FIBER LENGTH DISTRIBUTIONS AND FIBER QUALITY

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Abstract

Cotton (*Gossypium hirsutum L.)* is grown in Georgia on ~1 million acres by producers as a raw material input for textile mills. Georgia cotton fiber qualities continue to improve through crop management, genetic, and ginning improvements. 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. In order to determine a superior fiber variety in Georgia, six promising cotton varieties were grown in 6 Georgia counties and ginned at the University of Georgia's MicroGin. Ginned lint fiber properties were evaluated and spun at the USDA-ARS Cotton Quality Research Station pilot plant. The Advanced Fiber Information System (AFIS) analyzes cotton fiber length distributions because variations in fiber length distribution impacts spinning performance. The goal was to evaluate the entire AFIS fiber length distribution so distributions were evaluated rather than mean values. The objective was to evaluate differences in the shape of histograms between counties, varieties, and processing. Histograms and fiber length decreases through processing but the six varieties tend to maintain their relative positions in processing. Cotton fiber length distribution within plant varieties indicate that PHY375 has a consistent length distribution regardless of its growing location while ST5458 appears to have more variability dependent upon growing location. The distributions within counties appear to follow the same shapes but there appears to be significant differences between cotton fiber length distributions in counties. This shape discrepancy within counties could be due to harvesting equipment differences between locations or ginning differences.

Introduction

In the United States for 2009, Georgia ranked second in cotton acreage (1,000,000 acres) and second in production (average yield of 902 lb cotton/acre) with a market value of ~$640,000,000. Better fiber properties lead to higher market values. The USDA Agricultural Marketing Service provides cotton (*Gossypium hirsutum L*.) fiber quality measurements on every bale grown in the US using High Volume Instrumentation (HVI™). Little attention has been paid to understanding fiber quality variation, though it has long been recognized that cotton fibers are naturally variable (Balls, 1928). Each year new varieties are marketed to producers 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. Textile industries desire longer more uniform cotton fibers and the reason that states such as Georgia performs cotton variety trials. In order for these cotton variety trials to be sufficient they require additional testing, processing, and spinning.

The AFIS instrument provides additional information such as cotton fiber length and length distributions. Typically mean values are evaluated for processing however; length histograms provide additional information and could be an effective graphical method to demonstrate fiber length variability. It is useful to understand the histogram distribution differences between cotton varieties, cotton production counties, and stages of processing. This would assist in determining a cotton variety that not only has for example a high strength but a uniform fiber length distribution. It may also indicate the impact of geographical areas (that differ in soil and environmental conditions) on length histogram uniformity. Finally histogram analysis may indicate that certain cotton varieties respond differently to processing (less broken fibers) and thus be more desirable than others.

Excellent fiber properties do not always translate into first-rate yarn with high spinning efficiencies so different cottons require spinning trials. If fibers were more uniform in length there should be 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. More uniform fiber length and stronger yarns should lead to a reduction in spinning costs, knitting costs, weaving costs, and energy costs. Length can be affected by cultivar, maturity, environment, boll position, field weathering, production practices, harvest method and speed, ginning type and speed, and moisture content. The objective was to evaluate differences in the entire shape of cotton histograms between cotton varieties, counties, and stage of processing.

Materials and Methods

Cotton Samples

This study was conducted in 2010 with six (6) promising upland cottons. Cotton varieties were selected based on their adaptability to Georgia growing regions, potential yield, and potential fiber properties. These cottons were grown in Georgia in cooperation with producers and University of Georgia Extension Cotton Team Members. Cotton was grown on dry land in Candler, Coffee, and Colquitt counties and on irrigated land in Burke, Early, and Worth counties. Samples were spindle picked in harvest and then ginned at the University of Georgia's MicroGin. Cottons were ginned through two stages of cleaning (6 cylinder incline cleaner and stick machine followed by a 6 cylinder incline cleaner and Trashmaster), extractor feeder, 24 saw gin stand, air jet lint cleaner, and 1 lint cleaner. These samples were shipped to USDA-ARS Cotton Quality Research Station for fiber property evaluation and spinning.

Mechanical testing

Prior to testing, all cotton samples were conditioned for at least 24 hours at 65 % RH and 21 ^{o}C (ASTM, 1997d). Fiber length, length uniformity, strength, micronaire, trash, Rd, and +b for each bale were measured by USDA Agricultural Marketing Service (AMS) on a High Volume Instrumentation (HVI™) (Uster Technologies Inc., Knoxville, TN) according to ASTM D5867 (ASTM, 1999). HVI™ fiber properties were determined for these samples (Table 1)

The 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 measurements thus producing various distributions. AFIS™ analyzes fineness, upper quartile length (UQL), short fiber content (SFC), Maturity Ratio, Neps (count/gram), and visible foreign matter (VFM). Testing was completed on the raw stock cotton, card mat, card sliver, finisher drawing sliver, and white waste for ring and open-end spinning (ASTM, 2005). AFIS™ measurements were obtained for all cotton samples with three tests of 3,000 fibers. AFIS fiber length distributions were determined from these samples (Table 2).

Textile Processing

All spinning was conducted at USDA-ARS Cotton Quality Research Station in Clemson, SC. All fiber was processed through the same modern Truetzschler Opening and Cleaning line (American Truetzschler Inc., Charlotte, NC) and card to produce a 70 grain sliver at 100 lbs/hour. All fiber was processed through the following sequence: blending hoppers in a Fiber Controls Synchromatic Blending System (M & M Electric Service Inc., Gastonia, NC), Axi-Flo cleaner (American Truetzschler Inc., Charlotte, NC), GBRA blending hopper (American Truetzschler Inc., Charlotte, NC), a RN cleaner (American Truetzschler Inc., Charlotte, NC), RST cleaner (American Truetzschler Inc., Charlotte, NC), DUSTEX fine dust remover (American Truetzschler Inc., Charlotte, NC), and chute fed Truetzschler DK-803 card (American Truetzschler Inc., Charlotte, NC).

Rotor spinning sliver received one pass of drawing on a Rieter RSB-51 draw frame (Rieter Corp., Spartanburg, SC) with a leveler producing 55 grain/yard sliver and subsequently spun on a Schlafhorst SE-11 upgraded rotor spinning machine (Saurer Group, Charlotte, NC). Yarn was spun at 100,000 rotor RPM and a combing roll speed of 8,000 RPM with a T330 rotor and a twist multiplier α of 4.6 producing a 20/1 Ne yarn. Ring spinning sliver was processed through two passes of drawing first on a Rieter SB-951 draw frame (Rieter Corp., Spartanburg, SC) followed by a Rieter RSB-51 draw frame with leveler (Rieter Corp., Spartanburg, SC). The finisher drawing sliver was then processed into roving on a Zinser 660 roving frame (Saurer Group, Charlotte, NC) producing a 1.00 hank roving at a flyer speed of 850 RPM and a twist multiplier α based on the draftometer. Yarn (30/1 Ne) was then spun from the roving on a Zinser 321 ring spinner (Saurer Group, Charlotte, NC) at a spindle speed of 14,000 RPM and with a twist multiple α of 4.1. Processing efficiency was determined by physically counting and recording the number of ends down (number of yarn breaks) for the duration of processing. Ring and rotor spinning ends down was recorded and calculated for 1000 spindle and rotor hours, respectively Tables 3 and 4.

Results and Discussion

HVI™ data indicate that there are differences for varieties in mean uniformity, mean fiber strength, and mean fiber length. Cotton varieties ST5458 and FM1740 have significantly higher Micronaire values than varieties DP935 and PHY375. With regard to fiber length, the data indicates that varieties DP949, ST5458 and FM1740 are significantly longer in mean length than varieties DP935 and DP555. Fiber length uniformity data indicate that varieties FM1740 and DP949 have significantly higher mean uniformity values than varieties ST5458 and DP555. Fiber strength measurements indicate that variety ST5458, with the highest mean strength, differs significantly from variety DP 555 which has the lowest mean strength. Based on summary rank orderings of sample means of the four fiber properties, the six varieties fall into two distinct groups: the best varieties are FM1740, ST5458, and DP949 while the worst are DP935, DP555 and PHY375.

Table 1. HVI™ properties for six cotton varieties in Georgia study

Cotton	Micronaire	Strength	Length	Uniformity
DP0935	3.88	28.50	1.10	81.52
DP555	4.00	28.62	1.10	81.56
DP0949	3.95	29.03	1.15	82.52
FM1740	4.16	29.78	1.15	82.88
ST5458	4.17	30.32	1.14	81.48
PHY375	3.88	28.75	1.13	81.90

AFIS results indicate that there are fiber length differences for varieties in upper quartile length and short fiber content. Cotton varieties DP949, FM1740 and ST5458 have significantly higher upper quartile lengths than PHY375, DP555, and DP935. Short fiber content for cotton varieties indicates that DP949 and PHY375 contain the least amount of short fiber. There also appears to be some maturity differences as measured by fineness, immature fiber content, and maturity ratio. Cotton varieties DP949, DP555, DP935, and PHY375 produced some of the finest fibers while ST5458 was the most mature fiber variety. The best varieties appear to be DP949, FM1740, and PHY375. These AFIS results do not necessarily agree with the HVI™ data.

Table 2. AFIS properties for six cotton varieties in Georgia study

Cotton	Neps/ Gm	UQL (w) [in]	SFC (w) [%]	SCN [Cnt/g]	Fine [mTex]	IFC [%]	Mat Ratio
DP0935	387	1.16	11.2	28	158.8	7.0	0.86
DP555	319	1.17	9.3	19	157.4	6.6	0.88
DP0949	338	1.20	8.5	25	158.8	6.5	0.88
FM1740	292	1.20	9.3	32	165.0	6.3	0.88
ST5458	305	1.20	10.3	26	170.7	5.9	0.90
PHY375	332	1.17	8.9	25	157.7	6.3	0.87

In order for cotton variety fiber testing to be complete they require additional processing and spinning. Rotor and ring spinning fiber processing efficiency ends down data are in Tables 3 and 4. Table 3 demonstrates that the various counties demonstrate different processing efficiencies with Candler, Coffee, and Burke being the superior counties for rotor and ring spinning. It should be noted that Colquitt, Candler, and Coffee counties were not irrigated. The cotton varieties PHY375, DP935, and DP555 appear to be the best varieties suited for rotor spinning in the Georgia counties. While for ring spinning PHY375, DP935, and FM1740 appear to be the best varieties suited for ring spinning in the Georgia counties.

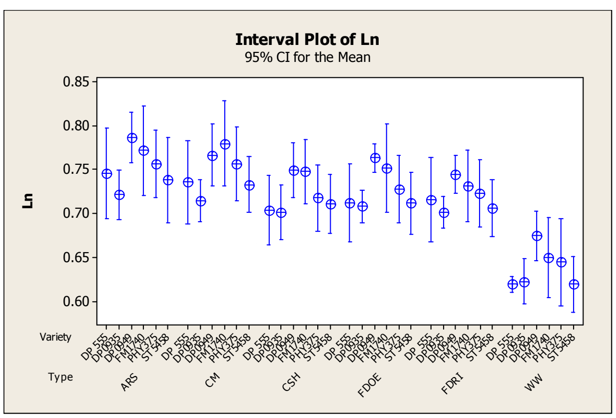
Table 3. Rotor spinning processing efficiency ends down per thousand rotor hours in Georgia study

County	DP0935	DP555	DP0949	FM1740	ST5458	PHY375	**MEAN**
Colquitt	125	42	63	167	854	42	**216**
Candler	42	0	0	21	63	42	**28**
Coffee	0	21	21	42	43	42	**28**
Early	42	83	83	-	167	21	**79**
Worth	0	-	42	42	396	42	**104**
Burke	21	0	63	21	83	21	**35**
Mean	**38**	**29**	**45**	**59**	**268**	**35**	

Table 4. Ring spinning processing efficiency end down per thousand spindle hours in Georgia study

County	DP0935	DP555	DP0949	FM1740	ST5458	PHY375	**MEAN**
Colquitt	19	7	9	6	19	0	**10.0**
Candler	6	3	0	0	13	3	**4.2**
Coffee	0	13	13	3	0	0	**4.8**
Early	6	9	28	-	25	0	**13.6**
Worth	0	-	3	3	38	6	**10.0**
Burke	0	0	6	3	19	6	**5.7**
Mean	**5.2**	**6.4**	**9.8**	**3.0**	**19.0**	**2.5**	

Changes in fiber length as the raw cotton is processed, measured by AFIS L(n) and SFC(n) are shown in Figures 1 and 2, one for all varieties together, and by processing stage. Fiber length [L(n)] decreases from card mat to card sliver, improves slightly with drawing, and drops from finisher drawing sliver to white waste. Short fiber content [SFC(n)] shows corresponding increases from card mat to card sliver and from finisher drawing sliver to white waste. For each of the length properties, the best varieties at each stage are DP949 and FM1740; the worst are DP555 and DP935. The six varieties tend to maintain their relative positions from stage to stage. When changes in fiber length from stage to stage are examined by variety one can see that varieties that are relatively 'good' (or 'bad') as raw stock tend to remain relatively 'good' (or 'bad') at subsequent stages.



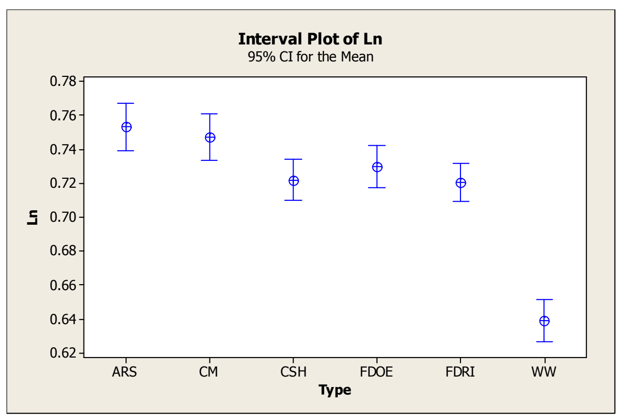


Figure 1. Fiber length interval plots of cotton varieties at various stages of processing.

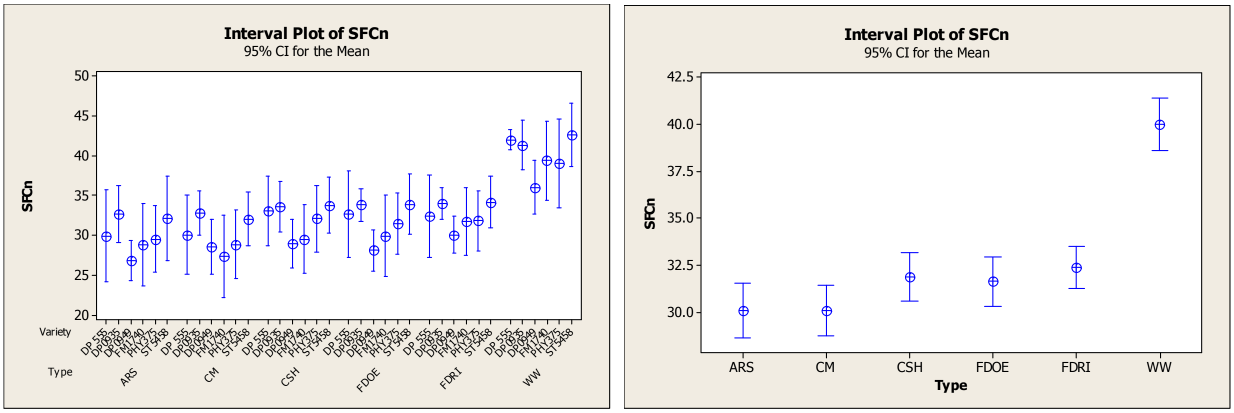


Figure 2. Short fiber content interval plots of cotton varieties at various stages of processing.

Figures 3 and 4 visibly demonstrate length histogram shape differences between the best and worst Georgia counties. The best and worst counties were determined using an equation (Calculated from 0.4*CVm + 0.2*Thins + 0.2*Thicks+ 0.1*Neps + 0.1*Hairiness) based on Uster statistics (Thibodeaux et al., 2011). The distributions within counties appear to follow the same shapes but there appears to be significant differences between cotton fiber length distributions in counties. This shape discrepancy within counties could be due to harvesting equipment differences between locations or ginning differences. Based upon the histogram distribution shape one would not necessarily indicate for example that Burke county was the best county based on the high percentage of short fibers compared to Candler or Colquitt county that did not appear to contain as many short fibers.

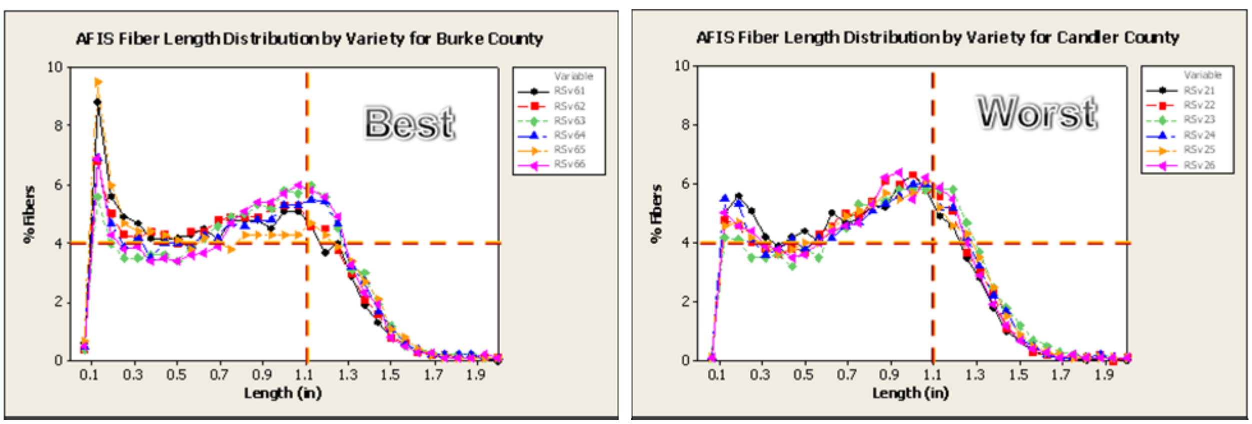


Figure 3. AFIS Fiber length distributions by varieties for Burke and Candler counties (Ring spinning).

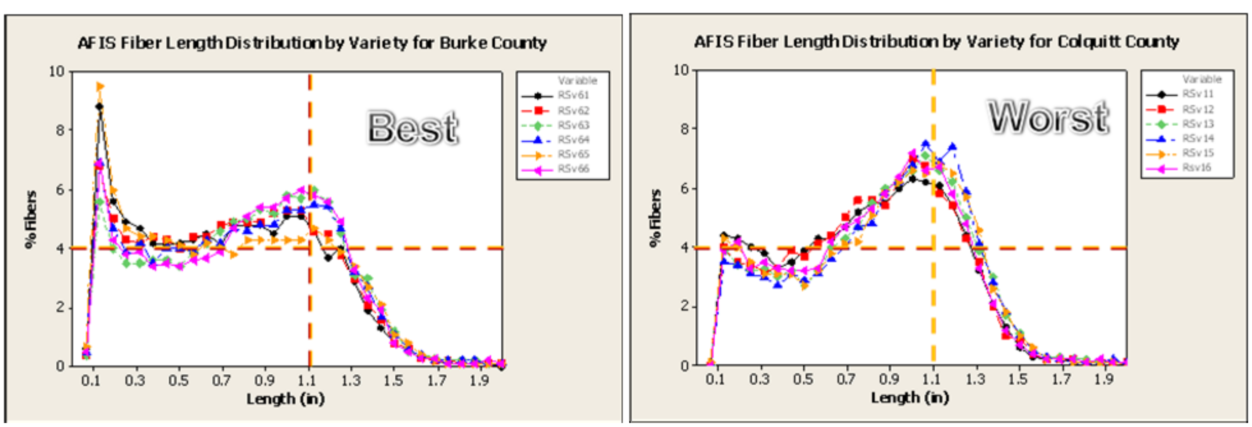


Figure 4. AFIS Fiber length distributions by varieties for Burke and Colquitt counties (Rotor spinning).

Figures 5 and 6 visibly demonstrate length histogram shape differences between the two cotton varieties within the 6 counties. The best and worst varieties were determined using an equation (Calculated from 0.4*CVm + 0.2*Thins + 0.2*Thicks+ 0.1*Neps + 0.1*Hairiness) based on Uster statistics (Thibodeaux et al., 2011). Cotton fiber length distribution within plant varieties indicate that PHY375 has a consistent length distribution regardless of its growing location while ST5458 appears to have more histogram variability dependent upon growing location.

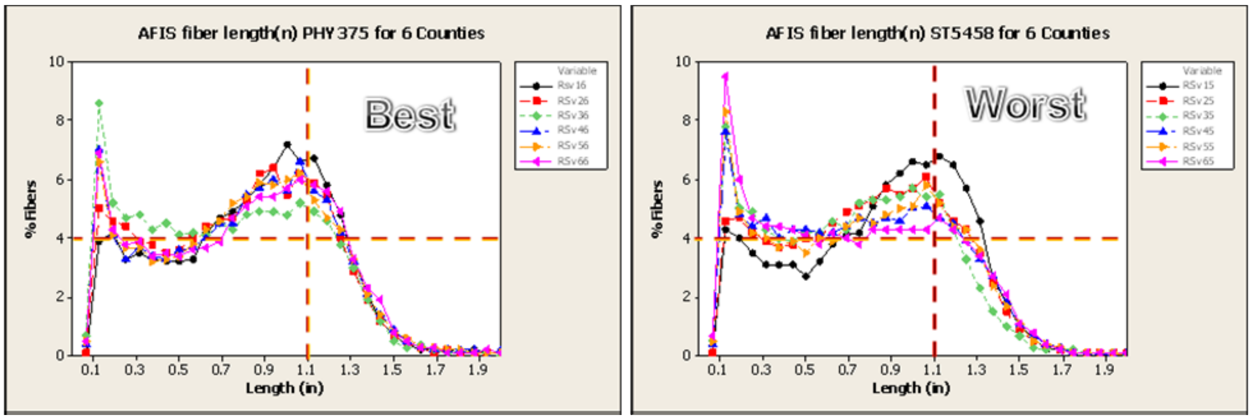


Figure 5. AFIS Fiber length distributions for 6 counties by variety (Ring spinning).

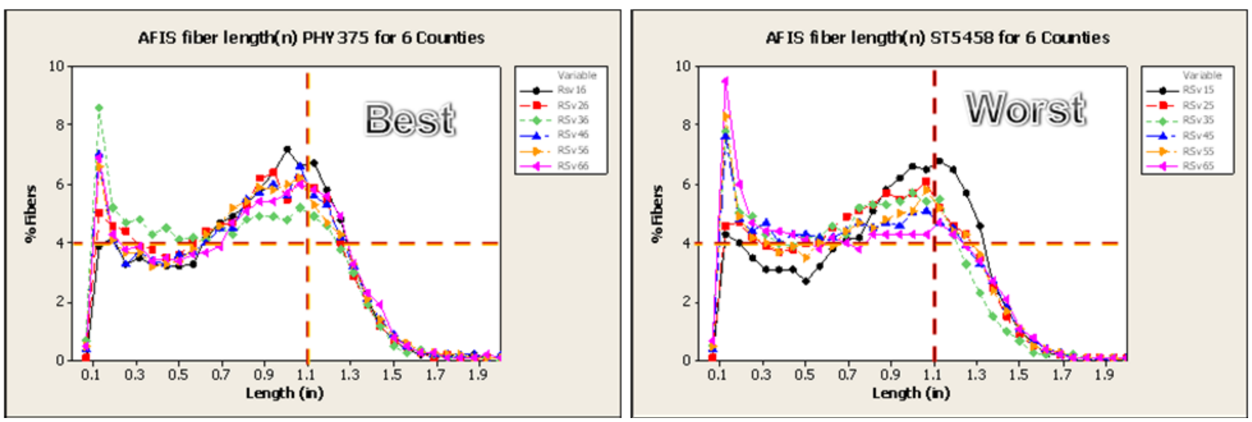


Figure 6. AFIS Fiber length distributions for 6 counties by variety (Rotor spinning).

Figure 7 visibly demonstrates length histogram shape differences throughout processing from raw stock to finisher drawing sliver and white waste. These differences are evaluated between the best and worst cotton varieties within Colquitt county (worst county) from raw stock (RS) to card mat (CM) to card sliver (CS) to finisher drawing sliver (FD) and to white waste (WW). The best and worst counties and varieties were determined using an equation (Calculated from 0.4*CVm + 0.2*Thins + 0.2*Thicks+ 0.1*Neps + 0.1*Hairiness) based on Uster statistics (Thibodeaux et al., 2011). Cotton fiber length distribution within plant varieties indicate that DP949 has a consistent length distribution regardless of its growing location while ST5458 appears to have more variability dependent upon growing location. The varieties tend to maintain their relative histograms through processing. When changes in fiber histograms from stage to stage are examined by variety one can see that varieties that are relatively 'good' (or 'bad') as raw stock tend to remain relatively 'good' (or 'bad') at subsequent stages.

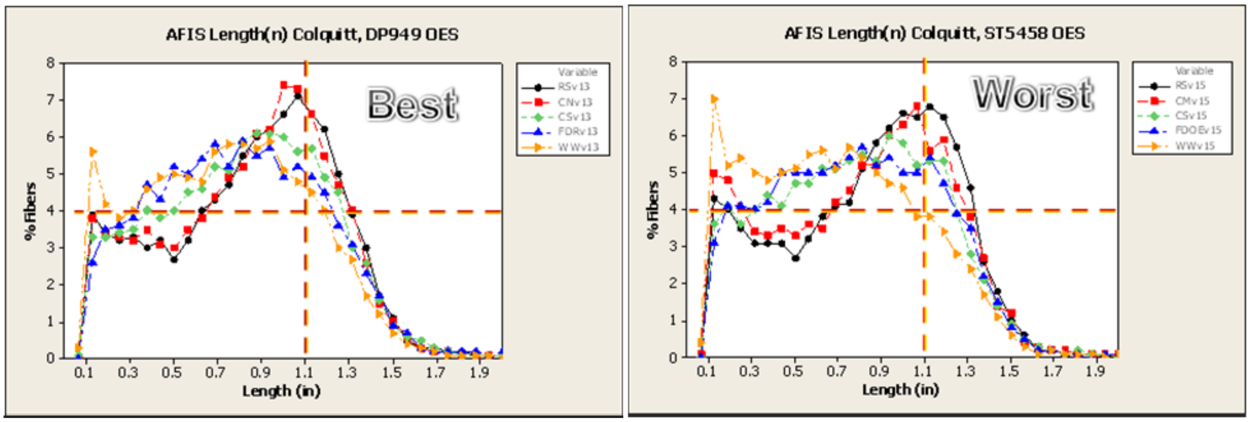


Figure 7. AFIS Fiber length distributions for the best and worst varieties in Colquitt County (worst county).

Figure 8 visibly demonstrates length histogram shape differences throughout processing. These differences are evaluated between the best and worst cotton varieties within Burke county (best county) from raw stock (RS) to card mat (CM) to card sliver (CS) to finisher drawing sliver (FD) and to white waste (WW). The best and worst counties and varieties were determined using an equation (Calculated from 0.4*CVm + 0.2*Thins + 0.2*Thicks+ 0.1*Neps + 0.1*Hairiness) based on Uster statistics (Thibodeaux et al., 2011). Cotton fiber length distribution within plant varieties indicate that PHY375 has a consistent length distributions regardless of its growing location while ST5458 appears to have more variability dependent upon growing location. The varieties tend to maintain their relative histograms through processing. When changes in fiber histograms from stage to stage are examined by variety one can see that varieties that are relatively 'good' (or 'bad') as raw stock tend to remain relatively 'good' (or 'bad') at subsequent stages.

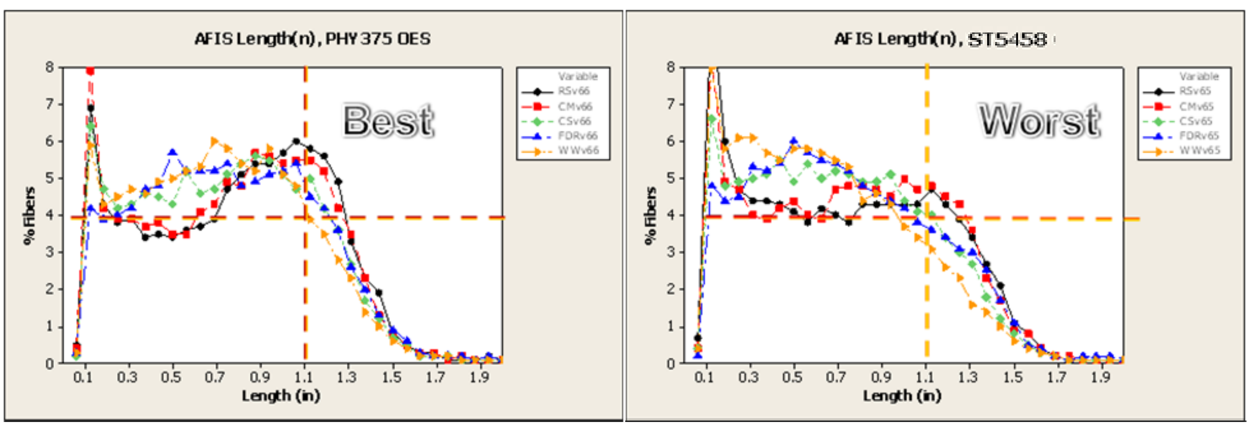


Figure 8. AFIS Fiber length distributions for the best and worst varieties in Burke County (best county).

Conclusions

Textile mills prefer to have cotton with fibers more uniform in length demonstrated by histograms that have a steeper slope and narrower base at longer lengths. HVI™ and AFIS differences were detected between Georgia county varieties and counties. However, AFIS and HVI™ data did not necessarily agree upon the best fiber variety. In order for cotton variety testing to be complete they require further processing and spinning. As expected histograms and fiber length decreases through processing but the six varieties tend to maintain their relative positions from stage to stage in processing. Processing ends down demonstrates that the various counties demonstrate different processing efficiencies with Candler, Coffee, and Burke being the superior counties for rotor and ring spinning. PHY375, DP935, and DP555 appear to be the best varieties suited for rotor spinning while PHY375, DP935, and FM1740 appear to be the best varieties suite for ring spinning. Variety distribution differences were detected in this study. Cotton fiber length distribution within plant varieties indicate that PHY375 has a consistent length distribution regardless of its growing location while ST5458 appears to have more variability dependent upon growing location. County distribution differences were detected in this study. The distributions within counties appear to follow the same shapes but there appears to be significant differences between cotton fiber length distributions in counties. This shape discrepancy within counties could be due to harvesting equipment differences between locations or ginning differences. From HVI™, AFIS, length measurements, and AFIS length histograms the rankings of cotton varieties in this study are PHY375, DP949, FM1740, DP555, DP935, and ST5458.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of a product to the exclusion of others that may be suitable.

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