The *Journal of Cotton Science 13:212–220 (2009)*
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TEXTILE TECHNOLOGY

Fiber and Yarn Properties Improve with New Cotton Cultivar

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ABSTRACT

Mill modernization and global market requirements necessitates the continual improvement of upland cotton, *Gossypium hirustum L.*, cultivars. Recent focus by breeders is to create upland cotton with superior fiber quality that approaches pima cotton, *Gossypium barbadense L.* The objective of this study was to perform in-depth analysis of fibers produced by 'FM832' and 'MD51neOK' and their progeny, 'MD15', that express transgressive segregation for fiber bundle strength. Results were generated via the Stelometer, Peyer AL101, Fibrograph, HVI™, AFIS, Favimat, Fiber Dimensional Analysis System (FDAS) 765, and miniature spinning. Single fiber strength and fineness testing was performed using the Favimat, whereas the FDAS 765 performed non-contact dimensional analysis along the fiber length. Traditional fiber bundle testing was compared to single fiber testing and miniature spinning yarn testing. Cottons in this study were broken at different loading rates from 0.3 cm/min for the Stelometer, 2 cm/min for the Favimat, 13.6 cm/min for the HVI™, and 25.4 cm/min for the Statimat-M, with respective progeny fiber or yarn strengths of 32, 32, 41, and 27 g/tex. Progeny fineness along with fiber and yarn strengths improved in MD15 compared with its parents with lower yarn hairiness values. The MD15 progeny "super cotton" displayed better quality fiber and yarn properties when tested under a wide range of conditions.

Cotton (*Gossypium barbadense L.* or *Gossypium hirsutum L.*) is a plant fiber crop that continues its long history of textile utilization because of its comfort level relative to manmade fibers. Competition from synthetic fibers, mill modernization, and global market competition have increased the demand for improved fiber quality, while changes in the textile industry and fiber measurement technology have resulted in a steady improvement in cotton fiber quality. International cotton fiber purchase contracts typically average approximately 28 g/tex, with an approximate length of 2.79 cm, and micronaire between 3.8 and 4.6 (M. Watson, personal communication). Each year many different upland cotton cultivars are marketed to producers. These varieties are distinguished from each other by plant type, maturity, fiber properties, added value traits (e.g., insect and/or herbicide resistance transgenes), yield, and environmental adaptation. In an effort to assist producers, both public and private entities conduct multilocation cultivar trials to evaluate plant and fiber performance. Stronger, longer, finer, and more uniform cotton fibers are desired for modern textile industries.

Currently, cotton fiber quality is a limiting factor for the exploitation of higher speed spinning machines. Textile processing is influenced by the distribution of fiber quality among and within bales that individually contain approximately 60 billion fibers (Steadman, 1997). The acceleration of spinning speeds towards 400 m/min requires uniform and enhanced cotton fiber qualities, which decreases production costs at these higher speeds. One objective of breeders at the USDA-Agricultural Research Service (ARS) Crop Genetics and Production Research Unit (CGPRU) is to develop new and improved fiber trait combinations and investigate factors related to these improved cottons. Fiber fineness, maturity, trash, uniformity, fiber-to-fiber adhesion, length, and strength affect spinning efficiency (Deussen, 1993). It is generally understood that fiber strength is one of the most important fiber properties (May and Green, 1994), and it is quantitatively inherited (Basra, 2000). Fiber length is critical for textile processing and varies greatly for different cottons due to genetic differences (Basra, 2000). Spinning requires long, strong fibers to endure stresses sustained during mechanical operations in ginning, opening, cleaning, carding, combing, and drafting. Yarn strength is determined

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by individual fiber strength and fiber interactions, including length, friction, and twist (Hsieh, 1999).

Cotton grading has progressed from subjective human classers to the high volume instrument (HVI™) that physically tests a specially combed fiber bundle containing approximately 2000 to 2500 fibers (Ellison and Rogers, 1995). Bundle testing results in a value that is confounded by the average length and the uniformity of fiber lengths, friction properties, and twist, as well as the strength of individual fibers. The Favimat (Textechno Herbert Stein GmbH & Co. KG, Mönchengladbach, Germany) provides traditional single fiber data, tensile strength, and percent elongation at a constant rate of extension, with additional fiber parameters such as fiber crimps, tenacity, linear density, and work to rupture on the same fiber section (Schneider et al., 1998; Stein and Morschel, 1998). The strongest fibers are not necessarily the best ones if they lack fineness (Deussen, 1993). Another single fiber testing instrument is the Fiber Dimensional Analysis System (FDAS) 765 (Dia-Stron Limited, Andover, UK) that performs non-contact dimensional analysis along the fibers length.

The fiber properties of 'MD15' in this study compare well with Acala cultivars and American Pima cultivars. California Acala and American Pima cotton are known worldwide for their enhanced fiber quality. In 2008, farmers in the San Joaquin Valley planted 35% of their acreage (USDA, Agricultural Marketing Service (AMS), 2008) with 'PhytoGen' (PHY 725 RF), a high yielding Acala cultivar that has a strength of 34.8 g/tex, length of 1.20 in and micronaire of 4.3 (PhytoGen Seed Co., 2008). In 2007, American Pima cotton had an average strength of 40.6 g/tex, length of 1.46 inches, and micronaire of 4.1 (USDA, AMS, 2007). A better understanding of new varieties is necessary to expedite processing in textile mills and to encourage the use of certain cotton varieties. The objective of this study was to perform in-depth analysis of fibers produced by cotton parents 'FiberMax® 832' (FM832) (PVP 9800258, PI 630955) and 'MD51neOK' (an okra leaf BC5 near-isogenic strain developed from 'MD51ne' (Reg. No. CV-103, PI 566941; Meredith, 1993)) and their "super" progeny MD15 (Reg. No. GP-869, PI 642769; Meredith, 2006) to validate initial findings and categorize how MD15 is superior to its parents. It should be noted that cotton selection during breeding for high fiber strength does not guarantee high yarn strength (May and Green, 1994), so yarn quality was concurrently evaluated. New processing techniques and/or instruments are necessary to provide rapid, consistent, and quantitative evaluation of cotton fibers developed for new and high-speed spinning machinery.

MATERIALS AND METHODS

Cotton. Modernization of US cotton mills and the demands of the global market requires that the US cotton industry develops longer, stronger, and finer cultivars with fewer short fibers than that currently produced in the US. Research was conducted on cotton produced from FM832 and MD51neOK and their progeny MD15. FM832 is okra leaf cotton with excellent fiber quality properties and a high percentage of first position bolls when grown under different growing conditions (Bayer CropScience, 2005). These fibers are considered to be relatively long, with a high uniformity and strong, that fall in the base micronaire range (3.5-4.9) (Bayer CropScience, 2005). FM832 is a commercial cultivar that along with its transgenic versions accounted for 3.0% of the US acreage planted in 2004 and 3.7% in 2005 (USDA, AMS, 2004, 2005). MD51neOK was developed by selecting for high fiber strength and has a good combination of insect resistance, high fiber strength, and lint yield (Meredith, 1993). MD51neOK is a BC5 near-isogenic line of the USDA-ARS cultivar MD51ne (Meredith, 1993). Both FM832 and MD51neOK have improved fiber bundle strength and other desirable yield and fiber quality characteristics. MD15 in this study consisted of the average performance of four F3:5 lines. All four of these lines descended from selfed seed of one F2 plant from the cross of FM832 and MD51neOK. The F2 plant progeny number 120 showed superior fiber strength (Meredith, 2006). F3 seed from number 120 were grown and produced 33 unselected lines. Evaluation in F3:4 showed four of these lines to have similar high fiber strength. One strain that was judged typical of the high-strength gene was selected and released as MD15 (Meredith, 2006). In this study all four lines were grown in a completely randomized design at three locations near Stoneville, MS with one observation of the four 120 strains and two for FM832 and MD51neOK. Each location was on a different soil type.

Sample cotton plants were hand harvested, ginned on laboratory-scale gin stands, and selected by cotton breeders because of their strength determined by the flat bundle method (ASTM, 1997b), and length determined using the advanced fiber information system (AFIS). Strength tests for cotton breeder samples at USDA-ARS, CGPRU are typically performed by private institutions such as Starr Laboratories (Knoxville, TN), whereas AFIS results are obtained in-house at Stoneville, MS.

Cotton Testing. Cotton samples were conditioned for at least 48 hours at 65% RH and 21 ºC prior to testing (ASTM, 1997d). Fiber bundle strength and elongation values were determined with a total of six breaks using a Stelometer (Spinlab, Knoxville, TN) (ASTM, 1997b). The Stelometer has estimated instrument breaking speed of 0.3 cm/min (Godbey et al., 1991). Fiber bundle fineness was determined via micronaire (ASTM, 1997a), and length measured using a Peyer AL-101 (Siegfried Peyer Ltd., Wollerau, Switzerland) (ASTM, 1993). To evaluate HVI™, cotton fineness, length and strength measurements (ASTM, 1999) were performed (six measurements each) on an HVI™ 900A (Uster Technologies Inc., Knoxville, TN) by the Testing Laboratory at Cotton Quality Research Station (CQRS). The HVI™ has an estimated instrument breaking speed of 13.6 cm/min (Godbey et al., 1991). AFIS (Uster Technologies Inc., Knoxville, TN) is a destructive method that aeromechanically opens fibers and separates fiber, trash, and dust for electro-optical measurement, thus producing various distributions. AFIS analyzes neps, fiber length, and fiber maturity. These AFIS measurements were obtained for all cotton samples.

To get a better representation of the longer fibers within these samples, the cotton was further divided into Suter-Webb array length groups (ASTM, 1997e). A Fibroliner AL-101 (Peyer Electronics, Spartanburg, SC) was used to help separate the fibers (ASTM, 1993). For fiber alignment, a 90-mg sample was inserted into the Fibroliner FL101 to be combed and sorted twice. Following fiber alignment, two pulls were performed on this fiber beard removing the longest fibers. Fibers were removed from the combs, placed on a black velvet board, and measured with a Suter-Webb array ruler graduated in 0.3175 cm. Repeatedly, these pulls removed the longest fibers remaining in the fiber tuft allowing fiber separation and storage into Suter-Webb array length groups 17 and 19 for further testing. These fibers range in length from 2.54 to 2.86 cm (length group 17) and 2.86 to 3.18 cm (length group 19).

Fiber dimensional measurements were obtained on 12 fibers (from length groups 17 and 19) using the FDAS 765. Length groups 17 and 19 represent fiber lengths of 2.54 and 2.86 cm. The FDAS performs non-contact dimensional analysis of fibers using the Mitutoyo Laser Scan Micrometer LSM500 (Mitutoyo America, Aurora, IL). This measurement technique rotates samples and transports them tangentially to measure segments along the fiber. Fiber samples in this study were divided into five segments along its length, and measurements were acquired every 15 degrees within these segments with an accuracy of 0.1 µm. Overall, 65 measurements were acquired for each fiber.

The Favimat measures the amount of force required to break up to 210 cN with a resolution of 1×10^{-4}; the fineness of these same fibers can be measured from 0.5 to 200 dtex. In a manner similar to the Mantis®, tensile strength is determined using a constant rate of extension. A gauge length of 10 mm and crosshead speed of 2 cm/min under a pretension of 0.20 cN/tex was used in testing. Fiber fineness is determined by the vibroscope method (ASTM, 1997c). Crimp number is determined through an opto-electrical sensor that evaluates the fiber under 0.03cN/tex. Twenty-five fibers from all cottons and each different length group were tested twice using the Favimat-Robot Standard Tensile Test procedure (Textechno, 1999).

For Favimat single fiber testing and ease of separation, a small tuft of fibers from one length group was laid onto a black velvet board. Using forceps, a single fiber was randomly separated from the group of fibers and placed in the Favimat-Robot magazine for testing. The Favimat Robot is an automatic sample changer that holds up to 450 fibers, from which fibers are transported by means of a transfer clamp to the Favimat for testing. Both upper and lower clamps of the Favimat have a clamping surface area 16 mm^2 with a soft and hard rubber face.

Miniature Spinning. For miniature spinning, clean and Shirley Analyzed samples were placed into a small, card feed tray on the back side of a Saco Lowell card (Ewald, 1975; Landstreet et al., 1959, 1962). The 100-g sample was carded to provide further opening, blending, cleaning, and production of a web (Ewald, 1975; Landstreet et al., 1959, 1962). This web was collected by vacuum on a drum in front of the card. The lap of the produced card web was 1.5 m long and 0.22 m wide. The lap was then processed three times through drawing to produce a parallel, uniform blend of fibers to deliver a sliver of a specified weight (Ewald, 1975; Landstreet et al., 1959, 1962). Cotton slivers were spun into a 22/1 Ne yarn on a miniature ring spinning system (Mitsui Bussan Kaisha Ltd., Osaka, Japan) to evaluate the impact of fiber strength on yarn.

Yarn Testing. Tensile properties of produced yarns from miniature spinning were evaluated for single end yarn strength on the Statimat-M (Lawson-Hemphill, Central Falls, RI) using standard test methods (ASTM, 1994). The Statimat-M has an instrument breaking speed of 25.4 cm/min. The Uster Evenness tester UT-4 (Uster Technologies, Knoxville, TN) contains a hairiness module to characterize yarn hairiness. The average hairiness H value is defined as the total length of all hairs within 1 cm of yarn.

The properties and mean data were statistically analyzed with the MEANS procedure in SAS to compute descriptive statistics for variables across all observations (SAS Institute Inc., 1985).

RESULTS AND DISCUSSION

Fiber bundle and single fiber results indicated that MD15 produced a statistically lower micronaire (mic), higher Stelometer strength, lower short fiber content, and finer fibers (Table 1). Percentage changes for MD15 were compared relative to FM832, the commercial cultivar parent with better fiber quality than MD51neOK, the other parent. Assuming cotton fibers obey Hooke's law with a straight load elongation curve, then the work-to-rupture cotton becomes equal to ½[breaking load x breaking elongation] (Morton and Hearle, 1997). The resulting product of strength and elongation demonstrates a difference in work to rupture in favor of MD15, 56% greater than its parents. MD15 is not statistically different than MD51neOK in yield, elongation, and maturity ratio. Cotton fiber perimeter and wall thickness estimates performed according to Montalvo and VonHoven (2007) indicated that MD15 has the smallest perimeter. It appeared that these fiber traits contributed to create cotton with exceptional fiber quality. Because this cotton was significantly stronger (38% stronger) with superior micronaire (7% finer) and fewer short fibers (29% lower short fiber content by weight) further evaluation and study were required to support finding on this cotton cultivar.

HVI™ and AFIS Fiber Measurements. MD15 produced superior ($p < 0.05$) micronaire values (6% finer) with a higher strength (22% stronger), higher uniformity (3%), and longer upper-half mean length (3% longer) according to HVI™ analysis (Table 2). The resulting product of strength and elongation of MD15 resulted in a greater work to rupture of 20% compared with its parents. AFIS results indicated that MD15 produced a finer fiber (5% finer) with longer length (6% for fiber mean length by weight and 10% for fiber mean length by number) than its parents (Table 3). Coefficients of variation values were lower for MD15 length by weight and length by number, 10% and 16%, respectively. The upper-quartile length of MD15 was longer than its parents. AFIS short fiber content by weight and number indicated that MD15 produces cotton with significantly lower quantities of fibers less than 1.27 cm. HVI™ and AFIS measurements indicated that MD15 has superior fiber properties than its parents.

Classical Fiber Quality Measurements. To assess results performed for USDA-ARS, CGPRU,

Table 1. Summation of fiber yield, bundle properties, and AFIS measurements from parents and their progeny*[z]

		Stelometer results			AFIS results						Modeling inference [y]	
Cotton [x]	Yield	Fineness	Strength	Elongation	Fiber mean length L(w)	SFC (w)	Fiber mean length L(n)	SFC (n)	Maturity ratio	Fineness	Fiber perimeter	Wall thickness
	(kg/ha)	(mic)	(g/tex)	(%)	(cm)	(%)	(cm)	(%)	(%)	(mtex)	(μm)	(μm)
FM832	1051 a	4.65 b	23.4 b	5.54 b	2.74 a,b	4.8 a	2.29 a,b	17.6 a	1.00 a	175 b	50.1	2.79
MD51neOK	831 b	4.88 a	21.4 c	6.04 a	2.62 b	5.2 a	2.21 b	18.3 a	0.99 a	182 a	51.3	2.82
MD15	827 b	4.34 c	32.2 a	6.27 a	2.79 a	3.4 b	2.44 a	13.8 b	1.00 a	170 c	49.4	2.75
Percent change (%)[w]	-21.3	-6.7	37.6	13.2	1.8	-29.2	6.6	-21.6	0.0	-2.9	-1.4	-1.4

*** Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.**

[z] Fiber yield and AFIS results were obtained at USDA-ARS, CGPRU, Stoneville, MS; Stelometer (ASTM, 1997b) and micronaire (ASTM, 1997a) were obtained by Starr Laboratories.

[y] Cotton fiber perimeter and wall thickness estimates performed according to Montalvo and VonHoven (2007).

[x] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD-51neOK.

[w] Percentage change (%) between FM832 and MD15.

additional fiber bundle results were performed by USDA-ARS, Cotton Quality Research Station (CQRS) in Clemson, SC. These results indicated that MD15 exhibited greater Stelometer strength (33% stronger; $p > 0.05$) than its parents (Table 4). Stelometer elongation values for MD15 were different than FM832 but similar to MD51neOK. The resulting product of strength and elongation demonstrated a difference in work to rupture in favor of MD15 of 44% greater than its parents. MD15 produced fibers with a lower mic than MD51neOK but not different than FM832. Behery (1993) reported that the Peyer AL-101 produced different fiber length results than other measurements, which was supported by the fiber length results (mean fiber length, short fiber content, and upper quartile length) in this study demonstrating little diversity as compared with HVI™ and AFIS measurements. Stelometer and micronaire measurements performed by USDA-ARS CQRS further indicated that MD15 is a superior fiber cultivar and different from its parents.

Single Fiber Testing. HVI™, Stelometer, and micronaire measurements were performed on bundles of fiber. The treatment and handling of these individual fibers during testing possibly affected the results. To evaluate individual fibers found within these bundles, single fiber testing was performed to determine if progeny MD15 is a superior fiber cultivar. The Favimat is a self-contained testing instrument that tests fiber fineness, tenacity, force to break, work to rupture, and crimp. Modifications of the current testing parameters and additional tests such as crimp stability and crimp extension present potential for additional research. In each cotton type, 50 fibers from the two length groups provided 300 or 600 single fiber properties for each of the three cotton types.

Table 2. Summary HVI™ results from the diverse cottons *

Cotton [y]	Fineness (mic)	Strength (g/tex)	Elongation (%)	Uniformity (%)	UHML (cm)	Short Fiber Index (%)
FM832	4.71 b	33.9 b	6.6 b	83.9 b	3.02 b	6.6 b
MD51neOK	4.95 a	33.1 b	7.2 a	83.2 b	2.92 c	7.2 a
MD15	4.44 c	41.3 a	6.5 b	86.6 a	3.12 a	6.5 b
Percent change (%) [x]	-5.7	21.8	-1.5	3.2	3.3	-1.5

* Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.

[z] HVI™ cotton quality fiber measurements were performed according to ASTM standards (1999) obtained on a HVI™ 900A.

[y] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD-51neOK.

[x] Percentage change (%) between FM832 and MD15.

Table 3. Summary of AFIS measurements from various cottons*[z]

	AFIS results									Modeling inference [x]	
Cotton [y]	UQL (w) (cm)	Fiber mean length L(w) (cm)	Fiber L(w) CV	SFC (w) (%)	Fiber mean length L(n) (cm)	Fiber L(n) CV	SFC (n) (%)	Maturity ratio (%)	Fineness (mtex)	Fiber perimeter (µm)	Wall thickness (µm)
FM832	3.33 a,b	2.79 b	31.8 a	5.4 a	2.34 b	45.1 a	18.7 a	0.96 a,b	167 a	49.9	2.64
MD51neOK	3.23 b	2.74 b	30.5 a	5.1 a	2.31 b	43.3 a	17.6 a	0.95 b	171 a	50.8	2.65
MD15	3.38 a	2.95 a	28.6 b	3.0 b	2.57 a	38.0 b	11.3 b	0.97 a	159 b	48.5	2.60
Percent change (%)[w]	1.5	5.7	-10.1	-44.4	9.8	-15.7	-39.6	1.0	-4.8	-2.8	-1.5

* Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.

[z] AFIS cotton quality results were obtained at USDA-ARS, CQRS, Clemson, SC.

[y] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD51neOK.

[x] Cotton fiber perimeter and wall thickness estimates performed according to Montalvo and VonHoven (2007).

[w] Percentage change (%) between FM832 and MD15.

To compare cotton parents and their progeny, Suter-Webb array length groups 17 and 19 were averaged across length groups and combined into their three cotton categories to evaluate single cotton fiber differences. Measuring single cotton fibers on the Favimat revealed that the force to break significantly increased from parents to their progeny (Table 5). MD15 displayed the longest time to break with a mean time of 2.59 sec. MD15 had the highest ($p < 0.05$) mean force to break of 5.62 g, followed by FM832 and MD51neOK with mean force-to-break values of 4.66 and 4.96 g (respectively). Tenacity values displayed the same trend with MD15 having the highest value of 31.9 gforce/tex, compared with 23.9 and 24.9 gforce/tex, for FM832 and MD51neOK, respectively. MD15 exhibited the lowest ($p < 0.05$) elongation before break of 7.06%; followed by FM832, 8.11%; and MD51neOK, 8.67%. Subsequently, in evaluating work to rupture, samples from FM832, MD51neOK, and MD15 were not statistically different. Single fiber properties further demonstrated that MD15 was the better quality cotton cultivar and did not have any atypical characteristics concealed within fiber bundle testing.

Cotton breaking strength is correlated to the refractive index parallel to the fiber axis, birefringence, and to spiral angle as determined by X-ray (Hamby, 1965). Moharir et al. (1998) verified that smaller spiral angles correspond to improved orientation of cellulose crystallites to the fiber axis and stronger fibers. Flax is a straight bast fiber, whose molecules

Table 4. Summary properties of classical cotton fiber testing*

	Stelometer results [z]		Micronaire [z]	Peyer results [z]					
Cotton [y]	**Strength (g/tex)**	**Elongation (%)**	**Fineness (mic)**	**Mean fiber length (n) (cm)**	**SFC (n) (%)**	**Mean fiber length (w) (cm)**	**SFC (w) (%)**	**Upper quartile length (cm)**
FM832	24.0 b	5.1 b	4.57 b	1.85 a	28.1 a	2.21 a	12.8 a	2.79 a
MD51neOK	23.1 c	5.4 a	4.87 a	1.80 a	30.3 a	2.13 a	14.5 a	2.69 a
MD15	32.0 a	5.5 a	4.43 b	1.83 a	31.1 a	2.24 a	14.2 a	2.82 a
Percent change (%)[x]	33.3	7.8	-3.1	-1.4	10.7	1.1	10.9	0.9

* Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.

[z] Stelometer (ASTM, 1997b), micronaire (ASTM, 1997a), and Peyer AL-101 (ASTM, 1993) cotton quality results were obtained at USDA-ARS, CQRS, Clemson, SC.

[y] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD51neOK.

[x] Percentage change (%) between FM832 and MD15.

Table 5. Summary properties of single cotton fiber properties*

		Favimat results							FDAS 765 results			Modeling inference [z]
Cotton [y]	**Sample number**	**Elongation (%)**	**Linear density (dtex)**	**Crimp (crimp/cm)**	**Force to break (gforce)**	**Tenacity (gforce/tex)**	**Work to rupture (g*cm)**	**Time to break (sec)**	**Cross sectional area (μm²)**	**Minor axis (μm)**	**Major axis (μm)**	**Perimeter (μm)**
FM832	300	8.11 a	3.07 a	4.2 a	4.66 b	24.9 b	0.201 a	2.34 a	176.9 a	14.2 b	14.8 a	47.1
MD51neOK	300	8.67 a	2.11 a	5.4 a	4.96 b	23.9 b	0.266 a	2.39 a	185.6 a	14.9 a	15.2 a	48.3
MD15	600	7.06 a	2.05 a	4.2 a	5.62 a	31.9 a	0.226 a	2.59 a	173.0 a	13.9 c	14.3 b	46.6
Percent change (%)[x]		-12.9	-33.2	0.0	20.6	28.1	12.4	10.7	-2.2	-2.1	-3.4	-1.1

*Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.

[z] Cotton fiber perimeter estimated using FDAS 765 cross-sectional area results in perimeter of a circle formula.

[y] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD-51neOK.

[x] Percentage change (%) between FM832 and MD15.

are near parallel to the fiber's axis and the fibers show a greater tenacity and lower elongation (Morton and Hearle, 1997). Fiber fineness measured by the vibroscope method indicated linear density increased from 2.05 dtex in MD15, to 2.11 dtex in MD51neOK, and 3.07 dtex in FM832 confirming that MD15 produced finer fibers than its parents. Finer cottons have been shown to contain a higher tenacity than coarse fibers (Morton and Hearle, 1997), and finer fibers increase yarn strength and improve spinnability (Deussen, 1993) probably because more fibers are contained in the cross section of a given size yarn. Morphology results generated using the FDAS 765 established that MD15 was smaller ($p < 0.05$) in both its major and minor axis (Table 5). Cotton fiber perimeter estimates using FDAS 765 cross-sectional area further demonstrated that MD15 had the smallest perimeter. MD15 single fibers demonstrated higher strength values and a lower elongation. These fibers have a similar area in the break zone with a lower, but statistically comparable, linear density that produces fibers with superior cellulose material. With similar linear densities, it appears that an ideal X-ray angle may exist to help create a stronger fiber. Identified single fiber traits obtained via the Favimat, FDAS 765, AFIS and other methodologies coupled with classical fiber quality measurements and HVI™ analysis may be a means to better quantify fiber quality.

Yarn Testing. Increases in fiber bundle and single fiber measurements indicated that there should be an increase in yarn strength with MD15. Brown and Taylor (1988) demonstrated that with different rates of loading between fiber and yarn testing that some cotton varieties with high fiber strength properties do not produce stronger yarn. To evaluate the impact of MD15 on yarn production miniature spinning was performed (Table 6). Yarns (22/1) produced from MD15 produced an improved yarn, with force to break, tenacity, and work to rupture significantly improved by 26% and elongation was significantly larger by 4.7%. MD15 yarns were produced with finer fibers that typically contain more convolutions than coarse fibers and increased fiber friction (Hussain and Nachane, 1998), along with increased fiber strength (Cho et al., 1996; Foulk and McAlister, 2002; Hsieh, 1999). FM832 and MD51neOK yarns also exhibited hairiness values higher than MD15. Yarn testing demonstrated that MD15 was the better cotton cultivar and did not have any uniqueness concealed within single fiber or fiber bundle testing. MD15 appears to have superior single and fiber bundle quality characteristics that translate into improved yarn characteristics and, in theory, respective fabric properties.

SUMMARY

MD15 displayed better quality fiber properties tested under a variety of testing protocols and machinery. These fiber quality characteristics (finer and stronger) translated into improved yarn characteristics and, in theory, would produce better textiles. Cottons in this study were broken at different loading rates from 0.3 cm/min for the Stelometer, 2 cm/min for the Favimat, 13.6 cm/min for the HVI™, and 25.4 cm/min for the Statimat-M with respective fiber or yarn strengths of 32, 32, 41, and 27 g/tex. Fiber quality measurements and yarn quality indicated that this upland cotton genotype has the potential to produce a

Table 6. Effect of cotton varieties on ring-spun yarn properties*

Cotton [z]	Yarn size	Sample number	Force to break [y] (g)	Tenacity [y] (gforce/tex)	Elongation [y] (%)	Work to rupture [y] (g*cm)	Hairiness index [x]
FM832	22/1	600	570.5 b	21.25 b	6.18 c	420.6 b	4.9 a
MD51neOK	22/1	600	534.9 c	19.93 c	6.35 b	417.2 b	5.0 a
MD15	22/1	1200	719.3 a	26.80 a	6.47 a	535.4 a	4.2 b
Percent change (%)[w]			26.1	26.1	4.7	27.3	-14.3

* Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.

[z] FM832 is FiberMax® 832; MD51neOK is a near-isogenic line of the USDA-ARS variety MD51ne; and MD15 is the average performance of four F3:5 lines descended from a selfed seed of one F2 plant from the cross of FM832 and MD-51neOK.

[y] Single end strength and elongation tested on a Statimat-M.

[x] Hairiness tested on a Uster Evenness Tester UT-4.

[w] Percentage change (%) between FM832 and MD15.

high quality cotton fiber for textile mills. To meet the needs of spinning, knitting, and weaving, cotton fiber properties must be continually improved to remain competitive with synthetic fibers and in the global market. All strength testing results confirmed the initial HVI fiber testing results that progeny MD15 has superior upland cotton fiber characteristics that compare well to Acala and even American Pima cultivars. Micronaire, AFIS , Favimat, and FDAS 765 fineness results demonstrated that progeny MD15 produced finer fibers as cotton fiber perimeter estimates concurrently indicate a smaller perimeter. Yarn testing further demonstrated that progeny MD15 was the better cotton cultivar and did not have any uniqueness concealed within single fiber or fiber bundle testing. If fibers are uniformly stronger, there is potential to produce a lower percentage of short fibers in cotton bales, sliver, and yarn, thus producing stronger more uniform yarns that can subsequently be processed at a higher speed. Stronger fibers and yarns should lead to a reduction in spinning costs, knitting costs, weaving costs, and energy costs.

ACKNOWLEDGMENTS

We gratefully acknowledge Mark Reese and Patrick Raines from Measured Solutions Inc.; Steve Bucknell and Nigel Winsey from Dia-Stron Limited; Raisa Moiseyev from USDA ARS at the Southern Regional Research Center; along with Carolyn Simpson, Robert Harrison, Linda James, Nancy Carroll, and Derrill Stephens from USDA ARS CQRS for assisting with testing and set-up.

DISCLAIMER

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture, information is for information purposes only, and does not imply approval of a product to the exclusion of others that may be suitable.

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