INVESTIGATION OF FIBER MATURITY EFFECT ON SAW-TYPE LINT CLEANER FIBER DAMAGE AND YARN PROPERTIES

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Abstract

One-half of plots of two cotton cultivars with similar mature fiber length were harvested after two defoliation treatments (early/late) to get less and more mature cottons. These seed cotton lots were ginned with the same seed cotton cleaning but with 0, 1, or 3 saw-type lint cleaners with low drying heat or 1 lint cleaner with moderate drying heat. Each of these cottons was then processed and 22 Ne yarn spun in a mini-spinning process. Samples of these fibers and yarns were tested. The early defoliation resulted in differences in fiber maturity, but the micronaire range was not large. The cottons defoliated early were shorter, weaker, with more short fiber. The gin processes affected the AFIS fiber length, but not the short fiber content. The cottons defoliated early decreased in fiber length during gin and mill processing more than those defoliated later. The early defoliated cotton, which was less mature, lost length and gained short fiber more during mill processing than the more mature cotton. The immature cotton processed gently at the gin (with no lint cleaner) was as long as the mature fiber processed normally at the gin, but after mill processing, the fiber length was lower for the gently processed less mature cotton than for any of the mature cottons. These differences seen with AFIS measurements were less obvious in the yarn, but the skein strength and yarn neps were of lower quality for the less mature cottons.

Introduction

The flow-through cotton lint cleaner for removing leaf particles, motes, cottonseed, grass and bark was first developed at the USDA Cotton Ginning Laboratory in Stoneville, MS, based on work beginning in 1939 (Stedronsky and Shaw, 1950). Many improvements have been made since then, both by USDA researchers and by private industry (Mangialardi and Anthony, 2003). These lint cleaners are effective in reducing non-lint content in the lint, which may improve the cotton leaf grade, but also reduce the weight of material and break some fibers (Mangialardi and Anthony, 1997). Breaking fibers often results in reduced fiber length and increased short fiber, although the lint cleaner also removes short fiber from the mix. Flow-though saw-type lint cleaners are extensively used because of their high cleaning efficiency and combing of the fiber.

Ethridge (2008) presented interesting results of a study in which known varieties of cotton were grown in different locations which (unintentionally) resulted in substantial differences in fiber maturity (Mat). These cottons were in bale form when Etheridge obtained the samples so no ginning testing could be performed on them. The HVI measurements on these cottons resulted in basically similar values except for wide differences in Micronaire (Mic) and to a lesser extent, Length Uniformity Index (LUI). Because the varieties were known, the differences in Mic were attributed to fiber maturity differences. The Advanced Fiber Information System (AFIS) data revealed more differences in fiber properties in these cottons related to Mic or immature fiber content. The cottons were carded and 40 Ne ring spun yarn produced and tested. Ethridge found that the yarn strength increased as Mic increased and attributed this relationship to the superior length distribution of the high micronaire (mature) fibers. For a given variety 'undesirably' high Mic cotton was less of a problem than low Mic cotton for the mill. Ethridge concluded:

> While immature fibers are capable of making a fairly strong bundle of fibers, each of the single fibers is weak and fragile; therefore, these fibers break under mechanical stresses, resulting in a bad length

distribution (i.e., elevated short fiber content). This bad length distribution is the fundamental cause of the poor performance in ring spinning. Furthermore, for the same variety, the bundle strength for the high-micronaire fibers is greater than that for the low micronaire fibers, so the increased numbers of fibers in the bundle does not completely compensate for the higher strength of the mature fibers.

Because the immature fibers are weaker, they are more likely to be damaged in saw-type lint cleaning in addition to being damaged by the mill cleaning and processing equipment. Krifa (2006) has shown a direct relationship between maturity and the shape features of fiber length distribution, affected by mechanical damage. This damage should be evident in the AFIS fiber length data in reductions in fiber length measurements, decreases in fiber length uniformity and increases in short fiber.

The purpose of this study was to examine the effect fiber maturity had on damage done to cotton fiber during processing in the gin and subsequent processing in a mill when producing yarn.

Materials and Methods

The control treatment was to harvest, gin, and mill-clean cotton fiber approximating commercial processing as closely as possible with research equipment. The experimental treatments used deliberately produced less mature cotton with both more and fewer saw-type lint cleaners at the gin. Conclusions were based on analysis of HVI and AFIS measurements of samples taken at different locations during processing.

A uniform field at Stoneville, MS, was divided in a split plot design of four replications of two defoliation treatments. Treatments were randomized within the field, and one half of each plot was planted with the variety Stoneville 4427 B2RF and the other half with Stoneville 4554 B2RF. These varieties were chosen to have similar mature fiber length but different fiber fineness. The early defoliation, designed to produce cotton with more immature fiber, was defoliated at 30-40% open boll. The late defoliation treatment was defoliated at the recommended 65 – 80% open boll to produce mature cotton fiber. This design resulted in 16 lots of seed cotton including two varieties each with two defoliation dates. Agronomic practices maintained best growing conditions for water and nutrients, and control of all insects and weeds throughout the growing season. Defoliation was applied with a ground rig at the recommended times for each treatment. Alleyways and borders were maintained between treatments to prevent drift. A commercial cotton picker modified for plot picking was used to harvest each plot separately.

Approximately 25 kg (70 lb) of each of the 16 lots were ginned with four different ginning treatments in the micro-gin at the Stoneville Cotton Ginning Research Unit. All had the same seed cotton cleaning and ginning of dryer 1, cylinder cleaner, stick machine, dryer 2, cylinder cleaner, and extractor feeder gin stand. The four treatments were: dryers at low heat with no lint cleaning, dryers at low heat with one saw-type lint cleaner, dryers at low heat with three saw-type lint cleaners in sequence, and dryers at moderate heat with one saw-type lint cleaner. Low heat was both burners set at 49 °C (120 °F) and moderate heat was both dryers set at 65 °C (150 °F). The first ginning treatment was expected to leave considerably more non-lint in the lint, but damage the fiber the least. The second treatment was the treatment which was expected to clean the lint to an acceptable level, but still do limited additional damage to the lint. The third treatment used more saw-type lint cleaners than used commercially. The last ginning treatment was considered to be most similar to commercial ginning. This procedure resulted in 64 lots of lint which were shipped to the Southern Regional Research Center (SRRC) for further cleaning and spinning. Five lint samples were taken for each gin treatment by cotton lot combination for moisture determination by the oven method (Shepherd, 1972).

The cottons were carded, prepared for spinning and spun into 22 Ne yarn using a miniature-scale processing system at the SRRC. The cottons were analyzed with HVI and AFIS as they arrived. Raw cotton samples were coarsely opened using a laboratory scale fiber opener (SpinLab, Knoxville, TN). Opened samples were carded into card web, using approximately 60 gram lots, on a modified commercial carding machine. Card web was drawn into sliver and processed into breaker and finisher sliver on a custom drawing frame. Samples were taken of the card web and of the finisher sliver which were also analyzed with AFIS. Yarns were ring spun directly from finisher sliver on a SDL Atlas (Stockport, UK) ring spinning frame. Two packages of yarn were produced for each lot. Finally the yarns were tested after they were spun utilizing an Uster (Charlotte, NC) UT4 for uniformity and Uster Tensorapid 4 for single-end strength. Yarn skein strength was measured utilizing an Instron (Norwood, MA) universal testing machine.

The resulting data set contained nearly 5000 measurements most of which were averages of several individual measurements. These data were analyzed the SAS Institute (2003) procedures MEANS and MIXED. With the procedure MIXED the variety, block in the field, defoliation, gin treatment and mill treatment (if appropriate) were classification variables. The block in the field and all interactions were the random factors. In general, the measured value of interest was modeled with variety, defoliation, ginning treatment, and mill treatment (when appropriate), and all interactions were in the model.

Results

The lint moisture content (mc) measurements of samples taken after all gin processing were modeled with variety, defoliation, gin treatment, and all interactions. The mean for Stoneville 4427 was 5.7, the mean for Stoneville 4554 was 6.0, and the difference was significant ($P<0.0001$). The mc for samples from early and late defoliation were 5.9 and 5.8 respectively and the difference was significant ($P=0.02$). The most significant factor affecting the mc was the gin processing; 6.3 for lint with no lint cleaning, 5.9 for one lint cleaner and low drying temperature, 5.7 for three lint cleaners with low drying temperature, and 5.4 for one lint cleaner with moderate drying temperature and these four mc means were significantly different from each other. All of these mc means were fairly high and the differences small so they would not be expected to significantly affect other measurements, except perhaps the difference due to gin treatment.

The means of selected HVI measurements by variety and defoliation are shown in table 1. The Mic of the cotton defoliated early was below the premium region for Stoneville 4427 and into the discount region (<3.5) for low Mic, for the Stoneville 4554, while the Mic for the cotton defoliated later was above the premium region for high Mic, (>4.2), for both varieties. None of the Mic values were particularly low or high compared to these reported by Ethridge (2008) which ranged from 2.3 to 4.9. The Upper Half Mean Length (UHML) was nearly the same for all four means with the range of 0.2 mm accounting for less than one staple length. The LUI was higher for both varieties for the late defoliation than for the early defoliation as was the strength (Str), but the differences were greater for Stoneville 4554 than for Stoneville 4427.

Table 1. Selected HVI means by variety and defoliation.

	Stoneville 4427		Stoneville 4554	
	Defoliation Early	Defoliation Late	Defoliation Early	Defoliation Late
Mic	3.6	4.5	3.4	4.5
UHML (mm)	11.2	11.2	11.1	11.3
LUI	81.9	82.8	80.5	83.2
Str (g/tex)	25.3	27.2	24.0	28.0
Rd	69.9	68.9	66.1	70.1
Pb	7.6	8.5	8.7	8.5
TrAr	0.88	0.72	0.95	0.59

Table 2 shows two HVI measurements not included in the official classing data. The HVI maturity was lower for the cotton defoliated early and was lower for the 4554 variety than for the 4427, although the difference for early defoliation and late defoliation within the variety was about the same. The HVI short fiber index (SFI) was higher for the cottons defoliated early than for those defoliated later and the difference was greater for the 4554 variety than for the 4427.

Table 2. Non-traditional HVI means by variety and defoliation.

	Stoneville 4427		Stoneville 4554	
	Defoliation early	Defoliation late	Defoliation early	Defoliation late
HVI Mat	0.859	0.881	0.843	0.867
HVI SFI	10.7	8.7	14.6	7.9

The AFIS maturity was analyzed with SAS Proc MIXED using variety (Var), defoliation (Def), gin treatments (Gin), and mill processing (Mill) including all interactions in the model. Def and Mill with their interaction plus Var were the only factors which contributed to the measured variation. The AFIS maturity for Stoneville 4427 had a mean of 0.900 and Stoneville 4554 had a mean of 0.876, or slightly lower maturity, but did not interact with any of the other factors so the difference was consistent over all other factors. Table 3 shows the AFIS maturity means calculated by defoliation and mill sampling location. The early defoliation was successful in producing less mature cotton. The gin treatments had no effect on AFIS maturity.

Table 3. AFIS maturity calculated by defoliation and mill sampling location.

	Mill sampling location		
	Bale	Card web	Finisher sliver
Defoliation early	0.852	0.830	0.865
Defoliation late	0.930	0.908	0.941

The AFIS fineness measurements were analyzed with SAS Proc MIXED using Var, Def, Gin, Mill, and all interactions in the model. The gin treatments had no effect on AFIS fineness. The defoliation timing had by far the largest impact on fineness of the factors studied. The AFIS fineness mean was 168 for Stoneville 4427 and was 160 for Stoneville 4554. Var interacted with Mill and Def, but the F Values were relatively small. Table 4 shows the most significant variations in the AFIS fineness. All of the cottons with later defoliation had higher fineness levels and the mill processing affected the AFIS measurement.

Table 4. AFIS fineness calculated by defoliation and mill sampling location.

	Mill sampling location		
	Bale	Card web	Finisher sliver
Defoliation early	151	151	157
Defoliation late	176	172	179

The AFIS measurement of mean fiber length calculated by weight measured in mm (Lwmm) was modeled with Var, Def, Gin, Mill, and all interactions. Seven of these factors and interactions were statistically significant with the Mill being the most significant, $P<0.0001$, and Def second most significant, $P=0.0001$ with early defoliation resulting in Lwmm 1.4 mm (1.8 staple lengths) shorter than the later defoliation. The variety contributed significantly with the Stoneville 4427 0.7 mm (0.9 staple lengths) longer than the Stoneville 4554, but for this project it was only important to control for the variety. The Var*Def interaction was significant, $P=0.01$, which meant that the defoliation did not have the same effect on both varieties, perhaps because the maturity of early and late defoliation was not the same for the two varieties. The Gin*Mill interaction was significant, $P=0.008$, meaning that the change in fiber length due to mill processing was not the same for all gin treatments as was the Def*Mill, $P=0.008$. Table 5 shows the least squares means of Lwmm by Gin, Mill, and Def plus the difference in Lwmm from the bale to the finisher sliver. The Lwmm after gin treatment 1 (low drying no lint cleaners) was the highest for both defoliations, but that extra length was lost in subsequent mill cleaning.

Table 5. AFIS mean fiber length by weight measured in mm.

	Bale	Card web	Finisher sliver	Bale – Finisher sliver
Early defoliation				
	Mill location			Difference
Gin treatment 1	23.7 bc[X]	20.9 c	21.0 b	2.7
Gin treatment 2	23.3 cd	20.9 c	20.9 b	2.4
Gin treatment 3	22.6 e	20.9 c	20.8 b	1.8
Gin treatment 4	23.0 d	21.5 b	21.2 b	1.8
Late defoliation				
	Mill location			Difference
Gin treatment 1	24.4 a	22.7 a	22.9 a	1.5
Gin treatment 2	24.0 b	22.8 a	22.6 a	1.4
Gin treatment 3	23.7 bc	22.6 a	22.5 a	1.2
Gin treatment 4	24.0 b	22.6 a	22.8 a	1.2

[X] Means within a column with different letters were significantly different, P<0.1.

Similarly, the AFIS Upper quartile length measurements were analyzed. The Mill effect was most significant (P<0.0001) with the Def*Mill interaction next (P<0.0001) followed by Def (P=0.0004). In addition Var, Var*Def, Gin, Var*Def*Mill and Gin*Mill were significant, but at lower levels of significance. Table 6 shows the least squares means over all factors except Mill, Def, and Gin, which is a mean over variety and all interactions with it. The mean difference between the two varieties was 0.6 mm (0.8 staple lengths). The table also shows the difference in UQL from bale to finisher sliver. This difference is much more pronounced for the cottons defoliated early and was lowest for the later defoliated cotton with the gin treatment of moderate heat and one lint cleaner. For the less mature cotton the decrease in fiber length was less for normally ginned cotton than for the gentlest process, treatment 1.

Table 6. AFIS Upper quartile length by weight measured in mm.

	Bale	Card web	Finisher sliver	Bale – Finisher sliver
Early defoliation				
	Mill location			Difference
Gin treatment 1	29.1 ab[X]	27.0 bc	27.2 b	1.9
Gin treatment 2	28.8 bc	26.8 c	27.1 b	1.7
Gin treatment 3	28.2 d	26.9 c	27.0 b	1.2
Gin treatment 4	28.4 cd	27.4 b	27.3 b	1.1
Late defoliation				
	Mill location			Difference
Gin treatment 1	29.4 a	28.4 a	28.9 a	0.5
Gin treatment 2	29.0 b	28.5 a	28.8 a	0.2
Gin treatment 3	28.8 bc	28.3 a	28.5 a	0.3
Gin treatment 4	29.0 b	28.3 a	28.9 a	0.1

[X] Means within a column with different letters were significantly different, P<0.1.

The AFIS short fiber content by weight, in percent, measurements were analyzed with SAS Proc MIXED using Var, Def, Gin, Mill, and all interactions in the model. The gin treatments had no effect on AFIS short fiber content. The

AFIS short fiber content was 14.1 for Stoneville 4427 and was 16.4 for Stoneville 4554 and no interactions with Var were significant. Table 7 shows the most significant variations in the AFIS short fiber content. The cottons with later defoliation had lower short fiber content than for the cottons with early defoliation at the same location in the processing which increased during mill processing. The Mill*Def interaction was highly significant, P<0.0001, showing that not only did the more mature cotton have lower short fiber content but also the mature cotton increased in short fiber content less than the less mature cotton during mill processing.

Table 7. AFIS short fiber content calculated by defoliation and mill sampling location.

	Mill sampling location		
	Bale	Card web	Finisher sliver
Defoliation early	12.8	19.2	21.3
Defoliation late	9.4	13.6	15.3

The AFIS trash count per g, measurements were analyzed with SAS Proc MIXED using Var, Def, Gin, Mill, and all interactions in the model. Mill, Def, and Gin plus Def*Mill and Gin*Mill were all significant. Table 8 shows the means by Mill, Def, and Gin. The card was effective in removing the trash. The gin treatment with three lint cleaners produced lint with significantly less trash and the treatment with no lint cleaners significantly more trash than the treatments using one lint cleaner. These differences tended to persist to the finisher sliver, although the differences there were too small to be significant. The less mature cottons had consistently more trash than the mature cottons with otherwise the same treatment.

Table 8. AFIS trash count per g.

Early defoliation			
	Mill location		
	Bale	Card web	Finisher sliver
Gin treatment 1	358 a[X]	26 a	22 a
Gin treatment 2	236 b	19 a	14 a
Gin treatment 3	136 d	15 a	12 a
Gin treatment 4	222 bc	15 a	11 a
Late defoliation			
	Mill location		
	Bale	Card web	Finisher sliver
Gin treatment 1	201 c	14 a	11 a
Gin treatment 2	136 d	10 a	8 a
Gin treatment 3	82 e	10 a	7 a
Gin treatment 4	113 d	8 a	8 a

[X] Means within a column with different letters were significantly different, P<0.1.

The AFIS nep count per g, measurements were analyzed with SAS Proc MIXED using Var, Def, Gin, Mill, and all interactions in the model. Mill, Def, Var, and Gin plus Var*Mill Def*Mill and Var*Def*Mill were all significant. Table 9 shows the means by Mill, Def, and Gin ignoring effects related to variety noting that the two varieties did not respond the same. The card was effective in removing neps. The gin treatment with three lint cleaners (gin treatment 3) produced lint with significantly more neps and the less mature cotton consistently had higher nep levels.

Table 9. AFIS nep count per g, mean over effects due to variety.

	Early defoliation		
	Mill location		
	Bale	Card web	Finisher sliver
Gin treatment 1	357 d[X]	130 a	102 a
Gin treatment 2	519 b	125 a	104 a
Gin treatment 3	654 a	131 a	99 a
Gin treatment 4	479 c	114 a	90 a
	Late defoliation		
	Mill location		
	Bale	Card web	Finisher sliver
Gin treatment 1	215 f	64 b	43 b
Gin treatment 2	269 e	59 b	44 b
Gin treatment 3	371 d	63 b	48 b
Gin treatment 4	251 ef	67 b	46 b

[X] Means within a column with different letters were significantly different, $P<0.1$.

The yarn measurements were examined and the yarn count mean was 21.8 with a somewhat lower mean for the variety 4554 than for 4427 and a somewhat lower mean for the cottons defoliated earlier than for those defoliated later, but no significant variations were found. As expected, the CSP was lower for the less mature, early defoliated, fiber, varied with variety and the difference between less and more mature fiber was different between the varieties. Similarly, the nep level for the yarns was lower for more mature fiber, varied with variety and the difference related to fiber maturity was different for the two varieties. The ginning treatments had no effect on these yarn properties.

Table 10. Some yarn measurements by variety and fiber maturity.

	Variety			
	Stoneville 4427		Stoneville 4554	
	Early defoliation	Late defoliation	Early defoliation	Late defoliation
Yarn count, Ne	22.0	22.0	21.5	21.9
CSP (count strength product)	1883	1904	1579	1873
Neps 200	273	224	848	201

The measured AFIS fiber maturity of samples taken at the finisher sliver was used in the model for CSP in place of the defoliation level and the fit was as good as when the defoliation level was used. The variety and maturity*variety were also significant, but the gin treatments were not significant, demonstrating that the measured fiber maturity functioned as the defoliation level. Using the HVI maturity measurement in the model did not predict CSP as well as when the AFIS maturity measurement was used.

Conclusions

Two varieties of cotton were grown in four repeated plots and half was defoliated early to create fiber with two levels of maturity. These cottons were then ginned in four different processes and each of these 64 lots of cotton was processed in a mini-spinning operation into 22 Ne yarn. HVI and AFIS data were collected for the fiber and measurements were made of the yarn.

The HVI data showed that the cotton defoliated early had a lower micronaire than that defoliated later. The effects were greater for the Stoneville 4554 than for the Stoneville 4427. The data showed that the early defoliation resulted in less mature and gravimetrically finer cotton.

The fiber quality as measured with AFIS was dependant on the defoliation with less mature fiber having lower quality. The AFIS short fiber content was not affected by the gin treatment, but was affected by the defoliation and mill sampling location. For those measurements which did depend on the ginning treatment, the effect was lower for the more mature cotton. This was because more mature fibers can better withstand normal ginning processes, while less mature and weaker fiber is more likely to be damaged during gin and mill processing. When the gentlest gin treatment was used, the difference during mill processing was much greater for the less mature fiber than for the more mature fiber. This data showed that for mature cotton the lint cleaners do some damage to the fiber, but the subsequent mill processing does very little additional damage. However, for the immature cotton, the gin processing does more damage than for the mature cotton and the mill processing does additional damage. This study shows that improvements in lint cleaner design may benefit the cotton producers, but make the marketing of cotton fiber more complicated because the official cotton class would be less reliable in predicting the value of the fiber for producing yarn.

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Abbreviations

AFIS	Advanced Fiber Information System
Def	Defoliation – early or late
Gin	Gin treatment – one of four
HVI	High Volume Instrument
LUI	Length Uniformity Index (HVI)
Lwcm	Upper quartile length in cm calculated by weight
Mat	Maturity
Mic	Micronaire (HVI)
Mill	Mill treatment – measured at three places during processing
Pb	Color Yellowness (HVI)
Rd	Color Reflectance (HVI)
SFI	Short Fiber Index (HVI)
SknBrkTen	Skein break tenacity
Str	Fiber Strength (HVI)
TrAr	Trash Area (HVI)
TrCnt	Trash Count (HVI)
UHML	Upper Half Mean Length (HVI)
UQL	Upper Quartile Length (AFIS)
Var	Variety – Stoneville 4427 or Stoneville 4554