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Article

Evaluation of Alternative-Design Cotton Gin Lint Cleaning Machines on Fiber Length Uniformity Index

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Abstract: Developing cotton ginning methods that improve fiber length uniformity index to levels that are compatible with newer and more efficient spinning technologies would expand market share and increase the demand for cotton products and give U.S. cotton a competitive edge to synthetic fibers. Older studies on lint cleaning machines showed that the most widely used feed mechanism that places fiber on the cleaning cylinder damages the fiber and reduces uniformity. The present study evaluates how conventional and experimental feed mechanisms affect uniformity. The lint cleaners were used with both saw and roller gin stands. Four diverse cotton cultivars from the Far West, Southwest, and Mid-South were used in the test. Statistical analysis used a random effects modeling approach which included constructing a 95% confidence interval for each ginning treatment around the predicted mean for the fiber property of interest, and then examining which treatments overlap (for comparison). Results show that the micro-saw gin with the direct-feed lint cleaner had the best uniformity at 85.8%. Prior research has shown that roller ginning is consistently higher in uniformity than any type of saw ginning. In this study, the roller ginning treatments had uniformities of 85.3 and 85.6%, so it is encouraging that the saw gin stand with the direct-feed lint cleaner had very high uniformity. This suggests that it may be beneficial to place fiber directly onto the lint cleaning saw without changing direction. Additionally, the saw gin-coupled lint cleaner had a uniformity of 84.3% which is also a respectable level of uniformity. These results indicate that the direct-feed lint cleaner and coupled lint cleaner warrant further testing under better controlled conditions.

Keywords: saw ginning; roller ginning; lint cleaning; fiber quality

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1. Introduction

In cotton ginning, machines and associated hardware transport, condition, clean (remove trash or foreign matter—material other than lint or seed), and separate the fiber from the cottonseed (ginning). After ginning, the process continues as the ginned fiber is further cleaned and packaged. Figure 1 shows a layout of a typical modern ginnery. Most by-products from the ginning process are reused for such things as cattle feed and cooking oil (cottonseed), medical supplies and cotton balls/swabs (linters from cottonseed), and biodegradable packaging and hydro mulch (parts of the cotton plant or trash). But the main product in a ginnery, ginned fiber, is sold to textile mills which transform the fiber into yarn and finished products such as clothing, bed sheeting, and towels.

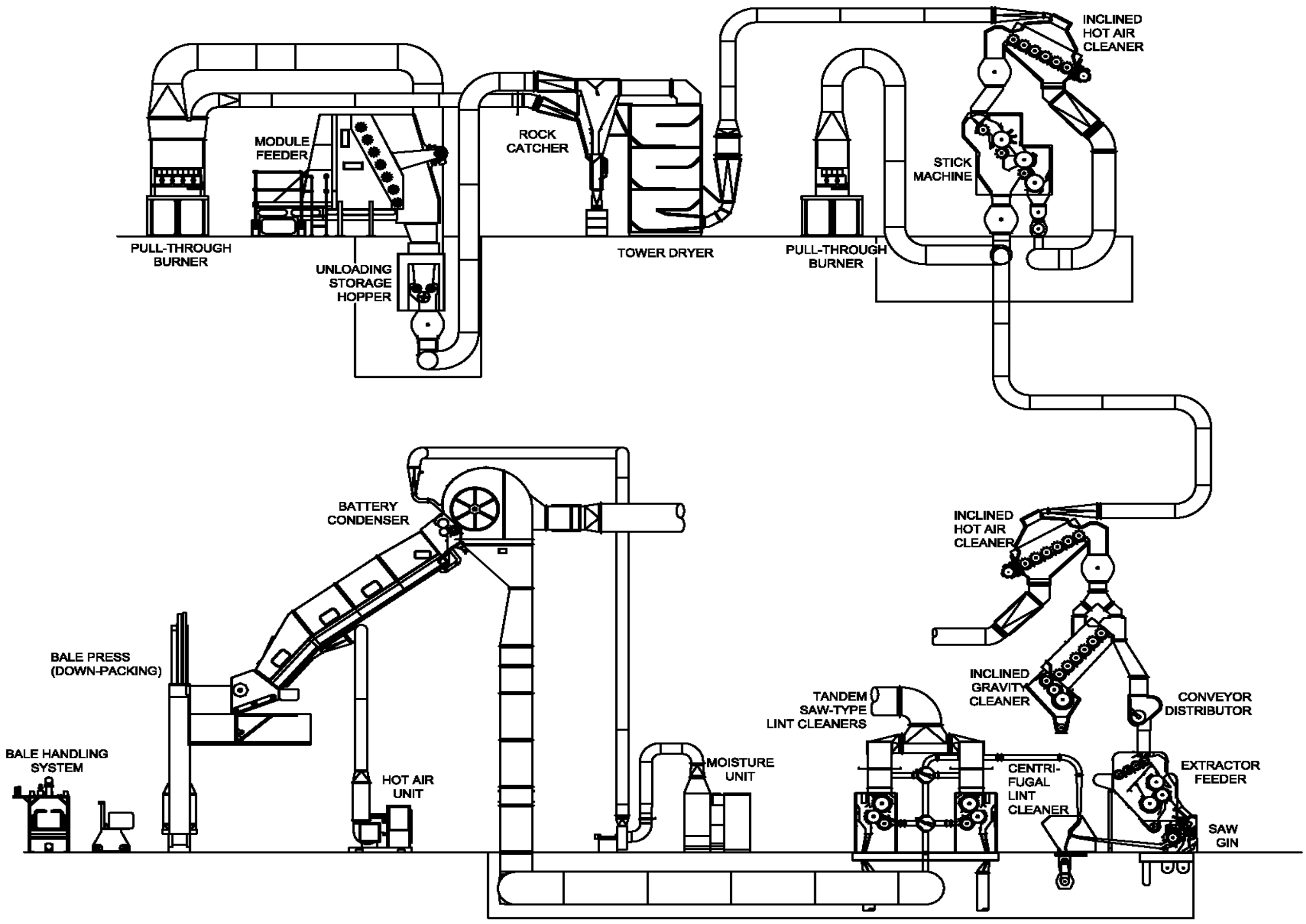

Figure 1. Typical saw ginning system for machine-picked cotton (Lummus Corporation).

Textile mills use different spinning processes and fiber types (in this case, cotton) to manufacture yarns for various intended end uses. For example, ring spinning is the predominant and oldest mechanical spinning process and produces the finest yarn, but it is slow and expensive and requires a long and more uniform fiber to manufacture yarns. Rotor spinning, a faster and less expensive process, requires mainly a stronger fiber and produces a coarser yarn than ring spinning. Air-jet or vortex spinning is a newer and very fast and efficient process that is used for a variety of products; its production rate is 10–20 and 3–5 times higher than ring and rotor spinning, respectively. Air-jet spinning requires long fibers that have a relatively uniform length distribution with few short fibers [1]. In the crop year 2021/22, the United States (U.S.) exported 70.5% of the cotton available (beginning stocks and new crop [2]). To remain competitive not only with other countries' cotton growths, but more importantly with the synthetic fiber industry, industry officials in the U.S. set a long-term goal to improve fiber length uniformity. By doing so, U.S. cotton could be more readily utilized for the very efficient air-jet spinning processes that now use mostly synthetic fibers that have very uniform distributions. And improvements would also support the larger ring-spinning industry to allow finer count yarns to be made with 100% cotton on this system (Figure 2). This would provide a higher financial return to the producer by having better-quality fiber to sell to the textile industry.

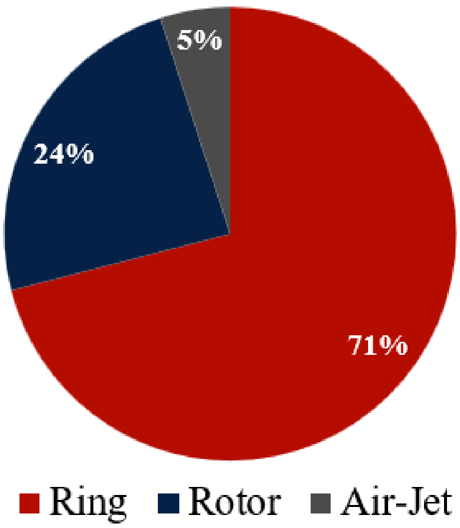

Figure 2. Proportions of ring, rotor, and air-jet spinning [3].

Fiber length uniformity index (hereafter referred to as "uniformity"), as measured using a High Volume Instrument (HVI®, Uster Technologies, Inc., Greenville, SC, USA), is defined as the ratio of mean fiber length to upper half mean fiber length expressed as a percentage [4]. Uniformity is categorically divided into the following ranges: very high (above 85%); high (83–85%); intermediate (80–82%); low (77–79%); and very low (below 77%). Uniformity can vary within a short time frame due to the introduction of new cultivars or adverse production events such as weather, pests, or disease. Figure 3 gives a perspective of the past and current levels of uniformity in regions of the U.S. [5]. Although uniformity can vary greatly from year to year, between 2000 and 2021 uniformity improved by only 0.1, 0.2, 0.4, and 0.4 percentage points in the Far West, Southwest, Midsouth, and Southeast regions, respectively, of the U.S. In general, uniformity lies within the "intermediate" range of 80 to 82% across the U.S.

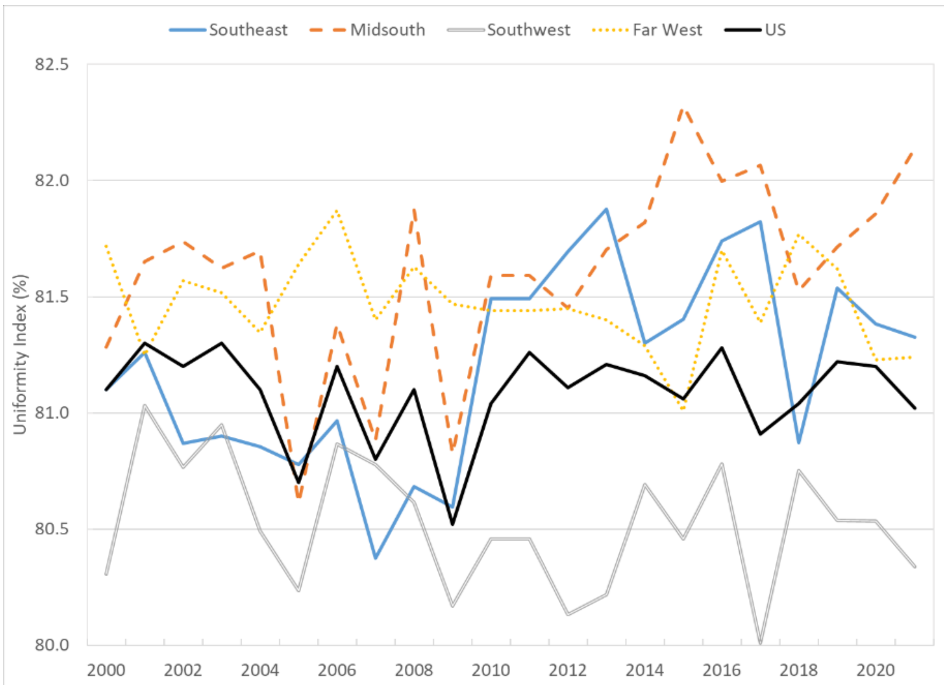

Figure 3. Fiber length uniformity (%) by region.

A small numerical improvement in uniformity (0.5 percentage points) results in significant gains in efficiency during spinning. Although genetic characteristics overwhelmingly dictate a cultivar's uniformity and weather plays a significant role, production and ginning practices also affect uniformity. Figure 4 is an example of how fiber length distribution (uniformity) can vary due to any of the reasons just mentioned. In Figure 4, the upper half mean length appears to be about the same between the two fiber profiles, but overall mean length is lower for the lower profile because it has a larger number of shorter fibers.

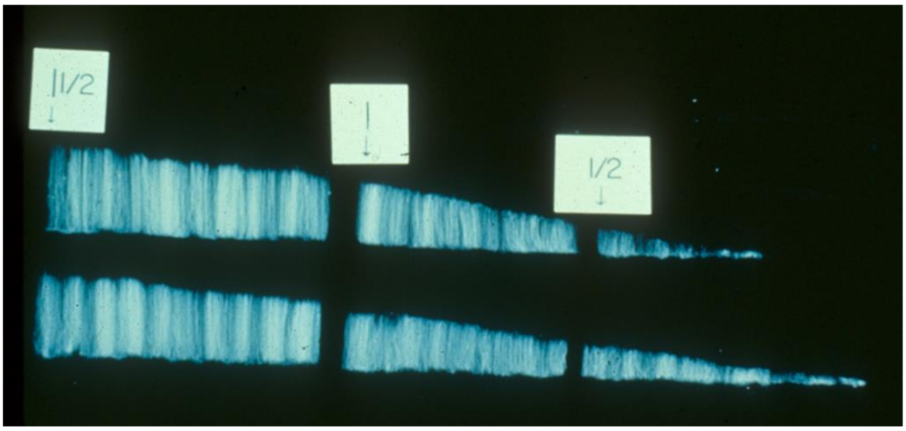

Figure 4. Example of two differing fiber length distributions.

Fiber damage may occur when cotton is harvested and put through the ginning process. A previous article summarized the results of harvesting and ginning studies within the past fifteen years that included uniformity [6]. The studies suggested that most of the decrease in uniformity occurs at the saw-type lint cleaner feed bar. Saw-type lint cleaners are used to clean Upland fiber (species *G. hirsutum*) after separating the fiber from the seed. Upland fiber makes up about 97% of the U.S. cotton crop [7]. (The remaining 3% of the crop is ginned and cleaned with gentler machines found in roller ginneries that process Pima cotton (species *G. barbadense*) and high-quality Upland cottons.)

Figure 5 shows a diagram of a conventional controlled-batt, saw-type lint cleaner where a batt of lint is formed on a condenser screen, and a feed works assembly removes the batt from the condenser and directs the batt to a feed plate. The inset shows a close-up view of the vicinity where the slow-moving batt is pinched tightly between the feed plate and feed roller, and a fast-moving saw cylinder with sharp teeth, traveling in the opposite direction of the batt, grabs the fiber at the tip of the feed plate; this is where fiber damage occurs.

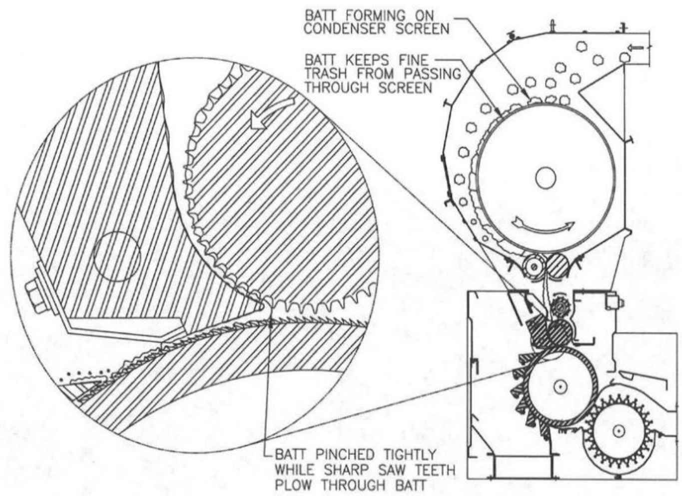

Figure 5. Side and close-up view of conventional saw-type lint cleaner.

There are other lint cleaners, both commercially available and experimental, that use non-conventional methods of placing fiber on the cleaning saw. One of these commercial methods does not form the ginned fiber into a slow-moving batt before placing the fiber onto the saw; another commercial method places the fiber onto the saw in the same direction as the rotating saw; and an experimental method not only does not form a batt, but also eliminates the feed mechanism altogether (coupled technology). Results on the comparative performance of these non-conventional commercially available methods have not been published, and although results of the experimental method are documented, the research was performed many years ago on older cultivars. The objective of this study was to determine how these non-conventional lint cleaning methods might affect uniformity. This study includes saw and roller gin stand technologies, conventional (control) and non-conventional lint cleaners, and Upland cultivars with diverse fiber properties. This preliminary study lays the groundwork for a more thorough investigation if certain lint cleaning methods of placing the fiber on the saw warrant further research. It should be noted that this study used different equipment in different geographical areas with different environmental conditions; an appropriate analysis was used to account for these differences.

2. Materials and Methods

A formal ginning test was run to determine how conventional and non-conventional lint cleaner feed mechanisms affect uniformity. The test included seven ginning treatments, four cultivars, and three replications for a total of 84 lots. Lots 1–48 were run in Las Cruces, NM, lots 49–72 were run in Stoneville, MS, and lots 73–84 were run in Tifton, GA. Table 1 shows the ginning treatments (gin stand and lint cleaner types) and locations where those treatments were run. The 20-saw and 46-saw gin stands were narrower than typical commercial gin stands, but otherwise contained the same-size components such as saw cylinder, ribs, etc. Anthony et al. [8] demonstrated essentially no difference in fiber properties between micro-size and full-size gin stands. Machinery for the individual ginning treatments were in New Mexico, MS, USA, and GA, USA. The settings and operation of the gin stands and lint cleaners were according to the manufacturer's or design specifications.

Table 1. Ginning treatment and location where treatment was run.

Gin Stand Type	Lint Cleaner Type	Treatment Designation	Treatment Location
Micro-size saw gin	Conventional saw-type	Micro-saw/conv	Stoneville, MS, USA
Micro-size saw gin	Batt-less saw-type	Micro-saw/batt-less	Stoneville, MS, USA
Micro-size saw gin	Direct-feed saw-type	Micro-saw/direct-feed	Tifton, GA, USA
Saw gin	Conventional saw-type	Saw/conv	Las Cruces, NM, USA
Saw gin	Coupled saw-type	Saw/coupled	Las Cruces, NM, USA
Roller gin	Conventional pin-type	Roller/conv	Las Cruces, NM, USA
Roller gin	Coupled saw-type	Roller/coupled	Las Cruces, NM, USA

2.1. Conventional Lint Cleaners

The configuration of a conventional saw-type lint cleaner (Figure 5) was discussed earlier. This type of configuration applies to the micro-size conventional saw-type lint cleaner in Mississippi and the full-size conventional saw-type lint cleaner in New Mexico.

The micro-size saw gin and conventional saw-type lint cleaner in Mississippi (micro-saw/conv) included a 343 mm (13.5 in.) wide, 20 saw, Continental Model 620 gin stand that was driven by a 7.5 kW (10 hp) motor, and was rated at about 214 kg m^{-1} h^{-1} (144 lb ft^{-1} h^{-1}). The lint cleaner was a like-width Continental-make saw-type lint cleaner with a spiral-wrapped 406 mm (16.0 in.) diameter lint cleaner saw, operated at about 900 rpm, and was driven by a 3.73 kW (5.00 hp) motor. The lint cleaner had five grid bars with 1.59 mm (0.063 in.) clearance between each bar and the saw.

The full-size saw gin stand and conventional lint cleaner in New Mexico (saw/conv) consisted of a 46-saw Continental/Murray Double Eagle saw gin stand and a Continental/Moss–Gordin Lodestar controlled-batt saw-type lint cleaner (Continental Gin Co.; Prattville, AL, USA). The saw gin stand was rated at about 1072 kg m^{-1} h^{-1} (720 lb ft^{-1} h^{-1}). The gin saws measured 406 mm (16.0 in.) in diameter, were spaced 15.9 mm (0.63 in.) apart, and operated at a 660 rpm. A 22.4 kW (30.0 hp), 1760 rpm motor drove the gin stand. The lint cleaner contained a spiral-wrapped lint cleaner saw that was 406 mm (16.0 in.) in diameter and operated at about 1000 rpm. The lint cleaner had five grid bars with 1.59 mm (0.063 in.) clearance between each bar and the saw.

The full-size roller gin and conventional pin-type lint cleaner in New Mexico (roller/conv) consisted of a 1016 mm (40.0 in.) wide Hardwicke–Etter roller gin stand and the same width pin-cylinder/air-jet cleaner. The roller gin stand was rated at about 268 kg m^{-1} h^{-1} (180 lb ft^{-1} h^{-1}). A diagram of the pin-cylinder lint cleaner is shown in Figure 6. It consisted of a 406 mm (16.0 in.) diameter pin cylinder that rotated at 1100 rpm and 16 grid bars situated around the pin cylinder with each leading edge spaced 19.1 mm (0.75 in.) apart from each other. The clearance between the pins and grid bars was 23.8 mm (0.94 in.). The air-jet cleaner connected to the pin-cylinder cleaner had an adjustable edge to skim off heavier trash.

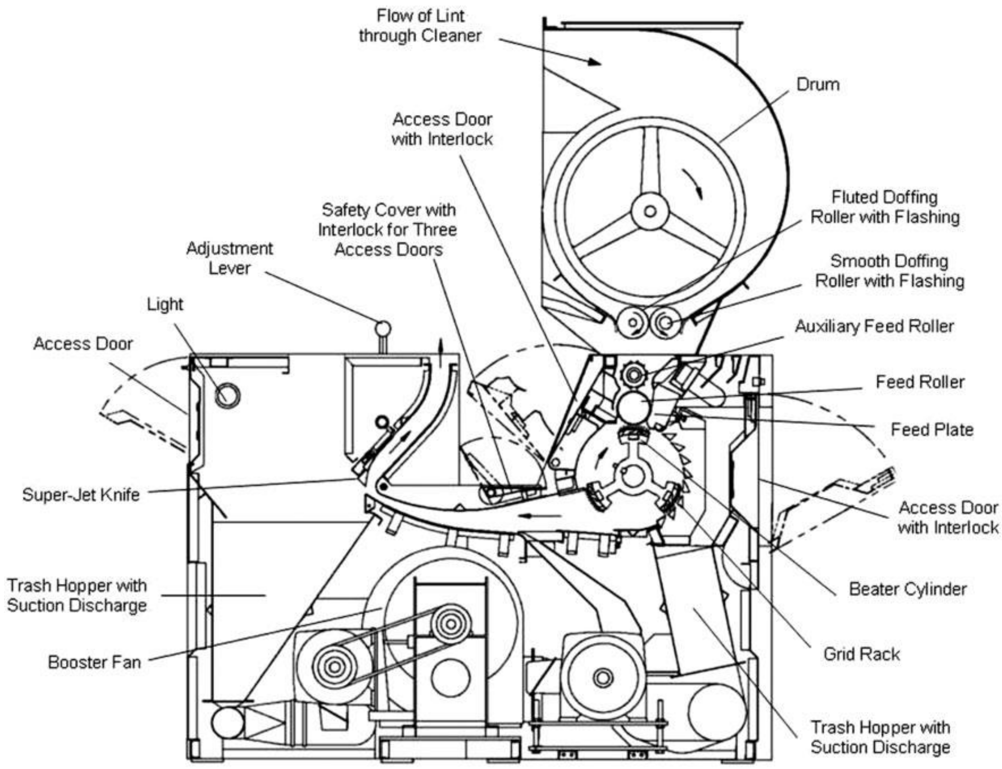

Figure 6. Diagram of pin-cylinder/air-jet lint cleaner similar to the Lummus Guardian lint cleaner (courtesy of Lummus Corporation, Savanna, GA, USA).

2.2. Alternative-Design Lint Cleaners

The micro-size saw gin stand in Mississippi (discussed earlier) was also used with the batt-less saw-type lint cleaner (micro-saw/batt-less). The batt-less lint cleaner was a narrow (343 mm (13.5 in.) cut-down version of a model currently being marketed by Lummus Ag Technology (Savannah, GA, USA) as the Sentinel II lint cleaner. Figure 7 shows a diagram of the batt-less lint cleaner where individual tufts of fiber are applied directly to the saw cylinder, thus eliminating the condenser batt. The feed works assembly is eliminated, but the feed plate is retained. The batt-less lint cleaner was developed based on the concept of the saw gin-coupled lint cleaner (discussed later), but the saw gin section remains separate from the lint cleaner section and pneumatic transport of the fiber is required. Field tests by the manufacturer have shown an improvement in the uniformity of fiber from the Sentinel lint cleaner compared to the conventional saw-type lint cleaner, but a formal laboratory test has not been conducted and published. The main components of the batt-less lint cleaner included a 533 mm (21.0 in.) diameter high-speed applicator brush cylinder running at 500 rpm, and a 406 mm (16.0 in.) diameter saw cylinder running at 1000 rpm. Six steel grid bars were spaced around the saw cylinder to remove foreign matter. A 5.6 kw (7.5 hp) motor drove the lint cleaner.

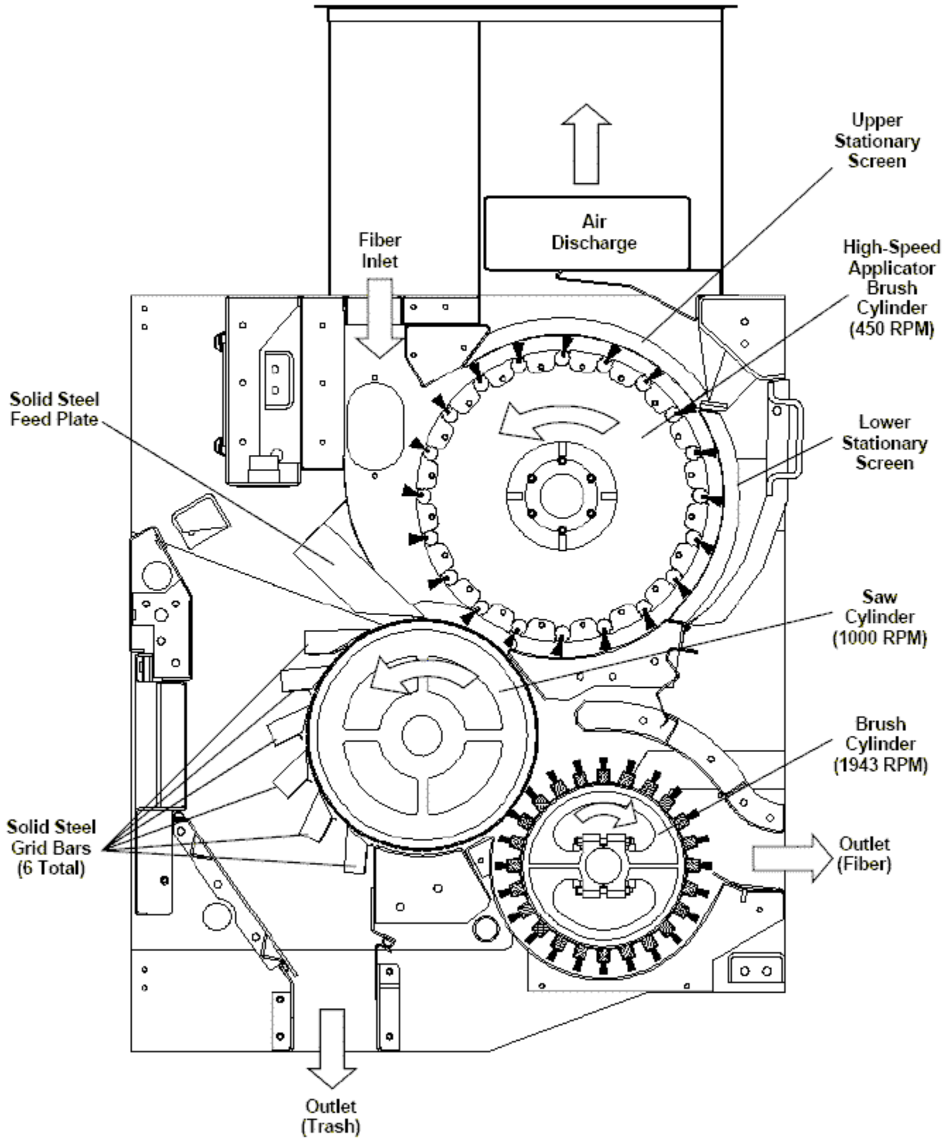

Figure 7. Diagram of batt-less saw-type lint cleaner (Lummus Sentinel II lint cleaner).

The micro-size saw gin and alternative direct-feed saw-type lint cleaner in Georgia (micro-saw/direct-feed) were models currently marketed by Cherokee Gin & Cotton Co. (Centre, AL, USA) as the Regal lint cleaner. The direct-feed lint cleaner was a narrow (457 mm (18 in.) wide) version of the Cherokee Regal lint cleaner. Figure 8 shows a diagram of the direct-feed lint cleaner where a rolling feed bar and splined roller remove the batt from the condenser drum and feed the batt directly onto the saw without changing direction. Less fiber damage may occur since the fiber does not change direction when placed onto the saw cylinder. The main components of the direct-feed lint cleaner included a 1067 mm (42.0 in.) diameter condenser drum running at 30 rpm, a 406 mm (16.0 in.) diameter saw cylinder, and a 406 mm (16.0 in.) diameter stick-type doffing brush. Six steel grid bars removed foreign matter from the lint on the saw cylinder. An 18.7 kW (25.0 hp) motor drove the lint cleaner.

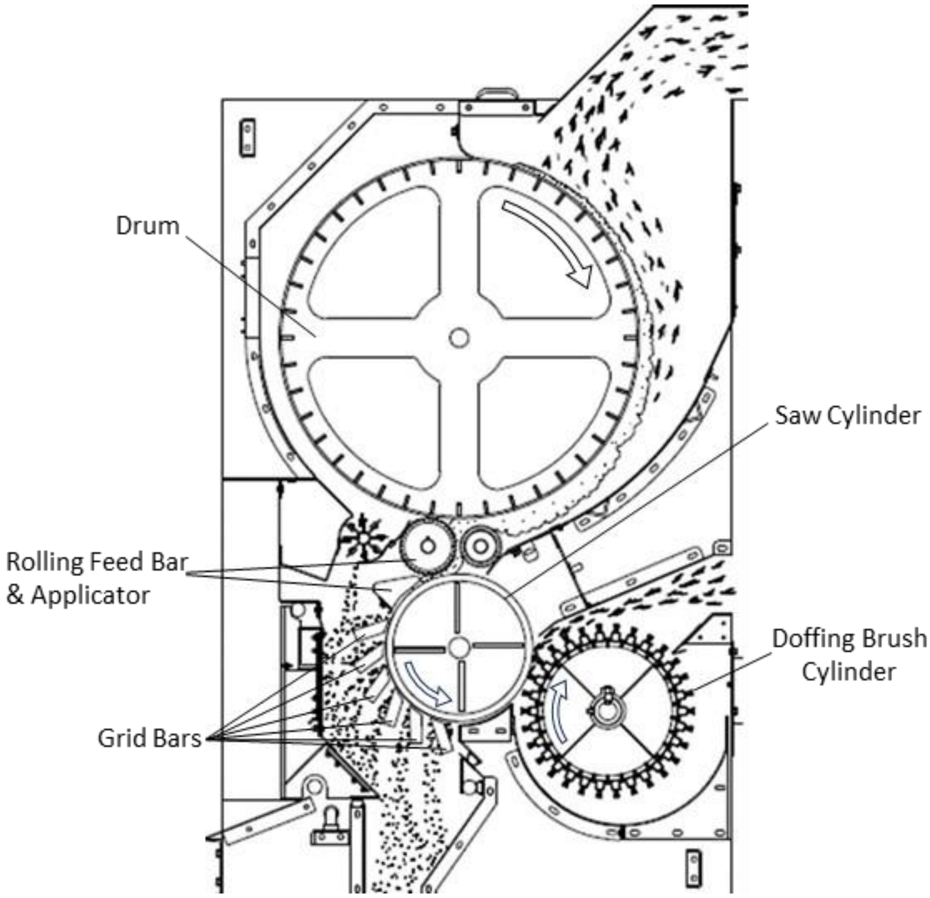

Figure 8. Drawing of direct-feed saw-type lint cleaner (Cherokee Regal lint cleaner).

Figure 9 shows a diagram of the saw gin-coupled saw-type lint cleaner (saw/coupled). For the ginning test, the second lint cleaner saw was by-passed. It is common practice nowadays in commercial ginneries to only use one lint cleaner to prevent further fiber damage. Two lint cleaners used to be commonplace but now are reserved only when ginning extremely dirty cotton. The gin stand on the saw gin-coupled lint cleaner is "coupled" directly to the lint cleaner section, and a doffing brush transfers fiber from the gin saw to the lint cleaner saw, eliminating the condenser batt, feed works, and feed plate. This experimental technology was developed and studied 30 years ago. Interestingly, the main objective of the coupled lint cleaner was to eliminate pneumatic transport between the gin stand and lint cleaner to reduce energy costs and particulate emissions; the lesser objective was to reduce fiber damage. Past research showed that fiber processed through a saw gin-coupled lint cleaner was significantly longer and had fewer short fibers compared to fiber processed through a conventional saw-type lint cleaner [9]. The ginning section of the saw/coupled includes a Lummus Imperial 108 saw gin stand that was brush doffed to transfer ginned fiber to the coupled lint cleaning section. The gin saws were 305 mm (12.0 in.) in diameter, spaced 15.9 mm (0.63 in.) apart, and operated at 830 rpm. The lint cleaning section included a 406 mm (16.0 in.) diameter wire-wrapped saw cylinder operating at 1080 rpm. A 406 mm (16.0 in.) diameter doffing brush operating at 1555 rpm transferred the ginned fiber to the lint cleaning saw cylinder. The working width of the gin stand and coupled lint cleaning section was 1727 mm (68.0 in.). More details of the concept of the saw/coupled can be found in a publication by Hughs et al. [9].

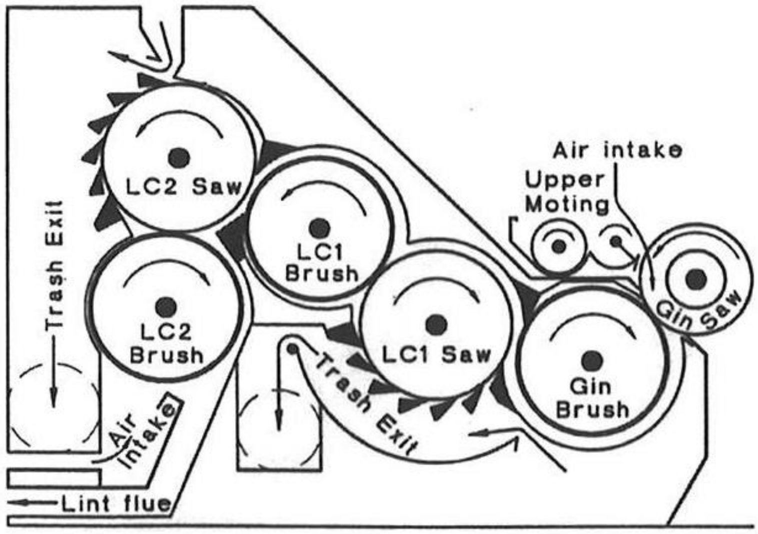

Figure 9. Drawing of the saw gin-coupled saw-type lint cleaner.

The full-size roller gin and coupled saw-type lint cleaner (roller/coupled) consisted of a Hardwicke–Etter roller gin stand coupled to an experimental saw-type lint cleaner. This roller/coupled treatment used the same Hardwicke–Etter roller gin stand that was used with the roller/conv treatment. Figure 10 shows a diagram of the roller gin-coupled lint cleaner where fiber tufts from the ginning roller are fed directly onto a saw cylinder. This technology was developed and studied 20 years ago for Pima cotton. A conventional roller gin lint cleaner is a bulk system that takes ginned fiber from many gin stands. The bulk system has high loading rates and requires pneumatic transfer but has low cost. The roller/coupled uses a unit system where each gin stand has a lint cleaner. A unit system has a lower loading rate and higher cleaning efficiency and eliminates pneumatic transfer of lint, but has a higher cost. However, with the advent of high-speed roller ginning or the possibility of wider gin stands, unit system costs may be reduced. The ginning section of the roller/coupled included a full-size 1016 mm (40.0 in.) wide Hardwicke–Etter gin stand. The lint cleaning section was the same width as the gin stand and included a 406 mm (16.0 in.) diameter saw cylinder running at 578 rpm, and a 406 mm (16.0 in.) diameter full-face doffing brush running at 1268 rpm. An aluminum guide bar helped place the ginned fiber onto the cleaning saw cylinder. Six aluminum grid bars removed foreign matter from the lint on the saw cylinder. A 14.9 kW (20.0 hp) motor drove the lint cleaner. More details of the roller gin-coupled lint cleaner can be found in a publication by Gillum et al. [10].

2.3. Cotton Cultivars

The Upland cotton cultivars used in the test were from different areas of the cotton belt with the hope of having varying fiber properties (Table 2). One cultivar was stripper harvested with a field cleaner to include a cotton with higher levels of foreign matter content. Field cleaners improve fiber quality (lint turnout, color grade, and leaf grade) and reduce ginning charges paid by the producer by approximately $10 per bale [11]. To prevent contaminating the samples taken between ginning lots of different cultivars, the test was blocked by cultivar and gin machinery was cleaned between cultivars. The seed cotton precleaning sequence used at all locations was a six-cylinder incline cleaner, stick machine, and six-cylinder incline cleaner with no drying.

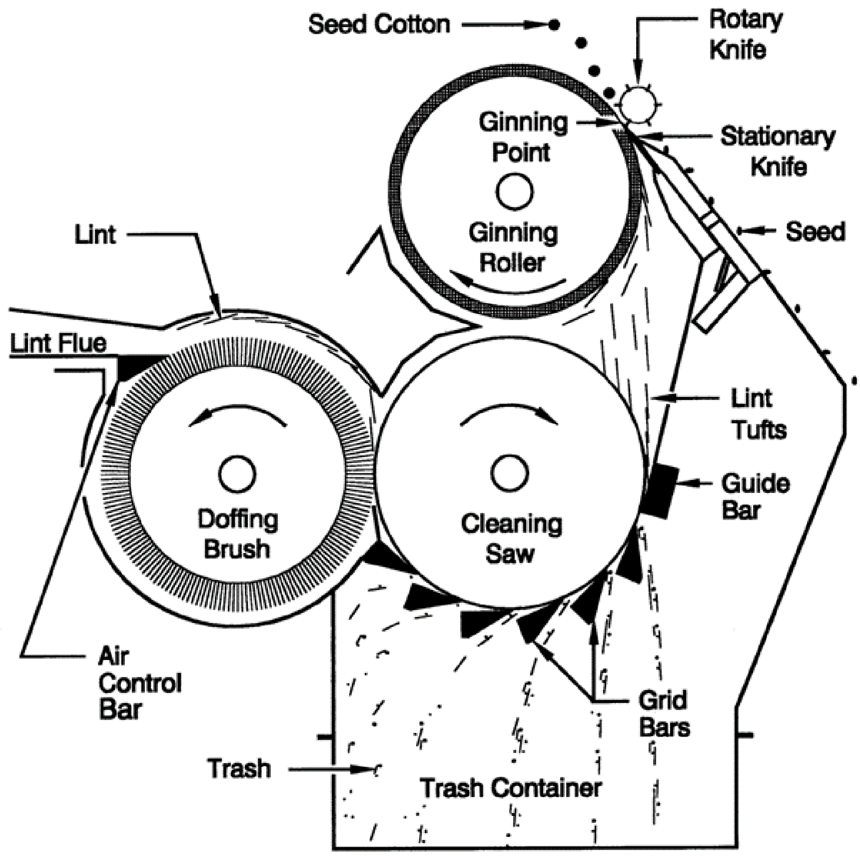

Figure 10. Drawing of roller gin and coupled saw-type lint cleaner.

Table 2. Cultivar, harvesting method, and harvest location.

Cultivar	Harvesting Method	Harvest Location
Dyna-Gro 3385 B2XF	Picker	Las Cruces, NM, USA
NexGen 4545 B2XF	Picker	Las Cruces, NM, USA
FiberMax 1830 GLT	Stripper	Lubbock, TX, USA
Phytogen 444 WRF	Picker	Stoneville, MS, USA

2.4. Experimental Design and Procedure

The test was run as a split–split–plot, randomized, complete block with three replications and cultivar serving as blocks. Ginning treatment (gin stand type/lint cleaner type) was randomized within replication, and replication was randomized within cultivar. As an example to further clarify how the test was run, Table 3 shows the order in which the first cultivar block was run on the test in Las Cruces, NM, USA. Statistical analysis used a random effects modeling approach. This specific model is also referred to as a conditional hierarchical linear model which partition variability in the levels of a random treatment by using characteristics of the levels [12]. The model entails the cultivar main effect, the random ginning treatment main effect, and their nested interaction. Analysis was performed with the MIXED procedure of SAS (version 9.2; SAS Institute, Inc., Cary, NC, USA). A 95% confidence interval of ginning treatments was constructed for each fiber property using the intercept from the results of the solution of the MIXED procedure. The ginning treatment effects can then be discussed (for comparison) by observing the degree of overlap in the confidence intervals (which are based on the standard error of prediction and best linear unbiased prediction).

Table 3. Order in which the first cultivar block was run.

Lot No.	Replication No.	Treatment Designation	Cultivar
1	1	Saw/coupled	Dyna-Gro 3385 B2XF
2	1	Saw/conv	Dyna-Gro 3385 B2XF
3	1	Roller/conv	Dyna-Gro 3385 B2XF
4	1	Roller/coupled	Dyna-Gro 3385 B2XF
5	2	Saw/coupled	Dyna-Gro 3385 B2XF
6	2	Roller/conv	Dyna-Gro 3385 B2XF
7	2	Roller/coupled	Dyna-Gro 3385 B2XF
8	2	Saw/conv	Dyna-Gro 3385 B2XF
9	3	Saw/coupled	Dyna-Gro 3385 B2XF
10	3	Roller/conv	Dyna-Gro 3385 B2XF
11	3	Saw/conv	Dyna-Gro 3385 B2XF
12	3	Roller/coupled	Dyna-Gro 3385 B2XF

Sampling during the test included seed cotton before seed cotton cleaning and after seed cotton cleaning, cottonseed at the seed belt, lint samples before (when possible) and after lint cleaning, and lint cleaner waste at the lint cleaner. There were two subsamples taken during each ginning lot of which the quality measurements were averaged together. The trash content of the seed cotton samples was determined using the pneumatic fractionation method [13], and the moisture content of lint samples was determined using the oven drying method [14]. This oven drying method is used by all of the USDA ginning laboratories and generally follows procedures prescribed in ASTM D2495: 2001 Standard Test Method for Moisture in Cotton by Oven-Drying [15]. The method covers the determination of the amount of moisture in cotton using oven-drying and is applicable to raw cotton, cotton stock in process, and cotton waste. The USTER (Uster Technologies, Inc., Charlotte, NC, USA) Advanced Fiber Information System (AFIS), High Volume Instrument (HVI), and Micro Dust and Trash Analyzer (MDTA3) at the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) Southern Regional Research Center (New Orleans, LA, USA) and Cotton Incorporated (Cary, NC, USA) were used to determine the fiber and lint cleaner waste properties. Loan rate was based on HVI fiber quality measurements using 2018 Commodity Credit Corporation (CCC) prices.

3. Results and Discussion

Tables 4–6 show the means and SD of High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) fiber properties of the cultivars used in the test. As sought, they represent a diverse group of cultivars. HVI staple, strength, reflectance, yellowness, and trash area ranged from 39.1 to 41.0 1/32 inch (a cotton industry measurement in English units), 27.9 to 34.8 g/tex, 78.4 to 81.0 Rd units, 7.98 to 10.4 +b units, and 0.21 to 0.46% area, respectively. AFIS short fiber content, nep count, seed coat nep count, total trash count, and visible foreign matter ranged from 7.98 to 12.2%, 201 to 397 counts per g, 22.9 to 40.5 counts per g, 358 to 402 counts per g, and 1.17 to 1.86%, respectively.

Table 7 shows the means and SD of the ginning test conditions, turnout, and bale value by ginning treatment. Lint moisture at the lint cleaner ranged from 4.9 to 6.4%. Ginning rate of the micro-saw gin treatments averaged 2.1 kg m^{-1} h^{-1}, while the roller ginning treatments averaged 1.5 kg m^{-1} h. Ginning rate on the full-size saw gin with the conventional lint cleaner averaged 4.4 kg m^{-1} hr^{-1} while ginning rate on the full-size saw gin with the coupled lint cleaner averaged only 2.3 kg m^{-1} h^{-1}, a bit lower than expected. Lint turnout ranged from 33.4 to 38.6% with the roller ginning treatments having the highest turnout. Loan rate ranged from 1.14 to 1.20 $/kg.

Table 4. Means (SD) of HVI fiber properties by cultivar.

Cultivar	Staple Length	Upper Half Mean Length	Uniformity	Strength	Micronaire	Reflectance	Yellowness	Trash
	1/32 in	mm	%	g/tex	reading	Rd	+b	% area
DG 3385	39.1	31.2	83.3	27.9	3.34	81.0	10.4	0.21
	(0.84)	(0.65)	(1.36)	(1.51)	(0.34)	(1.25)	(1.65)	(0.10)
NG 4545	39.2	31.1	83.6	32.8	4.09	80.3	10.2	0.22
	(0.56)	(0.41)	(0.92)	(0.99)	(0.19)	(0.94)	(1.52)	(0.11)
FM 1830	40.2	31.9	83.6	32.4	4.54	78.4	7.98	0.46
	(0.90)	(0.61)	(1.15)	(0.90)	(0.11)	(1.06)	(0.46)	(0.18)
PHY 444	41.0	32.5	84.7	34.8	3.30	80.2	8.87	0.29
	(0.51)	(0.38)	(0.92)	(0.98)	(0.08)	(0.52)	(0.80)	(0.11)

Table 5. Means (SD) of selected AFIS length and maturity fiber properties (by weight) by cultivar.

Cultivar	Length	Upper Quartile Length	Short Fiber Content	Fineness	Immature Fiber	Maturity Ratio	Nep Count	Nep Size
	mm	mm	%	m-tex	%	-	Per g	µm
DG 3385	25.1	32.0	12.2	154	9.94	0.78	397	714
	(1.26)	(1.05)	(2.96)	(4.28)	(1.46)	(0.04)	(83.4)	(19.6)
NG 4545	26.6	32.9	8.60	165	6.94	0.87	201	697
	(0.52)	(0.45)	(0.81)	(2.89)	(0.68)	(0.02)	(42.9)	(15.1)
FM 1830	27.3	33.6	7.98	162	6.50	0.88	208	694
	(0.63)	(0.47)	(1.30)	(2.59)	(0.67)	(0.02)	(39.2)	(21.1)
PHY 444	27.1	34.4	10.7	148	8.44	0.83	370	692
	(0.78)	(0.60)	(1.50)	(3.10)	(0.64)	(0.02)	(78.0)	(13.1)

Table 6. Means (SD) of selected AFIS foreign matter fiber properties (by weight) by cultivar.

Cultivar	Seed Coat Nep Count	Seed Coat Nep Size	Dust Count	Trash Count	Total Trash Count	Trash Size	Visible Foreign Matter
	per g	mm	per g	per g	per g	µm	%
DG 3385	40.5	1058	298	60.7	358	349	1.51
	(18.9)	(105)	(106)	(18.8)	(117)	(35.2)	(0.57)
NG 4545	24.5	998	343	53.4	397	53.4	1.17
	(7.38)	(104)	(204)	(10.3)	(211)	(10.3)	(0.38)
FM 1830	30.0	1007	313	83.3	396	386	1.86
	(14.5)	(100)	(128)	(19.6)	(144)	(32.7)	(0.65)
PHY 444	22.9	962	336	65.6	402	335	1.31
	(6.44)	(109)	(106)	(11.4)	(112)	(33.5)	(0.31)

Tables 8–12 show the predicted least squares means along with the intercept value (indicated in the tables as overall mean) of the solution of the HVI and AFIS fiber properties by ginning treatment. The predicted means of those fiber properties of interest (fiber lengths and foreign matter such as neps and trash) are highlighted in red with an asterisk ("*") and signify overlap in the 95% confidence intervals and therefore the treatment means can be considered the same. Table 8 shows that the micro-saw/direct-feed lint cleaner, saw/coupled lint cleaner, and both roller ginning treatments had similar predicted HVI fiber lengths and uniformity. The roller ginning treatments were expected to produce fiber with favorable uniformity (predicted means of 85.3 and 85.6%). It is encouraging that fiber from micro-saw/direct-feed had similarly favorable uniformity. This suggests that it may be beneficial to place fiber directly onto the lint cleaning saw without changing direction. The saw/coupled lint cleaner had a predicted uniformity of 84.3%. These results indicate that the micro-saw/direct-feed and saw/coupled lint cleaners warrant further testing under more controlled conditions. Table 8 also shows that except for the roller ginning treatments, all other ginning treatments had similar predicted HVI mean trash area in the lint. Previous research has shown roller ginning to have higher levels of trash in the lint than saw ginning [16].

Table 7. Means (SD) of ginning test conditions, ginning rate, lint turnout, and bale value.

Ginning Treatment	Trash Content After Seed Cotton Cleaning	Moisture Content after Seed Cotton Cleaning	Moisture Content after Lint Cleaner	Ambient Temp.	Ambient R. H.	Ginning Rate	Fiber Turnout	Loan Rate
	%	%	%	°C	%	kg m^{-1} h^{-1}	%	$/kg
Micro-saw/conv	2.24	7.52	5.53	22.9	49.6	427.0	33.7	1.14
	(0.73)	(0.80)	(0.39)	(1.63)	(3.55)	(50.5)	(2.66)	(0.11)
Micro-saw/batt-less	2.23	7.45	5.48	23.1	49.9	435.7	33.4	1.13
	(0.80)	(0.75)	(0.47)	(1.61)	(4.87)	(51.3)	(3.14)	(0.09)
Micro-saw/direct-feed	1.90	7.76	6.44	25.6	61.2	488.2	35.0	1.20
	(0.45)	(1.27)	(1.20)	(0.82)	(4.11)	(38.1)	(3.59)	(0.05)
Saw/conv	3.39	6.05	5.20	28.6	38.0	951.7	36.4	1.20
	(1.78)	(0.63)	(0.97)	(2.25)	(15.7)	(39.8)	(2.89)	(0.06)
Saw/coupled	3.41	5.69	4.93	29.5	34.5	499.8	37.3	1.20
	(1.17)	(0.79)	(1.10)	(2.31)	(15.8)	(84.8)	(3.11)	(0.06)
Roller/conv	3.15	5.90	5.08	27.9	38.9	318.8	38.6	1.18
	(1.52)	(0.65)	(0.69)	(2.27)	(11.2)	(19.2)	(3.43)	(0.05)
Roller/coupled	3.06	6.07	5.17	28.2	40.4	311.9	38.1	1.19
	(1.49)	(0.71)	(0.71)	(2.32)	(13.8)	(17.8)	(3.18)	(0.05)

Table 8. Predicted LS means of HVI fiber properties [1].

Ginning Treatment	Staple Length	Upper Half Mean Length	Uniformity	Strength	Micronaire	Reflectance	Yellowness	Trash
	1/32 in	mm	%	g/tex	reading	Rd	+b	% area
Overall mean	41.0	1.28	84.7	34.8	3.30	80.2	8.87	0.29
Micro-saw/conv	40.6	1.27	84.0	34.6	3.25	80.3	10.2	**0.32 ***
Micro-saw/batt-less	40.7	1.27	84.1	34.8	3.24	80.1	10.2	**0.34 ***
Micro-saw/direct-feed	**40.8 ***	**1.28 ***	**85.8 ***	35.0	3.38	80.0	9.44	**0.27 ***
Saw/conv	40.4	1.26	83.4	35.4	3.27	80.8	8.08	**0.19 ***
Saw/coupled	**41.0 ***	**1.28 ***	**84.3 ***	35.1	3.28	80.7	8.11	**0.15 ***
Roller/conv	**41.7 ***	**1.30 ***	**85.3 ***	34.6	3.36	79.7	8.02	0.41
Roller/coupled	**41.9 ***	**1.31 ***	**85.6 ***	34.3	3.32	79.9	8.06	0.36

[1] Means in a column highlighted in red with an asterisk signify that the 95% confidence intervals overlap.

Table 9. Predicted LS means of AFIS length and maturity fiber properties [1].

Ginning Treatment	Length [2]	Length [3]	Upper Quartile Length [2]	Short Fiber Content [2]	Short Fiber Content [3]	Fineness	Immature Fiber Content
	mm	mm	mm	%	%	m-tex	%
Overall mean	1.07	0.78	1.35	10.7	34.1	148	8.44
Micro-saw/conv	**1.07 ***	**0.80 ***	**1.35 ***	**9.91 ***	**31.2 ***	146	8.98
Micro-saw/batt-less	**1.08 ***	**0.81 ***	**1.36 ***	**9.72 ***	**30.8 ***	146	8.94
Micro-saw/direct-feed	**1.08 ***	**0.80 ***	**1.37 ***	**9.87 ***	**31.7 ***	148	7.61
Saw/conv	1.02	0.72	1.32	13.0	38.9	148	9.04
Saw/coupled	**1.05 ***	**0.76 ***	**1.34 ***	**11.4 ***	**36.0 ***	148	8.54
Roller/conv	**1.08 ***	**0.78 ***	**1.37 ***	**10.4 ***	**35.0 ***	150	7.83
Roller/coupled	**1.08 ***	**0.77 ***	**1.36 ***	**10.7 ***	**35.3 ***	148	8.11

[1] Means in a column highlighted in red with an asterisk signify that the 95% confidence intervals overlap. [2] By the weight method. [3] By the number method.

Table 10. Predicted LS means of AFIS maturity ratio, nep, and seed coat nep fiber properties [1].

Ginning Treatment	Maturity Ratio	Nep Count	Nep Size	Seed Coat Nep Count	Seed Coat Nep Size
	-	per g	µm	per g	mm
Overall mean	0.83	370	692	22.9	962
Micro-saw/conv	0.82	**362 ***	685	**13.6 ***	1010
Micro-saw/batt-less	0.83	**350 ***	688	**14.2 ***	1066
Micro-saw/direct-feed	0.87	**388 ***	703	**20.8 ***	1092
Saw/conv	0.82	446	683	**21.3 ***	860
Saw/coupled	0.82	406	682	**19.9 ***	887
Roller/conv	0.84	**326 ***	708	40.3	911
Roller/coupled	0.84	**311 ***	696	**30.3 ***	911

[1] Means in a column highlighted in red with an asterisk signify that the 95% confidence intervals overlap.

Table 11. Predicted LS means of AFIS foreign matter fiber properties [1].

Ginning Treatment	Dust Count	Trash Count	Total Trash Count	Trash Size	Visible Foreign Matter
	per g	per g	per g	µm	%
Overall mean	336	65.6	402	335	1.31
Micro-saw/conv	271	67.5	**339 ***	360	**1.19 ***
Micro-saw/batt-less	275	70.9	**347 ***	361	**1.26 ***
Micro-saw/direct-feed	275	69.6	**345 ***	376	**1.41 ***
Saw/conv	279	58.5	**337 ***	330	**1.03 ***
Saw/coupled	220	48.3	**267 ***	336	**0.80 ***
Roller/conv	536	76.3	613	294	1.87
Roller/coupled	494	68.0	563	289	1.64

[1] Means in a column highlighted in red with an asterisk signify that the 95% confidence intervals overlap.

Table 12. Predicted LS means of MDTA3 fiber properties [1].

Ginning Treatment	Fiber Content	Trash	Fiber Fragment	Dust
	per g	per g	per g	µm
Overall mean	97.3	2.28	0.26	0.11
Micro-saw/conv	98.0	**1.68 ***	**0.23 ***	0.10
Micro-saw/batt-less	97.7	**1.98 ***	**0.23 ***	0.10
Micro-saw/direct-feed	**97.1 ***	**2.61 ***	**0.23 ***	0.11
Saw/conv	97.7	**1.93 ***	**0.28 ***	0.11
Saw/coupled	98.1	**1.50 ***	**0.27 ***	0.12
Roller/conv	**96.0 ***	3.55	0.28	0.13
Roller/coupled	**96.8 ***	**2.75 ***	0.29	0.13

[1] Means in a column highlighted in red with an asterisk signify that the 95% confidence intervals overlap.

Table 9 shows that except for the saw/conv, all other ginning treatments had similar AFIS means of fiber lengths and short fiber content (by weight) that averaged about 1.07 mm and 10.3%, respectively. Fiber from the saw/conv lint cleaner had a predicted mean fiber length and short fiber content of 1.02 mm and 13.0%, respectively.

Table 10 shows that except for the saw/conv and saw/coupled lint cleaners, all other ginning treatments have similar predicted means of fiber nep count. Generally, nep count levels of less than 350 neps per gram are manageable, but lower counts are much preferred. Means of nep count of the roller ginning treatments were 25% lower than those of the saw ginning treatments; this was expected and follows results of other research [14]. What is interesting is that the micro-saw treatments had similar predicted means of fiber nep count as the roller ginning treatments. Except for the roller/conv lint cleaning, seed coat nep count means were similar, ranging from 13.6 to 30.3 seed coat neps per gram. These levels of seed coat nep count are in the low to medium count categories (low to medium seed coat neps per gram). Fiber from the roller/conv lint cleaner had 40.3 seed coat neps per gram, which is in the "high" category (31 to 45 seed coat neps per gram).

Table 11 shows that except for the roller ginning treatments, all other ginning treatments had similar predicted means of trash count and visible foreign matter. This result is entirely expected as fiber from roller ginning tends to contain more trash than fiber from saw ginning. Predicted means of trash count and visible foreign matter predicted means averaged 327 counts per gram and 1.14%, respectively, for the saw ginning treatments and 588 counts per gram and 1.76% for the roller ginning treatments.

Table 12 shows the MDTA3 results. Fiber from the roller/conv lint cleaner had the highest predicted mean trash content of 3.55 counts per gram; this is in contrast to all of the other treatments that shared overlapping 95% confidence intervals with a predicted mean trash content of 2.08 counts per gram. The roller ginning treatments had a predictive mean fiber fragment content of 0.29 fragments per gram, while all other treatments had a predictive mean of 0.25 fiber fragments per gram. These results agree with the HVI and AFIS trash measurements and prior studies showing roller ginning generally has higher levels of trash in the lint.

4. Conclusions

Our results show that ginning rate and fiber turnout were at normal levels for all ginning treatments. Fiber nep count was lower and trash content in the fiber was higher with the roller ginning treatments compared to the saw ginning treatments; these results are consistent with findings of prior research. The micro-saw/direct-feed lint cleaner had the highest fiber length uniformity at 85.8%; the 95% confidence intervals indicated that it was similar to the saw/coupled, roller/conv, and roller/coupled treatments which had 84.3, 85.3, and 85.6% uniformity, respectively. Prior research has shown that roller-ginned fiber has consistently higher uniformity than any type of saw-ginned fiber. So, it is encouraging that one of the alternative lint cleaning technologies was comparable. Additionally, the saw/coupled lint cleaner had similarly high uniformity. These results suggest that placing fiber directly onto the lint cleaning saw without changing direction may be beneficial, with or without forming a batt, and indicate that direct-feed and coupled lint cleaner technologies warrant further testing under better controlled conditions.

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References

1. Cotton Incorporated. Air Jet Spinning of Cotton Yarns. Technical Bulletin TRI-1001. 2004. Available online: https://www.cottoninc.com/quality-products/textile-resources/technical-bulletins/#EN (accessed on 8 August 2023).
2. Cotton Incorporated. Monthly Economic Letter. January 2023. Available online: https://lifestylemonitor.cottoninc.com/wp-content/uploads/2023/01/2023-01-Monthly-Economic-Letter.pdf (accessed on 8 August 2023).
3. International Textile Manufacturers Federation (ITMF). *International Textile Industry Statistics (IT IS)*; International Textile Manufacturers Federation: Zurich, Switzerland, March 2021; Volume 62/2019.

4. Cotton Incorporated. The Classification of Upland Cotton. 2023. Available online: https://www.cottoninc.com/cotton-production/quality/classification-of-cotton/classification-of-upland-cotton/ (accessed on 8 August 2023).
5. Cotton Incorporated. Final Cotton Crop Quality Summary Reports. 2023. Available online: https://www.cottoninc.com/cotton-production/quality/cotton-crop-quality/final-cotton-crop-quality-summary-reports/ (accessed on 8 August 2023).
6. Armijo, C.B.; Whitelock, D.P.; Funk, P.A.; Martin, V.B. How current cotton ginning practices affect fiber length uniformity index. *J. Cotton Sci.* **2019**, *23*, 66–77. [CrossRef]
7. USDA National Agricultural Statistics Service. 2023. Available online: https://www.nass.usda.gov/Statistics_by_Subject/result.php?AD36BD70-61FD-382A-AFCB-55DD6A885758&sector=CROPS&group=FIELD%20CROPS&comm=COTTON (accessed on 8 August 2023).
8. Anthony, W.S.; McCaskill, O.L. *Development and Evaluation of a Small-Scale Cotton Ginning System*; Agricultural Research Service ARS-S-36 Publication U.S. Department of Agriculture: New Orleans, LA, USA, 1974.
9. Hugh, S.E.; Gillum, M.N.; Bragg, C.K.; Lalor, W.F. Fiber and yarn quality from coupled lint cleaner. *Trans. ASAE* **1990**, *33*, 1806–1810.
10. Gillum, M.N.; Armijo, C.B.; Bragg, C.K. Combining roller ginning and lint cleaning into one machine. *Trans. ASAE* **1999**, *42*, 617–622. [CrossRef]
11. Stroup, W.W.; Milliken, G.A.; Claassen, E.A.; Wolfinger, R.D. *SAS for Mixed Models: Introduction and Basic Applications*; SAS Institute Inc.: Cary, NC, USA, 2018.
12. Wanjura, J.D.; Gamble, G.R.; Holt, G.A.; Pelletier, M.G. Influence of grid bar shape on field cleaner performance–field testing. *J. Cotton Sci.* **2012**, *16*, 255–267.
13. Shepherd, J.V. *Standard Procedures for Foreign Matter and Moisture Analytical Tests Used in Cotton Ginning Research*; Agriculture Handbook No. 422; U.S. Government Printing Office: Washington, DC, USA, 1972. Available online: https://www.govinfo.gov/content/pkg/GOVPUB-A-PURL-gpo25946/pdf/GOVPUB-A-PURL-gpo25946.pdf (accessed on 21 October 2023).
14. Funk, P.A.; Terrazas, A.A.; Yeater, K.M.; Hardin, R.G.; Armijo, C.B.; Whitelock, D.P.; Pelletier, M.G.; Wanjura, J.D.; Holt, G.A.; Delhom, C.D. Procedures for moisture analytical tests used in cotton ginning research. *Trans. ASABE* **2018**, *61*, 1985–1995. [CrossRef]
15. *ASTM D2495*; Standard Test Methods for Moisture in Cotton by Oven-Drying. ASTM International: West Conshohocken, PA, USA, 2001.
16. Armijo, C.B.; Foulk, J.A.; Whitelock, D.P.; Hughs, S.E.; Holt, G.A.; Gillum, M.N. Fiber and yarn properties from high-speed roller ginning of Upland cotton. *Appl. Eng. Agric.* **2013**, *29*, 461–471.