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ENGINEERING AND GINNING

Upland Fiber Changes Due to Ginning and Lint Cleaning

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ABSTRACT

A study was done to determine 1) how the length distribution of a medium staple upland cultivar was affected by the possible range of ginning and lint cleaning treatments, 2) the length distribution of the fiber lost during increasing levels of lint cleaning changed, and 3) how these changes affected textile processing. An upland cultivar that was midrange for length and strength was used for the study. In comparing roller ginning with saw ginning there was a significant shift towards shorter fibers in the length distribution with the saw-ginned fiber as would be expected. What was unexpected was the percentage of fibers in the 2.21 to 2.54-cm (0.87 to 1.00 in) length range stayed relatively constant whereas the percentage above this range decreased as the percentage below increased with increased mechanical processing. Some long fiber was lost to lint cleaning at all stages but most of that fiber was not of significant textile value and more than 33% of the fiber lost at any stage was equal to or less than 1.27 cm (0.50 in) in length. Subsequent textile processing showed that the carding operation removed approximately the same amount of total waste from cleanly harvested spindle-picked upland cotton regardless of the amount of machining the fiber received during ginning and subsequent lint cleaning. While the level of waste in the raw fiber was not a significant factor the differing levels of fiber distribution did significantly affect yarn quality. But the change in fiber distribution did not affect dying properties as indicated by white specks in dyed cloth. Future research should concentrate on reducing fiber breakage during lint cleaning.

The debate about cotton fiber quality and fiber damage due to the ginning process has been going on at least since Eli Whitney's time. As the saw-type gin started replacing earlier roller-type gins some merchants complained, "It appears as if it [ginned cotton fiber] had undergone some severe operation, so much so that its staple is nearly destroyed" (Lakwete, 2003). A cotton planter (ginner) in an 1821 letter stated that, "Carvers patent gins [a saw-type gin], separated the cotton from the seed without cutting or breaking the fibers"(Lakwete, 2003). Regardless of real or apparent fiber damage, by 1835 the saw gin had become the dominant means of separating the fiber from the seed of upland cotton varieties grown in the U.S. (Lakwete, 2003). The textile industry adapted to using this saw-ginned fiber for the next 100 years or so, but the quality of cotton fiber remained an issue in the marketplace.

Additional ginned cotton fiber quality questions arose with the advent of machine-picker harvesting of cotton in the 1940s and the need and eventual development of saw-type lint cleaners. Mangialardi (1972) summarized the research and development of lint cleaning, both public and private, from 1947—when 2% of the U.S. cotton crop was mechanically harvested—through the 1960s, when essentially 100% of the U.S. cotton crop was mechanically harvested. The fiber quality focus during this time period was grade (fiber color and trash content) and staple length. It was established that lint cleaners improved grade by reducing trash content of the ginned lint, but also shortened staple length by breaking fibers. These tradeoffs in cotton quality were recognized by the industry as indicated by the National Cotton Council (1963), "Therefore, in view of the vital importance of maintaining maximum cotton quality in today's highly competitive textile markets, both here and abroad, no more stages of lint cleaning than are essential to produce maximum bale value should be used."

Research and development of lint cleaning technology still continues. The general emphasis has been on increasing bale value by seeking to improve the efficiency of trash removal while minimizing fiber damage and limiting good fiber loss during the lint cleaning process. For example, Mangialardi (1972) reported that the upper-quartile length of the baled fiber after zero, one, two, and three lint cleaners averaged 3.14, 3.11,

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3.09, and 3.08 cm (1.236, 1.226, 1.215, and 1.212 in) respectively. The corresponding upper-quartile length of the fiber lost into the lint cleaner waste for one, two, and three lint cleaners averaged 3.11, 3.06, and 3.05 cm (1.224, 1.206, and 1.202 in) respectively. Besides damaging some good fiber and removing trash from the ginned lint, saw-type lint cleaners also lost a certain amount of relatively good lint into the lint cleaner trash.

The amount of lint cleaning needed for maximum bale value is not the same for all cottons. In a study by Bel et al. (1991a, 1991b), one lint cleaner produced the highest bale value for smooth-leaf cotton, but three lint cleaners produced the highest bale value for hairy-leaf cotton. However, one lint cleaner for both smooth- and hairy-leaf cottons produced the best dyed cloth and, therefore, the best textile value (Bel-Berger and Von Hoven, 1997).

Because saw-type lint cleaners have such a significant impact on fiber quality, there has been a significant amount of research to attempt to improve their cleaning efficiency while decreasing fiber damage. Baker (1978) documented the effects of cotton feed rate, lint cleaner operational speeds, and lint cleaner adjustments on cleaning efficiency, lint wastage, and fiber quality. Baker (1978) established feed rate and lint-cleaner saw-speed parameters to optimize cleaning efficiency and minimize lint wastage on stripper-harvested upland cottons. Kirk and Leonard (1977) modified the feed bar of a saw-type lint cleaner and determined that the modified lint cleaner could be used to efficiently clean roller-ginned Pima cottons without significantly decreasing fiber length parameters when compared to traditional beater-type lint cleaners then used in roller gins. Le (2007) essentially repeated much of Baker's (1978) work but with current machine-picker harvested hairy- and smooth-leaf varieties and found fundamentally the same results as the earlier work. Cleaning efficiency of saw-type lint cleaners is affected by lint-cleaner operating parameters over a range, as is fiber damage, as indicated by short fiber content.

Hughs et al. (1990) reported on research to modify the design of conventional saw-type lint cleaners that resulted in significantly improved fiber quality in terms of fiber length parameters. The experimental, coupled lint cleaner was basically two saw-type lint cleaners in one machine that operated without the lint condensers and conventional feed works of standard saw-type lint cleaners. Ginned and cleaned fiber from the coupled lint cleaner was also shown to result in improved textile quality. The improved fiber quality from this experimental lint cleaner resulted in the eventual development of the Sentinel[tm] Lint Cleaner that is currently marketed by Lummus Corp, Savannah, GA.

The quality of raw ginned and cleaned cotton fiber is important because of its relationship to textile utility quality. Most of the research on saw-type lint cleaners was evaluated not only on bale value but also on the textile utility of the ginned and cleaned fiber. Historically, upland cottons were processed through saw ginning systems that utilized saw-type lint cleaners and extra-long-staple Pima cottons were processed through roller ginning systems that utilized cylinder beater-type lint cleaners. However, there has always been interest in ginning shorter staple upland cottons through roller ginning systems. Gerdes et al. (1943) reported on outmoded reciprocating-knife roller gins versus saw gins and found little raw fiber difference, but some textile quality advantage for the roller gin. Hughs and Leonard (1986) and Hughs and Lalor (1990) evaluated the quality of upland cotton processed through the modern rotary-knife roller versus saw-type gin systems and reported significant ginned raw fiber length advantage for the rotary-knife roller gin. Armijo and Gillum (2007) reported that computer controlled high-speed rotary-knife roller gins could gin upland cottons at comparable throughput rates to saw gin stands and still maintain the improved ginned fiber quality that comes with roller ginning. Because of the industry response to the increased throughput rate and fiber quality from roller ginning shown by Armijo and Gillum (2007), there were 112,094 bales of upland cotton roller ginned in the San Joaquin Valley, CA, during the 2010 ginning season.

The cotton ginning industry in the U.S. has undergone significant changes in response to market pressures during the past decade regarding where cotton is grown, how much is grown in any area, and how that cotton should be processed in terms of how it is harvested, ginned, cleaned, and the resulting fiber quality. Whitelock et al. (2011) conducted a two-year survey during the 2005 and 2006 ginning seasons to evaluate current ginning industry lint cleaning practices for upland cotton and to establish a baseline fiber quality particularly for short fiber and neps. Historically, two saw-type lint cleaners were the norm for both spindle-picker and stripper-harvested seed cotton, with the ability to use one lint cleaner only on dry and cleanly harvested seed cotton (Mayfield et al., 1991). However, due to complaints from textile mill customers concerning short fiber and nep content, the U.S. cotton industry has sought to reduce the overall use of saw-type lint cleaners. Whitelock et al. (2011) found in their survey that current saw-type lint cleaning practices varied depending on location. Cotton gins sampled in the Mid-South and Southeast regions typically used one stage of saw-type lint cleaning exclusively during the season, whereas gins in the Southwest or Far-West might use one or two stages. For those gins using two stages of lint cleaning, fiber length parameters were reduced and short fiber and nep content were increased in going from the first through the second stage. However, due to wide cultivar differences across the cotton belt, length parameters of cotton cleaned by two stages of lint cleaning could still be superior to cultivars in other regions of the U.S. that were processed through only one stage of lint cleaning.

This study had three objectives. The first objective was to determine how the length distribution of a medium staple upland cultivar would be affected by the current possible range of possible commercial ginning and lint cleaning treatments. The second objective was to establish the length parameters of the fiber lost during lint cleaning. The third objective was to determine how changes in fiber length distribution affected textile processing.

MATERIALS AND METHODS

There are many upland cotton varieties grown across the U.S. cotton belt with a wide range of fiber properties. For this test, an upland cotton variety that was picker harvested was selected that was both widely grown and would be expected to fall somewhere in the midrange of U.S. upland varieties for both staple length and fiber strength. A module of irrigated 'Deltapine 455 BR' seed cotton was obtained from a cotton producer in Mesilla Valley, NM. This cotton was produced in crop year 2006 using normal production practices for the area and was harvested and moduled during dry weather. Deltapine 455 BR was reported to have an average staple length of 35 and strength of 284 kN m kg^{-1} (29.0 grams/tex) in the 2005, irrigated, regional, high quality test at the Texas Agricultural Experiment Station, Lubbock, TX (2005). The USDA-AMS, Cotton Market News National Season Report (USDA-AMS, 2010) reported that approximately 48% of the upland cotton classed was staple 35 or shorter and 43% was strength 284 kN m kg^{-1} (29.0 grams/tex) or lower. The Deltapine 455 BR used in this test was a reasonable representation of the midrange of U.S. upland cottons in terms of length and strength.

The ginning treatments consisted of a standard Continental/Murray Phoenix Rotobar roller gin (Continental Eagle, Prattville, AL) operated at a ginning rate of approximately 1 bale/h followed by two Aldrich Beater/superjet lint cleaners (control treatment) and a laboratory model 47-saw Continental Double Eagle saw gin followed by either zero, one, two, or three Continental Lodestar saw-type lint cleaners in series for a total of five test treatments. The five ginning treatments were replicated five times for a total of 25 ginning lots of 201 kg (450 lbs) of seed cotton per lot. Each of the five ginning treatments was randomized within each replicate. Data analyses were performed with PC-SAS (version 9.2, SAS Institute, Inc., Cary, NC) with a 5% level of significance. Analysis of variance was performed with the General Linear Model (GLM) procedure, and main effect means were tested with Duncan's multiple-range test ($P \leq 0.05$). The ginning sequence for each ginning lot of 204 kg (450 lbs) was a suction pipe, steady flow, six-cylinder incline cleaner, stick machine, six-cylinder incline cleaner, conveyer distributor, gin feeder, selected gin stand and lint cleaning treatment, and universal density (UD) bale press. There was no seed cotton drying on any of the ginning lots. Average seed cotton (before seed cotton cleaning) and ginned lint moisture levels (percentage dry basis) were 6.2 and 5.4 respectively. Each ginning lot was separated and identified within the bale press by paper separators and each bale was tied and wrapped after three ginning lots. Seed cotton samples were taken at the wagon suction and gin stand feeder apron and lint samples were taken at all three lint cleaners and the lint slide during the ginning process for seed cotton and fiber analysis. The bales containing the ginned lint from each of the 25 lots were then shipped to the USDA-ARS Cotton Quality Research Station, Clemson, SC for further fiber analysis and spinning tests.

All fiber was processed through the same modern Truetzschler opening and cleaning line (American Truetzschler Inc., Charlotte, NC) and card to produce a 4.53-mg (70 grain) sliver at 68 kg (150 lbs/h). 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 12000 RPM and a 1.30 twist multiplier. Yarn (35/1 Ne) was then spun from the roving on a Zinser 321 ring spinner (Saurer Group, Charlotte, NC) at a spindle speed of 16,500 RPM and with a twist multiple 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 spinning ends down was recorded and calculated for 1000 spindle hours.

Prior to testing, all cotton lint samples were conditioned for at least 24 h at 65% RH and 21°C (ASTM, 1997a). Mean fiber length, coefficient of variation, upper-quartile length, and short fiber content by weight were measured via the Suter-Webb Array method (ASTM, 1997b). Lint cleaner trash samples were passed through a Shirley Analyzer to remove trash prior to being analyzed for length distribution via the Suter-Webb array.

Tensile properties of produced yarns from spinning were evaluated for single end yarn strength on the Statimat-M (Lawson-Hemphill, Central Falls, RI) using standard test methods (ASTM, 1994c). Yarn evenness was determined using an ILE DS-65 Digital Evenness Tester (Industrial Laboratory Equipment Co., Charlotte, NC) using standard test methods (ASTM, 2004). Classifying and counting faults were determined using a Classimat II (Uster Technologies Inc., Knoxville, TN) using standard test methods (ASTM, 2005). Each test lot yarn was knit into fabric and dyed solid dark blue to accentuate any dying imperfections commonly called "white specks". White specks were manually counted using a magnifying lamp and a 64.5-cm^2 (10 in^2) template (Han et al., 1998). The template was randomly placed on each dyed lot of fabric four times for a total area of 258 cm^2 (40 in^2). The number of white specks occurring within the template area were counted each time and then averaged for the four counts. The result was the average number of white specks per 64.5 cm^2 (10 in^2).

DATA ANALYSIS AND DISCUSSION

Average Suter-Webb fiber array data for the five ginning treatments are given in Table 1. These Suter-Webb data indicate significant fiber length differences between treatments except for the S-1 and S-2 treatments, which are statistically not different from each other for the length parameters shown in Table 1. Roller ginning (followed by two beater-type lint cleaners) averaged the longest as indicated by Suter-Webb Array upper-quartile length of 3.05 cm (1.20 in). Saw ginning alone resulted in an upper-quartile length reduction to 2.95 cm (1.16 in). Adding one or two saw-type lint cleaners to saw ginning significantly reduced fiber upper-quartile length to approximately 2.90 cm (1.14 in), but it took three saw-type lint cleaners to significantly reduce upper-quartile length to 2.74 cm (1.08 in). Similar statements could be made about the other length parameters shown in Table 1. This would indicate that, although any saw-type lint cleaning clearly reduces fiber length, only excessive lint cleaning (three in this case) greatly reduces fiber length over one saw-type lint cleaner.

The Suter-Webb fiber array for the fiber portion of the lint cleaner trash for the three saw-type lint cleaner treatments is given in Table 2. Trash from each lint cleaner was collected and analyzed separately. A sample of the trash collected from each separate lint cleaner was first processed through a Shirley Analyzer to separate the waste fiber from the other trash material. The Shirley Analyzer cleaned fiber was then analyzed by the Suter-Webb Array method to determine length. The Shirley Analyzer likely damaged and shortened some of the waste fibers and changed their fiber distribution to some degree. However, the assumption was that the length distribution change would be relatively the same for all processed waste samples and would not materially affect the results. Only three of the ginning treatments are represented here, and in subsequent tables, as the type of lint cleaning for the roller ginning treatment produces low lint loss and no lint was collected. Also, the saw ginning treatment with no lint cleaning produced no lint cleaner trash. Except for the CV, there was no significant difference in fiber length properties shown in Table 2 between the LC-2 and LC-3 treatments. However, the fiber in the LC-1 trash was significantly longer with less short fiber than the other two cleaning treatments.

Table 1. Average ginned lint Suter-Webb array length parameters.

Treatment ID[z]	Upper-Quartile Length[y] cm (in)	Mean Length cm (in)	CV (%)	Fiber Shorter Than 1.27 cm (1/2 in) (%)
RG	3.05 (1.20)a	2.41 (0.95)a	35.6c	13.4d
S-0	2.95 (1.16)b	2.24 (0.88)b	38.9b	17.4c
S-1	2.90 (1.14)c	2.18 (0.86)c	40.0b	18.9b
S-2	2.87 (1.13)c	2.18 (0.86)c	39.6b	18.3bc
S-3	2.74 (1.08)d	2.06 (0.81)d	41.2a	21.7a

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners. [y]Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 2. Average lint cleaner trash lint Suter-Webb array length parameters.

Treatment ID[z]	Upper-Quartile Length[y], cm (in)	Mean Length, cm (in)	CV (%)	Fiber Shorter Than 1.27 cm (1/2 in) (%)
LC-1	2.41 (0.95)a	1.75 (0.69)a	48.3b	33.9b
LC-2	2.31 (0.91)b	1.69 (0.66)b	49.4a	35.7a
LC-3	2.27 (0.90)b	1.67 (0.66)b	48.2b	36.1a

[z] LC followed by number indicates order in series from where trash samples were taken. [y]Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Tables 3 and 4 show the equivalent High Volume Instrument (HVI) upper-half mean and classer's staple length as would be used in cotton marketing for the ginned lint and lint in the lint cleaner trash, respectively. The equivalent HVI upper-half mean (HVIUHM) lengths in Tables 3 and 4 were calculated from the Suter-Webb Array (SWAL) lengths shown in Tables 1 and 2. The equation used was:

$$HVIUHM = (SWAL + 0.3777)/1.3813$$

Table 3. Average ginned fiber calculated equivalent HVI and staple lengths.

Treatment ID[z]	HVI Length cm (in)	Classer's Staple Length
RG	2.90 (1.14)	37
S-0	2.82 (1.11)	36
S-1	2.79 (1.10)	35
S-2	2.77 (1.09)	35
S-3	2.67 (1.05)	34

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners.

This equation was provided by Thibodeaux (personal communication, 2011) and was derived from the data reported by Thibodeaux et al. (2008). The staple lengths were then determined from the calculated HVIUHM using the Agricultural Marketing Services conversion chart (USDA-AMS, 1993).

The staple length of the LC-1 fiber averaged the equivalent of 31 compared to 30 and 29 for the second and third lint cleaning treatments respectively (Table 4). These staple lengths were shorter than the range of 34 to 35 staple lengths for the corresponding baled fiber (Table 3). The upper-quartile length of the fiber lost to cleaning was only equivalent to the average mean length (Table 1) of the fiber that was roller ginned and had much higher short fiber content and indicates this waste fiber is of lesser quality and value than the baled fiber from which it was removed.

The value of the fiber lost in the lint cleaner trash is difficult to determine because of its high short fiber content and unknown color, uniformity, fiber strength, and micronaire values. However a conservative discount can be estimated for the lost fiber using staple length alone and assuming all other HVI fiber properties equivalent to the fiber that went into the bale for its respective treatment. The ginned lint for treatments S-1, S-2, and S-3 had an average HVI color code of approximately 21-2 and no discount for uniformity, micronaire, or strength. Using these average HVI fiber values and the staple length differences between the baled fiber and the fiber lost to lint cleaning results in the loan price discounts (CCC, 2011) shown in Table 4. Based on fiber length alone the fiber lost to lint cleaning is worth significantly less than the baled fiber.

Tables 5a and 5b show the average percentages of fiber length in increments for the ginned lint as determined by the Suter-Webb fiber array method. Figure 1 shows the plot for these same data. The roller ginned fiber had significantly more long fiber from the longest interval down to the 2.21/2.54-cm (0.87/1.00 in) interval. Also, the S-3 treatment had significantly less fiber in these intervals than any of the other treatments but there were few significant differences in the fiber distributions of the S-0, S-1, and S-2 treatments. At approximately the 2.54-cm (1 in) fiber length there was no significant difference between the five ginning treatments. Figure 1 shows all of the plots coming together at this point and then shows at the shorter fiber length intervals a divergence in percentage of fibers by the differing ginning treatments. The roller ginning treatment has significantly

Table 4. Average lint cleaner trash lint calculated equivalent HVI and staple lengths.

Treatment ID[z]	HVI Length, cm (in)	Classer's Staple Length	Loan Price Discount, cents/lb
LC-1	2.44 (0.96)	31	5.70
LC-2	2.36 (0.93)	30	5.80
LC-3	2.34 (0.92)	29	4.25

[z] LC followed by number indicates order in series from where trash samples were taken.

fewer fibers (Table 3b), whereas the S-3 treatment has the most fibers until the two shortest length intervals where there is no significant difference between treatments and the percentage of fibers in these intervals is something less than 5% total. Although there is some statistical separation in the length intervals starting at 1.9/2.21 cm (0.75/0.87 in) and below for the S-0, S-1, and S-2 treatments, they are generally not statistically significant and Fig. 1 shows little separation through these intervals even though there is a trend for more shortening of fibers with more machine cleaning.

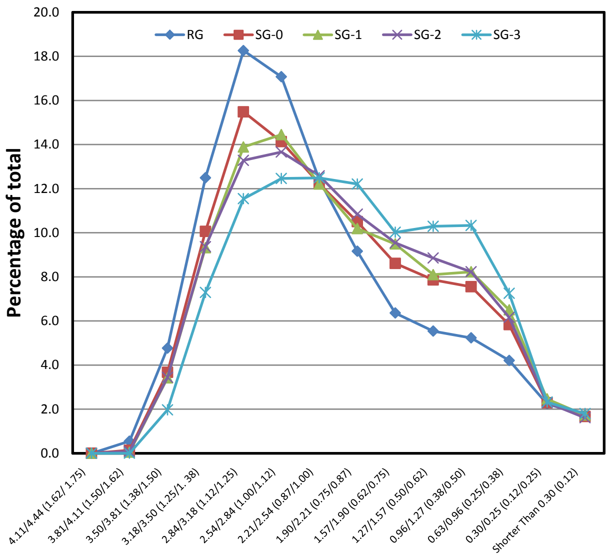

Figure 1. Suter-Webb Array data for the lint from all five ginning treatments.

More machining during ginning degrades cotton fiber length and has been generally expressed in totals as shown in Table 1. However Fig. 1 identifies what fiber lengths are lost as machining becomes more severe and what fiber lengths are subsequently increased. Tables 3a and 3b indicate that many of these length category changes illustrated in Fig. 1 are significant. Although there were significant changes in fiber length between roller and saw ginning and again between saw ginning and the addition of lint cleaning, there were fewer significant differences between minimal lint cleaning (one saw-type) and moderate lint cleaning (two saw-type lint cleaners). It is only when the cotton fiber received severe lint cleaning (three saw-type lint cleaners) that there was a great deal of separation between treatments. This might indicate that, because all saw ginned cotton receives as least one lint cleaning, the occasional use of two saw-type lint cleaners for removal of excessive trash might not excessively degrade fiber length for mature, strong cultivars. Tables 6a and 6b give the average fiber array length interval data for the lint portion of the trash removed by the saw type lint cleaners and Fig. 2 gives another view of the same data. As was indicated by the total averages shown in Table 2, the fiber length of the LC-1 waste fiber was significantly longer or tended to be longer than LC-2 or LC-3 down

Table 5a. Average percentage of ginned lint in specific Suter-Webb array sequences, cm (in).

Treatment ID[z]	4.11/4.44[y] (1.62/ 1.75)	3.81/4.11[y] (1.50/1.62)	3.50/3.81[y] (1.38/1.50)	3.18/3.50[y] (1.25/1. 38)	2.84/3.18[y] (1.12/1.25)	2.54/2.84[y] (1.00/1.12)	2.21/2.54 (0.87/1.00)
RG	0	0.55a	4.77a	12.49a	18.26a	17.07a	12.39
S-0	0	0.14b	3.67b	10.06b	15.48b	14.13b	12.22
S-1	0	0.05b	3.42b	9.32b	13.89c	14.45b	12.21
S-2	0	0.09b	3.44b	9.37b	13.28c	13.66b	12.58
S-3	0	0b	1.97c	7.29c	11.54d	12.46c	12.49

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners. [y]Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 5b. Average percentage of ginned lint in specific Suter-Webb array sequences, cm (in).

Treatment ID[z]	1.90/2.21[y] (0.75/0.87)	1.57/1.90[y] (0.62/0.75)	1.27/1.57[y] (0.50/0.62)	0.96/1.27[y] (0.38/0.50)	0.63/0.96[y] (0.25/0.38)	0.30/0.25 (0.12/0.25)	Less Than 0.30 (0.12)
RG	9.16c	6.36c	5.54d	5.23c	4.21c	2.24	1.73
S-0	10.5b	8.61b	7.86c	7.55b	5.83b	2.29	1.67
S-1	10.19b	9.49a	8.1bc	8.23b	6.5b	2.46	1.73
S-2	10.84b	9.54a	8.85b	8.23b	6.16b	2.30	1.61
S-3	12.21a	10.02a	10.29a	10.33a	7.25a	2.32	1.80

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners. [y] Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

to the 1.9/2.21 cm (0.75/0.87 in) fiber interval where the length averages were essentially the same. Below this length interval there were significantly less or tended to be less fiber in the S-1 array intervals than for the other two lint cleaning treatments. Figure 2 illustrates that none of these differences were particularly large for practical application even if they are statistically significant. Although there is a small percentage of long fibers in all of the trash from the different lint cleaner treatments, approximately 68 to 73% (estimated from averages shown in Table 6b) were in the 28 staple length (1.9/2.21 cm (0.75/0.87 in)) range or below and are not particularly valuable in terms of textile processing.

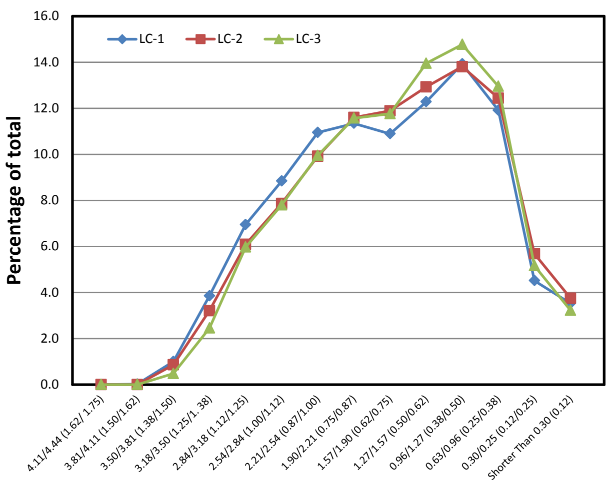

Figure 2. Suter-Webb Array data for the fiber portion of the lint cleaner waste for three ginning treatments with saw lint cleaning.

The cotton fiber content of each lint cleaner trash sample was determined by the Shirley Analyzer. The average fiber loss for each level of saw lint cleaning was then determined from these data. As would be expected, the average fiber loss increased as the amount of lint cleaning increased. For a 227-kg (500 lb) bale, the average total weight of the fiber-only loss calculated from trash weights and Shirley Analyzer data was 2.35, 3.45, and 4.21 kg (5.2, 7.6, and 9.3 lb) for LC-1, LC-2, and LC-3 lint cleaning treatments respectively. The average total lint cleaning trash weight loss calculated from gin test weights, including both fiber and trash, for a 227-kg (500 lb) bale, for the LC-1, LC-2, and LC-3 lint cleaning treatments was 8.0, 9.2, and 10.1 kg (17.6, 20.2, and 22.2 lb) respectively. These data illustrate that, although the first lint cleaner after the saw gin removes the most weight, a relatively low percentage of that weight is cotton fiber (approximately 30% in this test) and the average percentage of fiber lost relative to total trash removed increased with subsequent lint cleaning (58% fiber for the second and 75% fiber for the third lint cleaner). However, a significant percentage of the fiber lost, regardless of the amount of saw lint cleaning, was relatively short in length compared to the baled fiber.

Key properties for ring spinning systems are as follows: length, strength, fineness, and friction (Deussen, 1993). This study was performed using the same cotton variety thus removing the influences of fiber fineness, strength, and friction. Resultant cotton lint demonstrated different cotton trash levels and fiber lengths due to gin processing.

Table 6a. Average percentage of lint in trash in specific Suter-Webb array sequences, cm (in).

Treatment ID^{z}	4.11/4.44 (1.62/ 1.75)	3.81/4.11 (1.50/1.62)	3.50/3.81^{y} (1.38/1.50)	3.18/3.50^{y} (1.25/1. 38)	2.84/3.18^{y} (1.12/1.25)	2.54/2.84^{y} (1.00/1.12)	2.21/2.54^{y} (0.87/1.00)
LC-1	0	0.02	1.00a	3.85a	6.95a	8.84a	10.95a
LC-2	0	0	0.86a	3.21b	6.09b	7.86b	9.92b
LC-3	0	0	0.48b	2.45c	5.97b	7.80b	9.95b

^{z} LC followed by number indicates order in series lint cleaners from where trash samples were taken. ^{y} Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 6b. Average percentage of lint in trash in specific Suter-Webb array sequences, cm (in).

Treatment ID^{z}	1.90/2.21 (0.75/0.87)	1.57/1.90^{y} (0.62/0.75)	1.27/1.57** (0.50/0.62)	0.96/1.27^{y} (0.38/0.50)	0.63/0.96^{y} (0.25/0.38)	0.30/0.25^{y} (0.12/0.25)	Shorter Than 0.30^{y} (0.12)
LC-1	11.34	10.89b	12.28b	13.92ab	11.91b	4.51b	3.52ab
LC-2	11.60	11.89a	12.92b	13.80b	12.44ab	5.68a	3.75a
LC-3	11.57	11.76a	13.95a	14.77a	12.95a	5.16ab	3.22b

^{z} LC followed by number indicates order in series lint cleaners from where trash samples were taken. ^{y} Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 7a shows that additional passes of cotton lint through more than one lint cleaner does not significantly lower amounts of waste during textile opening and cleaning as well as total card waste. However, although additional lint cleaner passes did not result in lower card waste, spinning efficiency decreased with more ends down, yarn strength decreased, and yarn strength coefficient of variation increased with increased lint cleaning. Bel et al. (1991b) showed that at least one lint cleaner was necessary for trash removal at the cotton gin to obtain desirable processing results at the textile mill. As textile processing speeds increase, high-speed spinning machinery is less tolerant of short fiber, so continued improvements in lint cleaning with less fiber breakage is desirable. Fig. 1 demonstrates how additional lint cleaning produced different fiber length distributions that contain extra fibers shorter in length that are likely leading to the reduced yarn properties and spinning efficiencies. The roller ginned samples with its preferred fiber length distributions contain fibers of longer lengths that are indicative of better yarn formation. Table 7b further demonstrates that as the fiber length distribution changes to include more fibers shorter in length, measured yarn properties such as neps, thicks, thins, minor faults, and long thins all statistically increase with additional processing. Foulk et al. (2007) indicated that thins and Classimat long thins are significantly correlated to short fiber content and upper-quartile length whereas thicks and minor faults are correlated to short fiber content. Fibers more uniform in length should lead to 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. It is interesting to note in Table 7b that, even though yarn properties were significantly affected by additional gin processing, woven cloth dying properties, as indicated by white specks, were not affected.

CONCLUSIONS

A commercially grown upland cotton that was approximately midrange in staple length and strength for U.S. cotton was subjected to the current

Table 7a. Averages of selected carding and yarn measurements.

Gin Treatment[z]	WASTE		Spinning	SINGLE STRAND DATA (Statimat)		
	Opening & Cleaning[y], %	Total Card Waste [y], %	Cal. Ends Down [y], No./M Sp. Hrs.	Strength [y], g/tex	Elong. **, %	Str. [y] C.V., %
RG	1.25b	4.77b	6.4b	15.13a	6.79b	9.09c
S-0	4.13a	4.90b	6.2b	14.93a	7.02a	9.57bc
S-1	2.30b	4.89b	12.6b	14.58b	6.89ab	10.39b
S-2	1.18b	4.90b	9.6b	14.38b	7.06a	10.49ab
S-3	1.22b	5.17a	51.0a	13.68c	6.94ab	11.43a

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners. [y] Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 7b. Averages of selected yarn and cloth measurements.

Gin Treatment[z]	EVENNESS DATA No. /1000 m (1000 yds)			CLASSIMAT				White Specks
	Neps[y]	Thicks [y]	Thins [y]	Major Faults	Minor Faults [y]	Long Thicks	Long Thins [y]	No./258 cm^2 (40 in^2)
RG	612d	1482e	280e	7.0	1705c	12.2	309d	2.2
S-0	575e	1571d	401d	4.8	1585c	6.0	497dc	2.2
S-1	664c	1752c	506c	4.0	2082c	22.0	623c	1.8
S-2	707b	1857b	595b	7.6	3020b	8.0	884b	1.8
S-3	876a	2271a	931a	9.6	4655a	17.6	1475a	2.6

[z] RG indicates roller gin. S indicates saw gin followed by the number of saw-type lint cleaners. [y] Means followed by different letters are significantly different at the 5% level according to Duncan's Multiple Range Test.

practical range of ginning and lint cleaning treatments. The effect of gin processing on fiber length distribution and subsequent textile processing was investigated. Some conclusions that can be drawn from this test are:

1. In comparing roller ginning with saw ginning there was a significant downward shift in the length distribution with the saw ginned fiber. This is not new information but these data show that the length shift was a significant decrease of fibers above 2.54 cm (1.0 in) and a significant increase in fibers between 2.21 and 0.30 cm (0.87 and 0.25 in). The percentage of fibers in the 2.21- to 2.54-cm (0.87 to 1.00 in) length range stayed relatively constant.
2. The use of saw lint cleaners continued the fiber length distribution shift noted in Conclusion 1 above with the percentage of fibers in the 2.21- to 2.54-cm (0.87 to 1.00 in) length range continuing to stay relatively constant.
3. More long fiber was lost at the first lint cleaner than any subsequent lint cleaner, but at least two thirds of the fiber lost to the trash, regardless of the number of series lint cleaners used, was less than 2.21 cm (0.87 in.) in length and not of great textile processing value. A significant percentage of the fiber lost, regardless of the amount of saw lint cleaning, was relatively short with over 33% being equal to or less than 1.27 cm (0.50 in) in length.
4. The first lint cleaner after the saw gin removes the most weight from the ginned lint. However, less than a third of the weight lost from the first lint cleaner was cotton fiber. The average percentage of fiber lost relative to total trash removed increased with subsequent lint cleaning.
5. Additional lint cleaning produced different fiber length distributions that contain extra fibers shorter in length that are likely leading to the reduced yarn evenness properties and increased spinning ends down which decreases spinning efficiency. As stated earlier, key properties for ring spinning systems are length, strength, fineness, and friction. This study used the same cotton variety thus removing the influences of fiber fineness, strength, and friction. Resultant cotton lint contained different cotton trash levels and fiber lengths for testing their effects on textile processing. This is not a new idea but does demonstrate relative levels of fiber distribution differences and their impacts for an upland variety that was midrange in fiber length.
6. As the fiber length distribution is changed by mechanical processing to include more fibers shorter in length then measured yarn properties such as neps, thicks, thins, minor faults, and long thins all statistically increased with additional processing.
7. Fiber length distribution changes did not significantly affect dying properties as indicated by white specks in dyed cloth.

In summary, the textile carding operation removed approximately the same amount of total waste from cleanly harvested spindle picked upland cotton regardless of the amount of machining the fiber received during ginning and subsequent lint cleaning, and the level of waste in the raw fiber was probably not a major factor for this test. However, the differing levels of fiber distribution did significantly affect yarn quality. Reducing fiber breakage while maintaining reasonable levels of trash removal during gin lint cleaning should be a priority for future lint cleaning research.

DISCLAIMER

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