A Comparison of Two Cotton Cultivars Differing in Maturity for Within-Canopy Fiber Property Variation

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ABSTRACT

Improving uniformity in cotton (*Gossypium hirsutum* L.) fiber properties increases fiber processing performance. Our objective was to compare two cultivars differing in relative maturity for within-canopy variability of fiber physical properties and fiber surface chemical constituents. The cultivars (DPL 555 BG/RR [mid-full maturity] and PM 1218 BG/RR [early maturity]) were grown in plots on a Goldsboro loamy sand in 2004 and 2005. Fiber physical properties and extractable glucose and salts were determined on first (FP1) and second (FP2) reproductive branch position bolls. Whole-crop yield and fiber properties were determined after machine harvest. The two cultivars did not differ for whole-crop yield (2-yr mean of 1040 kg ha^{-1}) in either year. Averaged over all mainstem node positions, DPL 555 had fibers that were longer and finer than fiber of PM 1218 in both years. PM 1218 had higher fiber glucose and fiber extract conductivity than DPL 555 among FP1 bolls both years. First-branch-position bolls that developed early during a prolonged rain-free period in 2005 had shorter fibers that were coarser than bolls that began developing near the end of the rain-free period. The data suggest water-deficit stress conditions during boll development affects fiber length of these two cultivars similarly, but water-deficit stress effect on fiber secondary wall characteristics is genotype dependent.

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Abbreviations: AFIS, Advanced Fiber Information System; FP, fruiting position on reproductive branch; HVI, high-volume instrumentation.

Average cotton (*Gossypium hirsutum* L.) fiber physical properties are measured on every bale marketed in the United States by the USDA-Agricultural Marketing Service using high-volume instrumentation (HVI). Average fiber properties provide critical information for successfully spinning cotton into yarn and providing a measure of potential yarn quality. Most agronomic research on assessing and improving fiber properties has focused on improving average fiber quality measures. Less attention has been paid to quantifying the amount and causes of variation of fiber properties, although it has long been recognized that cotton fibers are naturally variable (Balls, 1928). Reducing the variability for individual fiber properties within bales appears important for further quality improvements of cotton crops. Lewis (1999) suggested that to improve cotton quality for modern spinning mill operations, as much attention should be paid to the amount of variability within a bale of cotton for fiber length, strength, and micronaire as to the average values of these properties.

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A bale of cotton's average fiber properties are from bolls that developed under different environments, both spatially and temporally. Earlier research showed that fiber properties differ among bolls that develop at different times during the season (Bennett et al., 1967; Meredith and Bridge, 1973). Management practices can influence the within-canopy distribution of fiber properties in a cotton crop. Planting date (Bauer et al., 2000; Davidonis et al., 2004) and plant population (Bednarz et al., 2006) influence fiber properties at specific canopy positions. Soil water availability also influences within-canopy distribution of fiber properties. Bradow et al. (1997) found differences between bolls at similar canopy positions from irrigated and rainfed plots. Bauer and Frederick (2005) found tillage management and soil type can influence the within-canopy distribution of fiber length and micronaire. In that work, it was proposed that differences in available soil water during the growing season between conventional and conservation tillage may be partially responsible for the differences in fiber properties at specific canopy positions. Bauer and Frederick (2005) also compared two soil types and found that cotton grown on the soil more susceptible to drought exhibited a greater amount of within-canopy variation for fiber properties than cotton grown on the other, more productive, soil.

Historically, most efforts to improve fiber quality have focused on the physical properties of the fibers. Recent evidence suggests that the chemical surface properties of cotton fibers also may impact the efficiency of cotton fiber processing and the quality of yarn (Gamble, 2004). Salts occurring on the surface of fibers have been correlated with reductions in interfiber friction (Gamble, 2004), which potentially could result in more efficient throughput during spinning. Soluble salt content of fibers has been reported to differ among cotton cultivars (Gamble, 2004). Soluble salt content, in conjunction with fiber moisture content, also may affect surface characteristics and processing performance of fiber through an antielectrostatic effect (Gamble, 2005). In addition to salts, simple sugar concentrations of fibers have been correlated with improved yarn quality through increased yarn tenacity (Gamble, 2007). There are no reports on within-canopy distribution of salt and sugar concentrations of fibers.

We hypothesized that cotton cultivars of different relative maturities would differ in both the magnitude and the distribution of fiber properties within the cotton canopy. Our objectives were i) to compare two cultivars differing in relative maturity for within-canopy fiber physical properties, and ii) to compare fiber glucose and salt contents of these two cultivars.

MATERIALS AND METHODS

A mid-full season maturity cultivar (DPL 555 BG/RR [DPL 555)] was compared with an early maturing cultivar (PM 1218 BG/RR [PM 1218]) in this study. The study was conducted in 2004 and 2005 at Clemson University's Pee Dee Research and Education Center near Florence, SC. Soil was Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Paleudults). Cultivars were planted into plots that consisted of 12 1-m-wide by 15-m-long rows. The experimental design was a randomized complete block with four replicates. Precipitation was measured with a weather station at the center that was approximately 500 m from the experiment.

Soil water content was monitored in two replicates of each cultivar to a depth of 1 m (at 10-cm intervals) using capacitance sensors (Sentek Sensor Technologies, Stepney, South Australia, Australia). Sensors were installed on 27 Apr. 2004 and remained in place throughout the two years of the study. Soil water content was recorded every 30 min throughout each season. Sensors were installed in an interior row near the middle of each plot. To avoid damage to the sensors, cotton plants immediately around each set of sensors were hand-seeded. Just before installing the sensors in 2004, all plots were in-row subsoiled to approximately 30 cm. The hand-seeded area immediately around each set of sensors was not subsoiled in 2005, but the rest of the plot area was subsoiled before planting in that year.

Cotton was planted on 11 May 2004 and on 10 May 2005. Plots were over-seeded and hand-thinned to approximately 8 plants m^{-1}. Before planting, soil samples were collected each year and P, K, secondary nutrients, and lime applied as recommended by Clemson University Extension. A 45 kg N ha^{-1} sidedress application of NH_4NO_3 was applied at planting and at about 4 wk after planting each year. Weeds were controlled with a combination of herbicides and hand-weeding. Insect pests were scouted regularly and insecticides applied as needed.

In both years, all plants in a 1-m section of row in each plot were selected for determining within-canopy fiber properties. These row sections were inspected daily from early July through mid-August, and dated tags were placed on blooms on the day of anthesis. At the end of the season, all bolls in the 1-m section of row were hand-harvested. Mainstem node position, branch node position, and flowering date (some tags lost to weathering) were recorded for each boll. Seedcotton weight of each boll was recorded. Each boll was hand-ginned separately by gently loosening the bolls and then clasping individual seeds and pulling them from the fibers. Bolls evaluated in this study were harvested at several times during each harvest season to minimize the effect of weathering. Some of the bolls were rained on in the field after they opened, although all open bolls were harvested in advance of predicted rain events.

Fiber length by weight, fiber maturity, and fiber fineness were determined on approximately 400 of these individual hand-ginned bolls each year (bolls evaluated were first- and second-node-position bolls on sympodial branches) using the Advanced Fiber Information System (AFIS) (Uster Technologies, Knoxville, TN). Glucose and fiber extract conductivity were measured using the methods described by Gamble (2004). Cotton fibers were placed in deionized water (20 mL g^{-1} of cotton fiber) and agitated with a glass rod. After allowing samples to stand for 15 min, excess water was removed from the cotton fibers, and electrical conductivity and glucose content of the extract were determined. Fiber extract conductivity was measured with a Model EP conductivity meter (Myron L. Co.,

Carlsbad, CA) and glucose in the extract was measured with a Model 2700 Bioanalyzer (Yellow Springs Instrument, Inc., Yellow Springs, OH) equipped with a glucose oxidase membrane.

The cotton plants were chemically defoliated with thidiazuron (*N*-phenyl-*N*′-1,2,3-thiadazol-5-ylurea) at 0.06 kg a.i. ha^{-1}, *S,S,S*-tributyl phosphorotrithioate at 0.84 kg a.i. ha^{-1}, and ethephon [(2-chloroethyl) phosphonic acid] at 1.12 kg a.i. ha^{-1} each year when >90% of bolls in all plots were open. Defoliation dates were 24 Sept. 2004 and 3 Oct. 2005. About 2 wk later in each year, seedcotton was harvested from two interior rows using a two-row cotton picker equipped with an onboard weighing system. Samples (approximately 500 g) of the machine-harvested seedcotton were ginned on a 10-saw laboratory gin. Ginned fiber was evaluated for fiber length, fiber length uniformity, fiber strength, and micronaire using high-volume instrumentation (HVI) analyses.

All data were analyzed over years using the MIXED procedure of SAS (Littell et al., 1996). For yield and HVI fiber properties, years and cultivars were considered fixed. For the individual boll data, years, cultivars, and mainstem branch nodes were considered fixed. Analysis was done separately for first-branch-position bolls (FP1) and second-branch-position bolls (FP2) because there were more mainstem branch nodes that had bolls at FP1 sites (nodes 5–16) than at FP2 sites (nodes 6–15).

RESULTS AND DISCUSSION

Precipitation during the growing season was favorable for cotton production both years. Cumulative precipitation during the growing season for the 2 yr is shown in Fig. 1. Both years had good rainfall distribution in May, June, and August, and total precipitation by the end of August (about Day 240) was nearly identical. A longer rain-free period occurred in July 2005 than July 2004, and September was dryer in 2005 than in 2004. The extended rain-free period in July 2005 caused water content of the surface 20 cm of the soil to remain at quite low levels for about a 2-wk period (from about Day of Year 195 to 210) in that year (Fig. 2) compared with in 2004. A succession of tropical storms and substantial rainfalls occurred during August of both years, resulting in relatively high soil water contents of the surface soil throughout that month.

There were no differences between the two years for lint yield or any HVI-determined fiber property (Table 1). Also, the two cultivars did not differ for lint yield, fiber length uniformity, or fiber strength. Small differences did occur between the cultivars for fiber micronaire and fiber length. Averaged over the 2 yr, micronaire of PM 1218 was 7% greater than the micronaire of DPL 555. A year × cultivar interaction occurred for fiber length, as fibers of DPL 555 were longer than those of PM 1218 in 2004, but there was no difference between the cultivars in 2005.

Even though the yield and HVI-determined fiber properties of the two cultivars were quite similar, they did differ in the distribution of bolls in the canopy (Fig. 3). The earlier maturing cultivar had more bolls on the lower branches in the canopy than the later maturing cultivar at both the first and second sympodial branch positions in both years, which supported earlier studies by Bednarz and Nichols (2005) and Jenkins et al. (1990). The two cultivars had similar growth rates, as measured by leaf area index two to three times per week from mid-June through July, and flowering times at individual mainstem and sympodial branch node positions (data not shown). Thus, the difference between these cultivars for relative maturity appears due to PM 1218 producing more flowers and retaining

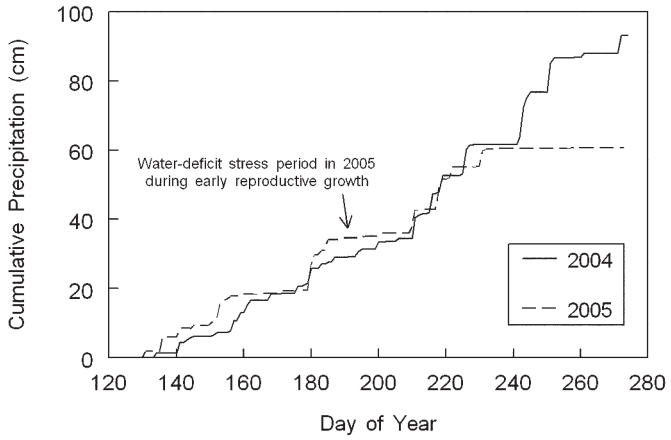

Figure 1. Cumulative precipitation in Florence, SC, from planting (mid-May) through September in 2004 and 2005.

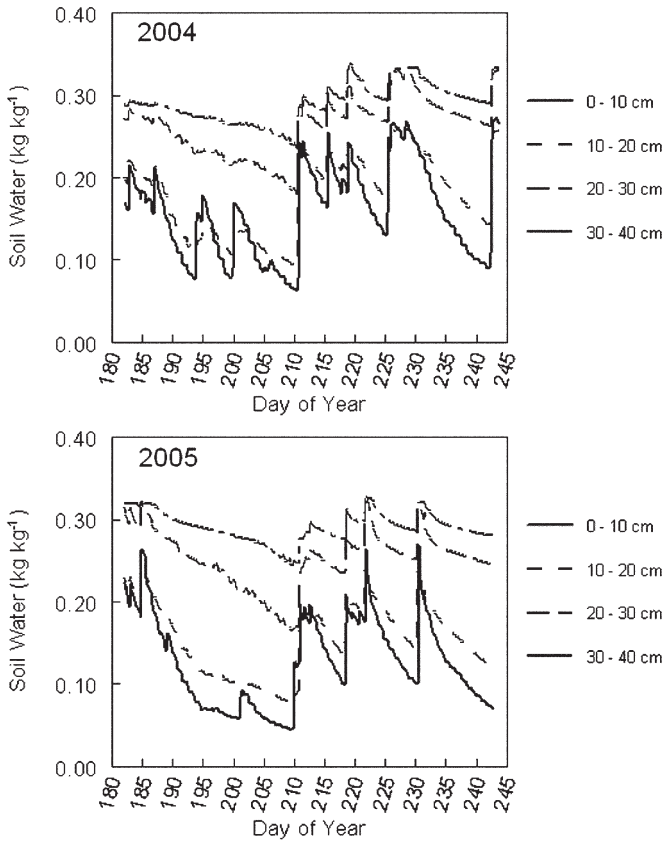

Figure 2. Average soil water content in the surface soil through the cotton flowering and boll development period (July through August) in 2004 (top) and 2005 (bottom), Florence, SC.

Table 1. Yield and high-volume instrument fiber properties of cotton cultivars DPL 555 and PM 1218 in 2004 and 2005, Florence, SC. Fiber properties were determined from grab samples at harvest.

Fiber property	Cultivar	Year		Mean
		2004	2005	
Yield (kg ha^{-1})	DPL 555	1024	997	1010
	PM 1218	1151	986	1068
	Mean	1088	991	
Fiber length (mm)	DPL 555	28.4†	27.8	28.1*
	PM 1218	26.9	27.9	27.4
	Mean	27.7	27.9	
Length uniformity (%)	DPL 555	83.0	81.8	82.4
	PM 1218	83.0	83.0	83.0
	Mean	83.0	82.4	
Fiber strength (kN m kg^{-1})	DPL 555	261	264	263
	PM 1218	266	257	261
	Mean	264	260	
Micronaire (units)	DPL 555	4.45	4.70	4.56**
	PM 1218	4.85	4.93	4.89
	Mean	4.65	4.81	

*Cultivar means significantly different at $P \leq 0.05$.

**Cultivar means significantly different at $P \leq 0.01$.

†Significant year × cultivar interaction, $LSD_{0.05}$ = 1.32 mm.

more bolls at the lower mainstem node branches rather than due to a difference in growth or development rate.

The AFIS fiber properties of fiber length by weight, fiber maturity, and fiber fineness were determined on individual bolls (Table 2). Averaged over all branch nodes, DPL 555 had longer (higher fiber length by weight values) and finer fibers than PM 1218 among both FP1 and FP2 bolls (Table 2). Interestingly, PM 1218 had coarser fibers (higher fineness values) with higher HVI-determined micronaire (Table 1) than DPL 555, but the fiber from PM 1218 was lower in maturity than DPL 555 at both fruiting positions. This suggests that PM 1218 had fibers with a larger perimeter than fibers of DPL 555. If so, then the lower maturity (indicative of less secondary cell wall development) implies that the lumen in the fibers of PM 1218 had a larger volume than the lumen in fibers of DPL 555.

The year × mainstem node interaction was significant for fiber length by weight for both FP1 and FP2 bolls. Fiber length by weight of the FP1 bolls was quite similar at all mainstem nodes in 2004 (Fig. 4, top). In that year, soil water content varied while bolls were developing throughout July and August, but there was no prolonged period with dry soil (Fig. 2). In 2005, soil water content was quite low from Days 195 to 210 and fibers were shorter for FP1 bolls at the bottom four nodes (5 through 8) than

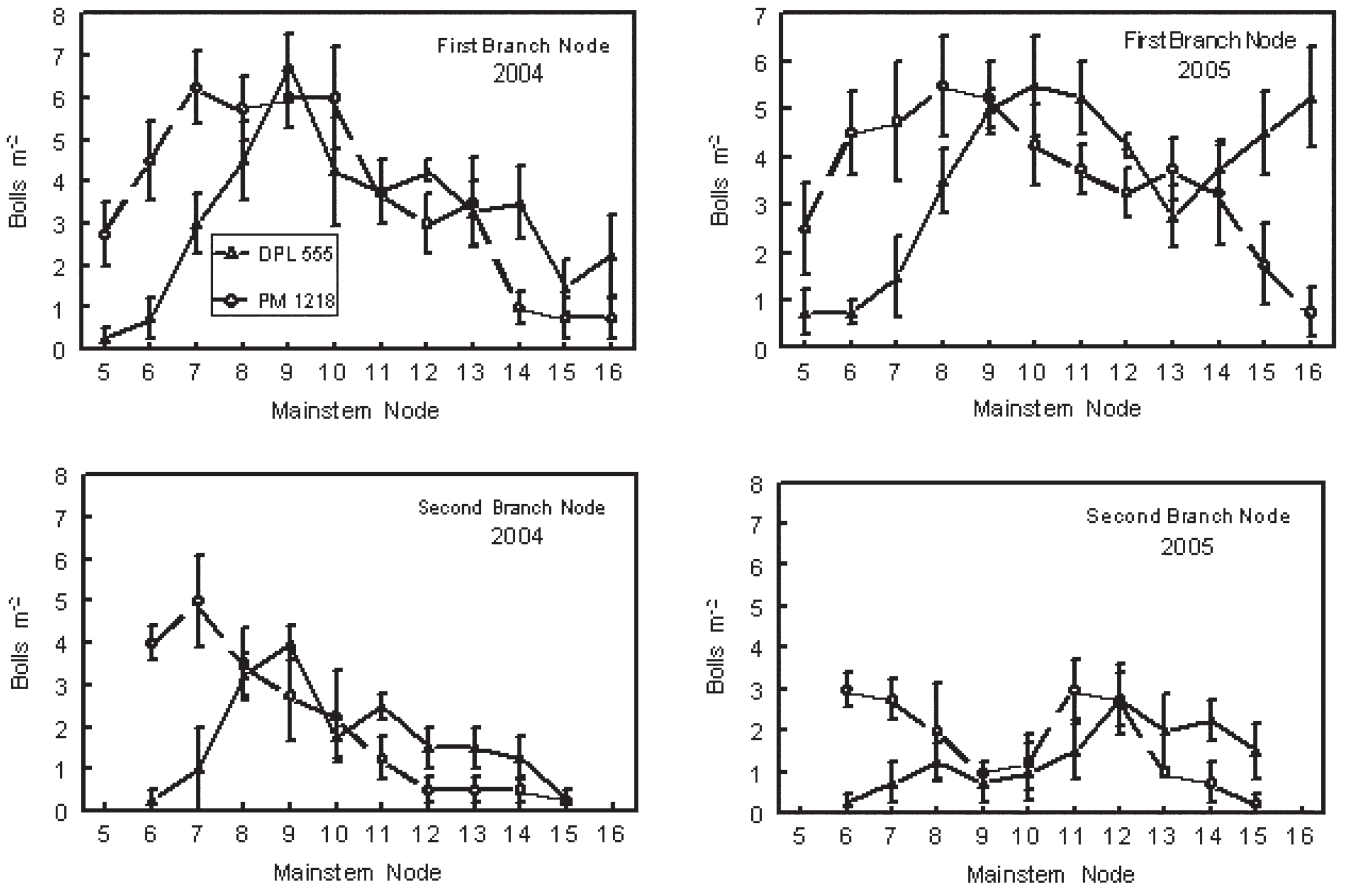

Figure 3. Cotton boll numbers at each mainstem node for an early maturing cotton cultivar (PM 1218) and a mid-full season cultivar (DPL 555) in Florence, SC. Top figures are first-branch-position bolls and bottom figures are second-branch-position bolls in 2004 (left) and 2005 (right). Error bars indicate standard errors of means.

Table 2. Advanced Fiber Information System properties, glucose content, and fiber extract conductivity of first- and second-sympodial-position bolls of cotton cultivars DPL 555 and PM 1218 in 2004 and 2005, Florence, SC. Means are over all mainstem nodes and both years.

Cultivar	Length	Maturity	Fineness	Glucose	Extract conductivity
	mm	ratio	mg km^{-1}	mg g^{-1} fiber	μS cm^{-1}
First-sympodial-position bolls					
DPL 555	27.5	0.94	173	0.04	607
PM 1218	26.4	0.90	182	0.08	692
Probability > *F*	<0.01	<0.01	<0.01	<0.01	<0.01
Second-sympodial-position bolls					
DPL 555	27.4	0.91	168	0.04	632
PM 1218	26.0	0.90	179	0.08	687
Probability > *F*	<0.01	0.05	<0.01	0.01	0.09

for FP1 bolls at the upper nodes (Fig. 4). The anthesis date for bolls at mainstem node 8 was Day 192, which was 18 d before the soil was rewetted with a substantial rainfall. Since cotton fiber length is determined from 3 to 20 d after anthesis (Stewart, 1986), the majority of the fiber elongation period for the first position bolls at the lower mainstem nodes occurred before the rainfall event. Fiber length began incrementally increasing beginning at mainstem node 9 (average anthesis date of 194) until node 12 (average anthesis date of 202), which flowered just 8 d before the rainfall.

The dry period in 2005 had the same influence on fiber length of the FP2 bolls as it had on the FP1 bolls (Fig. 4, bottom). Figure 5 shows average fiber length of these two fruiting positions plotted against flowering date. This suggests that lower quality (at least in terms of fiber length) that has been reported for FP2 bolls (Bednarz et al., 2006) is at least substantially due to differences in environment during development (they flower about 7 d after FP1 bolls on the same mainstem branch).

Among FP1 bolls, the year × cultivar × mainstem node interaction was significant for fiber maturity (Fig. 6, top) and for fiber fineness (Fig. 6, bottom). No interactions occurred among FP2 bolls for these two fiber properties. Similar to the results for fiber length, mainstem nodes did not differ much for these two fiber properties of the FP1 bolls in 2004. The dry period in 2005 seems to have affected maturity and fineness of PM 1218 to a larger degree than DPL 555 (Fig. 6). With the exception of mainstem nodes 5 and 7, maturity and fineness were quite uniform for DPL 555. Maturity and fineness of fibers of PM 1218, on the other hand, decreased at the same nodes that fiber length increased. Pace et al. (1999) reported that at early reproductive growth, a short-season cultivar partitioned a higher percentage of dry matter to reproductive growth than a long-season cultivar. It is possible that fiber fineness of the lower mainstem FP1 bolls of PM 1218 in 2005 was affected more by the dry period than the same

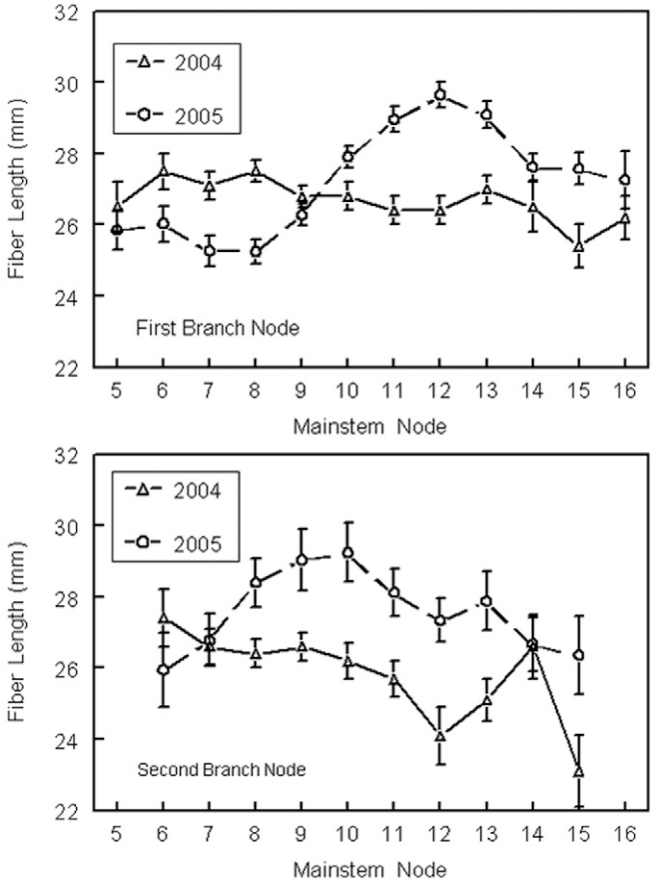

Figure 4. Within-canopy distribution of cotton fiber length of first-branch-position bolls (top) and second-branch-position bolls (bottom) in 2004 and 2005 over both cultivars in Florence, SC. Data are least square means and error bars indicate standard errors.

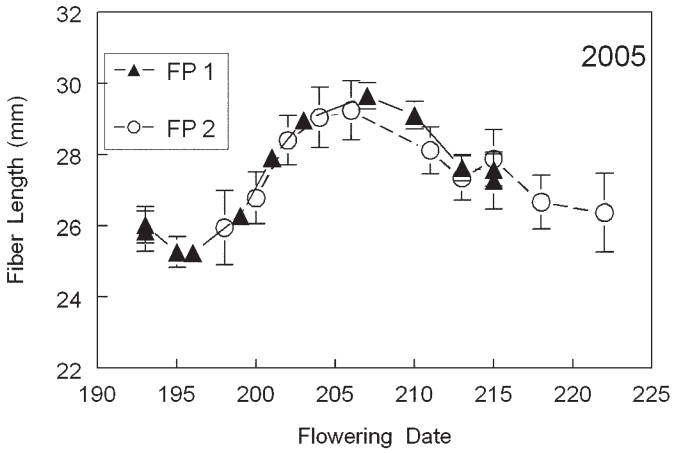

Figure 5. Average cotton fiber length by weight of first- (FP1) and second- (FP2) branch-position bolls plotted against flowering date in 2005, Florence, SC. Data are least square means and error bars indicate standard errors.

bolls of DPL 555 because PM 1218 was partitioning more carbohydrate to reproductive growth at that time.

Genetic differences for fiber glucose and extract conductivity were previously reported by Gamble (2004) who showed a wide range of fiber extract conductivity and

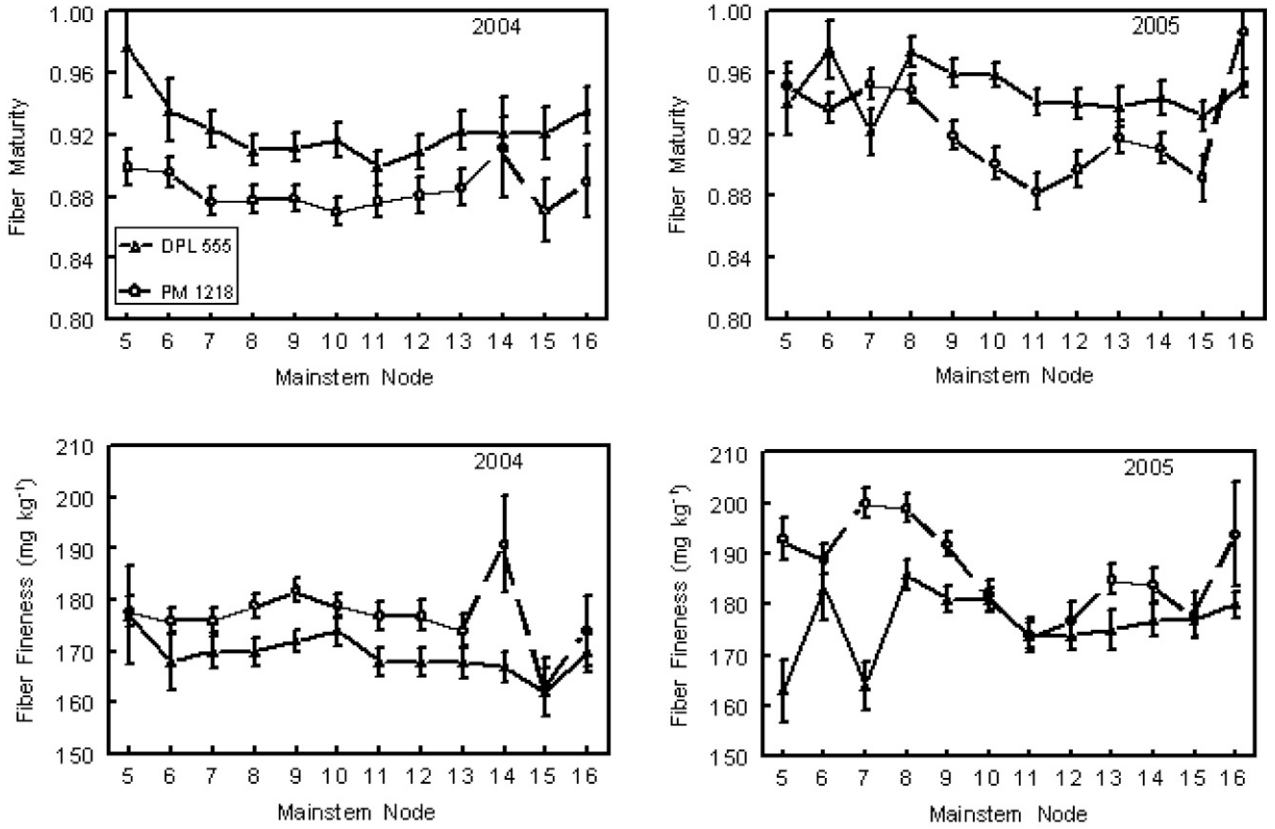

Figure 6. Within-canopy distribution of cotton fiber maturity (top) and fineness (bottom) of first-branch-position bolls of cultivars DPL 555 and PM 1218 in 2004 (left) and 2005 (right), Florence, SC. Data are least square means and error bars indicate standard errors.

glucose levels among 21 cultivars. In our study, PM 1218 had higher fiber glucose and extract conductivity than DPL 555 at both fruiting positions (Table 2). As discussed earlier, it is reasonable that PM 1218 has a larger fiber lumen than DPL 555 because of its higher micronaire, higher fiber fineness, but lower maturity. If this is so, then perhaps the reason for the higher fiber extract conductivity and fiber glucose in PM 1218 is that more glucose and salt molecules are found in the lumens of the fibers. Fiber anatomy studies may provide more insight.

Environmental conditions during fiber development affected fiber chemistry of FP1 bolls. The year × mainstem node interaction was significant for fiber glucose ($P \leq 0.10$) and extract conductivity ($P \leq 0.05$). In 2004, there was less difference among nodes for fiber glucose or extract conductivity of FP1 bolls than in 2005, though variability for fiber glucose at each mainstem node position was quite high (Fig. 7). In 2005, the year in which within-canopy fiber length distribution was impacted by the extended dry period (Fig. 4), both fiber glucose and extract conductivity increased with mainstem node from the lower to the middle nodes (Fig. 7). No significant interactions occurred among years, cultivars, and mainstem nodes for either fiber glucose or fiber extract conductivity of FP2 bolls.

This study demonstrated that the distribution of fiber properties within the canopy can be different, even when mean yield and HVI fiber properties are quite similar. The large effect of the short-term water-deficit stress period in 2005 on cotton fiber properties suggests that improved water management may be a possible method for reducing within-canopy variability. Because the overall influence of amounts of electrolytes and sugars on cotton processing remains to be determined (Foulk et al., 2007a, 2007b, 2008), the extent of improvement in cotton processing by reducing variability for these is not known. Our AFIS-determined fiber length data are different from commercial cotton production in that bolls in our study were hand-ginned, while most harvested cotton is saw-ginned. Histograms of the distribution of fiber length of saw-ginned cotton are often bimodal, with a peak occurring in the short fiber region and another peak near the mean fiber length of the sample (Krifa, 2006). It is often assumed that the peak in the lower fiber length is at least partially associated with fibers broken during ginning. None of the histograms that we inspected from the individual bolls in our study had a bimodal distribution. Thus, our data show how genotype and environment influence biological mean fiber length, not necessarily fiber lengths and fiber length distributions that will be encountered in commercial production channels. Further research appears warranted to identify if environmental conditions during boll development impact the ability of fibers to withstand breakage during mechanical ginning.

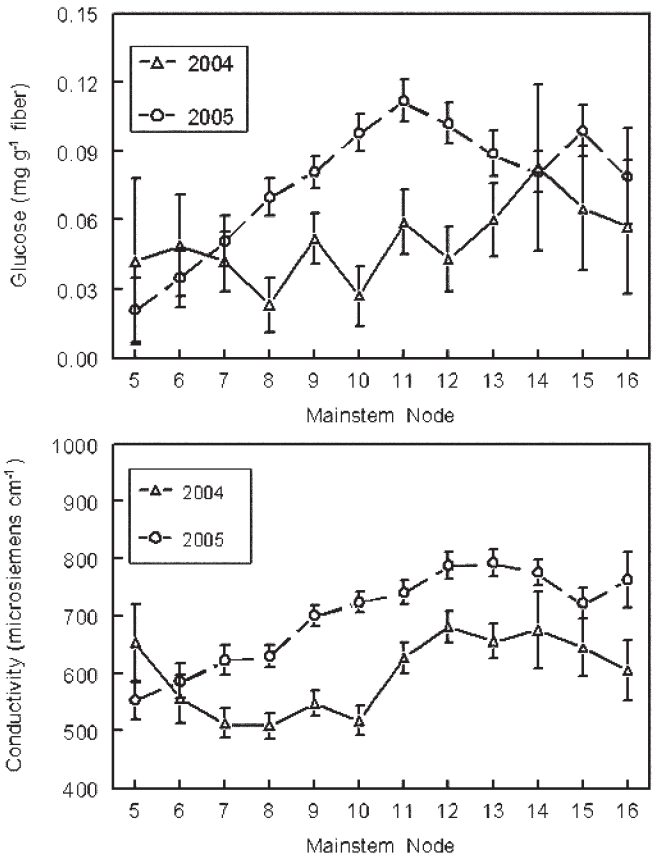

Figure 7. Within-canopy distribution of cotton fiber glucose (top) and fiber extract conductivity (bottom) of first-branch-position bolls in 2004 and 2005, Florence, SC. Data are least square means and error bars indicate standard errors.

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