REGULATION OF FIBER CELL INITIATION BY EARLY-SEASON TEMPERATURES IN AMERICAN UPLAND COTTON

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INTRODUCTION

The components of lint yield in cotton are the number of plants per acre, the number of bolls per plant, the number of seeds per boll, and the number of fibers per seed. This list may be reduced to the two essential components, i.e., the number of seeds per acre and the weight of fiber per seed. A great deal of attention has been paid to the first factor but the weight of fiber per seed has been grossly neglected.

A recent report (Lewis, 2000a) presented strong evidence that variations in daily minimum temperatures early in seedling development dramatically influence the expression of genes that control the number of fiber cell initials in the outer integuments of the egg sac apparatus of American upland cotton (Gossypium hirsutum). This finding is in good agreement and strongly supports the findings of Zeevart (1966) concerning the role of temperature and day length in regulating differentiation of plant reproductive tissue. Specifically, the proposition that the mechanism by which these environmental factors exert their influence involves the activation of specific gene loci.

The earlier report (Lewis, 2000a) involved dividing the whole plant into “Fruiting Zones,” which involved combining fiber from multiple bolls from different fruiting positions for subsequent analyses. This procedure could yield results which masked or obscured possibly important differences in fiber parameters from boll to boll in a given “fruited zone”. Because of this possibility, the experiment reported in this study was designed to examine individual bolls from single fruiting positions in “Fruiting Zone I”, that is, the first four first-position bolls. This paper reports the results from this study.

EXPERIMENTAL PROCEDURE

The immature cotton fiber mutant (imim) was used for these studies. This mutant is controlled by homozygous recessive alleles at a single locus (Kohel et al., 1974). Mutant plants are characterized by “tight-locked” bolls with immature fibers at boll opening. The absence of significant secondary cell wall greatly enhances gravimetric techniques of estimation of the number of fibers per seed.

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This is primarily due to the fact that fiber initiation and elongation are temporally separated from secondary cell-wall synthesis providing for direct estimates of the impact of environmental forces on primary cell-wall synthesis with minimum interference from secondary wall effects, which are influenced by environmental events occurring several days later.

Planting was done in replicated plots on May 6, 1997 and hand thinned to approximately three plants per foot of row. Plots were located in Mississippi County, Arkansas, about eight miles north of Keiser and 3.5 miles southwest of Dell. All agronomic practices were as prescribed by the Arkansas Cooperative Extension Service. No plant growth regulators were employed and no harvest aids were used. At open boll maturity, cotton from first-position bolls was hand-picked from first, second, third and fourth fruiting branches. This seedcotton was rigorously maintained in separate containers, being sure to keep each fruiting branch separate and free from contamination from the other three fruiting branches. Seedcotton from 30 plants was pooled for each first-position boll from each fruiting branch. These samples were weighed, ginned and subjected to intensive HVI and Afis fiber analysis. All fiber analyses were done by the Cotton Incorporated fiber laboratory, Raleigh, N.C. Daily high, low and average temperatures were obtained from the University of Arkansas Agricultural Weather Station located nearby at the Northeast Research and Extension Center, Keiser, Ark.

Emergence was determined, by visual observation, to be complete on 12 May 1997. Subsequent development sequences were based on the well established arithmetic progression of cotton fruiting-form development (Oosterhuis and Jernstedt, 1999), that is, about 3-day intervals between first-position bolls from fruiting branch (the vertical flowering interval) and approximately 6-day intervals between fruiting positions on the same fruiting branch (the horizontal flowering interval). Figure 1 is a graphical representation of the minimum daily temperatures and key developmental events. The basic design of this experiment assumes that leaf primordia begin initiation at or about emergence with the unfurling of the cotyledons and exposure of the epicotyl to the environment (Mauney, 1986). All measurements of fiber initiation and development are based on this starting point and the classical arithmetic progression of 3 days between elaboration of fruiting forms on sequential fruiting branches. Thus, it is assumed that the elaboration and expansion of the first true leaf begins on or about the day of emergence, the second true leaf initiates these activities about 3 days later and so on until the fourth true leaf, approximately 12 days latter. A further assumption is that the daily minimum temperatures between emergence and 3 days later are the critical temperatures which would influence differentiation of the first-fruiting position on the first fruiting branch, the next 3 days for the second fruiting branch and so forth; the next 3 days for the third fruiting branch and the next three days for the fourth fruiting branch. Figure 1 is a graphic/schematic representation of this experimental scheme.
RESULTS AND DISCUSSION

Table 1 shows the results of this experiment and the results of correlation analysis of all the components of the study. Weight of fiber per seed, numbers of fibers per seed, average fiber length, and weight per fiber increased from the first to the fourth fruiting branches. In addition, changes in these measures of fiber quantity per seed from fruiting branch to fruiting branch were highly and positively correlated with each other.

Based on the results of earlier studies (Lewis, 2000a), the role of daily minimum, overnight low temperatures in these phenomena was investigated. Table 1 also shows these results. The sequential 3-day average daily minimum temperatures postemergence ranged from 48.7 to 60.3°F over the 12-day period. This time-frame was predicated on the developmental scheme of 3 days between first-position bolls from fruiting branch to fruiting branch. The basic concept is that at emergence the cotyledons unfurl, exposing the apical meristem to surrounding air temperatures. At this time the first true leaf initiates expansion, which establishes the node of the first fruiting branch or the differentiation of reproductive tissue. Subsequent fruiting branches would be elaborated in 3-day intervals after the first. Figure 2 illustrates how the weight of fiber per seed changes in first-position bolls from fruiting branch to fruiting branch as daily minimum temperatures changed. Increase in weight of fiber per seed was nearly linear through the first three fruiting branches but leveled off between fruiting branches three and four. This is a polynomial regression line with a quadratic equation, which shows that the weight of fiber per seed did not increase in a linear fashion but with a continuously decreasing rate. Figure 3 further elucidates this relationship between the number (and thus weight) of fiber on the seed and the daily minimum temperature. Table 1 provides some additional insight into this relationship in that the daily average 3-day minimum temperature suffered a significant drop between the third and fourth fruiting-branch developmental sequence from about 60 to 52°F. The slope of the regression line indicates a change of approximately 329 fibers per seed with each degree change in the 3-day sequential daily average minimum temperature. These findings are in strong support of the earlier report by Lewis (2000a) that such temperatures play a critical role in the differentiation of cotton fiber cell initials. Daily maximum temperatures were less correlated with weight and numbers of fiber per seed than with daily minimum temperatures (Table 1).

The relationship between weight of fiber per seed and the number of fibers per seed is shown by Fig. 4. The slope of this regression line indicates that an increase of about 1 milligram of fiber per seed results in an increase of about 309 fibers per seed. The coefficient of determination shows that approximately 99 percent of the increase in weight of fiber per seed is accounted for by increased numbers of fibers per seed. Further examination of Table 1 shows that fiber weight per seed is well correlated with average fiber length (R=0.90) and less correlated with linear density (R=0.71). These findings strongly support the position that
fiber weight per seed is primarily controlled by the number of fibers per seed.

Overall, these data reveal the dramatic influence of the daily average minimum temperature on the number of fiber cells initiated early in the seedling stage when the corresponding true leaf is expanding and not on the subsequent development of the fiber after initiation is effected, that is, fiber length and linear density.

The most fascinating aspect of this study is the interaction of fiber-cell initial differentiation with the population of short fibers (fibers shorter than ½ inch) on the seed. This relationship is shown in Figure 5. The total number of fibers per seed increased from about 6000 to approximately 11000 from the first fruiting branch to the fourth fruiting branch. The number of short fibers per seed varied from a little over 2100 to nearly 3000 at the same time, a change of only about 900 short fibers per seed (Table 1). Nevertheless, when these values are converted to percent short-fiber content by number, a different picture arises. Namely, percent short fiber decreased from about 35% to 26% (Fig. 5.), a difference of approximately 9 percent; a highly significant change. The primary reason for the decrease in percent short-fiber content is not a dramatic decrease in the number of short fibers per seed but, instead, the large increase in the total number of fibers per seed. Thus, when these values are converted to percentages the large increase in total fibers per seed balanced against the small increase in the number of short fibers per seed results in a remarkable decrease in percent short fiber content. Percent short fiber was negatively and well correlated with average fiber length (R = -0.82), which gives an R-squared of 0.67 (Fig. 6). This finding is in excellent agreement with the earlier suggestion by Lewis (2000a) that percent short fiber may be improved in practical breeding programs by selecting for improved mean fiber length.

Review of the temperature data in Figure 1 leaves little doubt that May temperatures are highly variable and volatile. For example, between the fourth and eighth of May, daily minimum temperatures varied from 45 to 63°F, a spread of 18 degrees in 4 days. In addition, from May sixteenth through nineteenth daily minimum temperatures fluctuated from 43 to 71°F, another variation of 18°F but in only three days. Cotton growers seem to have an inchoate yearning to plant early. Data presented in this study suggest that this tendency could have undesirable effects and deserves careful study. This is especially relevant in view of the report (Lewis, 2000b) that variations in actual crop yield in the Delta region during recent years were highly correlated with the weight of fiber per seed (R² = 0.70) and poorly correlated with the number of seeds per acre (R² = 0.08).
LITERATURE CITED


Figure 1. May, 1997: Daily Minimum Temperatures, Degrees F, and Timing of Critical Developmental Events, imlin Cotton, N.E. AR.

FB = Fultondale Branch
Figure 2. Change in Weight of Fiber Per Seed with Fruiting Branch (1st Position)

\[ y = -2.25x^2 + 16.75x - 2.25 \]

\[ R^2 = 0.9384 \]

Fruiting Branch No.

Figure 3. Change in No. of Fibers Per Seed with Change in 3 Day Sequential Daily Avg. Min. T.

\[ y = 329.1x - 8272.7 \]

\[ R^2 = 0.6236 \]

Sequential 3 Day Avg. Min. T.

Figure 4. Change in Number of Fibers Per Seed with Change in Weight of Fiber Per Seed

\[ y = 309.11x + 2240.2 \]

\[ R^2 = 0.99 \]

Milligrams Fiber/Seed
Figure 5. Change in Percent Short Fiber Content (N)  
With Change in No. Of Fibers Per Seed  

\[ y = -0.0019x + 47.733 \]  
\[ R^2 = 0.8618 \]  

Figure 6. Change in Percent Short Fiber Content (N)  
With Change in Average Fiber Length  

\[ y = -3.4801x + 88.729 \]  
\[ R^2 = 0.6747 \]