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TEXTILE TECHNOLOGY

High Quality Yarns Produced via High-Speed Roller Ginning of Upland Cotton

Christopher D. Delhom*, Carlos B. Armijo, and S. Ed Hughs

ABSTRACT

Processing capacities of new high-speed roller ginning technology approaches that of saw ginning. Spinning mills are interested in mill performance data comparing new upland cultivars processed by both saw and roller ginning. Four diverse upland cultivars were processed by saw ginning and high-speed roller ginning and analyzed by ginning method. Ring-spun carded and combed yarns were produced, and their properties determined. Results overall (combining cultivars) showed that the roller gin, when compared to the saw gin, produced fiber that was more than 1 staple length longer, had two percentage points higher length uniformity, had 2.5 percentage points less short fiber, and contained 25% fewer neps. Yarn (carded and combed) produced from fiber from the roller gin, when compared to fiber from the saw gin, was about 0.2 percentage points more uniform, had 19% fewer thin places, 7.6% fewer thick places, and was 2.4% stronger. The roller gin lots had 30.8% fewer ends down than the saw gin lots when producing fine count combed yarn. Carded and combed yarns produced from the roller gin lots were consistently stronger for a given twist multiple than the saw gin lots, as demonstrated by twist strength curves. Spinning limit trials were conducted that demonstrated carded and combed yarn produced via high-speed roller ginning could be spun faster and into finer counts. The potential economic benefits of processing high-speed roller-ginned upland cotton in a textile mill were explored using data produced in the trials.

C.D. Delhom*, USDA-ARS Cotton Structure and Quality Research Unit, 1100 Robert E. Lee Blvd., New Orleans, LA 70124; C.B. Armijo and S.E. Hughs, USDA-ARS Southwestern Cotton Ginning Research Unit, PO Box 578, Mesilla Park, NM 88001
*Corresponding author: Chris.Delhom@ars.usda.gov

The global textile industry has been undergoing dramatic changes during the last two decades, this is especially true for the U.S. The U.S. domestic textile industry has evolved from consuming the vast majority of the domestic upland cotton (*Gossypium hirsutum* L.) crop to consuming only approximately 3.5 to 4 million bales out of an annual average crop of 16.9 million bales and exporting an average of 12.6 million bales per year over the last 10 years (USDA, 2016a). As part of the shift, the U.S. domestic textile industry has focused on the production of open-end yarns, which tend to be coarser counts than the traditional fine count ring-spun yarns. The major export market for the U.S. cotton industry is Asia, which is still largely focused on the production of ring-spun yarns. The change in markets for U.S. cotton, from domestic to Asia, has resulted in more U.S. grown cotton being destined for ring spinning.

Upland cotton has traditionally been used for medium and coarse count yarns whereas extra long staple (ELS) cottons, also known as Pima (*Gossypium barbadense* L.) have been used for fine count ring-spun yarns. ELS cottons tend to be longer, stronger, and finer than upland cottons (Table 1). The nature of ELS cottons also means that the fiber commands a premium price. In June 2016, the spot price of American Pima was $2.7668/kg ($1.2550/lb), whereas the Upland A Index averaged $1.7529/kg ($0.7951/lb) (Cotton Outlook, 2016). Historically, upland cottons are saw ginned at high speeds, whereas ELS cottons have been roller ginned at low speeds to preserve fiber length and uniformity. The development of high-speed roller ginning has increased the capacity of roller ginning such that ginning rates are equal on a per unit width basis (Armijo and Gillum, 2007). Roller ginning upland cottons is known to preserve the length and uniformity, as shown in Table 1. Roller ginning of upland cotton in California increased from 20,000 bales in 2004 to 188,000 bales in 2011. However, the loss of acreage in recent years has led to a drop in upland production and a decrease in roller ginning of upland cotton with only 40,000 bales roller ginned compared to 130,000 bales that were saw ginned in 2015 (Armijo et al., 2013; CCGGA, 2016).

Table 1. Average Upland and ELS Cotton Values for U.S. 2015/16 Crop Year[z]

Property	ELS	Upland (All U.S.)	Saw-Ginned Upland (CA)	Roller-Ginned Upland (CA)
Mic	3.92	4.42	4.35	4.41
Staple	44.6	35.9	36.8	39.3
UHML (mm)	35.4	28.4	29.21	31.19
UI	85.79	81.07	81.37	83.02
Strength (g/tex)	43.68	30.35	33.94	35.24
Leaf	2.1	3.4	2.1	2.3

[z] **Data taken from USDA classing results via EFS-US Crop Software (2016)**

Past research has demonstrated (Table 1) that roller ginning of upland cotton improves the staple length and the uniformity (Armijo and Gillum, 2007, 2010; Armijo et al., 2013; Byler and Delhom, 2012; Hughs and Lalor, 1989; van der Sluijs, 2015). Cotton breeders have made improvements to the germplasm of upland cotton in recent years, which when combined with the quality preservation of roller ginning and the processing efficiency gains of high-speed roller ginning might enable textile mills to employ upland cottons in roles that previously had been off limits to upland cotton unless combing was employed. Combing is a costly process, in both time and material, employed in textiles mills to remove short fibers during processing in an effort to improve the uniformity and enable finer count yarns to be produced (McCreight et al., 1997).

The overall objective of the research reported here was intended to determine the practical benefits that high-speed roller ginning upland cotton delivers to a textile mill. Specific objectives were: (1) to compare the differences in fiber quality due to high-speed roller ginning or saw ginning using multiple cultivars of upland cotton; (2) to highlight the textile processing differences of roller- and saw-ginned cotton for both carded and combed ring-spun yarn production; and (3) to use a roller-ginned Pima cultivar to demonstrate the functional differences between upland ELS cottons in a textile processing environment.

MATERIALS AND METHODS

Cottons. Four cultivars of upland cotton were used: Phytogen 339, Phytogen 375, Phytogen 565 (Dow Agrosciences LLC, Indianapolis, IN), and Acala 1517-08 (New Mexico State University, Las Cruces, NM). These cultivars were chosen because of their diverse fiber properties, such as length and foreign matter content and turnout, which might interact differently with the ginning and subsequent textile processing treatments. A single Pima cultivar, DP 340 (Monsanto Company, St. Louis, MO) was included to illustrate the quality differences that exist between upland cottons and true ELS cottons. All of the cultivars were picker harvested in the Mesilla Valley of southern New Mexico. The upland cultivars were ginned separately on a conventional saw gin stand and a high-speed roller gin stand at the USDA-ARS Southwestern Cotton Ginning Research Unit in Las Cruces, NM. The Pima cultivar was only roller ginned. One commercial bale (nominal 227 kg [480 lb]) was produced from each cultivar and ginning treatment.

High-Speed Roller Gin Stand and Feeder. A 1.0-m (40-in.) wide Consolidated HGM roller gin stand (Fig. 1) and feeder, previously converted to high-speed, were used in the experiment. Armijo and Gillum (2007) documented the details of converting the gin stand from conventional speed (approximately 273 kg m^{-1} h^{-1}[1.25 bales m^{-1} h^{-1}]) to high speed (872 to 1090 kg m^{-1} h^{-1}[4.0 to 5.0 bales m^{-1} h^{-1}]). The ginning roller measured 0.38 m (15 in.) in diameter and was made of a vulcanized rubber core wrapped with cotton packing. An air-fed cooling nozzle apparatus was added to the rear of the gin stand to cool the ginning roller and keep roller temperature below the recommended maximum of 107 °C (225 °F) (USDA, 1994).

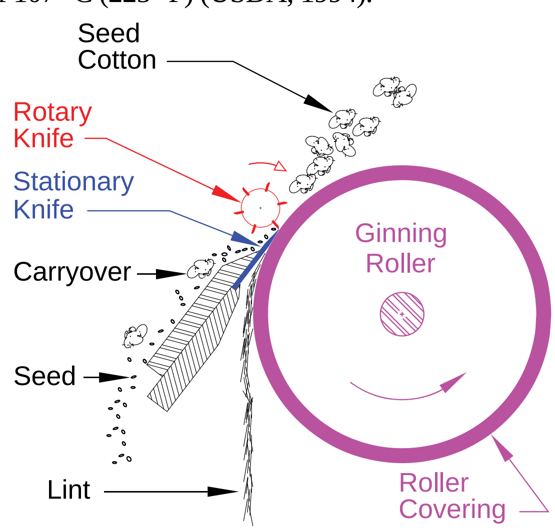

Figure 1. Diagram of a rotary-knife roller gin stand.

An original equipment 6-blade, spiral-wrapped steel rotary knife was used. The rotary knife measured 70 mm (2.75 in.) in diameter and had a knife angle (degrees of rotation per length) of 150 degrees. The rotary-to-stationary knife clearance was set to 0.25 mm (0.010 in.) (Consolidated, 1990). A 2.2-kW (3-hp) 1800-rpm auxiliary motor drove the rotary knife. The auxiliary motor was used in conjunction with an automatic computer control that monitored and adjusted the feed (ginning) rate of seed cotton to the gin stand. Past research has shown that computer control eliminated choke-ups at the rotary knife, and allowed elevated ginning rates without compromising fiber properties (Gillum and Armijo, 1991, 1995).

The feeder had two rows of spiked cylinders that removed fine trash and opened up the seed cotton for ginning. Each row had four spiked cylinders that measured 0.20 m (8 in.) in diameter and ran at 785 rpm. The path of seed cotton in the feeder was modified when the high-speed conversion was made to allow for the increased throughput of seed cotton for high-speed roller ginning (Armijo and Gillum, 2007).

Conventional Saw Gin Stand and Feeder. A 46-saw Continental/Murray Double Eagle saw gin stand (Fig. 2) and three-saw Continental/Moss-Gordin Galaxy extractor-feeder were used in the experiment. The saw gin stand was rated at approximately 1090 kg m^{-1} h^{-1} (5.0 bales m^{-1} h^{-1}). The gin saws measured 0.41 m (16 in.) in diameter, were spaced 15.9 mm (0.625 in.) apart, and operated at a 659 rpm. A 22-kW (30-hp), 1760-rpm motor drove the gin stand. The feeder saws ran at 315 rpm. A 2.2-kW (3-hp), 900-rpm motor drove the feeder.

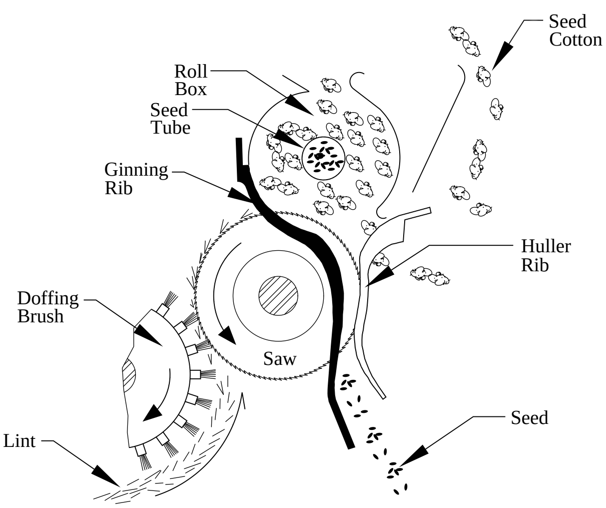

Figure 2. Diagram of a saw gin stand.

Seed Cotton Conditioning. Seed cotton conditioning in the overhead included two six-cylinder inclined cleaners, one three-saw stick machine, and no drying. The gravity-fed inclined cleaners were 1.27-m (50-in.) wide and contained grid bar cleaning surfaces. The cylinders of the inclined cleaners ran at 450 rpm. The gravity-fed stick machine was 1.83-m (72-in.) wide. The top, middle, and bottom saw on the stick machine ran at 360, 270, and 185 rpm, respectively.

Lint Cleaning. For the roller-ginned cotton, a mill-type lint cleaner with a pin cylinder and an air-jet lint cleaner (Fig. 3) were used. The pin-cylinder/air-jet cleaner combination is similar to the more recent Lummus Guardian lint cleaner (Fig. 4) (Lummus Corporation, Savannah, GA) used in some roller ginning plants. The lint cleaner was 1-m (40-in.) wide and the pin cylinder was 0.41 m (16 in.) in diameter and rotated at 1094 rpm. There were 16 grid bars situated around pin cylinder, with each leading edge spaced approximately 19 mm (0.75 in.) apart from each other. The clearance between the grid bar and individual pins was approximately 24 mm (15/16 in.). The air-jet cleaner was coupled directly behind the lint cleaner and was the same width as the lint cleaner and had an adjustable edge to skim off the heavier trash.

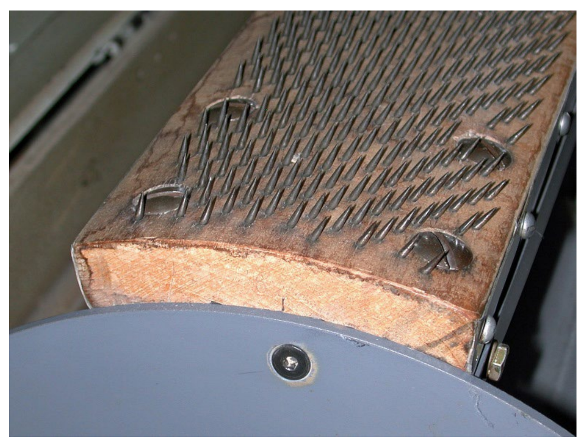

Figure 3. Roller-gin pin-cylinder lint cleaner.

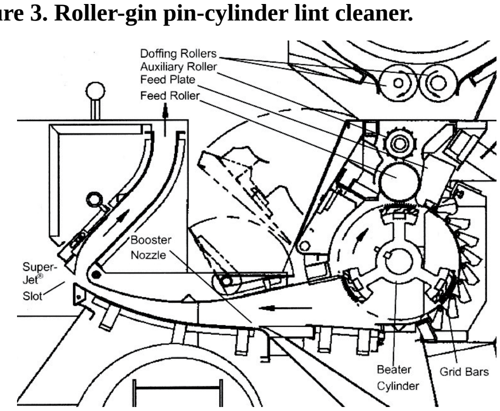

Figure 4. Diagram of Lummus Guardian lint cleaner.

A Continental/Moss-Gordin Lodestar controlled-batt saw-type lint cleaner (Fig. 5) was used for lint cleaning the saw-ginned cotton. The spiral-wrapped saw was 0.41 m (16 in.) in diameter, operated at 1025 rpm, and had a combing ratio of 24. The lint cleaner had five grid bars with 1.6 mm (1/16 in.) clearance between the bars and saw. The lint cleaner settings and operation were according to manufacturer's specifications.

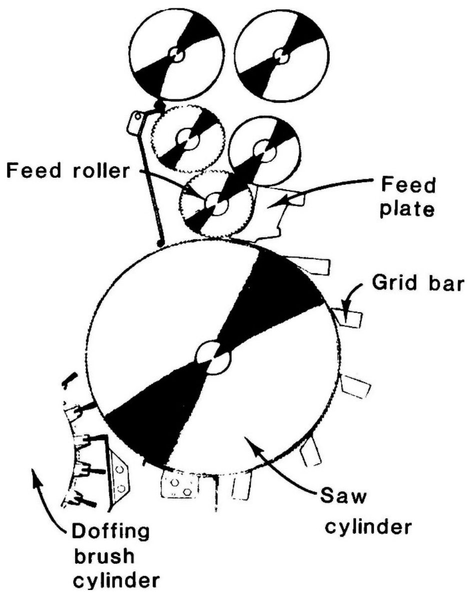

Figure 5. Diagram of saw-type lint cleaner.

Nine gin runs were performed for this study. The cultivars were processed in a random order with the ginning treatment order randomly chosen. However, both ginning treatments were run consecutively for a given cultivar (Table 2). Sampling during the ginning portion included two subsamples of approximately 0.45 kg (1 lb) of seed cotton at the wagon and feeder and a similar sized sample of ginned lint at the press for foreign matter and moisture content analysis. The analyses were determined using standard pneumatic fractionation and oven drying methods (Shepherd, 1972).

Fiber Quality Testing. Ginned lint bales were shipped to the USDA-ARS Southern Regional Research Center in New Orleans, LA for fiber testing and textile processing. The bales were sampled for fiber quality testing via high volume instrument (HVI), advanced fiber information system (AFIS), and Shirley Analyzer. The HVI testing was carried out on an Uster HVI 1000 (Knoxville, TN) utilizing five individual measurements of length, strength, micronaire, color, and trash content. AFIS analysis was performed using an Uster AFIS Pro (Charlotte, NC) with three replications of 5000 fibers for length, fineness, maturity, and nonlint content. The nonlint content was measured via a Shirley Analyzer (Shirley Developments Ltd, Stockport, UK) per ASTM D2812 (2012) with three replications.

Textile Processing Trials. The ginned lint bales were divided into three equal portions by mass to form replicates for processing trials. The 27 lots were opened and carded on a Truetzschler (Mönchengladbach, Germany) opening and carding line at 45.4 kg/hr (100 lbs/hr) as shown in Fig. 6 to produce 4960 tex (70 gr/yd) sliver. The card sliver was divided during the first drawing pass to allow for the production of both card and combed ring spun yarn. Samples were collected for AFIS analysis after opening, after carding, and during subsequent processing through finished sliver and included noil for analysis of material removed during combing (Fig. 7).

Table 2. Ginning Treatment and Turnouts

Run	Cultivar	Gin Type	Turn Out (%)	Wagon Trash (%)	Wagon Moisture (%)	Press Moisture (%)
1	Phytogen 339	Saw	34.1	7.28	7.56	6.19
2	Phytogen 339	Roller	37.1	8.14	6.26	5.76
3	Phytogen 565	Saw	33.0	10.23	7.57	6.19
4	Phytogen 565	Roller	35.8	10.28	8.26	5.85
5	Phytogen 375	Roller	39.5	9.76	6.68	5.60
6	Phytogen 375	Saw	37.9	9.76	6.75	5.74
7	DP 340 (Pima)	Roller	36.6	8.12	7.65	5.37
8	Acala 1517-08	Roller	36.6	7.80	7.26	4.96
9	Acala 1517-08	Saw	34.9	7.36	6.65	5.14
Means for Upland Cultivars						
		Roller	37.3	9.00	7.16	5.54
		Saw	35.0	8.66	7.13	5.82

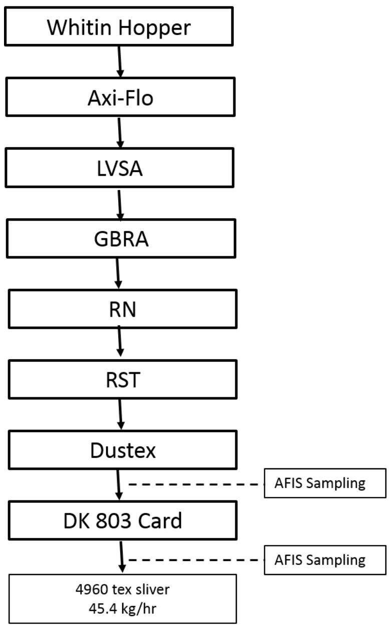

Figure 6. Opening and carding procedure.

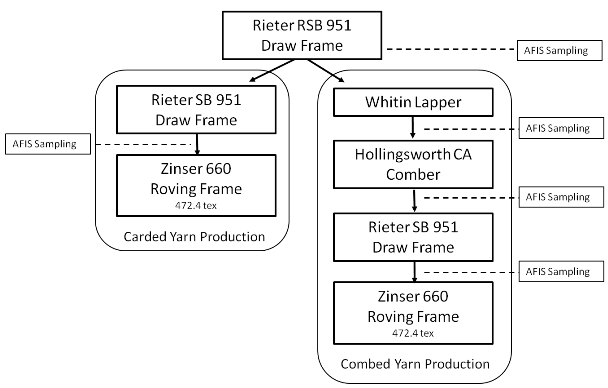

Figure 7. Drawing and combing protocol.

Optimum roving twist was determined using a draftometer (Delhom and Thibodeaux, 2016; Feil, 1982) during the production of 165 bobbins of both carded and combed 472.4 tex (1.25 hk) roving for each card lot. Spinning was carried out on a 160 spindle Zinser 321 ring frame (Saurer GmbH, Übach-Palenberg, Germany) for determination of yarn quality and spinning efficiency. Additional spinning was performed utilizing five spindles on an IMDS LabSpinner (texma.org AG, Oberglatt, Switzerland) ring frame for spinning limits (count and speed) and the production of twist-strength curves.

Multiple spinning trials were performed to aid in determining the impact on spinnability of the ginning treatments. Yarn quality and spinning efficiency were determined by producing carded and combed 16.4 tex (Ne 36/1) yarns using a twist multiple of 3.8 and a spindle speed of 16,000 rpm. Combed yarns were also produced at 11.8 tex (Ne 50/1) with a twist multiple of 3.8 and a spindle speed of 15,000 rpm. Ends down were recorded, in 15 min. increments, for two full doffs of each 16.4 tex yarn and one full doff of 11.8 tex to measure spinning efficiency. Yarn quality was determined by randomly selecting 20 bobbins from each spinning lot and testing on an Uster Tester 4 (Uster, Switzerland) with 1000 m of yarn at 400 m/min per ASTM D1425 (2014) on each bobbin. Single end yarn strength was tested by performing 20 breaks on each of the 20 bobbins utilizing an Uster Tensorapid 4 (Uster, Switzerland) per ASTM D2256 (2015).

Spinning limits were measured for each yarn construction to determine the finest yarn that could be spun and the highest production speed that could be run without excessive ends down. The count limits for each construction and processing lot were determined by starting with a finer yarn than the quality portion of the trials; beginning at 14.8 tex (Ne 40/1) for carded yarns and 9.8 tex (Ne 60/1) for combed with the same twist multiple and spindle speed as used in the quality portion. Yarns were spun for 10 min. and if no ends down were observed the count was increased in specific increments. For example, the initial count was 14.8 tex (Ne 40/1), then 11.8 tex (Ne 50/1), then 9.8 tex (Ne 60/1), and so forth until failures were observed at which point the count was reduced until spinnability was restored. Similarly, the production speed limits were determined by utilizing the same counts and twist multiple as the quality portion of the project but increasing spindle speed in increments of 1000 rpm until the cotton failed to spin efficiently at which time spindle speed was reduced until spinnability was restored.

Twist-strength curves were generated by utilizing the same count and spindle speed as the quality portion of processing trials, however yarns were produced with a range of twist multiples (3.1, 3.3, 3.5, 3.8, 4.0, 4.1, and 4.3). The five bobbins of each twist level were subjected to 20 breaks per bobbin on a Tensorapid 4, as done for the yarn quality testing.

Experimental Design and Statistical Analysis. Ginning was performed in a randomized block design, in which the cultivar was the block and the ginning method was the treatment to prevent contamination of cultivars in the ginning equipment between lots. Ginning was conducted with only one replication to produce the most uniform bale possible for textile processing. Fiber quality testing was carried out with multiple replications per test, as discussed in the previous sections, in a completely randomized design. Textile processing was carried out with three replications in a completely randomized design. Yarn testing was carried out with multiple replications, as previously discussed, with samples tested in a randomized design.

Statistical analysis was performed using one-way ANOVA with SAS version 9.3 (SAS Institute, Cary, NC) to determine statistical differences between upland cottons by ginning method. The ginning method was the focus of the statistical analysis, as opposed to the specific interaction with each cultivar and the ginning equipment. The Pima cotton values are shown in the tables but are not included in the statistical analysis as the emphasis is the improvement in upland cotton quality via high-speed roller ginning. The Pima results provide benchmarks that reflect the remaining quality gap.

RESULTS AND DISCUSSION

Fiber Quality. Roller ginning of the upland cotton resulted in an average of 2.3% increased turnout, as shown in Table 2. However, increases in turnout are tempered by the potential increase in leaf grade and nonlint content (Tables 3, 4, 5), which is due to the different lint cleaning equipment typically used for the two different ginning systems. On average, the roller-ginned cottons were 1.0 mm longer in upper-half mean length (UHML), which is more than 1 staple, and those same cottons contained less short fiber (defined as fiber less than 12.7 mm in length) than the saw-ginned cottons (AFIS SFC was 7.2 and 9.7 for roller and saw ginned, respectively). The combination of longer fiber and reduced levels of short fiber is reflected in the length uniformity of the cotton, such as the uniformity index (UI) as measured by the HVI. The UI was an average of 2% higher for roller-ginned cottons than saw ginned. The longer and more uniform length of the roller-ginned cottons, combined with the reduced short fiber content should allow for more consistent processing and higher quality yarns to be produced.

Saw-ginned cottons receive more aggressive cleaning through the saw-type lint cleaner, which reduces nonlint content and can improve color appearance through combing and aligning of the fibers, but also can cause entanglements of fibers, known as neps, to form more readily than in roller ginning and its associated lint cleaning (Tables 3, 4, 5). The saw-ginned cottons had an average of 78 additional neps per gram than the roller-ginned cottons (Table 4). Fibrous neps can cause appearance issues in yarns and fabrics and must be reduced substantially during the carding process or the mill risks quality problems in downstream processing. It is advantageous for a textile mill to begin processing with cottons that contain fewer neps as it reduces the need for the mill to remove material during processing.

Table 3. HVI Results

Var	Trt	Mic	UHML (mm)	UI	Strength (g/tex)	SFI	Rd	+b	Trash Count	Trash Area (%)	Leaf Grade
Phy 339	Roller	3.96	32.7	85.0	27.9	6.0	80.8	7.7	48.8	0.41	3
	Saw	3.82	32.1	83.8	28.5	7.1	81.3	7.5	44.0	0.45	4
Phy 375	Roller	4.58	30.3	84.8	28.8	6.9	81.3	9.1	37.0	0.25	2
	Saw	4.80	28.9	81.8	30.0	9.3	82.7	8.5	23.0	0.15	1
Phy 565	Roller	3.47	31.2	84.5	28.5	7.4	81.5	9.4	57.4	0.41	3
	Saw	3.24	30.4	81.6	30.0	9.5	82.7	9.5	39.0	0.24	2
Acala 1517	Roller	3.8	31.5	84.3	31.1	7.0	73.4	5.8	68.0	0.52	4
	Saw	3.5	30.5	83.4	31.7	8.5	74.1	5.6	92.0	0.56	4
DP 340 (Pima)	Roller	3.91	34.7	85.0	36.8	5.0	72.1	10.5	30.2	0.37	3
Means for Upland Cottons by Gin Type											
Roller		3.95	31.5	84.7	29.1	6.8	79.3	8.0	52.7	0.40	3.2
Saw		3.85	30.5	82.7	30.1	8.6	80.2	7.8	49.6	0.35	2.9
Observed Significance Level for Means Difference[z]											
		NS	0.013	< 0.001	NS	< 0.001	NS	NS	NS	NS	NS

[z] NS indicates not significant, $p > 0.10$

Table 4. AFIS Results

Var	Trt	UQL(w) (mm)	SFC(w) (%)	5% SL (mm)	MR	Fine (mtex)	IFC (%)	Nep Count (/g)	SCN Count (/g)	Trash Count (/g)	VFM (%)
Phy 339	Roller	34.5	6.1	38.6	0.99	182	4.3	199	35	87	1.84
	Saw	34.5	6.9	38.7	1.01	188	4.0	225	19	113	1.90
Phy 375	Roller	31.2	6.4	35.2	1.03	196	3.3	161	30	57	1.28
	Saw	30.1	9.6	34.0	1.02	199	3.8	255	24	36	0.56
Phy 565	Roller	32.3	9.9	36.5	0.98	179	5.0	337	40	105	2.57
	Saw	32.2	11.2	36.8	0.96	168	6.0	357	12	129	2.08
Acala 1517	Roller	32.0	6.3	37.1	1.00	163	4.0	226	35	163	3.44
	Saw	30.2	11.2	34.8	0.94	157	6.4	397	21	121	2.33
DP 340 (Pima)	Roller	37.5	5.1	43.0	1.06	181	2.7	177	3	35	0.72
Means for Upland Cottons by Gin Type											
Roller		32.5	7.2	36.8	1.00	180	4.1	231	35	103	2.28
Saw		31.8	9.7	36.1	0.98	178	5.1	309	19	100	1.72
Observed Significance Level for Means Difference[z]											
		NS	0.012	NS	NS	NS	0.048	0.026	0.001	NS	NS

[z] NS indicates not significant, $p > 0.10$

Table 5. Shirley Analyzer Results

Var	Trt	Lint (%)	Trash (%)	Dust (%)
Phy 339	Roller	95.4	3.1	1.5
	Saw	96.7	2.3	1.0
Phy 375	Roller	96.8	2.6	0.6
	Saw	97.8	1.4	0.8
Phy 565	Roller	93.8	4.2	2.0
	Saw	95.2	3.0	1.8
Acala 1517	Roller	94.0	4.1	1.9
	Saw	95.2	3.0	1.8
DP 340 (Pima)	Roller	96.4	2.2	1.4
Means for Upland Cottons by Gin Type				
Roller		94.8	3.6	1.6
Saw		96.0	2.6	1.4
Observed Significance Level for Means Difference[z]				
		0.017	0.001	NS

[z] NS indicates not significant, $p > 0.10$

Textile Processing. A substantial amount of material is removed in the blow room process during textile processing. The blow room process is the entire process from opening of the bales through carding and is the primary opportunity for a mill to remove nonlint content from the cotton fiber. As shown previously (Table 2), the roller-ginned cotton had a higher turnout during ginning, although a portion of that increased material was shown to be nonlint content (Table 5). Table 6 shows the "card loss" for the various treatments, which is the amount of material removed during blow room operations. There was no statistical difference in the amount of material lost during carding between the two ginning systems.

The production of high quality yarns generally involves the combing process. Combing, in textile processing, is designed to remove shorter cotton fibers, known as noil, which reduces the short fiber content of the cotton to allow for higher quality and finer count yarns to be produced. The comber can be adjusted to remove small amounts of material, also known as "scratch combing" or to remove increased amounts of material. Ideally, combing should remove short fibers, those that are less than 12.7 mm, which will not positively contribute to the overall quality of the yarn without removing longer fibers. Although noil has resale value, it is in the mill's interest to remove as little material as necessary to achieve the desired quality of yarn. For this research, the comber settings were not adjusted between lots to allow differences in fiber quality to be observed. Table 6 shows that the roller-ginned cotton produced less noil, meaning that a higher percentage of the material sent to combing in a textile mill would end up in yarn instead of the waste flow. The noil was subjected to AFIS testing. As shown by reduced upper-quartile length (UQL) and increased short fiber content, the roller-ginned noil was shorter than the saw ginned, but the differences were not statistically significant.

Three sets of ring yarn were produced from each card lot to examine yarn quality and spinning efficiency. No statistical differences were found for the overall uniformity between ginning treatments, however there were significantly fewer thin spots in the roller-ginned yarns (Table 7). The carded yarns were of generally similar quality, regardless of ginning method, however neither of the ginning treatments was able to approach the overall quality or spinning efficiency of the Pima samples. The 16.4 tex yarn is on the upper limits of what would be produced commercially without combing. The Phytogen 375 cottons were the coarsest and shortest cottons in the trials. This clearly impacted the spinning efficiency with both ginning methods for that cultivar having double the number of ends down for the roller ginned and almost three times the ends down for the saw ginned compared to the other upland cottons.

As stated, the 16.4 tex yarns are on the upper limits of yarn counts to be produced without combing; this also makes it an entry-level count for combed yarn production. The roller-ginned cottons generally contained less short fiber and had higher UIs than the saw-ginned cotton in the bales. Also, less material was removed during combing for the roller-ginned cottons and that which was removed was shorter and lower quality fiber for the roller-ginned versus the saw-ginned cottons. At 16.4 tex, the combing appears to have eliminated the differences in yarn quality and spinning efficiency (Table 8) between the ginning treatments with the exception of hairiness (H). The Pima sample is still of vastly higher quality than any of the upland cottons.

An 11.8 tex (Ne 50) fine count yarn requires high quality fiber for production (Table 9). At this count, the overall uniformity coefficient of variation (CV%) showed significant differences between the roller-ginned (16.65%) and saw-ginned cottons (17.05%), where the lower coefficient of variation is indicative of a yarn that is more uniform in mass and will therefore produce a more uniform fabric. The results for CV% are supported by the differences measured for thick spots. Although not shown to be statistically significant, the difference in ends down (88.1 per 1000 spindle hours for roller ginned, 120.9 per 1000 spindle hours for saw ginned) would be of practical significance in commercial production. It is likely that regardless of length properties, the higher micronaire of the Phytogen 375 samples limited the spinning performance of those cottons.

Table 6. Carding and Combing Results

Var	Trt	Card Loss (%)	Noil (%)	Noil UQL(w) (mm)	Noil SFC(w) (%)
Phy 339	Roller	17.1	14.6	18.4	55.4
	Saw	15.8	15.3	19.7	50.4
Phy 375	Roller	16.5	12.9	16.8	58.7
	Saw	16.6	14.5	15.9	60.8
Phy 565	Roller	17.3	15.7	17.9	56.7
	Saw	17.1	16.6	19.0	52.3
Acala 1517	Roller	14.9	15.7	16.0	61.1
	Saw	15.5	16.7	16.1	60.8
DP 340 (Pima)	Roller	16.1	10.5	19.0	53.7
Means for Upland Cottons by Gin Type					
Roller		16.5	14.7	17.3	58.0
Saw		16.3	15.8	17.7	56.1
Observed Significance Level for Means Difference[z]					
		NS	0.030	NS	NS

[z] NS indicates not significant, $p > 0.10$

Table 7. Carded Yarn Quality, 16.4 tex (Ne 36/1)

Var	Trt	50% Thin Spots (/km)	50% Thick Spots (/km)	200% Neps (/km)	H	CV%	Elong (%)	Tenacity (cN/tex)	Ends Down (/k-hr)
Phy 339	Roller	134.0	1150.3	808.0	5.1	19.84	5.0	13.8	57.7
	Saw	165.3	1174.7	702.0	5.1	20.02	5.2	13.8	55.2
Phy 375	Roller	155.3	1083.7	695.3	4.9	19.80	5.1	13.8	115.9
	Saw	161.3	1068.7	386.3	5.1	19.86	5.0	13.5	167.4
Phy 565	Roller	148.0	1267.3	1176.7	5.3	20.13	5.8	14.1	41.1
	Saw	194.7	1263.3	810.3	5.1	20.33	5.6	13.9	58.6
Acala 1517	Roller	94.7	1184.2	781.4	5.0	19.66	5.1	16.0	61.3
	Saw	129.2	1183.7	531.4	5.2	19.86	5.0	15.4	63.7
DP 340 (Pima)	Roller	18.3	341.3	150.0	4.4	16.41	5.5	21.9	3.6
Means for Upland Cottons by Gin Type									
Roller		133.0	1171.4	865.4	5.1	19.86	5.2	14.4	69.0
Saw		162.6	1172.6	607.5	5.1	20.02	5.2	14.2	86.2
Observed Significance Level for Means Difference[z]									
		0.030	NS	0.018	NS	NS	NS	NS	NS

[z] NS indicates not significant, $p > 0.10$

Table 8. Combed Yarn Quality,16.4 tex (Ne 36/1)

Var	Trt	50% Thin Spots (/km)	50% Thick Spots (/km)	200% Neps (/km)	H	CV%	Elong (%)	Tenacity (cN/tex)	Ends Down (/k-hr)
Phy 339	Roller	18.7	230.0	121.0	4.4	15.49	5.3	15.3	64.3
	Saw	21.0	241.0	110.3	4.7	15.60	5.3	14.7	42.9
Phy 375	Roller	31.0	242.0	107.3	4.4	15.94	5.2	14.7	71.2
	Saw	33.7	272.0	70.7	4.8	16.16	5.2	14.5	83.9
Phy 565	Roller	16.7	242.3	164.7	4.5	15.45	5.9	15.6	67.5
	Saw	19.3	256.0	137.3	4.7	15.65	6.1	15.4	67.1
Acala 1517	Roller	6.5	179.0	133.4	4.5	14.74	5.3	17.5	22.6
	Saw	9.0	205.1	116.1	4.8	14.97	5.2	17.1	25.6
DP 340 (Pima)	Roller	3.0	64.3	31.7	4.1	13.81	5.4	21.8	8.3
Means for Upland Cottons by Gin Type									
Roller		18.2	223.3	122.6	4.5	15.41	5.4	15.8	56.4
Saw		20.7	243.5	100.7	4.7	15.60	5.5	15.4	54.9
Observed Significance Level for Means Difference[z]									
		NS	NS	NS	<0.001	NS	NS	NS	NS

[z] NS indicates not significant, $p > 0.10$

Table 9. Combed Yarn Quality, 11.8 tex (Ne 50/1)

Var	Trt	50% Thin Spots (/km)	50% Thick Spots (/km)	200% Neps (/km)	H	CV%	Elong (%)	Tenacity (cN/tex)	Ends Down (/k-hr)
Phy 339	Roller	61.7	433.3	239.0	4.1	16.12	5.0	14.6	88.7
	Saw	52.0	397.0	214.7	4.3	16.66	4.8	14.3	122.7
Phy 375	Roller	47.0	372.0	164.0	4.2	17.04	5.0	14.8	118.3
	Saw	98.3	528.0	153.3	4.3	16.83	4.8	13.8	230.8
Phy 565	Roller	46.7	389.7	279.3	4.4	16.80	5.5	15.0	81.5
	Saw	58.7	435.3	258.7	4.5	17.73	5.5	14.7	65.6
Acala 1517	Roller	21.4	355.4	67.4	3.8	16.64	4.7	16.8	63.9
	Saw	33.4	447.9	61.2	3.9	16.97	4.8	16.2	64.5
DP 340 (Pima)	Roller	8.3	138.3	72.0	3.8	14.84	5.1	22.0	34.5
Means for Upland Cottons by Gin Type									
Roller		44.2	387.6	187.4	4.1	16.65	5.1	15.3	88.1
Saw		60.6	452.1	172.0	4.3	17.05	5.0	14.8	120.9
Observed Significance Level for Means Difference[z]									
		NS	0.045	NS	NS	0.077	NS	NS	NS

[z] NS indicates not significant, $p > 0.10$

Spinning limit trials were performed to determine the highest production speed (represented as spindle speed) and the finest count yarns that could be reached with the various cottons (Table 10). For both carded and combed yarns the roller-ginned cottons could be spun at higher speeds than the saw ginned, although the differences were only significant for the carded cottons. Higher spindle speeds directly translate to an increased number of meters of yarn per minute. Production efficiency is vital to the economic sustainability of a textile mill.

An alternative way to achieve higher production rates, besides increased spindle speed, is to reduce the amount of twist inserted in the yarn during spinning. Lower twist multiple, fewer turns per meter, allows for more meters per minute to be spun at a given spindle speed. Textile mills balance production speed against required yarn strength when determining the fiber qualities and spinning parameters needed to produce an acceptable product. A negative effect of lowering twist multiple is that it will generally reduce the strength of the resultant yarn. Similarly, to a certain extent, yarn strength can be increased by inserting additional twist into the yarn at the cost of production speed. All cottons will have a point at which increasing twist does not improve the strength of the yarn. To determine the relationship between twist and yarn strength, a twist-strength curve was produced by spinning yarns at a variety of twist levels. The averaged twist-strength curves, shown in Figs. 8 and 9, confirm that at all twist levels the roller-ginned cotton produced stronger yarns than the upland cottons for both carded and combed material. The difference is largest for the carded material, although at a twist multiple of 4.1, a relatively twist heavy yarn that would be typical of woven materials, the difference between the two ginning methods is minimal. At a twist multiple of 3.8, a typical knitting twist, there is a substantial difference in strength for both the carded and combed materials between the two ginning methods.

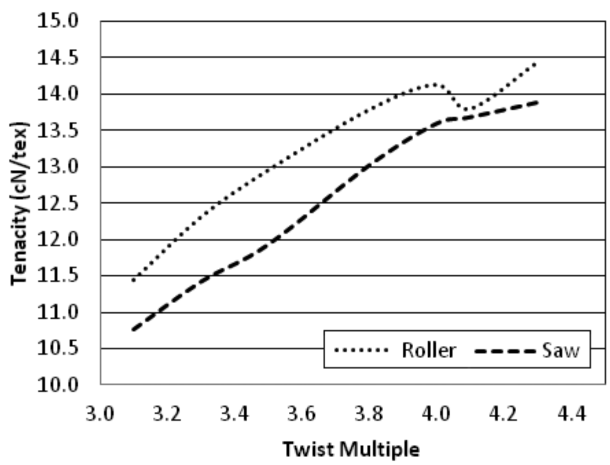

Figure 8. Twist-strength curve for carded upland cottons, 16.4 tex.

Table 10. Spinning Limits

Var	Trt	Carded		Combed	
		Maximum Spindle Speed (rpm)	Finest Count (tex) (Ne)	Maximum Spindle Speed (rpm)	Finest Count (tex) (Ne)
Phy 339	Roller	18,167	14.2 (41.7)	18,333	10.1 (58.3)
	Saw	17,500	15.4 (38.3)	17,667	11.4 (51.7)
Phy 375	Roller	18,000	14.2 (41.7)	17,833	11.4 (51.7)
	Saw	16,833	15.4 (38.3)	16,667	11.4 (51.7)
Phy 565	Roller	17,000	14.8 (40.0)	18,667	10.7 (55.0)
	Saw	16,833	14.8 (40.0)	17,333	10.7 (55.0)
Acala 1517	Roller	19,333	14.2 (41.7)	20,500	10.1 (58.3)
	Saw	17,833	14.2 (41.7)	20,667	10.1 (58.3)
DP 340 (Pima)	Roller	21,167	10.4 (56.7)	22,667	8.4 (70.0)
Means for Upland Cottons by Gin Type					
Roller		18,125	14.3 (41.3)	18,833	10.6 (55.8)
Saw		17,250	14.9 (39.6)	18,083	10.9 (54.2)
Observed Significance Level for Means Difference[z]					
		0.026	NS	NS	NS

[z] NS indicates not significant, $p > 0.10$

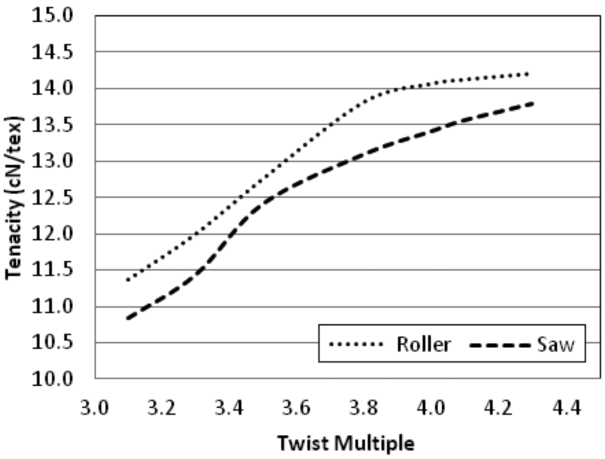

Figure 9. Twist-strength curve for combed upland cottons, 11.8 tex.

Economic Analysis. The economic impact of roller ginning versus saw ginning must be considered. In commercial settings the production rate of high-speed roller ginning is the same as saw ginning on a per unit of width basis. However in the small runs and laboratory conditions of this test the roller ginning was approximately 33% slower due to issues with static electricity and choking up of the reclaimer, which is not representative of normal commercial practice. The roller gin experienced an average of greater than 2.0% increased turnout (Table 2), which would equal an extra 2.86 bales at 37% turnout for every 50 bales produced at 35% turnout. Although both the roller- and saw-ginned cottons had staple lengths that are at the maximum premiums on the Commodity Credit Corporation (CCC) Loan Schedule of Premiums for Upland Cotton (USDA, 2016b), the improved uniformity index of the roller-ginned cotton provides for an additional 44.4 points/kg (20 points/lb) premium.

The textile processing showed an increase of only 0.2% more waste removal in the blow room for the roller-ginned cottons compared to the saw ginned, which was more than offset by the average 1.1% less noil removal during combing (Table 6). The decreased noil removal would equate to one saved bale for every 100 bales of roller-ginned cotton processed by the textile mill, whereas an even greater savings could be realized by further reducing the noil amount by adjusting the comber settings based on the short fiber content of the noil. Additionally, the ability to spin finer count yarns from roller-ginned cotton allows not only greater flexibility in the textile mill but higher profits. For example, the 24 June 2016 spot price of combed, ring-spun 100% cotton 20 tex yarn (Ne 30/1) was \$6.97/kg (\$3.16/lb), whereas that same cotton spun into a 15.6 tex yarn (Ne 38/1) was priced at \$7.12/kg (\$3.23/lb) (Textile World, 2016). Similarly, the ability to process the same count yarn at a higher spindle speed or a reduced twist can result in higher profits through increased production speed. The production rate of 20 tex yarn (Ne 30/1) with a 3.8 twist multiple (α) at 17,500 rpm is 21.4 m/min (23.4 yd/min). But, when the spindle speed is increased to 18,000 rpm the production rate climbs to 21.9 m/min (24.0 yd/min) per spindle. That 500 rpm increase in spindle speed on a 1,000 spindle spinning frame would result in an increase of 500 m/min of yarn production on the frame, which, for a 20 tex yarn, results in an 0.65 kg/hr (1.43 lb/hr) of yarn production, which equates to an additional \$4.53/hour. Similarly, reducing the twist multiple from 3.8 to 3.5 while holding the count at 20 tex and the spindle speed at 17,500 rpm results in an increased production rate of 23.2 m/min (25.4 yd/min), which translates to an additional 2.2 kg/hr (4.8 lbs/hr) or \$15.17/hr in increased revenue on a 1,000 spindle frame. The results of this small-scale study should not be interpreted as an in-depth economic analysis of the advantages of high-speed roller ginning. The economic analysis provided is applicable only to the result of this study.

CONCLUSIONS

The overall quality improvements of high-speed roller-ginned upland cotton over saw-ginned cotton are consistent and undeniable. High-speed roller ginning of upland cotton consistently produced longer and more uniform length fibers than saw ginning the same cotton. The roller-ginned upland cotton processed through the gin with more than two percentage points higher turnout. This was not simply a matter of increased nonlint content, as the higher turnout was preserved through blow room operations in the textile mill with only an average of 0.2 percentage points more loss for roller-ginned cotton compared to saw-ginned cotton.

The processing efficiency gains of the roller-ginned cotton continued through textile processing with combing at the same settings removing on average 1.1 percentage points less material from the roller-ginned cottons and the roller-ginned noil contained a larger proportion of short fibers than the noil from saw-ginned cotton. Carded yarn production for medium count yarns was more efficient, with fewer thin spots, neps, and ends down using roller-ginned cotton. Fine count, combed yarn spinning of roller-ginned cotton was more efficient and produced more uniform yarns. Finer count yarns were produced at higher production rates with roller-ginned cotton compared to the saw-ginned cottons for both carded and combed processes.

The superior fiber quality of upland fiber produced via high-speed roller ginning allowed for production of higher strength yarns at the same twist levels as saw-ginned cotton, which in turn means that the roller-ginned cotton can be used to produce similar strength yarns as saw-ginned cotton at lower twists and thus higher production rates.

High-speed roller ginning of upland cotton did not eliminate the quality gap that exists between upland and Pima cotton. However, the longer and more uniform roller-ginned lint does allow for higher quality yarn and more efficient production than saw-ginned upland. High quality upland cottons benefit from the length and uniformity improvements of roller ginning over saw ginning. For this test, high-speed roller ginning was slower than saw ginning due to static and reclaimer issues, but commercial production rates for high-speed roller ginning and saw ginning are the same for a given width. However, at this time, high-speed roller ginning can be justified only where premiums for the improved quality will offset the increased ginning costs due to the narrower width of roller gins. Individual textile mills might find that the more uniform cotton produced by high-speed roller ginning is worth the premium. The money recouped through selling comber noil is a small percentage of the cost the mill paid for the lint and that does not include the cost of handling and packaging the noil for resale. Thus, retaining more fiber through the combing process improves the economic efficiency of the textile mill. The longer and more uniform fiber produced via high-speed roller ginning allows textile mills to produce yarn at a faster production rate, either via higher spindle speeds or lower twist that translates into higher production rates at the same spindle speeds. The seemingly small efficiencies gained at each stage of processing have a cumulative effect, which makes the economic impact of roller ginning versus saw ginning complex. The longer and more uniform fiber also can be used to improve the overall fiber quality of a laydown when mixed with saw-ginned cotton but that might be an even more complex economic model. Individual textile mills need to evaluate their production speeds and targets, such as count, strength, uniformity, and twist to determine if the higher cost of roller-ginned cotton will result in significant savings. Ring spinning textile mills that produce high quality yarns will realize benefits when converting roller-ginned upland fiber into yarn.

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