the three became apparent when HVI_{str} / HVI_{mic} = 8.0. UA 48 fibers showed the largest $Skein_{ten}/HVI_{mic}$ among the four cultivars when HVI_{str} / HVI_{mic} = 6.0, in turn, it has the greatest ratio of yarn skein tenacity to HVI micronaire among the four cultivar. As a comparison, UA 48 fibers had smaller $Skein_{ten}/HVI_{mic}$ than the other three cultivars when HVI_{str} / HVI_{mic} = 8.0, leading to a weak ratio between yarn tenacity and fiber micronaire.

Table 3. Calculated $Skein_{ten}/HVI_{mic}$ from relationships in Figure 4

Cultivar	HVI_{str}/HVI_{mic} = 6.0	HVI_{str}/HVI_{mic} = 8.0
DP 393	8.9	12.9
FM 958	8.8	11.8
Phytogen 72	9.0	13.2
UA 48	9.7	11.1

Compared to the earlier strategy of multiple fiber property derived regression models for estimating yarn tenacity, it might be desirable to consider only 2 fiber quality components, micronaire and strength, as it avoids the need to develop multiple regression equations from a number of fiber quality input traits. Undoubtedly, introducing more fiber quality parameters into regression equations has improved the accuracy in predicting yarn tenacity. However, there are concerns about over-fitting the model and how to validate the equations by an independent set of fibers or cultivars. As observed in the present study, one cultivar (UA 48) could perform quite differently from other cultivars when simply relating micronaire corrected yarn tenacity to fiber strength, possibly leading to a compromised model if it was compiled into calibration, validation or independent set. Nevertheless, the ratio values of micronaire corrected fiber strength might be utilized as a semi-quantitative and fast approach to compare cultivar performance for yarn tenacity.

4. Conclusions

Numerous fiber quality parameters are accessible from routine and standard fiber testing procedures, including HVI measurement. This investigation was carried out to relate fiber strength with yarn tenacity on four cotton cultivars grown in three locations and two crop years. Instead of developing linear regression models to predict yarn tenacity with the consideration of multiple fiber property parameters, this study utilized simple micronaire corrected strengths to compare the relationship between fiber strength and yarn tenacity. The results indicate that, reasonably, the relations between two types of qualities were influenced by cotton cultivars. For example, DP 393, Phytogen 72, and FM 958 fibers showed a larger slope and r (> 0.80) than the UA 48 fibers, indicating that micronaire corrected yarn tenacities could be strongly related with micronaire corrected fiber HVI strength for these three cultivars. The observation suggests the feasibility of applying fiber micronaire and strength properties, as a semi-quantitative and fast tool, to compare cultivar performance for yarn tenacity.

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