



How Genotype and Temperature Modify Yarn Properties and Dye Uptake

I.M. Bradow and P.J. Bauer

USDA, ARS, New Orleans, LA 70124 and Florence, SC 29501, USA

ABSTRACT

Genotype and weather are important factors in determining both cotton fiber quality and yield. Examinations of the effects of genotype on those fiber properties most important to textile manufacturers have led to development of cotton genotypes with potential for producing high yields of fiber with improved spinning properties. However, significant genotype-temperature interactions complicate maximization of yields of fiber with the properties demanded for modern textile processing. Temperature [cumulative heat units above 15.6 °C] during the growing season alters micronaire and the fiber maturity properties most closely linked to spinning and dye-uptake success. When four Upland cotton genotypes were grown in South Carolina, AFIS fiber-quality assessment showed that genotype was a powerful determinant of fiber length, short fiber content, diameter, circularity, immature fiber fraction, area, fine fiber fraction, micronAFIS, and perimeter. Temperature also modified all AFIS fiber properties, and genotype interacted with temperature to modify fiber length, short fiber content, circularity, immature fiber fraction, and micronaire. Tests of yarns spun from fibers of the four genotypes showed genotype to be a significant factor in yarn nep count, strength, elongation, and tenacity. Temperature was also a factor in yarn nep count, evenness, strength, elongation, and tenacity. Genotype and temperature were significant factors in dye-uptake. Regression analyses of temperature-modified fiber properties vs. yarn testing and dye-uptake data described and predicted spinning and dyeing success.

Introduction

Each growth environment is a distinct composite of factors that can be controlled by the cotton producer (fertilization, planting date, irrigation) and uncontrolled weather factors (temperature, rainfall, and insulation). 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). Maturation rates are particularly sensitive to the temperature (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, is related to some yarn properties and, more specifically, to dye-uptake success (Smith, 1991; Pellow *et al.*, 1996). This report identifies significant effects of growth environment and genotype on fiber,

yarn, or dye-uptake properties of four Upland genotypes, discussing the role of a single environmental factor, temperature, in determining those fiber, yarn, and knit-textile characteristics.

Materials and methods

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 both. 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.

Results and discussion

Fiber samples grown under prevailing weather conditions with cultural inputs recommended for the growing region were tested. Staggered harvest dates resulted in minimal weathering of the field-opened bolls. 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. Colour variations [barré, 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 exist between DD16 heat-unit accumulation and yarn nep counts, uniformity, breaking strength, elongation percent, breaking tenacity, or CSP. Heat-unit accumulation before flowering affected nep counts and elongation percentages only. Higher DD16 accumulation 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 accumulation between cut-out and harvest decreased nep counts and increased yarn uniformity coefficients of variation and elongation percentages. Higher fall temperatures decreased yarn CSP. Correlation between DD16 and yarn elongation percent accounted for 67% of the variability, depending on year and genotype.

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 accumulation and yarn properties are noteworthy for three reasons: (1) thermal environment 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 colour 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 colour components of undyed fiber (Table 1). Higher temperatures before flowering (0 to 50 DAP) increased the 'whiteness' and 'redness' colour 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 cut-out 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 colour components accounted for 83% of the variation in greige knit colour, depending on the colour component being considered (independent of genotype). Undyed fiber whiteness and yellowness were most closely correlated with DD16 accumulations, and temperature-related modulations of the colour 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) colour 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 DD16 accumulations that decreased fiber maturity might also alter apparent fiber dye uptake by increasing the +L colour component of the dyed knits. This positive relationship between higher growth temperatures and lighter dyed-knit colour (more positive +L) was indeed found for DD16 accumulations between 0 and 50 DAP and between 50 and 100 DAP (Table 2). 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 colours. Higher temperatures from 0 to 100 DAP lightened the colour of the knit swatches. After cut-out, 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 colour components before and after dye application (Hunter, 1975). The three-dimensional Total Colour Difference (TCD) vectors compare the difference in the three colour components before and after dye application. The two-dimensional Chromaticity Difference (CD) vectors compare only the differences in $\pm a$ and $\pm b$. Environment was the only significant factor in either TCD or 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 $\leq 73\%$ of the variation in TCD and $\leq 64\%$ of the CD variation.

Environment (year + planting date), but not genotype, was an important factor in the significant Total Colour 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.

Summary

The strong effects of genotype on fiber and yarn properties were expected. The significant effects of growth environment on fiber characteristics, particularly those properties most closely associated with fiber maturity were also expected. The significant effects of growth environment on yarn uniformity coefficients of variation and nep counts were less predictable. Higher temperatures after cut-out 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 colour 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 colour component. Genotype was a factor in the 'lightness' and 'blueness' colour components of blue-dyed knits. Environment affected only the 'blue' and 'green' colour components of the dyed knits. However, environment, not genotype, was the significant factor in dye-uptake success quantified as Total Colour Difference or Chromaticity Difference. Environmental factors associated with decreased fiber maturity and increased yield were also linked to lighter colours 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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Table 1. Relationships between smooth-side colour components of undyed-fiber knits and heat unit (DD16) accumulations at 50 and 100 days after planting and at harvest.

Greige yarn knit colour component	Slopes of DD16 versus greige-knit colour-component regression equations and significance		
	0 to 50 DAP	50 to 100 DAP	At harvest, > 150 DAP
	+L, whiteness colour component		
+L, smooth side	+0.0186 ****	+0.0536 ****	+0.0169 ****
	+a, redness colour component		
+a, smooth	+0.0046 ****	NS	+0.0085 ****
	+b, yellowness colour component		
+b, smooth	-0.0133 ****	-0.0264 ****	-0.0154 ****

NS = significance level, $p > 0.1$. **** indicates significance level, $p < 0.0001$. (1991 and 1992 data pooled for four Upland genotypes).

Table 2. Relationships between smooth-side colour components of blue-dyed fiber knits and heat-unit (DD16) accumulations at 50 and 100 days after planting [DAP] and at harvest.

Dyed-yarn knit colour component	Slopes of DD16 versus dyed-knit colour-component regressions and significance of regression equations			
	0 to 50 DAP	50 to 100 DAP	100 to 150 DAP	At harvest, > 150 DAP
	+L, lightness colour component in dyed fabric			
+L, smooth	+0.0011 ***	+0.0043 **	-0.0013 ****	NS
	-a, greenness colour component in dyed fabric			
-a, smooth	NS	NS	NS	+0.0004 ***
	-b, blueness colour component in dyed fabric			
-b, smooth	-0.0009 ****	-0.0032 ***	+0.0008 ****	-0.0006 *

NS = significance level, $p > 0.1$. *, **, ***, **** indicate significance levels of $p < 0.1$, 0.05, 0.01, and 0.0001, respectively. (1991 and 1992 data pooled for four Upland genotypes).