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ENGINEERING AND GINNING

Survey of Seed-cotton and Lint Cleaning Equipment in U.S. Roller Gins

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ABSTRACT

Pima cotton is roller ginned to minimize damage to the fiber. The U.S. roller ginning industry has changed over the years. Since 1989, the majority of gins have shifted from Arizona to California. The number of gins in the United States has also fallen by nearly 50%, but those operating today have more gin stands and process cotton at nearly twice the rate. This survey was conducted in 2004-2005 to better understand how current roller ginning machinery affects Pima cotton quality. There were few similarities in machinery set-ups for seed-cotton cleaning among gins. Most gins use one or two cylinder cleaners and an air-type lint cleaner for lint cleaning. The trend in roller ginning today is toward aggressive seed-cotton cleaning and gentle lint cleaning to limit fiber damage. Cotton property measurements taken before and after cleaning showed that, in general, cleaning machinery significantly reduced foreign matter content in seed cotton and lint. Also, cleaning machines tended to reduce fiber length and increase neps. There was an average increase in lint value as measured by current classing standards from \$1.66 before lint cleaning to \$1.72 kg^{-1} (\$0.755 to \$0.781 lb^{-1}) after lint cleaning. This increase could not be attributed to any specific type of lint-cleaning machine. No definite recommendations for foreign matter removal at U.S. roller gins are made herein, but the results indicated the need for controlled evaluations of individual cleaning machines.

Pima cotton, an extra-long-staple cotton, is an important crop to the irrigated Southwest. It is valued for its longer and stronger fibers. Pima is roller ginned, a slower and less aggressive process than saw ginning, to minimize damage to the fiber. During the 1989-1990 ginning season, 49 roller gins operated in the United States: 28 in Arizona, 8 in Texas, 6 in California, 6 in New Mexico, and 1 in Mississippi (Supima, 1989). U.S. Pima cotton production has generally increased over the years, but the number of roller gins has decreased (Fig. 1). Also, the majority of Pima production has shifted from Arizona to California (Fig. 2). Supima (2003) reported that there were 27 gins operating during the 2003-2004 season; 16 in California, 5 in Arizona, 3 in New Mexico, and 3 in Texas. Of the 49 gins operating in 1990, only 12 remained in operation in 2004. Fifteen of the 27 gins that operated during 2003-2004 were constructed after 1990.

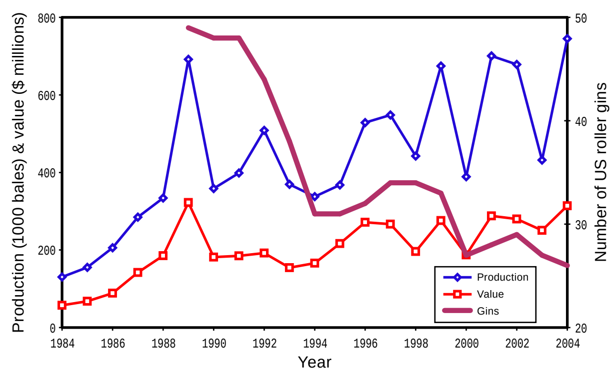

Figure 1. Historical U.S. Pima cotton production, value, and number of gins (USDA, 1990-2005a, 1990-2005c; Supima, 1989-2004).

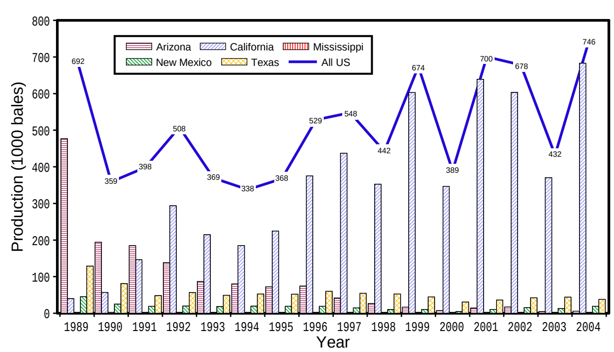

Figure 2. Historical Pima cotton production by state (USDA, 1990-2005b).

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Cleaning machinery in a modern cotton gin is used to remove large trash, so the gin will operate properly and to optimize grade and value (Baker et al., 1994). The machines used in U. S. roller gins for either seed-cotton or lint cleaning are variations of some basic gin machine designs. Cylinder cleaners (Fig. 3A) have spiked cylinders that convey cotton across grid bars or screens, mainly removing fine particles and opening-up the cotton (Baker et al., 1994). They are typically inclined and have four to seven cylinders, but can be horizontal and/or employ as many as 15 cylinders. Impact cleaners (Fig. 3B) are similar to cylinder cleaners, but have five or seven spiked cylinders with revolving serrated disks below the cylinders (Baker et al., 1994). Stick machines (Fig. 3C) are used mainly for removing burs and sticks from seed cotton by sling-off action of two or three channel saws (Baker et al., 1994). Air-type lint cleaners (Fig. 3D) clean lint by subjecting the air/lint flow to an abrupt change in direction as it passes over an ejection slot (Mangialardi et al., 1994). Mill-type lint cleaners (Fig. 3E), which clean the lint by a combination of centrifugal force and scrubbing action, employ smooth or spiked beater bars to convey lint across a series of grid bars (Mangialardi and Anthony, 2003). These lint cleaners are usually coupled to an air-type lint cleaner. Over the years, research on these seed-cotton and lint cleaning machinery for roller gins has been conducted by the USDA-ARS Southwestern Cotton Ginning Laboratory.

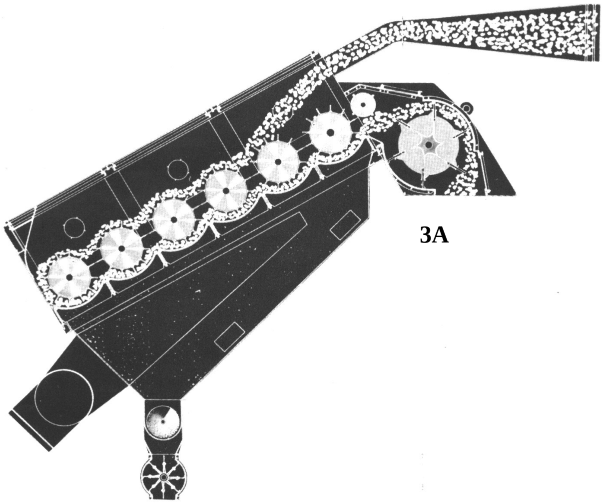
Alberson and Stedronsky (1964) determined that cleaning machine-picked cotton with an elaborate set-up (18 cleaning cylinders, bur extractor, and extractor feeder) increased grade without affecting fiber quality as measured by classing methods from that time. Pneumatic conveying and lint cleaning removed trash and increased average grade and caused no detectable damage to fiber.

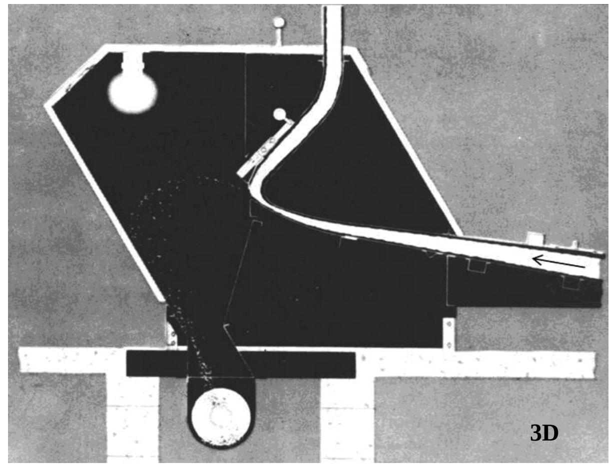
Chapman and Mullikin (1968) found that bale value was highest for roller-ginned Pima cotton with minimal seed-cotton cleaning and one mill-type lint cleaner. These bale values, however, were not significantly different from bale values of other ginning treatments, including elaborate seed-cotton cleaning with no lint cleaning. The lowest calculated cost per mass of comber sliver resulted from minimal seed-cotton cleaning with no lint cleaning, while the highest cost resulted from the minimal seed-cotton cleaning with one mill-type lint cleaner treatment.

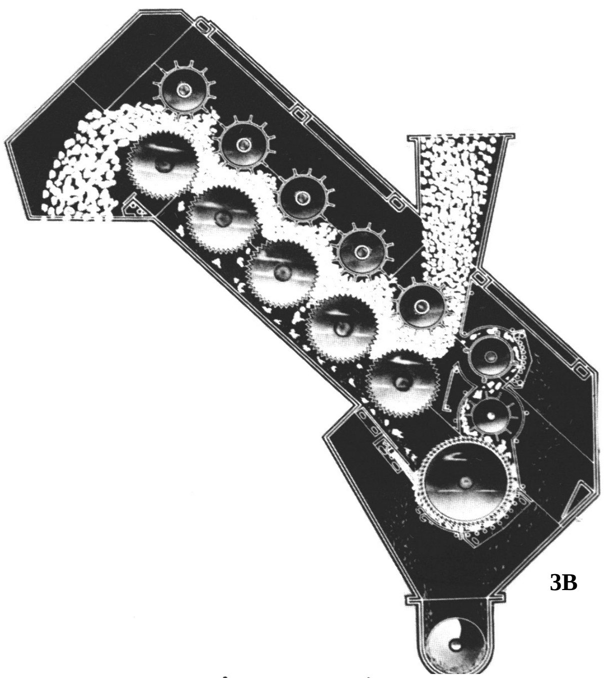
Hughs and Gillum (1991) conducted a survey of U.S. roller gins in 1989 to determine the type and effectiveness of seed-cotton and lint cleaning equipment. The study included recording information on gin machinery and taking seed-cotton and lint samples to evaluate gin machinery configurations. The gin machinery information included the number and type of seed-cotton and lint cleaning machines, the number and set-point temperature of seed-cotton dryers, and number and type of gin stands. They found that the number of seed-cotton cleaners used ranged from three to eight and the cleaning efficiency (percentage difference in trash content of the module seed cotton and the nonlint content before lint cleaning) ranged from 84.2 to 96.1%. Also, 83% of gins used either one or two cleaners (cylinder and/or impact) and one air-type cleaner for lint cleaning, and lint cleaning efficiency (percentage difference in the nonlint content before and after lint cleaning) ranged from 12.6 to 62.2%. Hughs and Gillum (1991, p. 676) were not able to make any specific recommendations on foreign matter removal practice, but they did find that gins realized an “average overall gain in bale value” from “some lint cleaning,” and fiber tests supported the general understanding “that color grade is the limiting factor in determination of composite grade.” They concluded that “more research will be necessary to develop better methods and guidelines for lint cleaning in modern roller-gin plants.”

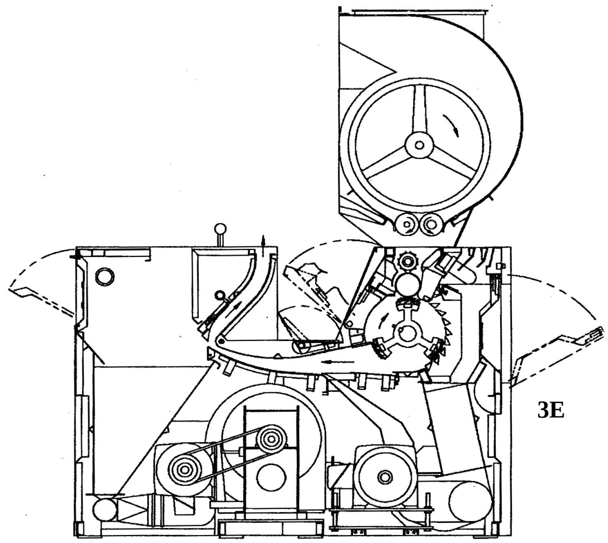
Gillum and Armijo (1997) performed tests to determine the optimum seed-cotton cleaning machinery sequence for Pima cotton. Cleaning efficiency ranged from 54 to 83% for one to nine machines, respectively. The highest bale value was achieved with nine machines, but that number was unrealistic for a commercial gin. No specific recommendations on the number of seed-cotton cleaning machines for the U.S. roller ginning industry were made.

The U.S. roller ginning industry has changed considerably over the years, shifting the majority of production to a different geographic area and increasing gin capacity. To better understand how current foreign matter removal practices affect Pima cotton quality, a survey was initiated in 2004 to document current roller ginning practices, including the types and sequences of current seed-cotton and lint cleaning equipment, to assess the effectiveness of the seed-cotton and lint cleaning regimes currently used by roller gins, and to develop recommendations for Pima cotton foreign matter removal.









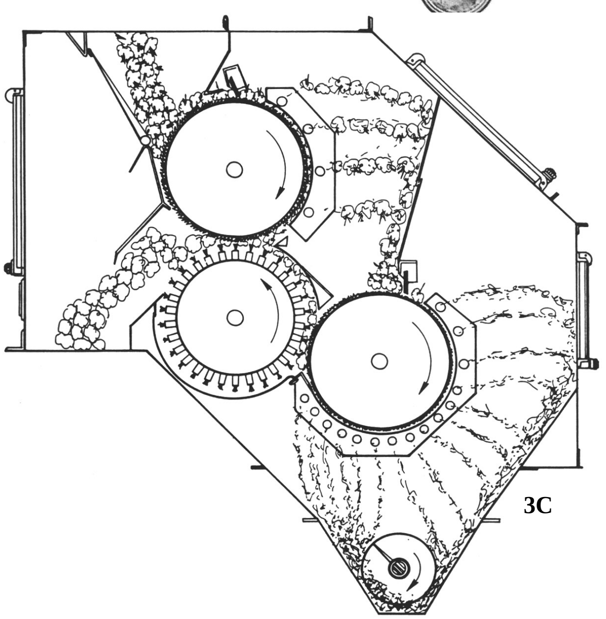


Figure 3. A. Inclined cylinder cleaner (Baker et al., 1994). B. Impact cleaner (Baker et al., 1994). C. Two-saw stick machine (Baker et al., 1994). D. Air-type lint cleaner (Mangialardi et al., 1994). E. Mill-type lint cleaner (Mangialardi and Anthony, 2003).

MATERIALS AND METHODS

The written survey that involved either gin visits or telephone calls was conducted in 2004. Of the 26 operating gins identified by Supima (2003), two did not participate and two closed permanently. Two additional gins, one that did not operate during the 2003-04 season, but would the next season, and one new gin, were added to the list. After the survey was completed, it was determined that another gin, not identified earlier, had operated during the 2003-04 season, but it was not contacted regarding the survey, so 24 gins were included in the database.

The survey included questions to determine the types and sequences of unloading machinery, drying equipment, seed-cotton cleaning machinery, feeders and gin stands, and lint cleaning machinery. Questions were also asked to ascertain the average ginning rate, total bales normally ginned, percentage of cotton in modules, and other characteristics of the operations.

To assess the effectiveness of the different seed-cotton and lint cleaning regimes used by the gins, seed-cotton and lint samples were collected during the 2004-2005 ginning season for foreign matter and fiber quality analyses. Based on an initial evaluation of the written survey, 16 gins that represented all the lint cleaning machinery variations and most of the seed-cotton cleaning machinery variations were selected for on-site sample collection. While ginning, a quality analyses sample and a moisture sample of seed cotton from the module or trailer, seed cotton before ginning, lint before lint cleaning, and lint after lint cleaning were taken at the beginning, middle, and near the end of processing a module or trailer. The seed-cotton and lint samples collected by Hughs and Gillum (1991) were from only one module or trailer at each gin, so they represented a very limited sample of the gin's product. To avoid this problem, sets of samples were taken from three different modules instead of one. Whenever practical, the three modules were from different growers and/or different cotton cultivars and/or from different fields.

Seed-cotton and lint moisture, and seed-cotton foreign-matter content were determined at the USDA-ARS Southwestern Cotton Ginning Research Laboratory in Mesilla Park, NM, by the standard oven-drying and pneumatic fractionator methods (Shepherd, 1972). Lint samples were sent to the USDA-AMS Cotton Classing Office in Phoenix, AZ, for grading. Additional High Volume Instrument (HVI) tests, and Advance Fiber Information System (AFIS) and Shirley Analyzer tests were performed by the USDA-ARS Cotton Quality Research Station, Clemson, SC. Seed-cotton cleaning efficiencies were determined by the difference in the trash content of the module/trailer seed-cotton samples and the seed cotton before ginning samples. Lint cleaning efficiencies were determined by the difference in Shirley Analyzer nonlint content before and after lint cleaning. Lint value was calculated with the 2004 Commodity Credit Corporation (CCC) Loan Schedule (USDA, 2004).

An analysis of variance was performed to test for differences between the pre- and post-cleaning seed-cotton and lint properties to evaluate the overall effectiveness of roller gin cleaning machinery on the cotton properties. The SAS procedure PROC MIXED (release 8.02; SAS Institute; Cary, NC) was used to analyze the mixed models with sampling location (pre- or post-cleaning) as the fixed effect, and gin and module nested within gin as the random effects. Least square means for the pre- and post-cleaning cotton properties were also calculated.

Stepwise regression was performed for each post-cleaning seed-cotton and lint property to identify the specific cleaning machines that had a significant impact on the cotton property. The STEPWISE model-selection method in PROC REG (SAS Institute) was used. Independent variables included number of cylinder cleaners and total number of cylinders, number of impact cleaners, machinery loading (mass rate of material through the machine per unit machine width), pre-cleaning moisture content, and the coinciding pre-cleaning cotton property. For lint cleaning, number of mill-type lint cleaners was added as an independent variable. The significance levels for variables to be added and removed from the model were set at 5%. This significance level was fairly restrictive, the default value in SAS is 0.15, and it is likely some variables that were correlated with certain fiber properties were not included in the final models. This level, however, was selected in an attempt to reduce the number of independent variables in the model to those that had a strong relationship with the cotton property.

RESULTS AND DISCUSSION

Besides the fact that the roller ginning industry has shifted geographically, some changes in the operation and machinery have also occurred (Table 1). The ginning rate has almost doubled (9.8 to 17.3 bales h^{-1}) since 1989, which was mainly due to the increased number of gin stands (8.8 to 15.8). This agrees with the fact that there has been a slight increase in production, but a sharp decrease in the number of gins. The number of seed-cotton cleaners and lint cleaners has changed little, but there has been a shift in the types of lint cleaning machinery used. In 1989, most gins (52%) employed two cleaners (either cylinder or impact) and an air-type cleaner for lint cleaning (Hughs and Gillum, 1991). Today fewer roller gins use that set-up (38%), and more lint cleaning set-ups (33% in 2004 vs. 9% in 1989) now fall into the category that Hughs and Gillum (1991) called “other,” meaning a set-up other than (1) two cylinder or impact cleaners and one air-type lint cleaner, (2) one cylinder or impact cleaner and one air-type lint cleaner, or (3) two mill-type cleaners and two air-type lint cleaners.

The current survey revealed that all gins used at least two stages of drying and two-thirds used three stages (Table 1). For seed-cotton cleaning, all gins used at least one cylinder cleaner and on average the total number of cylinders was 21. All gins surveyed, except one, used at least one stick machine with some using as many as three. Seven gins used impact cleaners, and one of those employed five impact cleaners for seed-cotton cleaning. Two gins employed seed-cotton cleaning machinery categorized as other. In both cases, these machines were additional extractor feeders set-up in the seed-cotton cleaning process before the conveyor distributor. There were very few similarities in machinery used for seed-cotton cleaning among gins.

For lint cleaning, 88% of gins used a cylinder cleaner (Table 1). Typically one or two cylinder cleaners were used with an average of eight (maximum of 14) cylinders processing lint. Four of the 24 gins surveyed used an impact cleaner. All gins, except one, used at least one air-type cleaner, but at some of those gins one of the air-type cleaners was used as part of a mill-type cleaning unit. Six gins employed a newer design mill-type cleaning unit, the Guardian (Lummus Corporation, Savannah, GA), that incorporates an air-type lint cleaner. One gin used two older model mill-type cleaners that have gone out of favor since their throughput is low. The most common machinery set-up for lint cleaning was one or two cylinder cleaners and one air-type lint cleaner. This was different from the 1989 survey when the most common lint cleaning set-up was one cylinder cleaner, one impact cleaner, and one air-type lint cleaner (Hughs and Gillum, 1991).

Table 1. Summary of roller gin machinery survey results

	1989[z]		2004-05 Survey[y]					
			All surveyed gins			Sampled gins		
	Mean	Range	Mean	Range	Gins (%)	Mean	Range	Gins (%)
Ginning rate (bales hr^{-1})	9.8	3 - 26	17.4	8 - 32		17.2	8 - 32	
Drying								
1 Stage [°C (°F)]			98 (208)	68 – 138 (155 – 280)	100	99 (210)	155 – 280 (68 – 138)	100
2 Stage [°C (°F)]			96 (204)	155 – 260 (68 – 127)	100	97 (207)	155 – 260 (68 – 127)	100
3 Stage [°C (°F)]			88 (191)	66 – 118 (150 – 245)	67	87 (188)	150 – 245 (66 – 118)	69
Total seed-cotton cleaners (no.)	4.6	3 - 8	5.0	3 - 11		5.2	3 - 11	
Cylinder cleaners (no.)			3.0	1 - 5	100	3.0	1 - 5	100
Total cylinders (no.)			21.0	6 - 49		20.6	6 - 49	
Stick machines (no.)			1.3	0 - 3	96	1.4	1 - 3	100
Impact cleaners (no.)			0.5	0 - 5	29	0.6	0 - 5	31
Other cleaners (no.)			0.1	0 - 2	8	0.2	0 - 2	13
Gin stands (no.)	8.8	3 - 16	15.8	6 - 30		15.8	6 - 30	
Total lint cleaners (no.)	2.8	1 - 5	2.6	1 - 4		2.6	1 - 4	
Cylinder cleaners (no.)			1.3	0 - 2	88	1.1	0 - 2	81
Total cylinders (no.)			8.6	0 - 14		7.5	0 - 14	
Impact cleaners (no.)			0.2	0 - 1	17	0.2	0 - 1	19
Air-type cleaners (no.)			0.9	0 - 1	88	0.9	0 - 1	88
Mill-type cleaners (no.)			0.3	0 - 2	29	0.4	0 - 2	38

[y] All surveyed gins corresponds to those gins that responded to the written survey. Sampled gins corresponds to those gins that were visited for on-site sample collection.

[z] Data taken from Hughs and Gillum (1991).

Summaries of the raw seed-cotton foreign matter analysis by pneumatic fractionation and the fiber analyses data are shown in Tables 2 and 3. For about half of the variables, the coefficient of variation was higher post-cleaning than pre-cleaning. These data were used in the analyses to generate the results that follow.

Results of the analyses comparing the pre- and post-cleaning seed-cotton foreign matter content are shown in Table 4. The percentage of clean seed cotton in the samples, as determined by pneumatic fractionation, was significantly higher after seed-cotton cleaning, and the percentages of all types of foreign matter were significantly lower after seed-cotton cleaning. These results indicate that the seed-cotton cleaning machinery used by U.S. roller gins is performing as intended.

Many post-lint-cleaning properties were different from the pre-lint-cleaning fiber properties, but in many cases the practical significance of the differences was small (Table 5). This was not surprising as roller gin lint-cleaning machinery tends to be low impact compared with saw gin lint-cleaning machinery (Gillum and Armijo, 1997). Post-cleaning classer color grade was significantly different and more than 1/3 of a grade better than the pre-cleaning average. This may be due more to appearance differences from less foreign matter and more "opening" than from intrinsic color change, as the differences in pre- and post-lint-cleaning HVI color grade, reflectance, and yellowness were significantly different, but very small. There were significant differences between the pre- and post-cleaning averages of classer leaf grade, HVI trash area, AFIS total foreign matter count, dust count, trash count, and visible foreign matter, and Shirley analyzer visible foreign matter, indicating significantly reduced foreign matter content in the fiber. The pre-cleaning values of most HVI and AFIS fiber length measurements were significantly higher than the post-cleaning values; the largest difference in the means occurred for AFIS length and upper quartile length by weight and was 0.05 mm (0.02 in). Not surprisingly, the number of neps was significantly higher after lint cleaning. Based on the 2004 CCC loan schedule, the average lint value increased significantly from \$1.66 kg^{-1} (\$0.755 lb^{-1}) before lint cleaning to \$1.72 kg^{-1} (\$0.781 lb^{-1}) after lint cleaning. These results indicate that current lint cleaning practices are improving grade and increasing lint value as measured by current classing standards, but reduce length and increase neps, which may affect spinning.

Step-wise regression analysis results for post-cleaning seed-cotton foreign matter content fitted to seed-cotton cleaning machines used, machine loading, pre-cleaning seed-cotton foreign matter content, and moisture content are shown in Table 6. The variables remaining in the model to predict the percentage of clean seed cotton in a post-cleaning sample were number of impact cleaners and pre-cleaning sample moisture content (varying from 4.6 to 11.6% wet basis). The parameter estimates show that there was a positive relationship between the number of impact cleaners and the percentage of clean seed cotton, while increasing moisture content had a negative effect on clean seed-cotton content. The percentage of hulls and percentage of total foreign matter remaining in the seed-cotton sample after cleaning tended to decrease with increasing number of impact cleaners. The percentage of sticks in the seed cotton was inversely related to the number of cylinder cleaners and "other" cleaners (machines other than impact cleaners, cylinder cleaners, or stick machines) and directly related to the pre-cleaning stick content. There was a

Table 2. Summary of seed-cotton fractionation results

	Pre-cleaning				Post-cleaning			
Seed-cotton property	**Mean[z]**	**CV**	**Min**	**Max**	**Mean[z]**	**CV**	**Min**	**Max**
Clean seed cotton (%)	**87.48**	**4.9**	**66.42**	**93.76**	**97.35**	**0.8**	**94.97**	**98.91**
Hulls (%)	**1.84**	**34.8**	**0.57**	**3.38**	**0.66**	**57.6**	**0.08**	**1.48**
Sticks (%)	**0.58**	**32.8**	**0.23**	**0.94**	**0.24**	**50.0**	**0.04**	**0.71**
Motes (%)	**3.67**	**82.8**	**1.02**	**20.89**	**0.47**	**42.6**	**0.19**	**1.18**
Leaf/pin trash (%)	**5.32**	**34.4**	**1.72**	**9.12**	**0.71**	**57.7**	**0.20**	**1.96**
Total foreign matter (%)	**11.41**	**36.8**	**4.98**	**32.28**	**2.09**	**36.8**	**0.79**	**4.19**
Moisture content (% wet basis)	**7.74**	**17.8**	**4.63**	**11.58**				
Machine loading [bales hr^{-1} m^{-1} (bales hr^{-1} ft^{-1})]	**4.86 (1.48)**	**52.7**	**1.44 (0.44)**	**12.30 (3.75)**				

[z] N = 45.

Table 3. Summary of fiber analyses results

	Pre-cleaning				Post-cleaning			
Fiber property[x]	Mean[y]	CV	Min	Max	Mean[y]	CV	Min	Max
Classing data								
Classer color grade	2.21	16.3	1.67	3.00	1.82	24.2	1.00	3.00
Staple length (0.8 mm or 1/32 in)	47.3	2.0	45.3	49.3	47.0	2.2	44.7	49.3
Micronaire	4.06	6.4	3.57	4.53	4.04	6.8	3.30	4.50
Strength [kN m kg $^{-1}$ (g tex^{-1})]	393 (40.1)	5.6	343 (35.0)	426 (43.4)	394 (40.2)	6.1	344 (35.1)	337 (44.5)
HVI color grade	1.38	36.2	1.00	3.00	1.25	33.6	1.00	2.67
Color reflectance (Rd)	70.5	2.5	66.0	74.7	70.7	2.3	66.3	74.3
Color yellowness (+b)	11.8	5.4	10.4	12.87	11.9	4.8	10.6	13.0
Classer leaf grade	2.86	31.8	1.33	5.00	2.14	31.8	1.00	4.00
Trash area (%)	0.61	39.4	0.27	1.23	0.36	41.2	0.17	0.80
Length [mm (1/100 in)]	35.0 (137)	1.9	33.8 (133)	36.3 (143)	35.0 (137)	1.9	33.5 (132)	36.1 (142)
Uniformity index (%)	85.2	0.8	83.3	86.3	84.9	1.0	83.3	87.0
AFIS data								
Length by weight [mm (in)]	30.8 (1.21)	2.6	29.1 (1.15)	32.9 (1.30)	30.4 (1.20)	2.5	28.9 (1.14)	32.5 (1.28)
Length by weight CV (%)	32.8	4.7	29.6	36.5	33.1	4.7	29.4	35.8
Upper quartile length by weight [mm (in)]	37.1 (1.46)	2.1	35.6 (1.40)	39.4 (1.55)	36.8 (1.45)	2.8	35.1 (1.38)	39.1 (1.5)
Short fiber content by weight (%)	5.13	18.5	3.33	7.50	5.27	17.8	3.60	7.03
Length by number [mm (in)]	24.9 (0.98)	4.1	22.4 (0.88)	27.2 (1.07)	24.4 (0.96)	4.2	22.6 (0.89)	26.9 (1.06)
Fineness (mTex)	149	2.8	142	156	149	2.3	140	156
Immature fiber content (%)	7.00	12.3	5.43	8.70	6.88	10.0	5.87	9.30
Maturity ratio	0.93	2.2	0.90	0.97	0.94	2.1	0.89	0.96
Nep size (µm)	627	4.1	574	706	637	3.9	588	703
Nep count (g^{-1})	129	38.5	56.3	306	161	28.6	65.3	275
Total foreign matter count (g^{-1})	757	53.1	249	2170	632	44.9	313	1751
Mean foreign matter size (µm)	224	8.4	189	268	219	8.6	186	276
Dust count (g^{-1})	705	53.5	227	2021	590	44.4	295	1619
Trash count (g^{-1})	51.9	52.6	20.0	149	42.6	57.0	17.3	132
Visible foreign matter (%)	1.10	50.0	0.42	3.40	0.95	54.7	0.44	3.30
Lint value [\$ kg^{-1} (\$ lb^{-1})]	1.69 (0.766)	5.7	1.45 (0.66)	1.81 (0.824)	1.74 (0.791)	5.3	1.4 (0.651)	1.82 (0.828)
Shirley analyzer visible foreign matter (%)	2.81	28.1	1.53	5.57	1.72	33.1	0.77	4.00
Cleaning efficiency (%)[z]	37.9	30.3	18.0	62.7				
Moisture content (% wet basis)	3.50	20.0	2.48	5.30				
Machine loading [bales hr^{-1} m^{-1} (bales hr^{-1} ft^{-1})]	4.56 (1.39)	37.4	2.30 (0.70)	8.69 (2.65)				

[x] Classing data determined by manual classing or High Volume Instrument (HVI) tests. AFIS data determined by Advance Fiber Information System. Lint value determined with the 2004 Commodity Credit Corporation (CCC) Loan Schedule (USDA, 2004).

[y] N = 45.

[z] Cleaning efficiency based on the difference in Shirley Analyzer nonlint content before and after lint cleaning.

Table 4. Pre- and post-cleaning seed-cotton foreign matter content

Seed-cotton property[x]	Pre-cleaning (%)[y]	Post-cleaning (%)[y]	*P*-value[z]
Clean seed cotton	87.5	97.4	<0.0001
Hulls	1.8	0.7	<0.0001
Sticks	0.6	0.2	<0.0001
Motes	3.7	0.5	<0.0001
Leaf/pin trash	5.3	0.7	<0.0001
Total foreign matter	11.4	2.1	<0.0001

[y] Determined by the Pneumatic Fractionator methods (Shepherd, 1972).

[x] Means are least square means from mixed models adjusted for random variables: gin and module within gin.

[z] *P*-value for significant difference between pre- and post-cleaning seed-cotton properties.

Table 5. Pre- and post-cleaning HVI and AFIS fiber properties

Fiber property[x]	Pre-lint cleaning[y]	Post-lint cleaning[y]	*P*-value[z]
Classing data			
Classer color grade	2.26	1.89	<0.0001
Staple length (0.8 mm or 1/32 in)	47.2	47.0	0.0266
Micronaire	4.02	4.00	NS
Strength [kN m kg^{-1} (g tex^{-1})]	391 (39.9)	392 (40.0)	NS
HVI color grade	1.49	1.33	0.0047
Color reflectance (Rd)	70.1	70.3	0.0203
Color yellowness (+b)	11.85	11.96	0.0004
Classer leaf grade	2.90	2.17	<0.0001
Trash area (%)	0.64	0.38	<0.0001
Length [mm (1/100 in)]	34.8 (137.2)	34.7 (136.5)	<0.0008
Uniformity index (%)	85.1	84.8	0.0195
AFIS data			
Length by weight [mm (in)]	30.7 (1.21)	30.2 (1.19)	<0.0001
Length by weight CV (%)	33.0	33.3	NS
Upper quartile length by weight [mm (in)]	37.1 (1.46)	36.6 (1.44)	<0.0001
Short fiber content by weight (%)	5.24	5.38	NS
Length by number [mm (in)]	24.6 (0.97)	24.4 (0.96)	0.0023
Fineness (mTex)	148.4	148.5	NS
Immature fiber content (%)	7.09	6.95	NS
Maturity ratio	0.93	0.93	NS
Nep size (µm)	629.6	637.8	NS
Nep count (g^{-1})	134.8	166.0	0.0014
Total foreign matter count (g^{-1})	764.7	643.4	0.0002
Mean foreign matter size (µm)	224.2	219.6	NS
Dust count (g^{-1})	712.3	599.9	0.0003
Trash count (g^{-1})	52.3	43.5	0.0002
Visible foreign matter (%)	1.10	0.97	0.0051
Shirley Analyzer visible foreign matter (%)	2.88	1.77	<0.0001
Lint value [$ kg^{-1}, ($ lb^{-1})]	1.66 (0.755)	1.72 (0.781)	<0.0001

[y] Classing data determined by manual classing or High Volume Instrument (HVI) tests. AFIS data determined by Advance Fiber Information System. Lint value determined with the 2004 Commodity Credit Corporation (CCC) Loan Schedule (USDA, 2004).

[x] Means are least square means from mixed models adjusted for random variables: gin and module within gin.

[z] *P*-value for significant difference between pre- and post-cleaning fiber properties. NS = not significant at *P*-value ≤ 0.05.

Table 6. Stepwise regression statistics for post-cleaning seed-cotton properties fitted to seed-cotton cleaning machine variations and pre-cleaning seed-cotton properties

Seed-cotton property (%)[w]	Significant variables[x]	Parameter estimate	P-value[y]	R^2
Clean seed cotton	Impacts	0.29	0.0015	0.26
	MC	-0.19	0.0218	
Hulls	Impacts	-0.09	0.0457	0.09
Sticks	CC	-0.06	0.0021	0.39
	Other	-0.08	0.0066	
	Pre	0.24	0.0034	
Motes	Impacts	0.08	0.0156	0.22
	MC	0.05	0.0090	
Leaf/pin trash	Sticks	0.38	<0.0001	0.33
Total foreign matter	Impacts	-0.25	0.0049	0.17
Cleaning efficiency[z]	Other	5.23	0.0049	0.56
	MC	-3.39	<0.0001	
	Pre	1.28	<0.0001	

[w] Determined by the Pneumatic Fractionator methods (Shepherd, 1972).

[x] CC = cylinder cleaners; impacts = impact cleaners; other = machines other than impact cleaners, cylinder cleaners, or stick machines; sticks = stick machines; mc = pre-cleaning seed-cotton moisture content (% wet basis); pre = pre-cleaning seed-cotton property.

[y] P-value for significance of variable in regression equation.

[z] Seed-cotton cleaning efficiency based on the difference in the total foreign matter content before and after seed-cotton cleaning.

positive relationship between the number of impact cleaners and the post-cleaning amount of motes and between the number of stick machines and the leaf/pin trash. These results were unexpected because typically foreign matter would decrease with additional cleaning machines. The only model generated with a R^2 >0.50 was for seed-cotton cleaning efficiency. It was not surprising that "other" cleaners and pre-cleaning foreign matter content had a positive effect on cleaning efficiency, while moisture content had a negative effect.

Results of the step-wise regression analyses for post-cleaning fiber properties fitted to lint-cleaning machines using (cylinder cleaners and number of cylinders, impact cleaners, air-type lint cleaners, and mill-type lint cleaners), machine loading, fiber moisture content, and pre-cleaning lint fiber properties showed that the pre-cleaning fiber property was often the only significant variable remaining in the model for a particular post-cleaning fiber property (i.e. micronaire, HVI color grade, uniformity index, AFIS dust count) (Table 7). For many of the resulting models, the R^2 values indicated strong relationships between the dependent and independent variables.

The number of cylinder cleaners and total number of cylinders that the fiber encountered during lint cleaning were significant variables for HVI length and AFIS nep size. For both fiber properties, the addition of cylinder cleaners had a negative effect on quality, reducing HVI length and increasing nep size, as expected. Additional cylinders, however, had a positive effect on quality measures, increasing length, and reducing nep size. The reason for the opposite effects by these two parameters is unknown. The effect of the number of cylinder cleaners was logical, because more processing could reduce length and increase neps; the effect of the number of cylinders was not so intuitive. One explanation might be that when the number of cylinders was greater, it was often because of machines with more cylinders and not more machines. Machines with more cylinders would have fewer transfer points than multiple machines and may affect fiber properties differently. These results raised the question that these regressors, number of cylinder cleaners and total number of cylinders, might not be independent, but further statistical analysis did not indicate collinearity.

Table 7. Stepwise regression statistics for post-cleaning fiber properties fitted to lint-cleaning machine variations and pre-cleaning fiber properties

Fiber property[v]	Significant variables[w]	Parameter etimate	*P*-value[x]	
Classing data				
Classer color grade	Mill	-0.24	0.0421	0.38
	Pre	0.67	<0.0001	
Staple length (0.8 mm or 1/32 in)	Impacts	0.91	0.0006	0.63
	Mill	-0.51	0.0200	
	Pre	0.72	<0.0001	
Micronaire	Pre	0.98	<0.0001	0.84
Strength [kN m kg^{-1} (g tex^{-1})]	Load	-0.41 (-3.99)	0.0003	0.79
	Pre	0.89	<0.0001	
HVI color grade	Pre	0.61	<0.0001	0.54
Color reflectance (Rd)	Pre	0.81	<0.0001	0.78
Color yellowness (+b)	Pre	0.86	<0.0001	0.91
Classer leaf grade	Pre	0.54	<0.0001	0.52
Trash area (%)	Load	0.026	0.0080	0.54
	Pre	0.40	<0.0001	
Length [mm (1/100 in.)]	CC	-0.39 (-1.52)	0.0187	0.82
	Cylinders	0.09 (0.31)	0.0023	
	Impacts	0.51 (2.00)	0.0001	
	Pre	0.78 (0.78)	<0.0001	
Uniformity index (%)	Pre	0.64	<0.0001	0.30
AFIS data				
Length by weight (mm or in)	Pre	0.81	<0.0001	0.59
Length by weight CV (%)	Pre	0.66	<0.0001	0.42
Upper quartile length by weight (mm or in)	Pre	0.83	<0.0001	0.60
Short fiber content by weight (%)	Pre	0.59	<0.0001	0.36
Length by number (mm or in)	Pre	0.70	<0.0001	0.47
Fineness (mTex)	Pre	0.58	<0.0001	0.50
Immature fiber content (%)	MC	0.22	0.0285	0.59
	Pre	0.58	<0.0001	
Maturity ratio	Pre	0.57	<0.0001	0.53
Nep size (µm)	CC	34.87	0.0055	0.19
	Cylinders	-3.78	0.0415	
Nep count (g^{-1})	---[y]	---	---	---
Total foreign matter count (g^{-1})	Pre	0.61	<0.0001	0.74
Mean foreign matter size (µm)	Impact	11.51	0.0392	0.50
	Mill	11.17	0.0185	
	Load	3.77	0.0062	
	Pre	0.53	<0.0001	
Dust count (g^{-1})	Pre	0.60	<0.0001	0.74

Table 7. continued

Fiber property[v]	Significant variables[w]	Parameter etimate	*P*-value[x]	
Trash count (g^{-1})	**Mill**	**8.31**	**0.0436**	**0.75**
	Load	**2.87**	**0.0156**	
	Pre	**0.71**	**<0.0001**	
Visible foreign matter (%)	**Impacts**	**0.29**	**0.0111**	**0.78**
	MC	**0.21**	**0.0017**	
	Load	**0.07**	**0.0030**	
	Pre	**0.72**	**<0.0001**	
Shirley visible foreign matter (%)	**Load**	**0.10**	**0.0017**	**0.71**
	Pre	**0.56**	**<0.0001**	
Cleaning efficiency (%)[z]	**Impacts**	**-14.82**	**0.0004**	**0.47**
	Mill	**7.97**	**0.0176**	
	MC	**-8.00**	**0.0020**	
	Load	**-3.49**	**<0.0001**	
Lint value (\$ kg^{-1} or \$ lb^{-1})	**Pre**	**0.74**	**<0.0001**	**0.60**

[v] **Classing data determined by manual classing or High Volume Instrument (HVI) tests. AFIS data determined by Advance Fiber Information System. Lint value determined with the 2004 Commodity Credit Corporation (CCC) Loan Schedule (USDA, 2004).**

[w] **CC = cylinder cleaners; Cylinders = total number of cylinders; Impacts = impact cleaners; Mill = Mill-type lint cleaners; Load = mass per unit machinery width loading (bales hr^{-1} m^{-1}); MC = pre-cleaning lint moisture content (% w.b.); Pre = pre-cleaning lint property.**

[x] ***P*-value for significance of variable in regression equation.**

[y] **No significant variables.**

[z] **Cleaning efficiency based on the difference in Shirley Analyzer nonlint content before and after lint cleaning.**

The number of impact cleaners was significantly related to two length measurements and three foreign matter measurements. Both staple length and HVI length tended to be longer when impact cleaners were used. Also, AFIS visible foreign matter and mean foreign matter size increased with number of impact cleaners, while cleaning efficiency tended to decrease. It could be assumed that when an impact cleaner was used, it often replaced another more aggressive and more efficient cleaner. This may explain the trend in length or foreign matter, but both need further investigation in a laboratory ginning plant.

The parameter estimates showed that a mill-type lint cleaner tended to reduce (improve) the classer color grade. This was interesting, because the mill-type cleaner did not show up as a significant variable for HVI color grade (Table 7), leading to the speculation that the cleaner did not actually affect the fiber color, but perhaps it affected the appearance of the sample through combing and smoothing. Staple length tended to decrease with the number of mill-type cleaners used. This trend with mill-type cleaners was expected, because they are more aggressive than other roller gin lint cleaners. There was a positive relationship between cleaning efficiency the number of mill-type lint cleaners used.

Machinery loading ranged from 2.3 to 8.7 bales h^{-1} m^{-1} (0.7 to 2.65 bales h^{-1} ft^{-1}) at the gins sampled and mainly showed up as a significant variable for foreign matter measurements. As loading increased, HVI trash area, AFIS trash count, visible foreign matter, mean foreign matter size, and Shirley visible foreign matter increased and cleaning efficiency decreased. All these trends were expected and reinforce the understanding that increasing the loading on lint-cleaning machinery reduces its cleaning effectiveness.

Lint pre-cleaning sample moisture content varied from 2.5 to 5.3% wet basis, and increasing moisture levels reduced lint cleaning effectiveness. AFIS visible foreign matter increased and cleaning efficiency decreased as moisture content increased. These results were not unexpected. Immature fiber content also increased with increasing moisture content.

At the 5% significance level, none of the machines used were shown to affect lint value. Though classer color grade improved with the use of a mill-type lint cleaner, the improvement was only about 1/3 of a grade level, not enough to affect value. As shown by the parameter estimates, the increase in staple length from using an impact cleaner or decrease from using a mill-type cleaner was less than a whole staple length, again not affecting value. The only significant variable for the other fiber properties used in determining lint value (leaf grade, micronaire, and strength) was their respective pre-cleaning values. The results for overall effectiveness showed that, industry wide, lint cleaning increased lint value (Table 5), but the results from the step-wise regression (Table 7) showed that the increase could not be attributed to any one type of lint-cleaning machine.

Although AFIS nep count significantly increased from pre- to post-lint cleaning (Table 5), no specific machine or variable was shown to have a strong relationship with AFIS nep count (Table 7). Relationships with machines or variables may not have been detected because the difference between the pre- and post-lint cleaning values was not great and because roller gin lint-cleaning machinery tend to be less aggressive than saw-type lint cleaners used for Upland cotton.

These results point to the need for further research in a laboratory gin plant on individual machines. In that setting, machine interactions can be separated. For this study, fiber waste could not be measured, though it can impact bale value. Lab work will enable measurement of those variables, like fiber waste, that can greatly impact Pima cotton quality and quantity.

CONCLUSIONS

The U.S. roller ginning industry has changed since 1989. The majority of gins have shifted from Arizona to California. The number of gins in the United States has fallen by nearly 50%, but those operating today are larger and process about the same number of bales at nearly twice the rate.

There were very few similarities in machinery set-up for seed-cotton cleaning among gins. Most gins use one or two cylinder cleaners and an air-type lint cleaner for lint cleaning. The trend in roller ginning today seems to be toward aggressive seed-cotton cleaning and gentle lint cleaning to limit fiber damage.

Cotton property measurements taken before and after cleaning showed that, in general, cleaning machinery reduced foreign matter content in seed cotton and lint. Also, cleaning machines tended to reduce fiber length and increase neps. There was an average increase in lint value from \$1.66 pre-lint cleaning to \$1.72 kg^{-1} post-lint cleaning (\$0.755 to \$0.781 lb^{-1}).

Moisture content was shown to have a negative impact on seed-cotton cleaning, reducing the percentage of clean seed cotton in a sample and reducing cleaning efficiency. On the other hand, impact cleaners generally increased the percentage of clean seed cotton, and cleaners falling in the "other" category (usually additional extractor feeders) tended to increase cleaning efficiency.

Some individual machines had significant impact on fiber properties. The number of cylinder cleaners and total number of cylinders that the fiber encountered during lint cleaning were significant variables for HVI length and AFIS nep size, but they affected the properties oppositely. HVI length and visible foreign matter tended to increase and cleaning efficiency tended to decrease with use of impact cleaners. Mill-type cleaners were shown to improve color grade and cleaning efficiency, but reduce staple length. Most fiber properties were not significantly affected by any one specific cleaning machine. Instead, the pre-cleaning value of the property in question was often the only significant variable affecting a fiber property. Machine loading and lint moisture content negatively impacted foreign matter removal. At the 5% significance level, no specific machine that was used significantly affected lint value.

These results do not point to any definite recommendations for foreign matter removal at U.S. roller gins, but these results do highlight the need for specific, controlled tests on individual cleaning machines to try to assess their impact on foreign matter content and fiber quality.

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DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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