HOW GENOTYPE AND TEMPERATURE MODIFY YARN PROPERTIES AND DYE UPTAKE

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Abstract

Every growth environment is a composite of factors that can be controlled by the cotton producer [fertilization, planting date, irrigation] and uncontrolled weather factors [temperature, rainfall, and insolation]. This 'quality' composite of the growth environment determines cotton fiber properties through modifications of metabolic rates during fiber development and through interactions between genotype and growth environment that limit realization of full genetic potential (Bradow *et al.*, 1996a; 1997a; 1997b; 1997c). Fiber maturity is quite sensitive to growth environment, alone and in interaction with genotype (Bradow *et al.*, 1996b); and maturation rates are particularly sensitive to the thermal growth environment (Johnson, et al., 1997; Bradow et al., 1996b; 1997a; Bradow and Bauer, 1997).

When the fiber properties of saw-ginned bulk samples of four Upland cotton genotypes (Bauer and Bradow, 1996) were quantified by AFIS [Zellweger Advanced Fiber Information System], growth environment was a strong factor in determining those fiber properties most closely related to fiber maturity [circularity, immature fiber fraction (IFF), cross-sectional area (An), fine fiber fraction (FFF), and micronaire] (Bradow *et al.*, 1996b; 1997a; 1997b; 1997c). Fiber maturity, in turn, was related to some yarn properties and, more specifically, to dye-uptake success (Smith, 1991; Pellow *et al.*, 1996).

Four commercial Upland [*Gossypium hirsutum* L.] cotton genotypes were used: Deltapine 20, Deltapine 50, Deltapine Acala 90, and Deltapine 5690. The experimental design is described elsewhere (Bauer and Bradow, 1996). Fiber properties were quantified by the AFIS airflow particle-sizer (Bradow et al., 1996a, 1996b; 1997a; 1997b; 1997c). All AFIS fiber property, yarn-testing and dye-uptake testing data were subjected to two-way analyses of variance with genotype and environment [crop year + planting date] as the main effects. Data were pooled over planting date [n=12]. Where significant effects of environment on a specific fiber, yarn, or dye-uptake characteristic were found, three-way analyses of variance were used to determine whether the environment-related modulations in that property were related to crop year, planting date, or the interactions of those two factors. Where planting date was found to be significant, linear regression models were constructed for individual fiber properties versus heat unit [Degree-Day 15.6°C = DD16] accumulations at 50, 100, 150 days after planting [DAP] and at harvest.

The fiber samples tested were bulk samples grown under prevailing weather conditions with cultural inputs recommended for the growing region. Staggered harvest dates resulted in minimal weathering of the field-opened bolls, and each of the fiber samples was randomly selected from a well-grown crop and could, therefore, be considered the equivalent of a bale sample sent to the USDA, AMS classing office in Florence, SC, in 1991 or 1992. Yarn production and testing were done with replication under standard opening, carding, and spinning conditions. Dye testing was done under standard conditions with replications, as were the Hunter colorimeter readings. Color variations [barr¾, but *not* white speck] among and within the 192 dyed swatches were easily detectable with the unaided eye.

Genotype was a significant factor in determining all 11 AFIS-quantified fiber shape and maturity properties [see Bradow *et al.*, 1996a; 1996b; 1997a; 1997b; 1997c]. The most significant environmental effects were found in those fiber properties most closely associated with fiber maturity [circularity, IFF, An, micronaire, and perimeter]. There were also significant interactions between genotype and growth environment in the short fiber content, circularity or IFF data. Genotype had no effect on yarn nep counts or uniformity. Yarn breaking strength and tenacity and yarn count strength product [CSP] were determined by genotype alone. Both genotype and environment determined yarn elongation percent, and a strong interaction existed between genotype and environment in the CSP data.

Significant relationships existed between DD16 heat-unit accumulations and yarn nep counts, yarn uniformity, breaking strength, elongation percent, breaking tenacity, or CSP. Heat-unit accumulations before flowering affected nep counts, and elongation percentages only. Higher DD16 accumulations in the spring decreased nep counts and increased yarn elongation percentages. Higher temperatures during flowering [roughly 50 to 100 DAP] increased yarn breaking strength, elongation percent, and breaking tenacity. Increased DD16 accumulations between cutout and harvest decreased nep counts and increased yarn uniformity coefficients of variation and elongation percentages. Higher fall temperatures decreased yarn CSP. Depending on year and genotype, correlations between DD16 and yarn elongation percent accounted for [67% of the variability.

Relationships between DD16 accumulations at different stages in the growing season and fiber properties have been discussed (Bradow and Bauer, 1997). The correlations between DD16 accumulations and yarn properties are noteworthy for three reasons: (1) thermal environment

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before and during flowering significantly modified cotton fiber characteristics at harvest; (2) the effects of those modifications persisted through yarn processing as significant differences in the properties of the yarn made from those environmentally modulated fibers; and (3) linear relationships between DD16 accumulations and yarn properties are independent of any specific fiber property. Linkages between fiber properties and spinning success and the effects of temperature on fiber maturation rates do occur, particularly in yarn elongation percent, the yarn property most closely associated with fiber maturity.

Genotype and genotype responses to the growth environment were the main factors in determining yarn properties, but growth environment determined the color of the *undyed* fibers. There were no significant genotype-related differences in whiteness [+L or Rd], redness [+a], or yellowness [+b] of the 'greige' knits made from these fiber samples. However, DD16 accumulations during the first 50 days after planting had significant effects on all three color components of undyed fiber. Higher temperatures before flowering [0 to 50 DAP] increased the 'whiteness' and 'redness' color components and decreased the 'yellowness'. Temperature during the bloom period had no effect on 'redness', but higher temperatures during the period of 50 to 100 DAP produced whiter fiber with less yellow tinge. Higher temperatures during the period between cutout and harvest also produced fiber with high +L and lower +b, but +a also increased with higher DD16 accumulations during that period. The correlations between DD16 and undyed knit color components accounted for [83% of the variation [independent of genotype] in greige knit color, depending on the color component being considered. Undyed fiber whiteness and yellowness were most closely correlated with DD16 accumulations, and the temperature-related modulations of the color components were the same for the smooth and looped sides of the greige knit fabrics.

Genotype, independent of growth environment, did affect the lightness (+L) of the blue-dyed knits. Genotype was also a factor in the green (-a) and blue (-b) color components of the dyed fiber. Growth environment, which did not interact significantly with genotype, modified the green component of the looped side of the dyed knits and the blue component of both the looped and smooth knit faces. Although there were no significant environmental effects on +L of the blue-dyed knits, thermal-environment effects on fiber maturity (Bradow and Bauer, 1997; Bradow *et al.*, 1997a) suggested that those DD16 accumulations which decreased fiber maturity might also alter apparent fiber dye uptake by increasing the +L color component of the dyed knits. This positive relationship between higher growth temperatures and lighter dyed-knit color [more positive +L] was indeed found for DD16 accumulations between 0 and 50 DAP and between 50 and 100 DAP. Higher temperatures early in the season and during flowering increased boll loading, yield, and competition for resources (Bauer and Bradow, 1996; Bradow and Bauer, 1997). This competition for metabolic resources resulted in higher immature fiber fractions and, in the case of the dyed knits, lighter colors. Higher temperatures from 0 to 100 DAP lightened the color of the knit swatches. After cutout, increased temperatures resulted in greater fiber maturity and improved dye uptake [negative slope in the DD16 versus +L regression equation].

Dye uptake success is more easily quantified by using vector geometry to compare the differences in the color components before and after dye application (Hunter, 1975). The three-dimensional Total Color Difference [TCD] vectors compare the difference in the three color components before and after dye application. The two-dimensional Chromaticity Difference [CD] vectors compare only the differences in !a and !b. Environment was the only significant factor in TCD and CD analyses of variance. Higher DD16 accumulations resulted in higher TCD, and the thermal environment during the period between 50 and 100 DAP had the greatest positive effect on dye uptake quantified as TCD. Lacking the whiteness/lightness component, CD decreased with increased temperatures, regardless of planting date. Depending on the crop year and post-planting interval within the year, the DD16 regression equations accounted for W73% of the variation in TCD and W64% of the CD variation.

Environment [year + planting date], but not genotype, was an important factor in the significant Total Color Differences and Chromaticity Differences of the blue-dyed knits and in fiber maturity. This report examined the effects of the thermal environment only, but temperature alone was not, of course, the sole determinant of fiber maturity nor of the dye-uptake and yarn properties related to fiber maturity. Neither were extrapolations from properties of field-matured fiber the best descriptors of fiber maturity and maturation rates. However, these effects of the overall thermal environment on fiber maturation and fiber-quality variability are consistent with those described in a time-line study of cotton fiber maturation (Johnson *et al.*, 1997; Bradow *et al.*, 1997a). Those reports described the effects of micro-environmental factors, including DD16, on the properties of fiber collected at 21, 28, 35, 42, and 56 days post floral anthesis.

In summary, the strong effects of genotype on fiber and yarn properties were expected. So too were the significant effects of growth environment on fiber characteristics, particularly those properties most closely associated with fiber maturity. Somewhat less predictable were the significant effects of growth environment on yarn uniformity coefficients of variation and nep counts. Higher temperatures after cutout decreased nep counts by increasing fiber maturity. The mechanisms by which higher spring temperatures decreased nep counts while higher fall temperatures increased yarn uniformity coefficients of variation have yet to be determined. Higher temperatures during flowering also increased yarn breaking strength and

tenacity, and elongation percentage, even though the first two yarn properties were not significantly affected by growth environment.

The color components of undyed fibers were determined by environmental, rather than genetic, factors. Higher temperatures during any part of the growing season increased fiber whiteness and decreased fiber yellowness. Higher spring and fall temperatures also increased the red color component. Genotype was a factor in the 'lightness' and 'blueness' color components of blue-dyed knits. Environment affected only the 'blue' and 'green' color components of the dyed knits. However, environment, not genotype, was the significant factor in dye-uptake success quantified as Total Color Difference or Chromaticity Difference. Environmental factors associated with decreased fiber maturity and increased yield were also linked to lighter colors in dyed knits.

The anticipated linkage between yarn elongation percentage and fiber maturity was found, as well as the expected relationship between fiber maturity and dye-uptake success. Unexpectedly, the pre-bloom thermal environment was a significant factor in fiber maturity levels as harvest. Even less foreseen were the persistence of early-season thermal-environment effects through yarn and dyed-knit production and the significance of those effects on dye uptake.

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