RELATIONSHIP BETWEEN CELLULOSE SYNTHESIS AND FIBER STRENGTH

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Abstract

Cellulose synthesis and other fiber characteristics during secondary cell wall development have been studied on several species, i.e.,*G. barbadense* (Pima S-7),*G. hirsutum* (Maxxa, Texas Marker 1),*G. arboreum* (A2-Asian 163),*G. herbaceum* (A1-Africa 51). Fiber length and cellulose deposition during the transitional period shows significant differences among varieties. The relationships between fiber characteristics and development are being further studied.

Introduction

Our research on cotton fibers has focused on single-fiber strengths and structure of developing fibers. Developing fibers at varying stages of cell growth, i.e., from the primary to secondary cell wall transition period, secondary cell wall synthesis, to maturity, have been studied (Hsieh et al, 1994, 1995, 1997, 1999; Hu and Hsieh 1996, 1997, 1998). Studies of fibers along their lengths and from different locations on the ovules show that fibers from the medial sections of the ovules have the highest tenacities, followed by those from the micropylar and the chalazal ends (Hsieh and Wang, in press; Hsieh and Hu, in press). Of the mature fibers, the ribbon width of fibers from the medial sections and those from the micropylar ends of the ovules are similar, but those from the micropylar ends have higher linear densities, indicating thicker secondary cell wall.

This paper reports on the patterns of cellulose synthesis and the development of strengths of several species of cottons.

Experimental

Fibers

Bolls from *G. barbadense* (Pima S-7),*G. hirsutum* (Maxxa, Texas Marker 1),*G. arboreum* (A2-Asian 163),*G. herbaceum* (A1-Africa 51) plants grown in greenhouse were used for this study. Flowers were tagged on the day of flowering (anthesis). The first position (closest to the main stem) bolls were randomly sampled between the fourth and the twelfth fruiting branches. This boll-sampling method has been confirmed not to cause variation among single fiber strength during development. Previously established procedures for boll storage and fiber preparation for single fiber strength measurements were followed (Hsieh, 1994).

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Single Fiber Strength and Property

One hundred fifty fibers from five most developed ovules of each boll were used for tensile measurements. All single fiber measurements were performed on the middle portion of fibers taken from the middle sections of the ovules or seeds. All tensile measurements were performed on the Mantis single fiber instrument with a 3.2 mm-gauge length and a 50 mm/min strain rate under a constant temperature of 21ºC and 65% relative humidity. The linear densities or tex (grams per kilometer length) of fibers were measured using fibers from mid-ovule areas of the same seeds. The middle one-centimeter sections of fibers were cut from an array of combed and aligned fibers. One-hundred 1-cm fibers were weighed to 0.1 mg and five such measurements were made from each boll. The means and standard deviations of the linear densities are reported.

Fiber Characteristics and Cellulose Content

Average lengths of fibers (mm) on each ovule were measured. The fibers were straightened with flowing water. The onset of secondary cell wall synthesis was indicated by the distinct reduction of angles (along the fiber direction) in fibril orientation using a polarizing microscope. The percentage of fibers with secondary cell wall was reported. Fiber mass and seed weights were obtained by weight of the seed cotton (seed plus fibers) and the fibers. The seed index (SI) and lint index (LI) are total weight of seed and fibers per seed, respectively. The lint percent was calculated from these values. Cellulose content was determined by acid purification (80% acetic acid and 15 ml conc. nitric acid) and acid hydrolysis (67% H_2SO_4) of cellulose to glucose. Calibration of standard glucose solutions gave the cellulose mass which was divided by the original fiber mass to give the cellulose content (%).

Results and Discussion

At 10 dpa, the average fiber lengths for the A1 and A2 cottons were shorter (~5 mm) than those the Acala and Pima (8-9 mm) cottons (Figure 1). The patterns of fiber elongation were similar among all varieties, i.e., most significant fiber elongation occurring between 15 and 18 dpa and reaching final lengths by 25 dpa.

The onset of secondary cell wall synthesis was observed between 16 to 20 dpa, with A2 starting at 16 dpa, A1 and Pima at 18 dpa, and Maxxa and TM1 at 20 dpa (Figure 2). By 25 dpa, all fibers in Maxxa and A2 have shown secondary cell wall whereas completion of secondary cell wall initiation was observed in A1, TM 1 and Pima fibers at 27 dpa. The total length of time between the first fiber develops secondary cell wall to the last varies from 5 days (Maxxa) to 9 days (A1, A2 and Pima).

The patterns of fiber elongation and initial secondary cell wall synthesis data show extreme overlapping for A1 and minimal overlapping for Pima cottons. Secondary cell synthesis begins in some A1 fiber when the average fiber length is only 10 mm, or ~40% of their final length as oppose to Pima whose average fiber length is ~25 mm (~80%) when secondary synthesis begins.

At 10 dpa, all fibers contain less than 10% of their cellulose (Figure 3). The most drastic increases in cellulose contents begin at 16-17 dpa for all varieties. The rates at which cellulose is synthesized are, however, very different among these varieties, in the decreasing order of A2, A1, Maxxa, TM 1 and Pima. Cellulose synthesis in A1 and A2 tapers in the mid-30 dpa and completes at 40 dpa. The rates taper off much more slow for the Acala and Pima cottons. Pima cotton shows the most gradual pattern of cellulose synthesis, basically throughout the entire secondary cell wall synthesis period.

Again, extreme overlapping of fiber elongation and cellulose contents is found for A1 and minimal overlapping is observed for Pima.

The forces to break single fibers increase with fiber development (Figure 4). Between 20 and 30 dpa, the increases in breaking forces are the highest for A2 followed by A1 and Pima where as those of TM 1 and Maxxa are lowest and similar to each other. Similar orders among varieties are found beyond 30 dpa, except that the Acala and Pima cottons follow essentially the same pattern.

The linear densities of these varieties exhibit the increasing trends with fiber development as well (Figure 5). The increases in linear densities are the highest for A2 followed by A1, TM 1, Maxxa and Pima.

In terms of the single fiber breaking tenacity, all varieties except for A1 exhibit increasing tenacities with fiber development (Figure 6). Of the most matured fibers, single fiber breaking tenacities are highest for Pima, followed by A1, the remaining three are similar. The independent relationship of tenacity with fiber development for A 1 is most intriguing. Further structural characterization of these fibers will help to give structural reasons to this and other differences among these developing fibers.

Summary

- Fibers from greenhouse-grown *G. barbadense* (Pima S-7),*G. hirsutum* (Maxxa, Texas Marker 1),*G. arboreum* (A2-Asian 163),*G. herbaceum* (A1-Africa 51) have been studied.
- Fiber elongation most significantly between 15 and 18 dpa and reaching final lengths by 25 dpa.
- The onset of secondary cell wall synthesis is between 16 to 20 dpa and complete 25-27 dpa.
- Initial secondary cell wall synthesis in A1 fibers is observed when fibers elongate to only ~40% of their final lengths where as that in Pima fibers occurs when fibers reach 80% of their final lengths.
- The most drastic increases in cellulose contents begin at 16-17 dpa.
- Cellulose synthesis in A1 and A2 tapers in the mid-30 dpa to 40 dpa whereas the rates taper off much more slow for the Acala and Pima cottons.
- The forces to break single fibers increase with fiber development between 20 and 30 dpa, in the decreasing order of A2, A1, Pima, TM 1 and Maxxa.
- The linear densities increase with fiber development in the descending order of A2, A1, TM 1, Maxxa and Pima.
- All varieties except for A1 exhibit increasing tenacities with fiber development.
- Single fiber breaking tenacities of the most developed fibers are highest for Pima, followed by A1, the remaining three are similar.
- Further structural characterization of these fibers will help to give structural reasons to this and other differences among these developing fibers.

Acknowledgement

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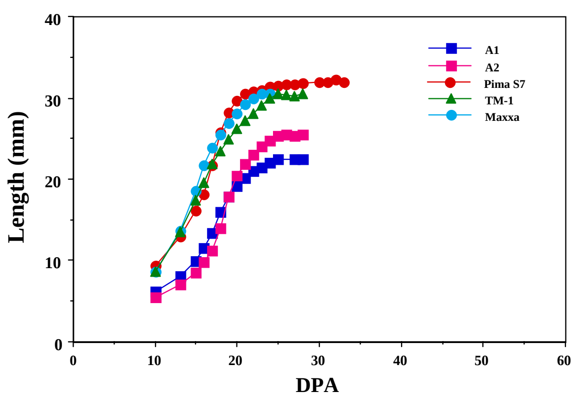

Figure 1. Average fiber lengths during fiber elongation

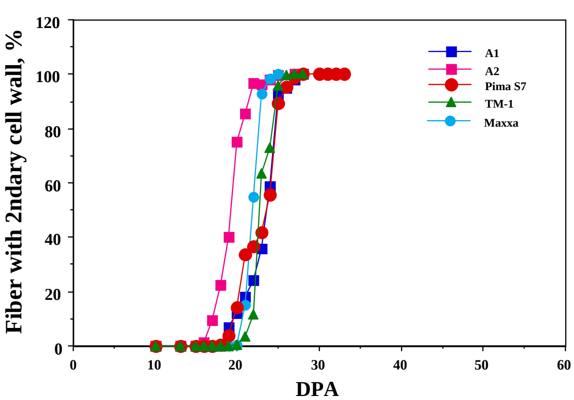

Figure 2. Percentage of fibers with secondary cell wall during the onset of secondary cell wall synthesis

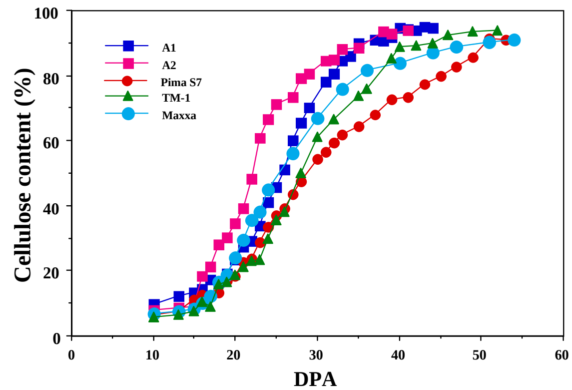

Figure 3. Cellulose content in developing cotton fibers

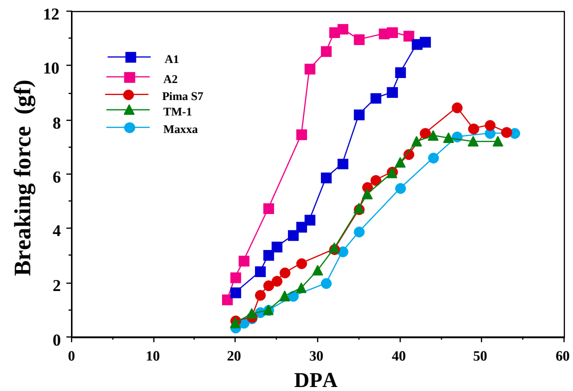

Figure 4. Single fiber breaking forces of developing cotton fibers

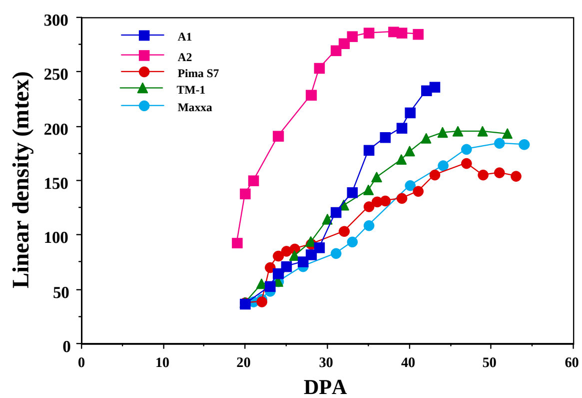

Figure 5. Linear densities of developing cotton fibers

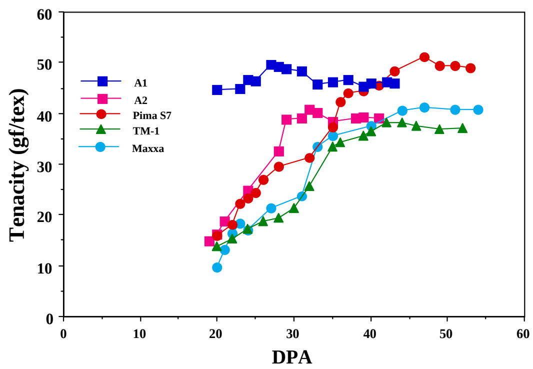

Figure 6. Fiber breaking tenacity of developing cotton fibers