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Historical Review on the Effect of Moisture Content and the Addition of Moisture to Seed Cotton before Ginning on Fiber Length

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ABSTRACT

Seed cotton drying equipment was first used in the U. S. during the 1940s. Problems with fiber length associated with excessive drying were observed almost immediately. At first, high drying temperatures were blamed for the damage, but later it appeared that the fiber moisture content was the more important factor. Increased drying consistently improved grade, mostly due to the improved cleaning efficiency, and the negative impact on fiber length was less consistently observed. Staple, the fiber length measurement used in pricing, was often, but not always, improved when ginning at higher moisture content. Significantly lower yarn strength often resulted from cotton ginned at lower moisture content even when the staple length was not affected significantly. Reviewed literature consistently supported ginning at moisture content levels above 6% to preserve fiber length quality, but current data show that this goal is not being achieved. It has been shown that during periods of good weather the seed cotton is drier than desirable for ginning without additional drying. Several studies supported the practice of adding moisture to low moisture seed cotton, either as a vapor or liquid spray, before the gin stand in order to better preserve the fiber length quality.

The moisture content of upland cotton fiber substantially affects many of its physical properties and its response to processing in the gin. The moisture content of cotton fiber changes readily, because of its exposure to moisture levels in the air. Excessive moisture content of cotton in the gin has been a problem, especially in the more humid areas of the US. The first successful pneumatic seed cotton dryers were introduced in the late 1920s (Gerdes et al., 1941). The U. S. Cotton Ginning Laboratory was established in Stoneville, MS, in 1930 and at first concentrated on the problems associated with excessive moisture in seed cotton, which resulted in the development of the vertical tower dryer (Gerdes et al., 1941). Dryers of several different designs were quickly accepted by the U. S. cotton industry (Mangialardi and Anthony, 2003). According to Gerdes et al. (1941), 1.6% of the U.S. gins were equipped with dryers in 1935, 6.6% by 1938, and by 1940 the proportion had increased to 11.5%. By 1951, 81% of the gins were reported to be equipped with dryers (Griffin and Merkel, 1953). Many of the early dryers used the low-pressure exhaust steam from the power plant of the gin through a heat exchanger as the source of heat (Bennett, 1936). Others used waste heat from internal combustion engine and independent “furnaces” fired by coal, oil, or gas (Gerdes et al., 1941). All of these dryers, referred to as pneumatic dryers, used heated air in contact with the seed cotton as the primary drying method.

These pneumatic dryers helped solve the problem of seed cotton with high moisture content that plagued farmers in certain years, especially in the Mississippi River Valley. Artificial drying of seed cotton resulted in more trouble free gin operation and facilitated removal of foreign matter. In addition, the resulting ginned lint had a “smoother” look for less grade penalty because of rough preparation (Griffin and Merkel, 1953). Gerdes et al. (1941) reported that some gins used excessive drying that resulted in reduced fiber length and strength, but no data were presented. Some gins used two or three dryers in series with drying temperatures as high as 177 °C (350 °F) (Gerdes, 1950). Compared with managers processing machine-picked cotton, those processing hand-picked cotton found that the cleaning with lint dried as low as 3.9% resulted in better grades and prices despite the penalties from damage to the fiber length and strength caused by ginning the dry cotton. Data collected by Gerdes (1950) showed that drying at temperatures up to 177 °C improved grade but had a tendency for lower fiber length and fiber tensile strength. The yarn spun from the more aggressively dried cotton had lower skein strength.

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These trends were presented graphically but did not include statistical analysis.

Early studies on the effect of drying on fiber length. In 1952, the National Cotton Council of America (1952) published a report compiled by an industry-wide committee of producers, gins, mills, USDA offices, and others. Collected data on 450 bales of cotton that had been processed in commercial gins and mills were statistically analyzed. The five treatments used in each of the six gins were as follows: 1) "normal," 2) faster ginning rate, 3) bypassing overhead cleaning, 4) bypassing lint cleaning, and 5) increasing temperature in the dryers. Each treatment at each gin was applied to five bales. The means of lint moisture content at the lint slide for the five treatments ranged from 1.8% to 7.8%. The ginning procedures significantly affected the lint moisture content, the grade of the lint (which included trash level at that time), the nep count in the raw cotton and in the spun yarn, and the yarn strength. The yarn strength was not significantly ($P < 0.05$) reduced by the high temperature drying but was affected by the non-lint levels because of the treatments. In only a few instances did ginning methods significantly ($P < 0.05$) affect lint staple length, fiber strength, and the fiber length measurements of upper half mean length, mean length, and length uniformity. It was concluded that "excessive drying improved grade" (National Cotton Council, 1952, p. 17) because of more efficient cleaning. There were differences in the total mill waste because gin cleaning equipment was bypassed. Drying at higher temperature contributed to increased neps, but mill processing also contributed to nep levels. The number of ends down was highest for the gin treatment with increased dryer temperatures, but the difference was not statistically significant. Statistical analysis of data from this relatively extensive test showed that ginning at increased temperatures improved the grade, which would result in a better price for the cotton, but did not consistently affect any other factors that influenced price, except weight. Drying at higher temperatures also did not consistently affect any of the spinning measurements included in the test. Selected data from this ginning study are presented in Table 1 along with data related to fiber length measurements from similar studies before 1990.

Montgomery and Wooten (1958) picked seed cotton in the early morning and afternoon from the same field in the Mississippi Delta and compared cotton grades. The ginned lint had substantially different moisture content (ranging from 4.4% to 8.1%), and the lint resulting from cotton harvested in the morning consistently had higher fiber moisture content than from cotton harvested in the afternoon ($P < 0.1$) with a mean difference of 1%. Cotton harvested in the afternoon resulted in significantly better composite grade, based on color and trash level ($P < 0.05$). There were no statistically significant differences in staple length or Pressley strength, but the mean fiber length measurement ($P < 0.05$) and upper half mean length ($P < 0.10$) from seed cotton harvested in the morning was higher than from cotton harvested in the afternoon. No

Table 1. Summary of statistical significance of moisture content effects on specified measurements and the moisture content range included in ginning studies conducted before 1990

Study	Range of lint moisture content (%)	USDA classing[z]		Fibrograph length[z]		Yarn strength[z]
		Staple	Grade	Uniformity	Upper half mean	
National Cotton Council of America (1952)	1.8 - 7.8	NS	<0.01	NS	NS	<0.01
Montgomery and Wooten (1958)	4.4 - 8.1	NS	<0.05	NS	<0.10	NS
Anderson et al. (1961a)	4.1 - 6.5	NS	<0.05	NS	<0.05	<0.05
Moore and Griffin (1964)	4.7 - 6.5	Y	--	--	Y	Y
Mangialardi et al. (1965)	3.3 - 6.2	NS	Y	NS	<0.01	<0.01
Leonard et al. (1970)	2.4 - 8.8	<0.01	NS	<0.05	<0.01	<0.01
Lafferty (1971)	3.7 - 7.6	<0.05	NS	<0.05	--	--
Cocke and Garner (1972)	3.9 - 5.6	<0.01	<0.01	<0.05	--	<0.01
Childers and Baker (1977)	3.6 - 6.7	NS	<0.05	--	--	<0.05
Mangialirdi and Griffin (1977)	5.5, 7.1	NS	Y	Y	Y	--

[z] Number refers to the probability that observed differences were due to chance; NS = the difference was not statistically significant, Y = difference was observed, but not supported with statistics, -- = not documented.

information about the number of specimens analyzed, the analysis procedures, or the statistics used was provided, but the level of significance for the mean differences was included.

Anderson et al. (1961a, 1961b) conducted a study at J. G. Boswell Company, Corcoran, CA, to examine how harvest and ginning procedures affected fiber quality. In the first report (Anderson et al., 1961a), five drying treatments were used on 45 bales of cotton with lint moisture content varying from 4.1% to 6.5% at the lint slide. Significant differences in moisture content related to drying treatments were observed ($P < 0.05$). The highest drying treatments resulted in a significantly better ($P < 0.05$) composite grade index for the lint. Although color and leaf varied, the reductions in composite grade were for leaf. There were no statistically significant variations in staple length, but there were significant differences in fibrograph-based mean length and upper-half mean length ($P < 0.05$). The variations in length uniformity ratio were not statistically significant. "The trend established in these data are in line with what one would expect" (Anderson et al., 1961a, p. 12) in a relationship between low moisture content of lint at ginning and fiber length degradation. The treatments that produced significantly lower moisture content fiber also produced significantly higher grade index and significantly lower fiber mean length and upper half mean length. Yarn appearance or neps in the yarn were not significantly different ($P < 0.05$) because of the drying temperatures, although the yarn appearance was degraded by running the seed cotton twice through the dryers with the highest settings. In the second report (Anderson et al., 1961b), the lint was dried to a range of 3.3% to 4.5%, which was a lower moisture content than in the previous study. This study was not primarily focused on drying, but the seed cotton that was dried the most produced fiber with lower fiber length properties, although the differences were not statistically significant.

Griffin (1964) recommended that moisture content of cotton fiber be 7% to maintain fiber quality while ginning and presented information to support the idea. Graphic data showed an approximately 3% decrease in yarn break factor for each percentage increase in short fiber content over the range of 7% to 11% short fiber content. Short fiber content increased with ginning at a fiber moisture content of 3% compared with a moisture content over 7%. Generally, an increase in short fiber content of 1% for each percentage decrease in fiber moisture content while ginning, which resulted in an approximate 2.6% decrease in yarn break factor.

Cocke and Garner (1972) ginned spindle-picked cotton with an average lint moisture content at the lint slide of 3.9% or 5.6%, which were achieved by controlling the drying. Two seed cotton cleaning levels and three lint cleaning levels were examined. Comparisons were made using a split-plot design. Processing at lower moisture content resulted in better cleaning efficiency and higher reflectance. Fiber length uniformity ratio and 2.5% span length before and after lint cleaning were adversely affected by ginning at the lower moisture content ($P < 0.05$). Before lint cleaning, the 2.5% span length was reduced from 28.7 mm to 28.4 mm (1.13 to 1.12 in), and after lint cleaning it was reduced from 28.4 mm to 27.9 mm (1.12 to 1.10 in). The USDA determined that mean staple length was reduced ($P < 0.01$) from 35.5 mm to 34.9 mm. The spinning results showed that the 50s yarn strength decreased ($P < 0.01$) from 412 N to 382 N (42 to 39 lbs) because of ginning at lower moisture content.

Moisture content vs. drying temperature. Extensive testing at Stoneville, MS, in 1949 and 1950 showed the following: 1) the greater the drying of seed cotton the better the color and leaf grade of the ginned lint; 2) fiber length, fiber strength, and yarn strength tended to decrease with increasing drying; 3) cotton fiber dried to 4% moisture content produced somewhat inferior fiber and spinning quality compared with those dried and ginned at 6.5% to 8%; 4) fiber and spinning quality due to gin drying correlated better with moisture content at ginning than with drying air temperature; and 5) cottons dried to 3% fiber moisture content using temperatures of 54, 93, and 159 °C (130, 200, and 318 °F) exhibited similar fiber and spinning properties (Griffin and Mangialardi, 1961). Moisture was restored to the seed using water vapor and liquid. The authors determined that "the efficiency of cleaning units following moisture restoration was seriously impaired" (Griffin and Mangialardi, 1961, p. 6).

Mangialardi and Griffin (1965) showed that fiber length quality deteriorated with added lint cleaning, especially at lower fiber moisture content. This work demonstrated trends and was intended to provide guidance to the ginning industry. Data were collected at 12 fiber moisture content levels and four lint cleaning levels and showed that the lint classification grade increased with increased drying and additional lint cleaning. Statistical analysis was not provided, but their data showed a consistent and "statistically highly significant" (Mangialardi and Griffin, 1965, p. 15) decrease in staple length related to ginning at lower moisture content and a decrease in 50% span length because of ginning at low moisture content and the use of additional lint cleaning.

Hughs and Price (1998) evaluated three drying treatments with four replications each to evaluate the impact of drying on fiber length. The three treatments involved were harvesting high moisture content seed cotton and ginning with considerable drying; harvesting at moderate fiber moisture content and ginning with considerable drying; and harvesting at moderate fiber moisture content and ginning with no additional artificial drying. Ginning at low fiber moisture content (3.1%) resulted in decreased fiber length quality compared with ginning at moderate moisture content (6.2%) ($P < 0.05$) even when the seed cotton was originally at 19% moisture content and 177 °C and 204 °C air temperatures were used in the dryers. Considerable mill-related measurements were provided. For example, single carded ring spun 50/1 skein strength was reduced for the dry seed cotton that was aggressively dried but not for the damp seed cotton that was aggressively dried ($P < 0.05$). Similar data was presented for rotor spun yarn. The authors emphasized that proper removal of moisture from lint did not result in reduced the fiber length quality in ginning, but excessive drying of fibers resulted in decreased quality. Ginning with lint at low moisture content, not high drying temperatures, resulted in the fiber damage.

Anthony and Griffin (2001a and 2001b) described the results of research by Griffin. These data provided much of the support for statements made in earlier publications by Griffin. Individual cotton fiber strength and fiber-seed attachment force varied over a wide range, but fiber strength/attachment force ratio was more constant at 1.8. Individual fiber strength increased with increasing moisture content, but that the fiber-seed attachment force remained constant or decreased somewhat in the 10% to 13% range. The study showed that drying air temperatures up to 100 °C (212 °F) for already dry seed cotton contributed no additional broken fibers, air temperatures in the range 125 °C to 175 °C caused increasing additional broken fibers, and drying air temperatures above 200 °C (392 °F) caused "intolerable" fiber damage. For the samples dried with air at or below 150 °C, fiber length damage at ginning could be prevented by moisture restoration before ginning, but, if higher temperatures were used, moisture restoration could not fully prevent additional fiber damage. Data to support the hypothesis that the reduced fiber strength was due to a permanent reduction in the fiber equilibrium moisture content was presented.

Anthony and Griffin (2001b) presented data from one test performed in a gin using drying temperatures in the range 20 °C to 250 °C (68 to 482 °F) with batch moisture restoration using four relative humidity levels. The fiber length was measured with the digital fibrograph on six samples per treatment. The statistical analysis showed that the fiber length data from some treatments was significantly different than from others ($P < 0.05$). The pattern in the data suggested that increasing drying temperatures resulted in increasing fiber length reduction, but the fiber moisture content was the key factor. Similarly, moisture restoration before ginning with higher relative humidity resulted in better fiber length. The slope of the relationship between fiber span length (2.5 and 50%) and fiber moisture content was 0.11 mm (0.0043 in) per percentage point of moisture content.

Mechanism for fiber length damage. Moore and Griffin (1964) presented data showing that single fiber breaking force increases with increasing moisture content in the range of 3% to 15%, while fiber-seed attachment forces remain constant from 3% to about 11% and then decrease up to 15% moisture content. These data provided an explanation for why ginning at higher moisture content improved fiber length quality. Increasing the dryer temperature decreased the fiber moisture content in the gin, and fiber length quality also decreased. Adding moisture at the lint slide did not improve the fiber length quality, but adding moisture before ginning did improve fiber length. Staple length was not measurably affected by the moisture content changes before ginning, but upper quartile length and short fiber measurements were affected. The Pressley strength was reduced for cotton ginned at lower moisture content. The yarn break factor and single strand strength were adversely affected by ginning at low moisture content. A moisture restoration test was described that used humid air or water spray before ginning. The data supported the idea of using moisture restoration by either method. This publication was intended to help improve ginning industry practices, but included little information about how the samples were obtained or analyzed and how well the conclusions were supported by the data. Although ginning at low moisture content did not have a measurable effect on staple length, it did affect short fiber content and led to decreases in yarn strength. The authors proposed that the broken fibers were the key to increased short fiber and lower fiber strength.

Data related to modeling. Wesley and Anthony (1979) ginned cotton under controlled conditions with 14 machine treatments. The treatments resulted in significant differences in lint moisture content in two ranges 7.4% to 8.3% and 4.8% to 5.7% ($P < 0.05$), but this research was not intended to study possible effects of ginning at different moisture content on fiber quality. There were no significant differences in staple length, the only length measurement used, within each of the two moisture ranges. Between the two moisture ranges, staple length was lower for the treatments with lower fiber moisture content, but no conclusions or statistics regarding this relationship were presented.

Barker and Baker (1986) used data found in the literature to develop mathematical models of fiber quality properties as a function of initial lint moisture content and lint cleaner properties for a system of lint cleaners, including the effects on fiber quality due to lint moisture content before the lint cleaners. In their models, the fibrograph length was not affected by the fiber moisture content, but the length uniformity ratio was affected. Statistics about the fit of the models to the data were provided.

Anthony (1990) developed equations to describe many cotton fiber properties as they were affected by various specific gin machine combinations using three lint moisture levels (4.1%, 5.5%, and 8.4%) and two cotton cultivars. The fiber length measurements were staple length, and length uniformity, as measured by the High Volume Instrument (HVI), and fiber length distribution, as measured by the Peyer AL-101. The Peyer length data included mean length, length coefficient of variation, short fiber content, and length levels at 2.5% and 25%. The statistical analysis of the data showed that the measured fiber length properties were variable, as expected. The staple length, HVI length, and Peyer length data all varied significantly with ginning moisture content ($P < 0.05$). The coefficient of determination (R^2) of his models to the fiber length data for his "standard" gin configuration generally was 0.86 or higher. The probability that the coefficients for the moisture terms could actually be zero for the staple length and HVI length equations was nearly 0.2, so the models would often not be considered to be statistically significant. The fit to the Peyer length data was more convincing because the probability for most of the coefficients being significantly different from zero was less than 0.1. Table 2 shows the results from analysis of selected fiber length data by several researchers since 1990.

Anthony (1996) performed extensive testing using several cotton cultivars with different ginning equipment sets to determine the performance characteristics of gin machinery. Two sets of data, each having three moisture content levels obtained by ginning with different drying temperatures, were collected. The first data set had a moisture content low of 3.4% and a high of 6.6%, and the second data set had a low of 3.8% and a high of 6.3% after lint cleaning. The Peyer AL-101 was used for fiber length measurement, and data from HVI measurements were provided. The data consistently showed that ginning at lower drying temperatures resulted in decreased cleaning efficiency, which resulted in higher leaf and HVI trash and in lower color grade index. The data also consistently showed that ginning with lower drying temperature resulted in improved

Table 2. Summary of statistical significance of moisture content effects on specified measurements and the moisture content range included in ginning studies conducted after 1990

Study	Range of lint moisture content (%)	USDA classing[z]		HVI[z]		AFIS length[z]	
		Staple	Grade	Length	Uniformity	Upper quartile	Coefficient of variation
Anthony (1990)	4.1 - 8.4	<0.05	<0.05	<0.05	<0.05	--	--
Anthony (1996)	3.4 - 6.6	<0.05	<0.05	<0.05	<0.05	--	--
Hughs and Price (1998)	3.1 - 6.2	<0.05	<0.05	<0.05	NS	--	--
Byler (2003)	4.7 - 5.8	--	--	--	--	<0.01	<0.01
Byler (2005)	4.6 - 6.1	--	--	NS	NS	<0.01	<0.01
Boykin (2005)	4.2 - 5.5	--	--	<0.01	--	<0.01	<0.01

[z]Number refers to the probability that observed differences were due to chance; NS = the difference was not statistically significant, -- = not documented.

fiber length properties, as measured by HVI or Peyer. For example, the Peyer upper quartile length was improved from 25.49 mm to 26.92 mm (1.00 in to 1.06 in) in the first data set and from 24.89 mm to 25.91 mm (0.98 in to 1.02 in) in the second set by ginning with lower drying temperatures ($P < 0.01$). Also, HVI length was improved from 28.19 mm to 28.96 mm (1.11 in to 1.14 in) in the first data set and from 27.43 mm to 28.19 mm (1.08 in to 1.11 in) in the second ($P < 0.01$). The HVI strength was improved ($P < 0.01$) by processing with lower drying temperature in both data sets.

Moisture restoration before ginning. For the years 1947 to 1949, Griffin and Merkel (1953) reported that nearly 80% of the ginned lint from the Mississippi Delta had moisture content below 6% and about 45% had moisture content below 5%. If the lint was dried below 5%, the cotton grade was not improved, but the upper half mean length and the resulting yarn strength were decreased. Laboratory tests supported the feasibility of adding moisture in the ginning process before seed cotton cleaning and at the lint slide after ginning. Staple measurements did not respond to moisture restoration in one test but did respond in another test. The means of the fibrograph and Suter-Webb fiber length measurements and yarn strength measurements demonstrated the advantage of using moisture restoration before ginning. When the fiber moisture content was increased from 3.7% to 6.8%, the fibrograph upper half mean length was improved from 25.4 mm to 26.4 mm (1.00 to 1.04 in), and the Suter-Webb mean length was improved from 22.4 mm to 23.9 mm (0.88 to 0.94 in). Statistical significance was not reported, but trends in the data supported the concept of adding moisture to seed cotton before ginning to maintain fiber length when the moisture content was below 5%. Adding moisture after ginning did not help maintain fiber length and yarn strength.

Mangialardi et al. (1965) ginned lint from one cultivar with various drying procedures and with moisture added before ginning using vapor or spray methods for some treatments. Fiber length quality was measured with the Suter-Webb array and the fibrograph. There were no statistical differences in staple length, but most of the other fiber length properties had significant differences related to the treatments. The higher moisture content cottons tended to have higher trash content and resulted in significantly higher Pressley fiber strength ($P = 0.01$). Data were also presented linking lower moisture content fiber at ginning to lower yarn break factor ($P = 0.01$). When moisture was added to the seed cotton after drying and cleaning but before ginning, the fiber and yarn properties improved. For "heavy drying", two 24-shelf tower dryers both set at 121 °C (250 °F) were included. The heavy drying in 1962 resulted in fiber moisture content of 2.7% and fibrograph upper half mean length of 26.7 mm (1.05 in), while heavy drying followed by spray-type moisture restoration resulted in fiber moisture content of 8.1% and upper half mean length of 27.7 mm (1.09 in).

Leonard et al. (1970) ginned one cultivar in 1961 and another cultivar in 1962 and applied several moisture treatments, including moisture restoration before ginning. The moisture treatments produced significantly different fiber moisture in the range 2.4% to 8.8% content entering the first lint cleaner. The vapor phase moisture restoration treatment was done in the extractor-feeder. The spray method involved spraying liquid water onto the seed cotton after seed cotton cleaning and storing the cotton for 30 min before ginning. The fiber length properties were measured with the Suter-Webb array and the fibrograph. The lint moisture contents were highly correlated with the fiber length with higher moisture content resulting in better fiber length quality ($P < 0.01$). The Suter-Webb array upper quartile length for cotton grown in Marana, AZ, varied from 29.0 mm to 30.0 mm (1.14 in to 1.18 in) and was significantly affected by the treatment ($P < 0.05$). The method of moisture content addition did not affect the results. Spinning data showed a significantly higher break factor for seed cotton ginned at higher moisture content in the gin ($P < 0.01$), which was achieved by less drying or by moisture restoration before the gin stand for the testing in 1961; however, the difference was not significant for similar work in 1962.

Lafferty (1971) ginned 137 bales in a commercial gin in 1963 through 1966 using moisture restoration with vapor or spray methods after seed cotton cleaning, as well as controls with no moisture restoration. The spray method involved storing the seed cotton in bins for about 25 min after moisture application before ginning, but the vapor method maintained normal cotton flow in the gin. All seed cotton was dried to moisture content in the 4.4% and 5.2% range. For cotton with moisture restoration, the seed cotton moisture content was above 7% at the feeder apron. At the lint slide, the cotton with moisture restoration averaged 1.7% higher than the control cotton. The results of a number of measurements and the results of statistical analysis of the data were presented. For the data from 1965 and 1966, the 2.5% span length was improved from 26.9 mm to 27.4 mm (1.06 in to 1.08 in) with the spray method and was statistically significant ($P < 0.05$). This length change was based on a moisture content at the lint slide of 5.2% versus 7.5%. The composite grade, including a trash component, of the treated cotton tended to be lower than the control, but the difference was not statistically significant. The fiber length and uniformity usually were higher for the treated cotton, and the difference in staple length of 0.2 mm was statistically significant for two years, but the same difference in staple length was not significant for two other years ($P < 0.05$). The percentage of short fibers, fibers with length less than 12.7 mm (0.5 in), were significantly higher ($P < 0.05$) for the drier cotton for all four years, and the fiber strength was significantly lower ($P < 0.05$) for cotton ginned at lower moisture content. The bale value was estimated, and there were no statistically significant differences in value between the control and the cotton treated by the vapor method; however, some of the cotton with spray moisture restoration had significantly lower value than the control because of lower composite grade.

Columbus and Baker (1975) described a pilot model of a closed-loop system for cotton moisture restoration before ginning at Lubbock, TX. The system proved the feasibility of recirculating high humidity air in a gin to restore moisture to seed cotton. This engineering design reused air that had been humidified in order for the energy and equipment necessary to increase the seed cotton moisture content to be more efficiently used. Humidified air at approximately 100% relative humidity (RH) was added to the closed-loop system, which was maintained at about 50% RH. During the testing in 1972, the seed cotton moisture content at the feeder apron was 7.4% to 7.8%, as determined by the oven method. The fiber properties did not vary during the 2-hr test run.

Childers and Baker (1977) used five moisture treatments involving drying and moisture restoration before the gin stand on stripper-harvested cotton that arrived at the gin at a moisture content suitable for ginning. The treatments with no moisture restoration resulted in lint moisture content at 3% to 5%, and the treatments with moisture restoration had moisture content at 5% to 6%. The treatments did not result in significantly different staple length or mean fiber length ($P > 0.05$). Generally, there were differences in the short fiber percentage that "tended to increase with the level of drying" (Childers and Baker, 1977, p. 382), and some of the differences were statistically significant ($P < 0.05$). Increased drying treatments resulted in lower non-lint content, but the improvement was generally too small to improve the composite grade, and therefore reduced the bale value because of reduced bale weight. There were significant differences in the yarn average break factor with lower fiber moisture content corresponding to lower break factor ($P < 0.05$). It was concluded that "moisture restoration before ginning tended to offset most of the harmful effects of drying" (Childers and Baker, 1977, p. 383).

Mangialardi and Griffin (1977) reviewed weather patterns for the humid Mid-south for September and October and concluded that in order to preserve fiber length quality, there was a need for moisture restoration before of the gin stand when cotton lint contained less than 6.5% moisture content between 10:00 AM and 7:00 PM. The need for moisture addition was particularly acute late in the season when it was not unusual for the ambient relative humidity to be as low as 20%. Eight replications each consisting of a control with no moisture restoration and an experimental with moisture restored by atomized water spray were ginned. The average lint moisture content of samples for the control taken between the gin stand and the lint cleaner was 5.5%, and average lint moisture content was 7.1% with moisture restoration. The cotton with moisture restoration resulted in significant improvement in digital fibrograph 2.5% span length ($P < 0.01$), 50% span length ($P < 0.01$), and length uniformity ratio ($P < 0.05$). The 2.5% span length was 28.3 mm (1.11 in) for the control and 28.7 mm (1.13 in) for the lint with moisture restoration, and the 50% span length was improved from 13.3 mm for the control to 13.6 mm (0.52 in to 0.54 in) for the lint with moisture restoration.

Byler (2001) used humid air in what is normally the second stage of drying in a gin to add moisture to seed cotton and compared that treatment to low temperature drying in the second dryer. Lint samples between the gin stand and the lint cleaner averaged 4.7% for the low moisture treatment and 5.7% for the high moisture treatment. Fiber properties, as measured by the Advanced Fiber Information System (AFIS), were better when ginning at the higher moisture content ($P < 0.01$), except for fiber length by weight and number coefficient of variation which were significant at $P < 0.05$. AFIS total trash count

($P < 0.01$) and AFIS visible foreign matter ($P < 0.05$) for the samples ginned after moisture restoration were higher, but the difference was small (2.00% vs. 2.21% AFIS visible foreign matter).

Byler (2003) used humid air mixed with the seed cotton in what would normally be the second stage of drying and alternatively in a plenum above the gin stand and compared those moisture restoration methods with no moisture restoration. Fifteen bales of cotton were ginned, and the moisture content of lint samples taken between the gin stand and the lint cleaner varied from 4.7% to 5.8%. None of the AFIS trash levels were affected by the treatments ($P = 0.05$). Every AFIS fiber length property of samples obtained from the lint slide was better when the higher moisture content was used ($P < 0.01$). The improvement in AFIS fiber length properties was not dependent on the method of moisture restoration, but they were dependant on the fiber moisture content level. AFIS fiber length increased by of 0.8 mm (0.03 in) for each percentage increase in fiber moisture content. The AFIS short fiber content decreased by 0.9 percentage points for each percentage point increase in fiber moisture content of samples taken behind the gin stand.

Boykin (2005) ginned five cotton cultivars using different dryer temperatures and also added moisture to the seed cotton above the gin stand using water vapor. This study was conducted on bale-sized lots, 227 kg (500 lb). A Humidaire unit and conditioning hopper (Samuel Jackson, Inc.; Lubbock, TX) was used to add moisture to the seed cotton, and nine lint samples were collected behind the gin stand per bale plus five samples were collected from the lint slide. Samples were collected to determine the HVI properties, as well as the fiber properties as measured by the AFIS. Drying temperatures, which ranged from 40 to 120 °C (104 to 248 °F), affected the lint moisture content for the samples obtained behind the gin stand by 0.74%. Two settings, on and off, were used for moisture restoration that changed the fiber moisture content of samples taken behind the gin stand by 0.63%. Statistical analysis showed that these differences in measured moisture content were significant ($P < 0.02$).

Boykin's analysis of HVI data showed differences because of cultivar ($P = 0.0001$) for every measurement. In addition, the HVI leaf was decreased ($P < 0.01$) by 0.20 units per 50 °C increase in dryer temperature, but was not affected by the addition of moisture above the gin stand ($P = 0.18$). The HVI strength was degraded by 0.39 cN/tex per 50 °C increase in dryer temperature ($P < 0.05$), and increased by the moisture addition above the gin stand ($P < 0.01$) by 0.59 cN/tex. The HVI fiber length decreased ($P < 0.05$) by 0.14 mm per 50 °C increase in dryer temperature and improved by the moisture addition above the gin stand ($P < 0.01$) by 0.19 mm. Statistical analysis of AFIS fiber length data showed that the cultivar, drying temperature, and moisture addition above the gin stand affected all of the AFIS fiber length measurements ($P < 0.01$). For example, the AFIS mean fiber length calculated by weight decreased by 0.34 mm per 50 °C increase in dryer temperature, and the AFIS upper quartile fiber length decreased by 0.27 mm per 50 °C increase in dryer temperature. AFIS mean fiber length, calculated by weight, increased by 0.42 mm, and the AFIS upper quartile fiber length increased by 0.33 mm because of the moisture addition above the gin stand.

Byler (2005) configured a Humidaire unit to produce two treatments, either warm dry air or warm humid air, and used the air in the second stage of drying with bale-size lots. Because of the treatments, moisture content data showed a significant difference ($P < 0.01$) of about 1% for three test days and 0.3% on the fourth day for lint samples taken before the lint cleaner. Only one HVI sample was taken per bale, and the HVI length was greater for the bales with higher moisture content, but the difference was not statistically significant. Five lint samples before the lint cleaner and at the lint slide were tested by AFIS, and they all showed significant improvement when ginning at the higher moisture content ($P < 0.05$). For example, the AFIS fiber length averaged by weight was improved by 0.4 mm and the upper quartile length calculated by weight was improved by 0.3 mm when ginning at the higher moisture content. The improvement of the AFIS length was about 0.5 mm per percentage increase in moisture content.

Related issues. Anthony (2003; 2004) surveyed 18 and 20 gins in 2002 and 2003, respectively, in the Mid-south regarding lint moisture levels. In 2002, the average moisture content of all lint samples per gin taken from the lint slide before moisture restoration varied between 3.7% and 6.2%. In 2003, the average lint moisture content of all samples after ginning but before moisture restoration at each gin ranged from 3.0% to 5.8%. The overall mean moisture content for all gins was 5.1% in 2002 and 4.4% in 2003. These data show that the problem of ginning at lower moisture content than recommended has not been solved. This problem results from the ability of farmers to harvest during good weather and to place the seed cotton in modules, which often results in seed cotton drier than ideal for ginning. Other contributors include the improvement to cotton value because of better cleaning efficiency resulting from ginning at lower moisture content, as well as the limited ability of the grading system to detect the fiber damage done by ginning at lower moisture content.

Interest exists in including an additional appropriate measurement of fiber length that better predicts fiber-processing at the mill in official USDA Agricultural Marketing Service (AMS) classing (Bradow and Davidonis, 2000; Cui et al., 2004; Krifa, 2004; and Knowlton, 2004). Robert (2005a; 2005b) and Krifa and Ethridge (2004) have investigated the interrelation between different fiber length measurements focusing particularly on how they could detect fiber breakage during processing.

Researchers are interested in ginning methods that improve the fiber length properties, which affect price and mill processing. Additions to the moisture content of the lint before the gin stand would be limited under commercial ginning conditions because of the short time the seed cotton is available for treatment in the gin plant and the mass flow rate of material through the plant. Moisture addition techniques, which require storage of the seed cotton, would disrupt normal ginning operations and would not likely be adopted without substantial financial incentive for the gin managers.

SUMMARY

Almost since the initial adoption of the cotton gin dryer in the 1940s, scientists have documented the decrease in fiber length quality when ginning at moisture contents below 5%. Moore and Griffin (1964) presented a possible explanation; cotton fiber strength increases over the range 3% to 15%, while the attachment of the fiber to the seed is relatively constant from 3% to 11% and then decreases up to 15%. The ratio of the force required to remove the fiber from the seed to the strength of the fiber decreases with increasing moisture content. Much fiber is at a moisture content below 5% when harvested without additional drying, even in the humid Mississippi Delta. The fiber length property for the cotton pricing structure was staple length until the HVI fiber length was adopted. In general, the difference in staple length because of the ginning moisture level has not been statistically significant, but the negative impact on mills ginning at lower moisture content has been consistently documented.

Studies were conducted in which moisture was added, either by spraying water on the seed cotton or by exposing the seed cotton to moist air, to increase the lint moisture content after seed cotton cleaning but before ginning. Several studies have shown improved spinning properties of cotton associated with moisture restoration before ginning, but the measures of fiber length quality that have been used in cotton marketing have not been shown to consistently respond significantly either when ginning at various moisture content levels or with moisture restoration before the gin stand. Additional drying has consistently resulted in better cleaning efficiency; therefore, the market system has not provided an incentive to producers and ginners to concentrate on the problem of fiber length quality reduction because of ginning at low seed cotton moisture content. Many of the Suter-Webb, fibrograph, and AFIS length measurements and yarn strength measurements made in different studies were improved when ginning after adding moisture to the seed cotton relative to ginning at lower moisture content. Ginning affects the fiber length quality, and it is important for ginning researchers to better understand this problem s o that higher quality fiber can be produced for the mills. Interest exists in including an additional appropriate measurement of fiber length quality which predicts fiber-processing at the mill in official USDA-AMS classing and ginning. Researchers are concerned with how gins can minimize the fiber length quality reduction before such a measurement is adopted.

DISCLAIMER

Mention of a trademark, warranty, proprietary product or vendor 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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