# COTTON FIBER PHYSICAL AND PHYSIOLOGICAL MATURITY VARIATION IN RESPONSE TO GENOTYPE AND ENVIRONMENT

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## Abstract

Cotton fiber *chronological* maturity is estimated by days post floral anthesis [DPA], but cotton classing and processing qualities depend on *physical* fiber maturity [ratio of fibers of acceptable wall thickness]. *Physiologically*, maturing cotton fibers thicken as cellulose is deposited in the secondary wall, a process that results in dilution by weight of primary wall components [pectins and associated calcium]. Fiber *chronological*, *physical* and *physiological* maturation rates were compared when bolls from field-grown Upland and Pima varieties were harvested from 21 to 56 DPA. Fiber *physical* maturities were assayed at the boll-level by AFIS-F&M. Fiber physiological/biochemical maturities were determined by x-ray fluorescence [Ca-XRF] as the weight ratio of calcium-rich primary cell wall to low-calcium secondary wall. Fiber maturities and maturation rates were species- and genotype-specific, regardless of maturity measurement methodology. Growth environment [crop year, flowering date, temperature, and field or greenhouse] significantly altered maturation rates.

## Introduction

Fiber maturity has different meanings for producers and processors of cotton [*Gossypium hirsutum* L. and *G. barbadense* L.]. The quantitative estimate of chronological fiber maturity is DPA, days post [floral] anthesis. Cotton classing, processing, and marketing, however, depend on physical fiber maturity, the ratio of fibers reaching an acceptable thickness. Maturing cotton fibers thicken as cellulose is deposited in the secondary cell wall, a physiological/biochemical process that results in dilution, over time, of primary cell wall chemical components, *e.g.*, calcium associated with primary wall pectins .

The several definitions of fiber maturity [chronological, physical, and biochemical/physiological] were compared when bolls from two field-grown upland cotton genotypes, 'Deltapine 5415' and 'DES119'; and field-grown 'Pima S-6', were tagged at floral anthesis and harvested at dates ranging from 21 to 56 days post anthesis. The physical fiber maturity parameters of fiber from individual bolls of varying chronological maturity were determined by an Advanced Fiber Information System [AFIS] equipped with Fineness and Maturity [F&M] module. Fiber calcium concentrations, determined by x-ray fluorescence [XRF], were used to evaluate the ratio of calcium-rich primary cell wall to low-calcium secondary cell wall.

Quantitative fiber maturity was species- and genotype-specific, regardless of maturity measurement methodology. Growth environment [crop year, flowering date, and field or greenhouse] significantly altered maturation rate. During physiological/biochemical maturation, changes in the AFIS parameters and relative calcium levels in the fiber cell walls were closely related. These results can be used to improve the timing of harvest-aid applications and in production of cotton fiber that meets the maturity requirements of the spinning and dyeing segments of the textile industry.

## Materials and Methods

Cotton genotypes, harvest dates, and fiber chronological maturities are shown in Table 1. Immediately after harvest, all bolls were freeze-dried and held frozen for hand-dissection and separation of fiber from other boll components.

Fiber physical maturity parameters, *i.e.*, micronaire [as micronAFIS], fineness, and circularity, were determined on a boll-by-boll basis, using a commercial Zellweger Advanced Fiber Information System [AFIS] instrument equipped with a prototypic Fineness and Maturity module [AFIS-F&M] (1). Physiological/biochemical maturities [Ca-XRF] were measured by calcium x-ray fluorescence spectroscopy (2), using all fiber from a single boll as the unit of replication. The AFIS-F&M and Ca-XRF evaluations of each fiber sample were made sequentially.

AFIS-F&M and Ca-XRF data were analyzed as Completely Randomized Designs in which $n = 6$ individual bolls. These data were subjected to multi-way and one-way Analyses of Variance, and fiber maturation rates were obtained through regression analyses.

## Results and Discussion

In both crop years, 1992 and 1993, rainfall was normal and did not significantly affect cotton fiber maturation rates. The most important environmental influence on fiber maturity at harvest was heat unit accumulation, *i.e.*, Degree Day 60 [DD60], during the period between floral anthesis and harvest. Total DD60 at 56 DPA [post natural boll opening] was higher in 1993 [491 for bolls from 7/93 flowers, compared to 402 for bolls from 7/92 flowers and 343 for bolls from 8/93 flowers].

Environment and genotype interacted to alter fiber physical maturity, quantified as micronAFIS, a micronaire analog

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calculated by the AFIS-F&M (Bradow, et al., in press). In Table 2, Upland and Pima chronological fiber maturities [DPA] are compared to micronAFIS. Genotype and species differences in micronaire are evident throughout the fiber maturation period, as is the effect of the lower temperature regime experienced by fibers from the August flowering date. The non-significant decreases between 42 and 56 DPA in DPL5415 and Pima S-6 micronAFIS also appeared in other physical maturity and physiological/biochemical maturity quantitations. These decreases might have occurred because the 56-DPA bolls only had opened before harvest and subsequent freeze-drying. Natural fiber maturity variations among fruiting sites (1) could also have contributed to this effect.

Upland fiber maturation rates based on micronAFIS were the same for DES119 grown in 1992 and DPL5415 grown in 1993 (Table 3). The Pima S-6 physical-chronological maturation rates were the same in 1992 and 1993. MicronAFIS of Upland fiber from 8/19 bolls maturing increased more rapidly than did the physical maturity of 7/23-boll fiber, but 7/23-boll fiber micronAFIS at 56 DPA was significantly higher. There was no comparable flowering-date-related increase in Pima S-6 maturation rate.

Genotype characteristics and responses to growth environment altered both crop micronaire and rates of maturation. Predictably, Upland micronAFIS was consistently higher than that of Pima, regardless of chronological maturity and Upland genotype. The lower temperatures, *i.e.*, lower cumulative DD60, during fiber formation in 1992 and the August to October period in 1993 reduced micronAFIS of Upland and Pima genotypes. Maturation rates, quantified as micronAFIS reflected species and genotype differences, as well as environmental effects.

Similar patterns were seen in the micronaire component, fiber cross sectional area. Unlike HVI, AFIS-F&M provides separate quantitations of A[n], fiber cross-sectional area, and, $\theta$, fiber circularity. The quantities, A[n] and $\theta$, are the 'fineness' and 'maturity' components, respectively, of micronaire, the fiber specific surface area. Increases in fiber A[n], over time are reported in Table 4, where species differences between Upland and Pima fiber A[n] are clearly seen. At 56 DPA, 8/19 DPL5415 fiber A[n] was the same as that reported for DPL5415 bolls from 7/23. There was no increase over time in 8/19 Pima S-6 A[n], and 8/19 Pima S-6 A[n] was significantly lower than that for 7/23 Pima S-6 fibers. Both genotype and temperature altered physical maturation rates measured as increases in A[n] over time (Table 5). Species differences in fiber fineness were greater than were the effects of environmental and genotype factors on that fiber quality parameter. Crop year had no effect on Pima A[n] at 56 DPA, and the conditions experienced by bolls from the August flowering reduced fiber fineness in both species.

Fiber fineness is desirable, but fineness must not be achieved at the expense of decreased fiber wall thickening, a fiber property that is quantified as fiber circularity. Fiber circularity is the 'maturity' component of micronaire and is represented by $\theta$, a ratio of fiber cross-sectional area to the square of fiber perimeter. Thus, $\theta$ is a quantitative descriptor of the normal, collapsed shape of a cotton fiber; and the circularity of a completely filled *circular* fiber would be $\theta = 1$. The distribution of $\theta$, is analyzed by AFIS-F&M to provide Immature Fiber Fraction [IFF], the percentage of fibers for which $\theta < 0.25$.
The fiber circularities of the Upland and Pima genotypes under discussion are shown in Table 6. At 56 DPA, Pima fiber circularities were not significantly different from those of the two Upland genotypes. August flowering had no effect on Upland fiber circularity, but 8/19 Pima fiber circularities at 56 DPA were significantly lowest. Regression analyses produced the maturation rates based on fiber circularities shown in Table 7. Environment and genotype did not significantly affect fiber filling rates. Environment and genotype factors did, however, alter IFF at 56 DPA. DPL5415 IFF was 6.3% for the 7/23 bolls and 8.1% for the 8/19 bolls, respectively. The corresponding Pima S-6 IFF values were 11.5% for 7/23/93 bolls and 11.3% for 8/19/93 bolls. In 1992, DES119 IFF at 56 DPA was 7.7%, and Pima S-6 IFF was 12.1%.

Relative fiber wall thickening can also be quantified as Ca-XRF, a ratio of primary to secondary cell wall (2). Fiber circularity was closely correlated to Ca-XRF in this study. When dilution of primary wall components, specifically pectin-associated calcium, was followed over time, environment and genotype were found to interact in determining the rates of physiological/biochemical fiber maturation (Table 8).

The Ca-XRF maturation rate equations are described in Table 9. Secondary cell deposition was most rapid in 1992, regardless of species. The physiological/biochemical maturation rates of 7/23 and 8/19 DPL5415 fibers were similar. The longer, finer Pima S-6 secondary cell walls accumulated less cellulose on a weight basis. Therefore, Pima S-6 maturation rates based on Ca-XRF were lower than those of the Upland varieties. Calcium content of fibers from the late-season Pima S-6 bolls was highly variable, and that variation combined with the low maturities noted above resulted in a flat to slightly positive slope for the 8/19 Pima S-6 regression analysis.

Over time, dilution of non-cellulosic fiber primary wall components by secondary wall cellulose was affected by both genotype and environment. Primary:secondary cell wall ratios were higher in 1992 than in 1993, and secondary wall deposition was slowest in Pima S-6 fibers from 8/19 bolls. At 56 DPA, mean fiber calcium concentrations by weight were: Upland [Ca] = 888 ppm and Pima [Ca] = 1075 ppm without the 8/19 data or 1256 ppm when late-season fibers were considered. The calcium

content of undifferentiated cotton callus tissue exceeded 3,000 ppm and increased with time in culture.

Close correlations were found between chronological, physical, and physiological/biochemical maturities of the Upland genotypes when the bolls from July flowers were compared (Table 10). The correlations were less close in the case of Pima S-6 in 1993, particularly when Ca-XRF was used as the maturity quantitation method. Using regression equations describing physical maturation rates, based on micronAFIS, θ, or A[n], and physiological/biochemical [Ca-XRF] rates, Upland fiber chronological maturities ranging from 51 to 57 DPA were *predicted* for fibers with a true chronological age of 56 DPA. The Pima S-6 predictive equations were less precise with range from 51 to 60 DPA for the predicted chronological maturities of fibers from July flowers. The effects of late-season flowering reduced the precision of the 8/19 DPL5415 chronological maturity predictions which ranged from 47 to 59 DPA. Although there were no correlations between 8/19 Pima S-6 DPA and the corresponding A[n] or Ca-XRF, those predictions of chronological maturity were most precise, i.e., 55 to 57 DPA. The micronAFIS, θ, A[n], and Ca-XRF regression equations predicted Upland chronological maturity within 4 DPA [$r < 0.84$]. In the case of Pima S-6, the micronAFIS and θ equations predicted chronological maturities within 1 DPA [$r < 0.86$].

The fiber maturation rate regression equations could also be used to estimate the DPA at which fiber micronaire could be expected to fall within the 3.5 to 4.9 range and to predict the ranges of θ, A[n], and Ca-XRF corresponding to the non-penalty micronaire range. Those predictions for both the Upland and Pima genotypes are presented in Table 11. These results suggest that lowering Upland chronological maturity through premature crop termination would achieve the targeted micronaire range. However, premature crop termination significantly increases Immature Fiber Fraction. When DPL5415 fiber micronaire is between 3.5 and 4.9, the corresponding IFF is 15 to 25%, compared to the IFF of 6 to 8% for 56 DPA fiber. The IFF percentages of DES119 fiber in the micronaire target range are between 11 and 26%, compared to 8% at 56 DPA. Similar computations and comparisons can be made with the Pima S-6 maturation rate equations and AFIS-F&M data.

## Conclusions

Preliminary results indicate that early crop termination might improve micronaire, but that improvement would occur at the expense of both yield and those fiber characteristics that most affect cotton processing success, i.e., fiber cell wall thickening and Immature Fiber Fraction.


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Table 1. Cotton genotypes and fiber harvest dates. [56-DPA bolls were field-opened].

| GENOTYPE | YEAR | FLOWERING DATE | HARVEST DATE | DPA |
|---|---|---|---|---|
| DES119 | **1992** | 7/23 | 8/13, 20, 27 & 9/17 | 21, 28, 35, & 56 |
| DPL5415 | 1993 | 7/28 | 8/19, 26, & 9/9, 23 | 21, 28, 42, & 56 |
| PIMA S-6 | **1992** | 7/23 | 8/13 & 9/17 | 21 & 56 |
| PIMA S-6 | 1993 | 7/28 | 8/19, 26 & 9/9, 23 | 21, 28, 42, & 56 |
| DPL5415 | 1993 | *8/19* | 9/13 & 10/13 | 21 & 56 |
| PIMA S-6 | 1993 | *8/19* | 9/9 & 10/13 | 21 & 56 |

Table 2. Comparisons of DES119, DPL5415, and Pima S-6 chronological and physical [micronAFIS] maturities. [Fibers grown in Mississippi in 1992 and 1993.]

| | **micronAFIS** | | | | | |
|---|---|---|---|---|---|---|
| DPA | DES119 **7/92** | DPL5415 7/93 | PIMA S-6 **7/92** | PIMA S-6 7/93 | DPL5415 *8/93* | PIMA S-6 *8/93* |
| 21 | 0.05 | 1.01 | 0.33 | 0.33 | 0.63 | 0.33 |
| 28 | 1.37 | --- | --- | --- | --- | --- |
| 35 | 3.82 | 4.07 | --- | 2.88 | --- | --- |
| 42 | --- | 6.74 | --- | 4.05 | --- | --- |
| 56 | 5.36 | 6.08 | 4.55 | 4.25 | 4.25 | 4.22 |

Table 3. Fiber maturation rates of DPL5415, DES119, and Pima S-6 from regression equations comparing increasing micronAFIS to increasing chronological maturity [DPA]. All linear regressions were significant.

| | Regression slope [rate] | Regression Intercept | Regression Coefficient [*r*] |
|---|---|---|---|
| DES119 **7/92** | 0.125 | -1.775 | 0.910 |
| DPL5415 7/93 | 0.124 | -0.335 | 0.849 |
| Pima S-6 **7/92** | 0.108 | -1.930 | 0.947 |
| Pima S-6 7/93 | 0.100 | -0.892 | 0.868 |
| DPL5415 8/93 | 0.140 | -2.280 | 0.933 |
| Pima S-6 8/93 | 0.078 | -1.584 | 0.753 |

Table 4. Comparisons of DES119, DPL5415, and Pima S-6 chronological and physical [**fineness**] maturities. [Fibers grown in Mississippi in 1992 and 1993.]

| | **CROSS-SECTIONAL AREA, A[n], $\mu m^2$** | | | | | |
|---|---|---|---|---|---|---|
| DPA | DES119 **7/92** | DPL5415 7/93 | PIMA S-6 **7/92** | PIMA S-6 7/93 | DPL 5415 *8/93* | PIMA S-6 *8/93* |
| 21 | 89.33 | 75.13 | 70.7 | 57.8 | 81.41 | 70.76 |
| 28 | 81.27 | --- | --- | --- | --- | --- |
| 35 | 118.82 | 120.2 | --- | 82.51 | --- | --- |
| 42 | --- | 146.0 | --- | 92.91 | --- | --- |
| 56 | 127.07 | 138.4 | 96.69 | 95.60 | 135.60 | 81.32 |

Table 5. Fiber maturation rates of DPL5415, DES119, and Pima S-6 from regression equations comparing cross-sectional areas, A[n], versus time [DPA]. All linear regressions were significant.

| | Regression slope [rate] | Regression Intercept | Regression Coefficient [*r*] |
|---|---|---|---|
| DES119 **7/92** | 1.09 | 64.92 | 0.800 |
| DPL5415 7/93 | 1.48 | 62.73 | 0.815 |
| Pima S-6 **7/92** | 0.76 | 54.10 | 0.844 |
| Pima S-6 7/93 | 0.93 | 46.99 | 0.819 |
| DPL5415 *8/93* | 1.55 | 48.92 | 0.901 |
| Pima S-6 *8/93* | 0.30 | 64.41 | 0.264 |

Table 6. Comparisons of DES119, DPL5415, and Pima S-6 chronological and physical [**circularity**] maturities. [Fibers grown in Mississippi in 1992 and 1993.]

| | **CIRCULARITY, θ** | | | | | |
|---|---|---|---|---|---|---|
| DPA | DES119 **7/92** | DPL 5415 7/93 | PIMA S-6 **7/92** | PIMA S-6 7/93 | DPL 5415 8/93 | PIMA S-6 8/93 |
| 21 | 0.214 | 0.269 | 0.214 | 0.231 | 0.227 | 0.219 |
| 28 | 0.290 | --- | --- | --- | --- | --- |
| 35 | 0.438 | 0.461 | --- | 0.442 | --- | --- |
| 42 | --- | 0.651 | --- | 0.543 | --- | --- |
| 56 | 0.565 | 0.605 | 0.533 | 0.559 | 0.559 | 0.433 |

Table 7. Fiber maturation rates of DPL5415, DES119, and Pima S-6 from regression equations comparing fiber circularity, θ, versus time [DPA]. All linear regressions were significant.

| | Regression slope [rate] | Regression Intercept | Regression Coefficient [*r*] |
|---|---|---|---|
| DES119 **7/92** | 0.009 | 0.053 | 0.931 |
| DPL5415 7/93 | 0.008 | 0.173 | 0.858 |
| Pima S-6 **7/92** | 0.009 | 0.023 | 0.957 |
| Pima S-6 7/93 | 0.008 | 0.127 | 0.875 |
| DPL5415 8/93 | 0.009 | 0.027 | 0.944 |
| Pima S-6 8/93 | 0.007 | 0.048 | 0.805 |

Table 8. Comparisons of DES119, DPL5415, and Pima S-6 chronological and physiological/biochemical [**Ca-XRF**] maturities. [Fibers grown in Mississippi in 1992 and 1993.]

| | **[CA], ppm by weight** | | | | | |
|---|---|---|---|---|---|---|
| DPA | DES 119 **7/92** | DPL 5415 7/93 | PIMA S-6 **7/92** | PIMA S-6 7/93 | DPL 5415 8/93 | PIMA S-6 8/93 |
| 21 | 2733 | 1483 | 1925 | 1467 | 1925 | 1500 |
| 28 | 1733 | --- | --- | --- | --- | --- |
| 35 | 1467 | 1220 | --- | 1167 | --- | --- |
| 42 | --- | 785 | --- | 1195 | --- | --- |
| 56 | 991 | 864 | 1051 | 1101 | 1051 | 1618 |

Table 9. Fiber maturation rates of DPL5415, DES119, and Pima S-6 from regression equations comparing Ca-XRF versus time [DPA]. All linear regressions were significant.

| GENO-TYPE | Regression slope [rate] | Regression Intercept | Regression Coefficient [*r*] |
|---|---|---|---|
| DES119 **7/92** | -41.41 | 3240.4 | -0.920 |
| DPL5415 7/93 | -15.13 | 1648.8 | -0.807 |
| Pima S-6 **7/92** | -24.97 | 2449.5 | -0.827 |
| Pima S-6 7/93 | -6.782 | 1506.9 | -0.451 |
| DPL 5415 8/93 | -19.67 | 1913.5 | -0.814 |
| Pima S-6 8/93 | +3.368 | 1429.3 | +0.095 |

Table 10. Chronological maturities of 'mature' fibers predicted from regression equations describing physiological/biochemical and physical fiber maturities

| | **Chronological fiber maturities with correlation coefficients** | | | | | |
|---|---|---|---|---|---|---|
| Maturity Quantitation Method | DES 119 7/92 | DPL 5415 7/93 | PIMA S-6 7/92 | PIMA S-6 7/93 | DPL 5415 8/93 | PIMA S-6 8/93 |
| micron AFIS | 57<br>0.91 | 52<br>0.85 | 58<br>0.95 | 51<br>0.87 | 47<br>0.93 | 57<br>0.75 |
| θ | 57<br>0.93 | 54<br>0.86 | 57<br>0.96 | 54<br>0.87 | 59<br>0.94 | 55<br>0.81 |
| A[n] | 57<br>0.80 | 51<br>0.81 | 56<br>0.84 | 51<br>0.82 | 56<br>0.90 | 56<br>0.26 |
| Ca-XRF | 54<br>-0.92 | 52<br>-0.81 | 56<br>-0.83 | 60<br>-0.45 | 56<br>-0.81 | 56<br>0.09 |

Table 11. Chronological maturities, fiber physical qualities, θ and A[n], and Ca-XRF levels at which Upland and Pima fibers would be within the micronaire range of 3.5 to 4.9.

| GENO-TYPE | DPA: 3.5 4.9 | θ: 3.5 4.9 | A[n]: 3.5 4.9 | Ca-XRF: 3.5 4.9 |
|---|---|---|---|---|
| DES119 | 41.3 | 0.425 | 110.0 | 1528.4 |
| **7/92** | 51.4 | 0.515 | 120.8 | 1113.7 |
| DPL5415 | 31.0 | 0.421 | 108.5 | 1179.7 |
| 7/93 | 42.3 | 0.511 | 125.2 | 1008.5 |
| Pima S-6 | 50.5 | 0.477 | 92.5 | 1189.4 |
| **7/92** | 63.5 | 0.594 | 102.4 | 864.5 |
| Pima S-6 | 42.1 | 0.464 | 86.1 | 1221.2 |
| 7/93 | 53.3 | 0.553 | 96.5 | 1145.3 |
| DPL5415 | 41.3 | 0.400 | 112.9 | 1100.3 |
| 8/93 | 51.4 | 0.490 | 128.4 | 903.3 |
| Pima S-6 | 44.0 | 0.355 | 77.7 | 1577.4 |
| 8/93 | 58.0 | 0.453 | 81.9 | 1624.6 |