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ENGINEERING AND GINNING

The Effects of Dryer Temperature and Moisture Addition on Ginning Energy and Cotton Properties

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ABSTRACT

Damage to cotton fibers during ginning can be reduced by minimizing dryer temperatures and restoring moisture to over-dried fibers. This paper reports the effects of seed cotton moisture conditioning on fiber quality and gin stand energy consumption. Dryer temperatures were varied, and humidified air was added to seed cotton above the extractor-feeder. Each test lot concluded with a 227-kg (500-lb) bale. The addition of moisture with humidified air raised the final lint moisture content from 4.55% to 5.08% (5.3 g/kg or 2.7 lb/bale). This increase was estimated to be 10 g/kg (5 lb/bale) lint or more at the gin stand feeder apron, so some of the added moisture was lost before reaching the bale. Increasing dryer temperatures by 50 °C (90 °F) decreased the final moisture content by 0.81% (8.1 g/kg or 4.0 lb/bale). Changes in gin stand energy consumption were related to moisture addition, dryer temperature, and lint moisture. Moisture addition reduced energy consumption from 21.4 to 21.1 MJ (5.94 to 5.86 kWh) per bale (1.4%), regardless of dryer temperature or the moisture content of the cotton. As dryer temperature increased and lint moisture dropped, energy consumption initially increased, but energy consumption began to decrease at higher dryer temperatures with lint moisture contents below 5%. These changes were attributed to changes in fiber strength and cohesive properties of the fiber, though these were not measured during ginning. All HVI and AFIS fiber length properties were improved by adding moisture with humidified air and reducing dryer temperature. The addition of humidified air improved gin turnout, HVI strength, AFIS neps, immature fiber content, and maturity ratio, but it increased AFIS trash levels, nep size, and the number of seed coat neps. Increasing dryer temperature improved HVI and AFIS trash properties and reduced seed coat neps, but it reduced HVI strength, increased AFIS neps, increased immature fiber content, and reduced maturity ratio. Dryer temperature did not change gin turnout or micronaire.

Cotton gins clean cotton before and after removing seed and baling the finished product into 227-kg (500-pound) bales for shipment. Cotton arriving at the gin is often too moist, which reduces the cleaning efficiency of the gin and makes the cotton difficult to process. Air, the primary method of conveying cotton within a gin, is heated to remove excess moisture from the cotton. Moisture can transfer to or from the conveying air, depending on the moisture content of the cotton and the condition of the conveying air. For a specific temperature and humidity, cotton seeks an equilibrium moisture content (Hughs et al., 1994).

Ginning cotton at the proper moisture content is one of the most important factors in cleaning cotton and minimizing fiber damage. Cotton that is too moist will not clean well, and cotton that is too dry will be damaged. Anthony (1990) measured the trash content of seed cotton at the gin stand feeder, lint foreign matter, and HVI trash and showed that increasing moisture from 4.1% to 8.4% reduced cleaning efficiencies of seed cotton and lint. This increase in moisture also resulted in higher fiber length and uniformity and decreased short fiber content. Much of the fiber damage occurred during lint cleaning but very little occurred during seed cotton cleaning. There was a significant amount of unmeasured fiber damage in the gin stand where seed were removed. Changes in fiber length due to over-drying cotton appeared to be comparable to the damage caused by using two or three stages of lint cleaning.

In the gin stand, gin saws pull fibers through the ginning ribs that are too narrow for seed to pass. Fibers are broken as the force required to extract these fibers exceeds the strength of the fibers. Anthony and Griffin (2001) addressed two components of this relationship by measuring individual fiber strength

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and its attachment to the seed at various moisture contents. From 3.6% to 11.8% fiber moisture, the attachment force remained constant at 1.9 g per fiber, while fiber-breaking force increased almost linearly from 3.1 to 4.8 g per fiber (Fig. 1). The percentage of broken fibers (those removed at less than full length) dropped as the ratio of fiber breaking force to attachment force increased. Above 11.8% moisture, the attachment force dropped sharply and fiber breakage was nearly eliminated, so fiber damage may increase as lint moisture drops due to a reduction in fiber strength, but no changes in attachment force are expected to influence fiber damage below 11% lint moisture.

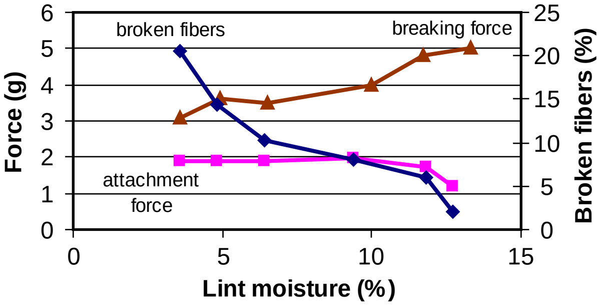

Figure 1. Effect of lint moisture (%) on fiber to seed attachment force, breaking force, and percentage broken fibers as reported by Anthony and Griffin (2001).

Drying cotton at high temperatures has been shown to irreversibly reduce individual fiber strength. Anthony and Griffin (2001) showed that dryer temperatures over 175 °C (350 °F) for as little as 3 s can reduce individual fiber strength and increase fiber breakage even after restoring moisture, but fibers dried below 120 °C (250 °F) were unaffected after restoring moisture. The equilibrium moisture content of fiber was reduced as dryer temperatures increased, so dryer temperatures around 175 °C (350 °F) may reduce fiber strength and cause fiber damage that can not be prevented with moisture restoration before ginning.

Byler et al. (2001) found that HVI bundle strength increased as lint moisture increased from 6.5% to 8.5%. Strength at 7.5% lint moisture (26.3 cN/tex) increased 7.6% with 1% moisture. From the previously discussed values reported by Anthony and Griffin (2001), the single fiber breaking strength at 7.5% lint moisture (3.85 g/fiber) increased 4.8% with 1% moisture. This difference indicates that factors in addition to individual fiber strength change with moisture content and influence fiber bundle strength. One property may be fiber cohesion. If cohesive forces between fibers and fiber strength both increase with lint moisture, both could also influence the energy required to extract the fibers from the gin stand seed roll.

Fiber-to-fiber friction in cotton is related to the orientation of the fibers, the ability to take up electrostatic charge, the natural lubrication of the waxy cuticle layer, the length and fineness of the fibers, and other factors (El Mogahzy et al., 1997). Static charge between fibers can be reduced with moisture by increasing the conductivity of the fiber and its surface (Slade, 1998). The electrical resistance of fibers increases as the moisture content decreases. As moisture content drops below 5%, the electrical resistance increases rapidly as it approaches that of the dry fiber, because of the disruption of “moisture channels”. Electrical resistance may be lowered at low moisture contents with ample surface moisture. Static friction in the gin stand may exist between fibers or between machinery and fibers. Fibers may cling together as they flow through the gin stand, so static friction between these fibers would resist the separation of the fibers. The force required to extract the fibers from the seed in the gin stand may be lowered by reducing static electricity with either fiber moisture or surface moisture.

Moisture can affect hydrodynamic friction differently than static friction. Moisture regain in fibers has been shown to increase hydrodynamic friction by swelling fibers and increasing the area of contact between fibers (Slade, 1998). High humidity can reduce the lubricating effect of some fiber finishes, but no information was found in this regard for natural cotton wax. The force required to extract the fibers from the gin stand seed roll may be increased with fiber moisture or surface moisture by increasing hydrodynamic friction. Hydrodynamic friction in the gin stand could be important between fibers or between machinery and fibers.

An increase in temperature may increase the ability of fibers to conduct electrical charge (Slade, 1998), but in a gin this effect is likely to be minimal compared with the effect of moisture, especially low moisture. An increase in temperature may decrease the viscosity of the waxy cuticle material on the fiber (Slade, 1998). Increased temperature may reduce the force required to extract fibers from the gin stand seed roll by reducing hydrodynamic friction.

Since most of the cleaning and little fiber damage is done before removing the seed, moisture should ideally be removed as it enters the gin and restored before removing the fiber from the seed. The ideal place to add moisture is just above the extractor-feeder, since this machine sits on top of the gin stand. Also, this allows some time for the moisture to be incorporated into the lint before entering the gin stand. Restoring moisture to seed cotton prior to seed removal and lint cleaning has been shown to reduce fiber damage. Mangialardi and Griffin (1977) added moisture by delivering humidified air to a conditioning hopper above the extractor-feeder and by using nozzles to mist cotton falling onto the conveyor-distributor. Each of these methods and the combination of both successfully increased lint moisture and fiber length. The humidified air system increased seed cotton moisture entering the gin stand from 7.6% to 8.6%, increased lint moisture from 5.5% to 6.2%, and increased the fibers 2.5% span length from 2.835 cm to 2.860 cm (1.116 in to 1.126 in). Results from mist and combination moisture addition were even more dramatic.

The purpose of this study was to determine the effect of dryer temperature, moisture addition with humidified air, and their interaction on fiber properties and energy consumed by the gin stand. It was suspected that fiber moisture and fiber surface moisture had separate effects on fiber properties and energy consumption.

MATERIALS AND METHODS

Cotton was ginned at the U.S. Cotton Ginning Laboratory in Stoneville, MS, with a typical ginning machine sequence as follows: first cylinder cleaner, stick machine, tower dryer, second cylinder cleaner, extractor-feeder, gin stand, and lint cleaner. Two similar experiments were conducted. Both experiments used a randomized complete block design with cotton cultivar as the block effect. There were three blocks in each experiment. In the first experiment, there was a factorial arrangement of treatments with two levels of moisture addition (on and off) and three dryer temperatures of 40, 80, and, 120 °C (100, 175, and 250 °F). In the second experiment, there was a factorial arrangement of treatments with two levels of moisture addition (on and off) and four dryer temperatures of 60, 80, 105, and 120 °C (140, 180, 220, and 245 °F). Within each experiment, all treatments were applied once to each cultivar. Since dryer temperature has a quantitative treatment structure, it was treated as a trend in the analysis of variance. With dryer temperature considered a trend, the two experiments were combined and analyzed as a randomized complete block with six blocks and a factorial arrangement of treatments of moisture by dryer temperature. All dryer temperatures were measured at the mix point in the second shelf of the dryer. Each treatment was applied to cotton producing one bale of lint weighing 227 kg (500 lb).

The three cultivars of cotton used for experimental blocks in the first experiment (ginned April 2003) were SureGrow 521RR (SG521RR, harvested October 2001; Delta Pine and Land Co.; Scott, MS); Stoneville BXN49B (BXN49B, harvested September 2002; Stoneville Seed Co.; Memphis, TN); and Stoneville 4892BR (ST4892BR-02, harvested September 2002; Stoneville Seed Co.). The three cultivars of cotton used for experimental blocks in the second experiment (ginned October 2003) were Deltapine 555BR (DP555BR; Delta Pine and Land Co.), SureGrow 105 (SG105; Delta Pine and Land Co.), and Stoneville 4892BR (ST4892BR-03; Stoneville Seed Co.) all harvested in September 2003. All cotton, except DP555BR, was stored in covered trailers prior to ginning. The cultivar DP555BR was stored in a covered module for 7 d prior to ginning.

A Humidaire Unit (Samuel Jackson, Inc.; Lubbock, TX) was used to add moisture to seed cotton by forcing heated, humidified air into both sides of a conditioning hopper (Samuel Jackson, Inc.) above the extractor-feeder. The ducts entering the hopper were equipped with valves that opened only when ginning. The temperature of the air and water in the humidaire unit were adjusted to alter the amount of moisture applied to the cotton with the humidified air. These settings were not constant throughout the experiment but were varied to deliver near maximum amounts of moisture without impairing the flow of cotton. Since only small amounts of moisture could be added, there were only two levels of moisture addition, off and on.

A Continental Eagle 93-saw Double Eagle gin stand (Prattville, AL) was used for ginning. Since no device was available for real-time measurement of ginning rate, the gin stand feeder control was adjusted to maintain the gin stand amperage load in the normal operating range to minimize fluctuations in ginning rate. The power consumption of the gin stand was recorded over time using a watt-hour meter. The weights of the seed cotton and lint were recorded for each bale.

For each bale, samples were taken throughout the gin to determine moisture content (wet basis). In order of ginning sequence, these included five samples taken from seed cotton entering the gin, five samples taken after drying, nine samples taken after moisture addition, nine lint samples taken after ginning, and five samples taken at the lint slide. The moisture content of the cotton was determined by the oven method (Shepherd, 1972). Five seed cotton samples per bale were taken at the gin stand feeder apron to determine foreign matter content by pneumatic fractionation (Shepherd, 1972). For each bale, five lint samples were analyzed by HVI (USDA, Agricultural Marketing Service; Dumas, AR), and nine samples were analyzed by Advanced Fiber Information System (AFIS, Uster Technologies; Knoxville, TN). Ambient temperature and relative humidity were recorded once per bale. Observations were averaged for each bale prior to statistical analysis.

The MIXED and General Linear Model procedures (version 8.2, SAS Institute, Inc.; Cary, NC) were used to analyze the effects of moisture addition, dryer temperature, and their interaction on ginning parameters and fiber properties. Lint moisture was included in the model if it explained variation not attributed to these treatments. With dryer temperature analyzed as a trend and only two levels of moisture addition, there was one degree of freedom in the analysis of each factor. Cotton cultivar was included in each model representing experimental blocks with five degrees of freedom. Treatment replications, as described earlier, were blocked by cultivar. This was intended to broaden the inference base for treatment analysis. The interactions between cultivar and treatments were considered random sources of variability and were not the focus of this report. Differences in cultivars were discussed, but other major sources of variation, such as crop year, field location, planting date, harvest data, gin date, were confounded in this factor. All factors were tested for differences at the 5% level of significance.

RESULTS

Moisture content. The moisture content (wet basis) of the seed cotton as it entered the gin (wagon moisture) varied among cultivars but was consistent between treatments (Table 1). Moisture was measured after the dryer and subtracted from

Table 1. Means, regression parameters, and statistical significance for seed cotton and lint moisture content

Factor	**Seed cotton moisture**				**Lint moisture**		
Cultivar	**Wagon (%)**	**Removed (g/kg lint)**	**Restored (g/kg lint)**	**Feeder (%)**	**Before lint cleaner (%)**	**After lint cleaner (%)**	**Change (g/kg lint)**
BXN49B	**10.09**	**58.59**	**-6.28**	**7.83**	**4.43**	**4.46**	**0.27**
DP555BR	**7.90**	**50.48**	**20.75**	**6.73**	**4.75**	**4.49**	**-2.55**
SG105	**9.52**	**37.67**	**2.16**	**8.25**	**5.26**	**5.45**	**1.88**
SG521RR	**9.70**	**54.62**	**-10.34**	**7.68**	**4.47**	**4.15**	**-3.21**
ST4892BR - 02	**9.13**	**48.43**	**15.84**	**8.02**	**4.81**	**4.50**	**-3.09**
ST4892BR - 03	**9.16**	**41.71**	**7.91**	**7.91**	**4.92**	**5.26**	**3.38**
Moisture							
Off	**9.18**	**45.04**	**-1.90**	**7.53**	**4.51**	**4.55**	**0.34**
On	**9.12**	**49.48**	**14.54**	**7.89**	**5.14**	**5.08**	**-0.72**
Dryer temperature				**Slope[z]**			
Per 50 °C	**0.24**	**26.66**	**na**	**-0.54**	**-0.46**	**-0.81**	**-2.59**
Interaction							
Moisture off, per 50 °C	**na**	**na**	**12.99**	**na**	**na**	**na**	**na**
Moisture on, per 50 °C	**na**	**na**	**-4.68**	**na**	**na**	**na**	**na**
				Probability values[z]			
Cultivar	**0.0001**	**0.2339**	**0.0056**	**0.0001**	**0.1857**	**0.0001**	**0.2586**
Moisture	**0.7633**	**0.4211**	**0.0059**	**0.0092**	**0.0044**	**0.0001**	**0.5997**
Dryer temperature	**0.1797**	**0.0001**	**0.3404**	**0.0001**	**0.0176**	**0.0001**	**0.1685**
Dryer temp*moisture	**na**	**na**	**0.0462**	**na**	**na**	**na**	**na**

[z] na = not applicable. The appropriate analysis for dryer temperature and moisture included the interaction only if it was significant.

wagon moisture to calculate the amount of moisture removed. The assumption was made that seed moisture did not change, so the difference in seed cotton moisture was divided by gin turnout to determine "moisture removed" from lint. Dryer temperature was the only factor affecting "moisture removed" (Table 1). As dryer temperature was increased by 50 °C (90 °F), moisture was reduced by 26.66 g/kg lint (2.67 % of lint weight).

After adding moisture with humidified air above the extractor-feeder, the moisture content of cotton entering the gin stand (feeder moisture) was measured. The moisture content after drying was subtracted from feeder moisture, and the difference was divided by turnout to calculate "moisture restored" to lint (Table 1). With moisture addition, "moisture restored" was 14.54 g/kg lint, but it was -1.90 g/kg lint without moisture addition. These values were averaged over dryer temperature. There was a significant interaction between dryer temperature and moisture addition. Without moisture addition, "moisture restored" increased with dryer temperature as fibers became dryer and collected moisture from the conveying air. Overall, the difference in "moisture restored" due to moisture addition was 16.44 g/kg lint (1.64% of lint weight).

With the addition of moisture, feeder moisture increased from 7.53% to 7.89%. Feeder moisture decreased with dryer temperature (-0.54% per 50 °C), but there was no interaction with moisture addition. Assuming differences in feeder moisture were in the lint fraction only, the difference due to moisture addition (0.36% of seed cotton) considering turnout was converted to 10 g/kg lint (1.0% of lint weight). This amount was less than the difference in "moisture restored". Based on the same assumption, as dryer temperature increased by 50 °C (90 °F), moisture was reduced by 15 g/kg lint (1.5 % of lint weight).

After seed were removed at the gin stand, direct measurements of lint moisture were made before and after the lint cleaner (Table 1). Before the lint cleaner, lint moisture was increased with moisture addition from 4.51% to 5.14% (0.63% or 6.3 g/kg) measured. This difference was 0.53% (5.3 g/kg) measured after the lint cleaner. As dryer temperatures increased by 50 °C, lint moisture dropped 0.46% before the lint cleaner and 0.81% after the lint cleaner. None of the treatments affected the change in lint moisture across the lint cleaner, so treatment differences before and after the lint cleaner were similar (Table 1).

The amount of moisture added to seed cotton with humidified air was estimated by "moisture restored" (1.64% of lint weight) and feeder moisture (1.0% of lint weight). These amounts were larger than differences in lint before lint cleaning (0.63%) or after lint cleaning (0.53%). These results indicate that some of the moisture restored to the cotton was lost as cotton passed the gin stand. As dryer levels increased by 50 °C (90 °F), the reduction in lint moisture content was estimated by "moisture removed" (2.67% of lint weight) and feeder moisture (1.5% of lint weight). This change was 0.46% before and 0.81% after the lint cleaner, so moisture removed at high dryer temperatures was restored to lint from the atmosphere.

Ambient conditions. Air temperature and relative humidity was different between cultivars as they were ginned on separate days, but this variation was consistent between treatments (Table 2). Therefore, some of the variation in the experiment due to changes in ambient conditions was separated with block effects.

Energy consumption. Lint weights were adjusted to the mean moisture content for each cultivar, and energy consumption was based on the adjusted weight. The biggest difference in gin stand energy consumption was seen between experimental blocks (cotton cultivars). The cultivar ST4892BR-03 consumed the most energy averaging 22.6 MJ (6.27 kWh) per bale, while SG521RR consumed the least energy averaging 14.8 MJ (4.11 kWh) per bale (Table 2). The reported gin stand energy consumption did not include idling energy.

Other than SG521RR, DP555BR consumed the least amount of energy, averaging 19.5 MJ (5.42 kWh) per bale. The cultivar SG521RR consumed considerably less energy than the other cultivars and responded differently to moisture addition. For SG521RR, energy consumption was similar to other cultivars when moisture was restored (18.3 MJ/bale) but dropped almost 40% to 11.3 MJ/bale without moisture addition. For this reason, SG521RR energy data was excluded from the energy data analysis. For the other cultivars, energy consumption averaged 21.3 MJ (5.91kWh) per bale and varied 14.4% between cultivars.

Properties that stood out for SG521RR compared with the other cultivars were low turnout (Table 2), low moisture (Table 1), high content of hulls, sticks, and motes in seed cotton samples taken at the gin stand feeder (Table 3), low strength (Table 4), high AFIS trash levels (Table 5), and poor fiber length properties (Tables 4 and 6). The cultivar SG521RR was also picked one year earlier than the other cultivars in that test, and it was kept in a covered trailer for over a year before ginning. Reduced energy consumption for this cultivar could have been related to low fiber strength, but it is unknown why moisture addition increased energy consumption. For all other parameters measured, cultivars showed similar responses to treatments. As described earlier, treatment replications were blocked by cultivar, and interactions between cultivar and treatments were considered random sources of variability. For this reason, statistical analyses of these interactions are not presented in this report.

One model for energy consumption included cultivar, dryer temperature, moisture addition, and their interaction (Table 2). Overall, energy consumption was reduced 1.0% with the addition of moisture, but the difference was larger at lower dryer temperatures. As dryer temperatures increased by 50 °C (90 °F), energy consumption decreased 0.82 MJ (0.23 kWh) per bale (3.9%) without moisture addition, but energy consumption varied less with dryer temperature when moisture was added (Fig. 2).

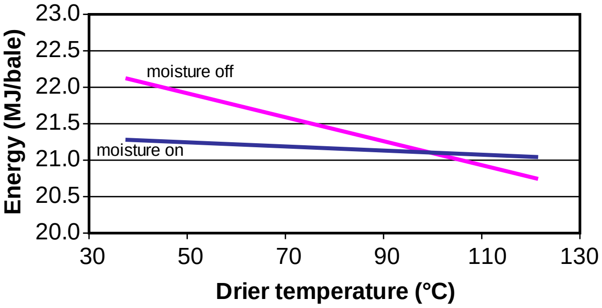

Figure 2. Regression of gin stand energy consumption with dryer temperature for each moisture addition treatment (on or off).

Table 2. Means, regression parameters, and statistical significance for ginning rate, energy consumption, turnout, and ambient conditions

Factor	Ginning rate (bale/h)	Energy [MJ (kWh)/ bale]^y	Turnout (%)	Temp. (°C)	Relative humidity (%)
Cultivar					
BXN49B	**4.83**	**22.2 (6.17)**	**34.74**	**18**	**47**
DP555BR	**5.66**	**19.5 (5.42)**	**39.23**	**28**	**67**
SG105	**5.81**	**21.9 (6.09)**	**36.04**	**24**	**86**
SG521RR	**5.85**	**14.8 (4.11)**	**31.20**	**22**	**40**
ST4892BR - 02	**5.35**	**20.1 (5.59)**	**33.93**	**18**	**58**
ST4892BR - 03	**5.68**	**22.6 (6.27)**	**37.10**	**26**	**74**
Moisture					
Off	**5.54**	**21.4 (5.94)**	**35.70**	**23**	**66**
On	**5.61**	**21.2 (5.88)**	**36.08**	**24**	**65**
Dryer temperature			**Slope^z**		
Per 50 °C	**-0.13**	**na**	**-0.14**	**-0.24**	**2.82**
Interaction					
Moisture off, per 50 °C	**na**	**-0.82 (-0.23)**	**na**	**na**	**na**
Moisture on, per 50 °C	**na**	**-0.15 (-0.04)**	**na**	**na**	**na**
			Probability values^z		
Cultivar	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Moisture	**0.2663**	**0.0033**	**0.0365**	**0.4216**	**0.8691**
Dryer temperature	**0.0344**	**0.0003**	**0.3938**	**0.4561**	**0.2794**
Dryer temp.*moisture	**na**	**0.0086**	**na**	**na**	**na**

[y] SG521RR is not included in data analysis for energy consumption.

[z] na = not applicable. The appropriate analysis for dryer temperature and moisture included the interaction only if it was significant.

Table 3. Means, regression parameters, and statistical significance for fractionation of seed cotton at the gin stand feeder

Cultivar	Total (%)	Hulls (%)	Grass (%)	Sticks (%)	Motes (%)	Leaf (%)	Pin (%)
BXN49B	2.09	0.06	0.027	0.20	1.46	0.3090	0.0231
DP555BR	3.42	0.13	0.000	0.16	2.07	0.2167	0.0221
SG105	3.02	0.07	0.070	0.13	1.66	0.2397	0.0196
SG521RR	4.38	0.39	0.000	0.37	3.33	0.2192	0.0419
ST4892BR - 02	2.76	0.14	0.003	0.16	2.12	0.2915	0.0397
ST4892BR - 03	3.62	0.04	0.001	0.07	2.18	0.1955	0.0191
Moisture							
Off	3.26	0.13	0.016	0.15	2.12	0.2406	0.0263
On	3.24	0.12	0.021	0.19	2.07	0.2360	0.0252
Dryer temperature				Slope			
Per 50 °C	-0.05	-0.02	-0.001	0.01	-0.03	-0.0037	-0.0031
				Probability values[z]			
Cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Moisture	0.6700	0.5688	0.3583	0.0948	0.1919	0.4152	0.5394
Dryer temperature	0.3697	0.1757	0.8334	0.6147	0.424	0.5146	0.0989

[z] There were no significant interactions between dryer temperature and moisture addition.

Table 4. Means, regression parameters, and statistical significance for HVI data

Factor	Micronaire	Strength (cN/tex)	Length (cm)	Area (%)	Leaf	Rd	+B
Cultivar							
BXN49B	4.89	27.63	2.853	0.213	2.93	79.17	9.49
DP555BR	4.24	28.27	2.764	0.386	3.10	80.22	7.08
SG105	4.61	28.71	2.781	0.506	3.74	75.92	7.61
SG521RR	4.25	23.99	2.713	0.453	3.77	70.50	9.87
ST4892BR - 02	4.64	28.55	2.765	0.413	3.67	73.07	9.47
ST4892BR - 03	3.90	28.12	2.711	0.472	3.80	76.48	8.24
Moisture							
Off	3.85	27.46	2.752	0.405	3.46	76.23	8.38
On	3.87	28.05	2.771	0.433	3.57	76.38	8.38
Dryer temperature				Slope			
Per 50 °C	-0.049	-0.39	-0.014	-0.081	-0.20	0.17	0.06
				Probability values[y]			
Cultivar	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Moisture	0.4917	0.0035	0.0058	0.0622	0.1763	0.4780	0.9623
Dryer temperature	0.2101	0.0322	0.0167	0.0001	0.006	0.4044	0.1902
Lint moisture[z]	na	na	na*	na*	na*	na	0.0161

[y] na = not applicable. The appropriate analysis for dryer temperature and moisture included the interaction only if it was significant. There were no significant interactions between moisture, temperature, and lint moisture.

[z] Means and regression parameters were not adjusted for lint moisture. * = the factor was significantly related to lint moisture, but the differences were associated with dryer temperature and moisture addition.

Lint moisture alone did not significantly explain variation in energy consumption. When factors were included that described how moisture was adjusted, lint moisture did contribute significantly to the model. An alternate model for energy consumption included cultivar, moisture addition, dryer temperature, lint moisture before lint cleaner, and the interaction between lint moisture and dryer temperature (Table 7). This alternate model explained more variation in energy consumption than the first model. The standard errors for these parameters were also reported in Table 7. The regression parameters were used to plot gin stand energy with lint moisture (Fig. 3). Lines were plotted with and without moisture addition at three dryer temperatures (40, 80, and 120 °C), which represent the low, medium, and high dryer levels used in the experiment. Each line was plotted over the range of lint moistures seen in the experiment under those conditions. Energy consumption initially increased as dryer temperature increased and lint moisture decreased, but as dryer temperatures continued to rise and moisture fell below 5%, energy consumption began to decrease. Overall, moisture addition decreased energy consumption by 1.37% or 0.3 MJ (0.08 kWh) per bale (std. err. = 0.037) regardless of dryer temperature or lint moisture content.

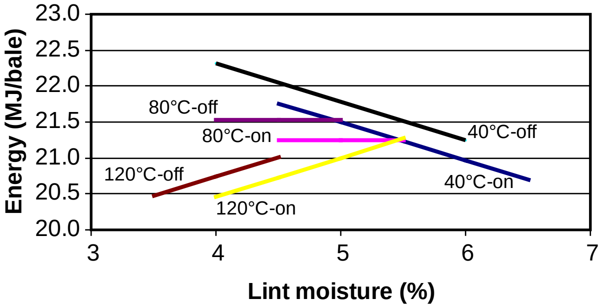

Figure 3. Regression of gin stand energy consumption with lint moisture before lint cleaning for each moisture addition (on or off) and dryer temperature treatment.

Table 5. Means, regression parameters, and statistical significance for AFIS trash, nep, and maturity data

Factor	Dust/g lint	Trash/g lint	Visible foreign matter (%)	Nep size (µm)	Neps/g lint	Seed coat neps/g lint	Immature fiber content (%)	Maturity ratio	Fineness (mTex)
Cultivar									
BXN49B	**310**	**67**	**1.29**	**694**	**194**	**10.80**	**2.84**	**0.905**	**188.1**
DP555BR	**345**	**72**	**1.37**	**690**	**278**	**9.11**	**4.00**	**0.872**	**165.4**
SG105	**390**	**89**	**1.64**	**698**	**218**	**12.81**	**3.27**	**0.894**	**179.3**
SG521RR	**654**	**111**	**2.27**	**703**	**271**	**17.39**	**4.61**	**0.832**	**174.4**
ST4892BR - 02	**495**	**107**	**1.95**	**700**	**180**	**13.44**	**3.13**	**0.901**	**184.9**
ST4892BR - 03	**405**	**99**	**1.71**	**689**	**254**	**10.93**	**3.72**	**0.868**	**171.8**
Moisture									
Off	**410**	**86**	**1.60**	**694**	**247**	**11.68**	**3.68**	**0.875**	**175.7**
On	**430**	**93**	**1.75**	**696**	**227**	**12.42**	**3.54**	**0.882**	**176.4**
Dryer temperature					**Slope[y]**				
Per 50 °C	**-51**	**-14**	**-0.26**	**na**	**13.6**	**-0.82**	**0.11**	**-0.007**	**-1.1**
Interaction									
Moisture off, per 50 °C	**na**	**na**	**na**	**-3.2**	**na**	**na**	**na**	**na**	**na**
Moisture on, per 50 °C	**na**	**na**	**na**	**4.3**	**na**	**na**	**na**	**na**	**na**
					Probability values[y]				
Cultivar	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Moisture	**0.0254**	**0.0006**	**0.0002**	**0.0144**	**0.0003**	**0.0228**	**0.0061**	**0.0007**	**0.2647**
Dryer temperature	**0.0001**	**0.0001**	**0.0001**	**0.6735**	**0.006**	**0.0059**	**0.0106**	**0.0002**	**0.0934**
Dryer temperature*moisture	**na**	**na**	**na**	**0.0041**	**na**	**na**	**na**	**na**	**na**
Lint moisture[z]	**na***	**na***	**na***	**na**	**na***	**na***	**na***	**na***	**na**

[y] n.a. = not applicable. The appropriate analysis for dryer temperature and moisture included the interaction only if it was significant.

[z] * = the factor was significantly related to lint moisture, but the differences were associated with dryer temperature and moisture.

Table 6. Means, regression parameters, and statistical significance for AFIS fiber length distribution

Factor	Fiber length distribution by weight				Fiber length distribution by number				
Cultivar	**Mean (cm)**	**Coeff. of variation**	**Upper quartile (cm)**	**Short fiber content (%)**	**Mean (cm)**	**Coeff. of variation**	**Short fiber content (%)**	**Upper 5% (cm)**	**Upper 2.5% (cm)**
BXN49B	2.477	32.29	2.988	8.08	2.019	47.59	24.36	3.358	3.554
DP555BR	2.394	35.73	2.960	10.56	1.875	52.77	29.98	3.354	3.581
SG105	2.468	30.93	2.928	7.07	2.031	46.48	22.80	3.280	3.480
SG521RR	2.358	33.06	2.839	9.06	1.925	47.40	25.52	3.208	3.418
ST4892BR - 02	2.463	31.27	2.926	7.24	2.054	44.71	21.72	3.294	3.498
ST4892BR - 03	2.424	31.72	2.888	7.72	2.012	45.19	22.55	3.243	3.450
Moisture									
Off	2.409	32.96	2.906	8.74	1.956	48.20	25.53	3.273	3.480
On	2.451	32.18	2.939	7.92	2.009	46.92	23.77	3.308	3.517
Dryer temperature					**Slope**				
Per 50 °C	-0.034	0.49	-0.027	0.57	-0.039	0.79	1.16	-0.028	-0.029
					Probability values[z]				
Cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Moisture	<0.0001	<0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	0.0003
Dryer temperature	<0.0001	0.0020	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	0.0010	0.0008
Lint moisture	0.0106	0.0193	0.0159	0.0171	0.0168	0.0308	0.0176	0.0278	0.0542

[z] There were no significant interactions between dryer temperature, moisture addition, or lint moisture. Probability values for moisture and dryer temperature were less than 0.0001 for all measurements when lint moisture was excluded from the model. Means and regression parameters were not adjusted for lint moisture.

Table 7. Regression parameters and statistical significance of values for the alternate model of gin stand energy consumption

Parameter	Energy consumption		
	Estimate (MJ/bale)	**Standard error of estimate**	**P-value for estimate**
Intercept	27.1	0.37	<0.0001
Lint moisture (%)	-1.07	0.066	<0.0001
Dryer temperature (°C)	-0.074	0.0040	<0.0001
Lint moisture*dryer temp.	0.0135	0.00084	<0.0001
Moisture addition on	-0.29	0.037	0.0353
Least squares means	**MJ/bale**		
Moisture off	21.4		
Moisture on	21.1		

Ginning rate and turnout. Ginning rates varied between cultivars and ranged from 4.83 bale/hr for BXN49B to 5.85 bale/hr for SG521RR (Table 2). Despite efforts to maintain constant ginning rates between treatments within each block (cultivar), ginning rate decreased by 0.13 bale/h as dryer temperatures increased by 50 °C (90 °F). Ginning rate did not change when moisture was added. Differences in gin stand energy consumption were not related to changes in ginning rate. Gin turnout increased by 0.38% (2.4 kg or 5.3 lb per bale) when moisture was added, but dryer temperatures were not shown to impact gin turnout (Table 2).

Seed cotton properties. The fractionation of seed cotton entering the gin stand did not reveal any differences due to adding moisture with humidified air or to changing dryer temperatures (Table 3). Differences were seen among cultivars.

Fiber properties. Increased dryer temperatures reduced leaf grade and HVI percentage area, but moisture addition did not have a significant impact on these properties (Table 4). Increased dryer temperatures reduced AFIS trash levels, and moisture addition increased AFIS trash (Table 5). Leaf grade, HVI percentage area, and AFIS trash properties were all increased with lint moisture, but the differences were associated with the treatment factors (dryer temperature and moisture addition). Color grades, based on HVI reflectance (Rd) and yellowness (+B), were not influenced by dryer temperature or moisture addition, but +B decreased by 0.092 per percentage of lint moisture (Table 4).

Fiber length (HVI) improved by 0.019 cm (0.008 in) with moisture addition and decreased 0.014 cm (0.006 in) with a 50 °C (90 °F) increase in dryer temperature (Table 4). Similar trends were seen for all AFIS fiber length properties (Table 6). The addition of moisture improved the average fiber length by weight by 0.042 cm (0.016 in) and the upper quartile length by 0.033 cm (0.013 in). A 50 °C (90 °F) increase in dryer temperature reduced average length by 0.034 cm (0.014 in) and the upper quartile length by 0.027 cm (0.011 in). The short fiber content by weight (percentage of fibers under 1.27 cm or 0.5 in) was reduced by 0.82% with the addition of moisture and increased with dryer temperature by 0.57% per 50 °C (90 °F). Similar trends were seen for changes in AFIS fiber length distribution based on number of fibers. For fiber length distributions by both weight and number, treatment differences were larger for mean values than upper percentile values. The coefficient of variation for fiber length decreased with the addition of moisture and increased with dryer temperature. All HVI and AFIS fiber length properties showed significant improvements with moisture addition and significant damage with increased dryer temperature. These properties also improved with increased lint moisture, but the treatment effects of dryer temperature and moisture addition explained changes in these properties more completely.

The addition of moisture reduced neps by 8.1% from 247 to 227 per gram of lint but increased seed coat neps by 6.3% from 11.68 to 12.42 per gram lint (Table 5). Increasing dryer temperatures by 50 °C (90 °F) increased neps by 14 per gram lint (5.7%) but reduced seed coat neps by 0.82 per gram lint (6.8%). This was due to improved cleaning of cotton under dryer conditions where seed coat neps were more likely to loose their "seed coats" (or other material) and become neps. The addition of moisture increased the size of neps from 694 to 696 μm, but dryer temperature affected nep size differently depending on moisture addition. Without the addition of moisture, nep size was reduced by 3.2 μm (4.6%) per 50 °C (90 °F), but with the addition of moisture, nep size was increased by 4.3 μm (6.2%) per 50 °C (90 °F). As lint moisture increased, nep counts increased and seed coat nep counts decreased, but these differences were associated with dryer temperatures and moisture addition.

Fiber strength (HVI) increased 0.59 cN/tex (0.60 g/tex) with the addition of moisture and decreased 0.38 cN/tex (0.39 g/tex) with a 50 °C (90 °F) increase in dryer temperature, but strength did not change with lint moisture (Table 4). The addition of moisture reduced the immature fiber content (IFC) from 3.68% to 3.54% and raised the maturity ratio from 0.875 to 0.882 (Table 5). Increasing dryer temperatures by 50 °C (90 °F) raised the IFC 0.11% and decreased the maturity ratio by 0.007. Changes in IFC and maturity ratio correlated with lint moisture but more closely followed changes in dryer temperature and moisture addition. Micronaire (Table 4) and fineness (Table 5) were not influenced by moisture addition, dryer temperature, or lint moisture content.

DISCUSSION AND CONCLUSIONS

This research investigated the impact of moisture conditioning on fiber quality and gin stand energy requirements. Humidified air added to cotton as it entered the extractor-feeder raised lint moisture (wet basis) by 0.53% (5.3 g/kg or 2.6 lb/bale) measured after the lint cleaner. This increase was 1.0% (10 g/kg lint) estimated from the gin stand feeder moisture and 1.6% (16 g/kg lint) estimated from the difference in seed cotton moisture before and after moisture addition. This indicated that much of the moisture added to seed cotton was lost before reaching the bale.

Increasing dryer temperatures by 50 °C (90 °F) decreased lint moisture by 0.81% (8.1 g/kg or 4.1 lb/bale) measured after the lint cleaner. This decrease was 15 g/kg lint estimated from the gin stand feeder moisture and 27 g/kg lint estimated from the difference in seed cotton moisture before and after drying. This indicated that cotton dried at high temperatures picked up moisture from the conveying air.

Net energy consumed by the gin stand (difference between ginning and idling) averaged 21.3 MJ (5.91 kWh) per 227-kg (500-lb) bale. Increasing dryer temperatures increased energy consumption as the fiber was dried to 5%, but as dryer temperatures continued to increase and the moisture content dropped, energy consumption was reduced. In addition to this response to dryer temperature and lint moisture, the addition of moisture with humidified air reduced the energy consumption of the gin stand by 1.4% (0.3 MJ or 0.08 kWh per bale), regardless of the actual lint moisture content.

It has been shown that the electrical resistance of a fiber increases as it is dried, and the static charge between fibers can be reduced by adding moisture (Slade, 1998). It has also been shown that drier fibers are weaker, both individually (Anthony and Griffin, 2001) and in a bundle (Byler et al., 2001). Electrical properties of fibers, static charges, and fiber friction were not measured in this experiment, and instantaneous fiber strength measurements were not made in the gin stand, but it was speculated that a reduction in fiber moisture with increased dryer temperature may have increased the electrical resistance of the fiber and, therefore, static, while fiber strength was reduced. As the fiber dried, initial increases in energy consumption may be attributed to increased static charge, but as moisture continued to drop below 5%, the reduction in fiber strength may have caused a drop in energy consumption that overshadowed the effect of static. Below 5% lint moisture, static charge may have stabilized because of the electrical resistance of the fibers reached a maximum, a phenomenon reported by Slade (1998). The drop in energy consumption with moisture addition may be attributed to changes in surface moisture, since these differences were not explained by total moisture content. These differences could be due to the lubricating effect of the applied surface moisture or its influence on static dissipation. Most of the changes in energy consumption may be attributed to changes in fiber-to-fiber friction, fiber-to-metal friction, static energy, or fiber strength. These changes were probably not related to fiber-seed bond strength.

The results of this research support previous experiments where fiber quality was preserved by proper moisture conditioning. All HVI and AFIS fiber length parameters were significantly improved by adding moisture before the gin stand and minimizing dryer temperature. The addition of humidified air improved gin turnout, HVI strength, AFIS neps, immature fiber content, and maturity ratio. Humidified air also increased AFIS trash levels, AFIS nep size, and number of seed coat neps. Humidified air did not significantly alter HVI trash, micronaire, +B, or AFIS fineness. Increasing dryer temperature improved HVI and AFIS trash properties and reduce seed coat neps, but raising dryer temperature also reduced HVI strength, increased AFIS neps, increased immature fiber content, and reduced maturity ratio. Dryer temperature did not change gin turnout or micronaire.

This research points out changes in gin stand energy consumption that occur with moisture conditioning, and the corresponding changes in fiber quality. Understanding what causes changes in energy consumption could lead to improvements in moisture conditioning practices and reduction in fiber damage. Strengthening fibers, lubricating fibers, and reducing static charge in the gin stand seem to be important factors to consider in future experiments.

DISCLAIMER

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