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SINGLE COTTON FIBER PROPERTIES

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Abstract

The objective of this study was to evaluate fibers produced by cotton parents and their progeny using results generated via the Stelometer, Peyer AL101, Fibrograph, HVI™, AFIS™, Favimat, and miniature spinning. The Favimat, a single fiber testing machine, was used to measure fibers from samples consisting of cottons containing two different parents (FM832 and MD51neOK) and their progeny. In order to get a representation of certain fibers within these samples, the cotton was further divided into the 17 and 19 Suter-Webb array length groups. These fibers range in length from 1.00 to 1.125 in (length group 17) and 1.125 to 1.25 (length group 19). Traditional fiber testing was compared to single fiber testing and miniature spinning. Single fiber testing was performed using the Favimat, which measures the amount of force required to break up to 210 cN with a resolution of 1 X 10-4, while the fineness of these same fibers can be measured from 0.5 to 200 dtex. Following single cotton fiber image capturing, fiber fineness is determined by the vibroscope method. 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. Concurrently, calculated crimp characteristics indicated that the progeny fiber contained more undulations. The progeny cotton displayed better-quality fiber and yarn properties tested under a wide range of conditions.

Introduction

Cotton (*Gossypium barbadense L.* or *Gossypium hirsutum L.*) is a plant fiber crop that has a long history of being utilized in clothing by the textile apparel industry due to their comfort level. Cotton is grown primarily as a source of fiber and secondarily for its cottonseed (meal, oil). Each year many different upland cotton varieties are marketed to producers. These varieties are distinguished from each other due to 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 multi-location variety trials to evaluate plant and fiber performance. One cotton bale contains approximately 60 billion fibers (Steadman, 1997) with varying fiber properties. Ultimately, textile processing is influenced by these properties found within cotton. Cottons are diverse in nature and respond differently to textile cleaning and further processing.

Fiber fineness, maturity, trash, uniformity, fiber-to-fiber adhesion, length, and strength affect spinning efficiency. It is generally understood that fiber strength is one of the most important fiber properties and due to many genes that are quantitatively inherited (Basra, 2000). Fiber length is critical for textile processing and varies greatly for different cottons due to genetic differences (Basra, 2000). It is common practice for textile mills to process cotton on several pieces of opening and cleaning equipment prior to the card. The card is perhaps the single most important piece of textile processing equipment that influences spinning. Fundamentally, carding separates fiber tufts into individual fibers and reassembles the fibers into a sliver for subsequent yarn production. Stresses sustained during mechanical operations in opening, cleaning, and carding require longer and stronger fibers. Sliver utilized for yarn production typically makes use of approximately 30 to 70% of single fiber strength (Hsieh, 1999). Yarn strength is determined by fiber strength and fiber interactions, including length, friction, and twist (Hsieh, 1999).

Cotton grading has progressed from subjective human classers to the HVI™, a high volume instrument. Prior to the HVI™, classical cotton fiber properties such as strength, elongation, and fineness were generated using the Pressly tester, Stelometer, and Fibronaire. HVI™ and Stelometer tests physically test a specially combed fiber bundle. The number of single fibers in a fiber bundles on the HVI™ contains approximately 2000-2500 fibers (Ellison and Rogers, 1995). Fibronaire and HVI™ measurements of fineness use known weights of cotton fibers. The Favimat (Textechno Herbert Stein GmbH & Co. KG, Mönchengladbach, Germany), a low volume single fiber-testing instrument, provides single fiber values, which are not currently generated in cotton grading that tests fiber bundles. The Favimat provides traditional single fiber data, tensile strength and percent elongation at a constant rate of extension with additional fiber parameters such as capturing fiber crimps, tenacity, linear density, and work to rupture. The Favimat has the capability to test and differentiate single fibers based on tensile strength, fineness, crimp extension, crimp rigidity and crimp number on the same fiber section (Schneider et al., 1998; Stein and Morschel, 1998).

Many events impact cotton fibers, so a better understanding of new varieties is desired to expedite processing in textile mills and to encourage certain cotton varieties. Cotton hairs grow to various lengths from cells on the seed to form elongated tubular shapes that appear as solid rods (circular cross section). These fibers are not solid, but hollow, and twist and crimp when dried. Crimp is a characteristic of all cotton fibers and determines the capacity of fibers to adhere under light pressure. Coarse cotton fibers typically have fewer convolutions than fine fibers with fiber friction increasing with convolutions (Hussain and Nachane, 1998). Increases in cotton convolutions have been linked to an increase in fiber strength (Cho et al., 1996, Hsieh, 1999). Manufacturing processes likely manipulate and transform a fibers crimp.

The objective of this study was to evaluate fibers produced by cotton parents and their progeny using results generated via the Stelometer, Peyer AL101, Fibrograph, HVI™, AFIS™, Favimat, and miniature spinning. Cottons containing two different parents (FM832 and MD51neOK) and their progeny were selected to cover a cotton breeding succession and to determine breeding influences on fiber results. As processing speeds increase, high-speed spinning machinery is less tolerant of weak and short fibers so continued improvements in the cotton breeding are desirable. New processing techniques and/or instruments are necessary to provide rapid, consistent, and quantitative cotton fiber results.

Materials and Methods

Cotton

Research was conducted on cottons containing two different parents (FM832 and MD51neOK) and their progeny referred to as I, II, and III, respectively. The study was replicated with three separate plantings. Within each of these plantings there existed a subset of two parents and four progeny.

Fibermax 832 is a commercial variety of okra leaf cotton with excellent fiber quality properties grown under many different growing conditions that produce a high percentage of first position bolls (Bayer CropScience, 2005). Relatively, these fibers are considered to be very long with a high uniformity that are very strong at a base micronaire (Bayer CropScience, 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).

Sample cotton plants were all harvested and ginned by small scale laboratory methods and selected by cotton breeders because of their strength determined by the flat bundle method (ASTM International, 1997b) and length determined using the advanced fiber information system (AFIS™). Strength tests for cotton breeder samples at USDA-ARS, Crop Genetics and Production Research Unit (CGPRU) are typically performed by private institutions such as Starr Laboratories (Knoxville, TN) while AFIS™ results are obtained in-house at Stoneville, MS.

Cotton testing

Prior to testing, all cotton samples were conditioned for at least 48 hours at 65 % RH and 21 ^{o}C (ASTM International, 1997d). Fiber bundle strength and elongation values were determined with a total of six breaks using a Stelometer (ASTM International, 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 High Volume

Instrumentation (HVI™), cotton fineness, length and strength measurements (ASTM International, 1999) were performed (six measurements each) on a HVI™ 900A (Uster Technologies Inc., Knoxville, TN) by the Testing Laboratory at Cotton Quality Research Station (CQRS). The HVI™ has estimated instrument breaking speed of 13.6 cm/min (Godbey et al., 1991). Advanced Fiber Information System (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.

In order to get a better representation of the longer fibers within these samples, the cotton was further divided into Suter-Webb array length groups (ASTM International, 1997e). A Fibroliner AL-101 (Peyer Electronics, Spartanburg, SC) was used to help separate the fibers (ASTM International, 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 and placed on a black velvet board to be 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 1.00 to 1.125 in (length group 17) and 1.125 to 1.25 (length group 19).

The Favimat measures the amount of force required to break up to 210 cN with a resolution of 1×10^{-4}, while 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 International, 1997c). Crimp number is determined through an opto-electrical sensor that evaluates the fiber under a 0.03cN/tex. Twenty-five fibers from each cotton 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.

Images, captured using the Favimat's opto-electrical sensor, are internally converted into X and Y values and stored as a local file. Fibers visually contain crimp often described as undulations, waviness, curls, waves, or succession of bends. When plotted in a spreadsheet, it was observed that each fiber has its own unique "fingerprint", yet all have a set of similar characteristics, which can be quantified to analyze each of these fibers. Figure 1 is a plot of data recorded from the Favimat of a representative fiber. In order to evaluate these fibers further, the X and Y data were imported into a spreadsheet and a Macro program written to calculate fiber characteristics such as wavelength(WL), crimp angle (ANG), crimp width (CW), amplitude (AMP), crimp length (CL), straight fiber length (SFL), crimp index (CI), crimp frequency (CFQ), crimps/in (CPI), crimp intensity (CAR), fiber crimp/in (FCPI), fiber crimp frequency (FFQ), number of max and min (MXMN), observed crimp (OBCP), and crimp tally (CTAL). Identified fiber traits may be a means by which to quantify fiber quality. These characteristics may help identify more desirable cottons, since better understandings of new varieties is desired to expedite processing in textile mills and to encourage certain cotton varieties.

Figure 1 demonstrates that a cotton fiber has crimp characteristics similar to an asymmetric non-periodic sinusoidal waveform, and as such, its set of characteristics can be defined using many of the same definitions applied to a sinusoidal waveform. An ideal, symmetric, periodic, sinusoidal waveform is defined by the function (Fitzgerald et al., 1975):

$$y(x) = A \cos(2\pi f x + \theta) \tag{1}$$

where:

A = the peak magnitude, or amplitude, of the waveform,
f = the frequency of the repeating sinusoid over a given period, T,
θ = the phase angle displacement.

For the purposes of defining the characteristics of the fiber data, the phase angle displacement is irrelevant, and can be ignored (θ=0), simplifying the equation to:

$$y(x) = A \cos (2\pi f x). \quad (2)$$

The above equation is used as a basis for characterizing fibers. Analogous to equation (2), the following characteristics are calculated for each fiber:

Period, T (mm): For use in calculating certain fiber characteristic, a period has been defined as the distance from the first local minima to the last local minima. Defining the period in this manner allows a simple and consistent method by which to calculate certain characteristics. As a result, those characteristics do not include the leading and tailing ends of the fiber, with this portion of the fiber next to the instruments clamps consistently ignored. Where not stated in the definition, all other characteristics include all data points captured by the Favimat.

Average Wavelength, WL (mm): The wavelength of the ideal waveform of equation (2) is defined as the distance (in the *x* direction) between adjacent minimums or adjacent maximums. For purposes of this analysis, the average fiber wavelength is defined as the average distance between local minimums within the period, T, defined above.

Average Crimp Width, CW (mm): The average crimp width is simply one-half the average wavelength. Intuitively, this is the average distance between adjacent local minimums and local maximums within the period, T. As such, CW does not include the leading and tailing ends of the fiber with this portion of the fiber next to the instruments clamps consistently ignored.

Average Amplitude, AMP (mm): Analogous to the A, the peak magnitude of the waveform, in equation (2), the average fiber amplitude is defined as the average amplitude of the peaks of all local minimums and local maximums. However, since the fiber data is asymmetric, determination of the average amplitude was done by summing the vertical leg distances from each local minima to the adjacent local maxima over the period, T. This value was divided by four (two rising and two falling leg lengths), then divided by the number of wavelengths in the period to achieve the average.

Average Crimp Length, CL (mm): This is defined as the average straightened fiber length between local minimums and local maximums within the period, T. This length of fiber forms the fiber crimp structure.

Crimp Angle, ANG (°): This is defined as the average angle of the wavelength, calculated at the peak of the fiber crimp. This value potentially provides an indication of fiber crimp and undulations, waviness, curls, waves, or succession of bends.

Crimped Fiber Length, CFL (mm): This is defined as the overall length of the crimped (unstraightened) fiber, including the leading and tailing ends of the fiber. Or, in other terms, the first *x* value of the individual fiber's data set subtracted from the last *x* value.

Straight Fiber Length, SFL (mm): If the crimped fiber were pulled at both ends to form a straight line, SFL is the length of this straight line. This value could be an indirect measure of the amplitude of crimp. It is calculated by summing the distance between consecutive (x, y) data points from the first to the last point of the dataset. The distance between two data points $\{(x_1, y_1, z_1), (x_2, y_2, z_2)\}$ is, by definition (Kreyszig, 1988):

$$\text{distance} = [(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2]^{1/2} \quad (3)$$

where, for our calculations, $z = 0$ and the equation simplifies to:

$$\text{distance} = [(x_2-x_1)^2 + (y_2-y_1)^2]^{1/2} \quad (4)$$

Crimp Index, CI (dimensionless): This index is an indirect measure of the amplitude of crimp and quantifies the amount of "kink" in a crimped fiber. It is simply the length of straight fiber minus crimped fiber that was divided by the straight fiber length multiplied by 100. Crimped fiber length was performed with a pretension of 0.20 cN/tex. A low CI indicates a significant amount of "kink", whereas a CI equal to one indicates a perfectly straight fiber.

Crimp Intensity, CAR (mm^2): This is another indicator of "kink" or an indirect measure of the amplitude of crimp in a fiber. It is defined as the area underneath the waveform in the period, T, divided by the number of crimps in this same period. A high CAR indicates a significant amount of "kink", whereas a low CAR indicates a straight fiber with very little "kink".
Crimp Frequency, CFQ (crimps/ mm): The crimp frequency is the frequency with which crimps occur over the length of a crimped fiber within the period, T. It is defined as the inverse of the average crimp width, or CFQ = 1 / CW. CFQ does not include the leading and tailing ends of the fiber with this portion of the fiber next to the instruments clamps consistently ignored.

Crimps per Inch, CPI (crimps/ in): This is similar to CFQ, except where CFQ is the frequency with which crimps occur over the length of a crimped fiber, CPI is the frequency with which crimps occur over the length of a straightened fiber over the same period, T. Mathematically, CPI = (CL / T) * 25.4. CPI does not include the leading and tailing ends of the fiber with this portion of the fiber next to the instruments clamps consistently ignored.

Number of maximums and minimums, MXMN (count): The total number of local maximum and minimum peaks were detected and counted for each set of data collected by the Favimat. The maximum and minimum points in the fiber (undulations, waviness, curls, waves, or succession of bends) were detected by a change in slope from positive to negative or vice-versa.

Observed Crimp, OBCP (count): The number of maximums and minimums was divided by 2 to arrive at this number.

Crimp Tally, CTAL (crimp/mm): The crimp tally was calculated by dividing the observed crimp by the straight fiber length (CTAL=OBCP/SFL). CTAL includes the leading and tailing ends of the fiber.

FCPI (crimps/in): Fiber crimps per in were calculated by subtracting 1 from the number of minimum multiplying by 25.4 and dividing by the crimped fiber length. FCPI includes the leading and tailing ends of the fiber.

FFQ (crimps/mm): Fiber crimp frequency was calculated by subtracting 1 from the number of minimums and dividing by the length of the straight fiber. FFQ includes the leading and tailing ends of the fiber.

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., 1962, Landstreet et al., 1959). The sample was carded to provide further opening, blending, cleaning, and production of a web (Ewald, 1975, Landstreet et al., 1962, Landstreet et al., 1959). 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 (4.92 ft) long and 0.22 m (8.5 in) wide. The lap was then processed through drawing to produce a parallel, uniform blend of fibers to deliver a sliver of a specified weight (Ewald, 1975, Landstreet et al., 1962, Landstreet et al., 1959). Cotton slivers were spun into a 22/1 Ne yarn on a miniature ring spinning system to evaluate the impact of the fibers 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 International, 1994). The Statimat-M has an instrument breaking speed of 25.4 cm/min.

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 (Table 1) performed for USDA, ARS, CGPRU indicate that the progeny, cotton III, produces a statistically lower micronaire, higher Stelometer strength, lower short fiber content, and finer fiber. Cotton III is not statistically different than its one parent (MD51neOK) for its yield, elongation, and maturity ratio. It appears that these fiber traits contribute to create cotton with exceptional fiber quality. Since this cotton was significantly tougher (27% 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 variety.

HVI™ results (Table 2) further demonstrates that compared to its parents cotton III statistically produced superior micronaire values (6% finer) with a higher strength (20% stronger), higher uniformity (3% additionally consistent), and longer upper half mean length (3% longer). Supplementary studies were performed on the AFIS™ to evaluate single fiber characteristics such as fineness and length measurements (Table 3). AFIS™ results again indicate that cotton III statistically produces a finer fiber (5% finer) with longer length (5% for fiber mean length by weight and 9% for fiber mean length by number) than its parents. Coefficients of variation values were statistically lower for its length by weight and number, respectively 6 and 10 %. Short fiber content by weight and number calculated by AFIS™ demonstrates that cotton III produces cotton with significantly lower quantities of fibers less than half of an inch. HVI™ and AFIS™ measurements further indicate that cotton III is a superior fiber variety and different from its parents.

To assess results performed for USDA, ARS, CGPRU, fiber bundle results (Table 4) were performed by USDA, ARS, CQRS in Clemson, SC. These results indicate that cotton III produces a statistically superior Stelometer strength (25% stronger). Stelometer elongation values for cotton III were statistically different than cotton I but similar to cotton II. Cotton III produced the finest cotton (micronaire 4.43) but was only significantly different than cotton II (micronaire 4.87). It is understood that the Peyer AL-101 produces different fiber length results than other measurements (Behery, 1993) with fiber length results in this study demonstrating very little diversity. Stelometer and micronaire measurements performed by USDA ARS CQRS further indicate that cotton III is a superior fiber variety and different from its parents.

HVI™, Stelometer, and micronaire measurements are performed on fiber bundles with the treatment and handling of these individual fibers throughout testing possibly affecting results. To evaluate individual fibers found within these bundles single fiber testing must be performed to determine if cotton III is a superior fiber variety. Single fiber Favimat robotic procedures appear to streamline the process beyond simply hand-loading single fibers into the Favimat. Once fibers were loaded into the automatic sample changer, no intervention occurred, with all testing performed sequentially on the same fiber section. The Favimat is self-contained testing instrument to test 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, fifty fibers from the two length groups provided 300 or 600 single fiber properties for each of the three cottons (Table 5).

In order to better compare cotton parents and their progeny, Suter-Webb array length groups 17 and 19 were all averaged across length groups and combined into their three respective cotton categories to evaluate single cotton fiber differences. Assessed Favimat fiber quality parameters for the cotton parents and progeny are listed in Table 6. Measuring single cotton fibers on the Favimat showed that the force to break the cotton significantly increased from parents to their progeny. Cotton III displayed the longest time to break with a mean time of 2.59 sec. Cotton III had the highest significant mean force to break of 5.62 g, followed by cottons I and II with respective mean force to break values of 4.66 and 4.96 g. Tenacity values displayed the same trend with cotton III having the highest significant value of 31.9 gforce/tex (22% stronger than cottons I and II). Cottons I and II displayed respective mean tenacity values of 23.9 and 24.9 gforce/tex. Cotton III elongated the least, 7.06%, followed by cotton I, 8.11%, and cotton II, 8.67%. Subsequently, in evaluating work to rupture, samples from cottons I, II, and II were not statistically different, increasing from cotton I (0.20 g*cm) to cotton III (0.23 g*cm) to cotton II (0.27 g*cm). Single fiber properties further demonstrated that cotton III was the better-quality cotton variety and did not have any atypical characteristics concealed within fiber bundle testing.

Cotton breaking strength is greatly 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 are very nearly parallel to the fibers axis and 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 cotton III to 2.11 dtex in cotton II and 3.07 dtex in cotton I. While these linear density values are unlike traditional airflow principals, they confirmed that cotton III had the lowest fineness. Finer cottons have been shown to contain a higher tenacity than coarse fibers (Morton and Hearle, 1997). In order to better compare linear density values to traditional airflow fineness values, the frequency distributions must be determined across length groups. Cotton III single fibers demonstrated a lower elongation that produces a stiffer material with higher strength. 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 exists in cotton III fibers to help create a stronger fiber.

Cotton crimps are similar to an asymmetric non-periodic sinusoidal waveform and were defined using the same definitions (Tables 7-8). Images were captured on the Favimat using an opto-electrical sensor, internally converted into X and Y values, and stored for sinusoidal waveform analysis. Fibers contain crimp (undulations, waviness, curls, waves, or succession of bends) with different cotton fiber varieties and lengths groups potentially having its own unique “fingerprint”. Cottons I, II, and III were all combined into two respective length groups (17 and 19) to evaluate testing results. Length group 19 statistically had a larger crimp angle (150 vs. 147°), smaller crimp index (7.9 vs. 9.4), larger fiber crimp frequency (1.06 vs. 1.02 crimp/mm), larger crimp tally (1.22 vs. 1.18 crimp/mm), larger force to break (5.55 vs. 4.88 gforce), and larger tenacity (29.3 vs. 27.0 gforce/tex). Longer fibers in length group 19 are likely more mature and in regards to crimps should be a straighter fiber with a larger crimp angle, smaller crimp index, larger crimp frequency, and larger crimp tally. As expected these longer more mature fibers have a larger force to break and tenacity.

Statistically there were few significant differences, α =0.05, between cotton III and its parents according to Duncan’s new multiple range test. Generally, cotton III fibers produced fibers having a lower wavelength, crimp width, and crimp angle. Cotton III simultaneously displayed fibers having the longest straightened fiber length and highest crimp index, both indicators of increased cotton crimp. Calculated cotton III waveform quantities were mathematically closer to the wavelength, amplitude, crimp width, straight fiber length, crimp index, crimp frequency, crimp area, fiber crimps/inch, total max and minima and observed crimp of cotton II values. Further evaluation of these cottons at α=0.15 established that the calculated values for cotton III such as wavelength and crimp width were significantly lower than cotton I. Lower wavelengths and crimp widths signify that the fiber crimps are spaced close together at a high regularity. At α=0.15, cotton III further demonstrated that straight fiber length, crimp index, crimp frequency, fiber crimps per inch, fiber crimp frequency, total maxima and minima, and observed crimp were significantly larger than cotton I. Increases in these values indicate that cotton III is more highly crimped. Increases in cotton convolutions, which create fiber crimps, have been linked to increased fiber strength (Cho et al., 1996; Hsieh, 1999; Foulk and McAlister, 2002).

Increases in fiber bundle and single fiber measurements indicated that there should be an increase in yarn strength. Brown and Taylor (1988) demonstrated that with different rates of loading between fiber and yarn testing some cotton varieties with high fiber strength properties do not translate into higher yarn strength. To evaluate the impact of cotton III on yarn production miniature spinning was performed to evaluate relative differences (Table 9). Yarns (22/1) produced from cotton III produced a product with superior properties. The force to break, tenacity, and work to rupture were significantly different and 21% greater than cottons I and II. Its elongation was significantly larger (2%) than cottons I and II. Yarn testing further demonstrated that cotton III was the better cotton variety and did not have any uniqueness concealed within single fiber or fiber bundle testing. Cotton III appears to have superior single and fiber bundle quality characteristics that translate into improved yarn characteristics and in theory respective fabric properties.

The progeny, cotton III, displayed better-quality fiber and yarn properties tested under a wide range of conditions. 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. Textile equipment has become less tolerant of short, non-uniform, coarse, and weak fibers with increases in processing speed. Fiber and yarn testing demonstrates that cotton III demonstrates better properties regardless if testing single fibers, fiber bundles, or produced yarns. In the past there has typically been a negative association between yield and strength. Fiber quality measurements and their results indicate that this cotton variety has potential to create a high quality cotton fiber for textile mills. Miniature spinning further indicates that this variety narrows the gap between quantity and quality. These preliminary results may allow textile mills and cotton breeders to better understand the importance of superior cotton quality varieties. In other words, cotton breeding information may help explain the impact of new cotton varieties on high speed processing.

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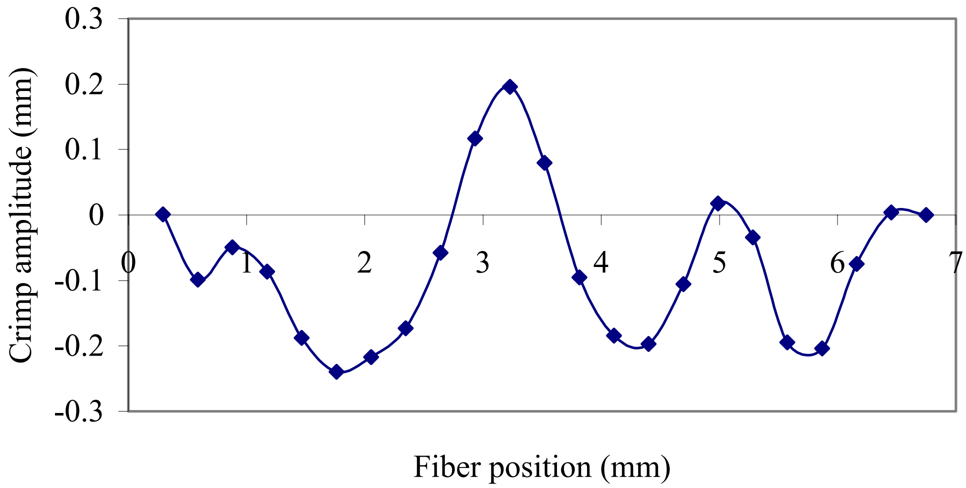

Figure 1. Cotton fiber image captured via Favimat's opto-electrical sensor.

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

			Stelometer results		AFIS™ results					
Cotton [b]	Yield	Fineness	Strength	Elongation	Fiber mean length L(w)	SFC (w)	Fiber mean length L(n)	SFC (n)	Maturity ratio	Fineness
	(lb/ac)	(mic)	(g/tex)	(%)	(in)	(%)	(in)	(%)	(%)	(mtex)
I	938 a	4.65 b	23.4 b	5.54 b	1.08 a,b	4.8 a	0.90 a,b	17.6 a	1.00 a	175 b
II	741 b	4.88 a	21.4 c	6.04 a	1.03 b	5.2 a	0.87 b	18.3 a	0.99 a	182 a
III	738 b	4.34 c	32.2 a	6.27 a	1.10 a	3.4 b	0.96 a	13.8 b	1.00 a	170 c

* Values followed by different letters within columns are significantly different, $P < 0.05$, according to Duncan's new multiple range test.
[a] Fiber yield and AFIS™ (Uster Technologies Inc., Knoxville, TN) results were obtained at USDA, ARS, CGPRU, Stoneville, MS while Stelometer (ASTM International, 1997b) and Micronaire (ASTM, 1997a) were obtained by Starr Laboratories (Knoxville, TN).
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

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

Cotton [b]	Fineness (mic)	Strength (g/tex)	Elongation (%)	Uniformity (%)	UHM (in)	Short Fiber Index (%)
I	4.71 b	33.9 b	6.6 b	83.9 b	1.19 b	6.6 b
II	4.95 a	33.1 b	7.2 a	83.2 b	1.15 c	7.2 a
III	4.44 c	41.3 a	6.5 b	86.6 a	1.23 a	6.5 b

* Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] HVI™ cotton quality fiber measurements were performed according to ASTM standards (1999) obtained on a HVI™ 900A (Uster Technologies Inc., Knoxville, TN) by the Testing Laboratory at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

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

Cotton [b]	UQL (w) (in)	Fiber mean length L(w) (in)	Fiber L(w) CV	SFC (w) (%)	Fiber mean length L(n) (in)	Fiber L(n) CV	SFC (n) (%)	Maturity ratio (%)	Fineness (mtex)
I	1.31 a,b	1.10 b	31.8 a	5.4 a	0.92 b	45.1 a	18.7 a	0.96 a,b	167 a
II	1.27 b	1.08 b	30.5 a	5.1 a	0.91 b	43.3 a	17.6 a	0.95 b	171 a
III	1.33 a	1.16 a	28.6 b	3.0 b	1.01 a	38.0 b	11.3 b	0.97 a	159 b

* Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] AFIS™ (Uster Technologies Inc., Knoxville, TN) cotton quality results were obtained at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

Table 4. Summary properties of cotton fiber bundles *[a]

Cotton [b]	Strength (g/tex)	Elongation (%)	Fineness (mic)	Length (n)	SFC (n)	Length (w)	SFC (w)	L1	L25
I	24.0 b	5.1 b	4.57 b	0.73 a	28.1 a	0.87 a	12.8 a	1.40 a,b	1.10 a
II	23.1 c	5.4 a	4.87 a	0.71 a	30.3 a	0.84 a	14.5 a	1.37 b	1.06 a
III	32.0 a	5.5 a	4.43 b	0.72 a	31.1 a	0.88 a	14.2 a	1.42 a	1.11 a

* Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] Stelometer (ASTM International, 1997b), Micronaire (ASTM, 1997a), and Peyer AL-101(ASTM, 1993) cotton quality results were obtained at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

Table 5. Effect of Suter-Webb length group cottons on single cotton fiber properties via Favimat *[a]

Cotton [b]	Length group	Sample number	Elongation (%)	Linear density (dtex)	Crimp (crimp/cm)	Tenacity (gforce/tex)	Work to rupture (g*cm)	Time to break
I	17	150	6.6 a	3.3 a	10.9	23.7 b,c	0.14 a	2.4 a
	19	150	9.7 a	2.8 a	10.3	26.1 b	0.26 a	2.3 a
II	17	150	10.8 a	2.0 a	17.6	23.0 c	0.26 a	2.4 a
	19	150	6.6 a	2.2 a	9.6	24.8 b,c	0.28 a	2.3 a
III	17	300	6.9 a	2.2 a	11.3	30.6 a	0.25 a	2.7 a

	19	300	7.2 a	1.9 a	10.1	33.1 a	0.20 a	2.5 a

*Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] Length groups correspond to Suter-Webb length groups (ASTM, 1993) at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

Table 6. Effect of Suter-Webb length group cottons on single cotton fiber properties via Favimat *[a]

Cotton [b]	Sample number	Elongation (%)	Linear density (dtex)	Crimp (crimp/in)	Force to break (gforce)	Tenacity (gforce/tex)	Work to rupture (g*cm)	Time to break (sec)
I	300	8.11 a	3.07 a	10.6 a	4.66 b	24.9 b	0.201 a	2.34 a
II	300	8.67 a	2.11 a	13.6 a	4.96 b	23.9 b	0.266 a	2.39 a
III	600	7.06 a	2.05 a	10.7 a	5.62 a	31.9 a	0.226 a	2.59 a

*Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] Length groups correspond to Suter-Webb length groups (ASTM, 1993) at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

Table 7. Single cotton fiber image analysis *[a]

Cotton [b]	Sample number	Wavelength [c] (mm)	Amplitude [c] (mm)	Crimp width [c] (mm)	Crimp length [c] (mm)	Crimp angle (°)	Crimps/in [c] (crimp/in)	Straight fiber length
I	300	0.726 a	0.0482 b	0.363 a	0.392 a	148.7 a,b	34.3 a	7.47 b
II	300	0.713 a,b	0.0569 a	0.357 a,b	0.402 a	149.1 a	35.0 a	7.67 a,b
III	600	0.707 b	0.0542 a,b	0.353 b	0.392 a	147.4 b	34.8 a	7.74 a

*Values followed by different letters within columns are significantly different, P < 0.15, according to Duncan's new multiple range test.
[a] Length groups correspond to Suter-Webb length groups (ASTM, 1993) at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.
[c] Defined characteristics defined do not include the leading and tailing ends of the fiber with this portion of the fiber next to the instruments clamps consistently ignored

Table 8. Single cotton fiber image analysis *[a]

Cotton [b]	Sample number	Crimp Index	Crimp Freq [c] (crimp/mm)	Crimp Intensity [c] (mm^2)	Fiber crimps/in (crimp/in)	Fiber Crimp freq (crimp/mm)	Total max & min	Observed crimp	Crimp tally
I	300	7.98 b	2.86 b	0.099 a	28.0 b	1.02 b	17.4 b	8.7 b	1.18 b
II	300	8.40 a,b	2.94 a	0.150 a	29.2 a	1.06 a	18.0 a	9.0 a	1.22 a
III	600	9.13 a	2.94 a	0.121 a	29.0 a	1.04 a	17.8 a	8.9 a	1.20 a,b

*Values followed by different letters within columns are significantly different, P < 0.15, according to Duncan's new multiple range test.
[a] Length groups correspond to Suter-Webb length groups (ASTM, 1993) at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.

Table 9. Effect of cotton varieties on ring-spun yarns via Statimat *[a]

Cotton [b]	Yarn size	Sample number	Force to break (g)	Tenacity (gforce/tex)	Elongation (%)	Work to rupture (g*cm)
I	22/1	600	570.5 b	21.25 b	6.18 c	420.6 b
II	22/1	600	534.9 c	19.93 c	6.35 b	417.2 b
III	22/1	1200	719.3 a	26.80 a	6.47 a	535.4 a

* Values followed by different letters within columns are significantly different, P < 0.05, according to Duncan's new multiple range test.
[a] Length groups correspond to Suter-Webb length groups (ASTM, 1993) at USDA, ARS, CQRS, Clemson, SC.
[b] Cotton varieties Fibermax 832 (parent), MD51neOK (parent), and progeny are referred to as I, II, and III, respectively.