VARIATION OF SINGLE FIBER STRENGTH

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Abstract

Single fiber strengths of greenhouse-grown Texas Marker 1 (TM 1) and Pima S7 cotton fibers at varying stages of development from 20 days pass anthesis to maturity are reported and compared with those of Maxxa and SJ-2 cotton fibers. The forces required to break single fibers increase most significantly during the fourth week and are similar between TM 1 and Pima varieties through the end of the fourth weeks of development. Beyond 30 dpa, both the single fiber breaking forces and tenacities of the Pima cotton fibers are higher than those of the TM 1 cotton fibers**.** Variations of single fiber strength from different ovule locations, i.e., chalazal end, medial regions, and micropylar end, as well as along fibers from the medial sections of the ovule are also reported.

The strength of cotton fibers is attributed to the rigidity and the high molecular weight of the cellulose chains, the extensive intermolecular and intra-molecular hydrogen-bonding, and the highly fibrillar and crystalline structure of the fibers. Cotton fiber strength has been shown to be associated with molecular weight of the cellulose, crystallinity, and reversal and convolution characteristics of the fibers. These relationships have, however, not been clearly verified on developing cotton fibers. This paper reports the single fiber breaking strength of developing cotton fibers and the strength-structure relationship. Texas Marker 1 and Pima S7 were studied. The single fiber tensile measurements were performed using the Mantis single fiber instrument.

Experimental

Fibers

Bolls from nine Texas Marker 1 and nine Pima S7 plants grown under greenhouse conditions 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 [1].

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 ?g and five such measurements were made from each boll. The means and standard deviations of the linear densities are reported.

Wide Angle X-Ray Diffraction

Wide angle X-ray diffraction (WAXD) of fibers ground in a Wiley mill to pass through a 20-mesh screen was performed using a Scintag XDS 2000 X-ray diffractometer. Diffraction intensities were counted at 0.05^{o}-steps between a 5^{o} to 40^{o} two theta (2?) angle range. The WAXD scattering was corrected, normalized and resolved into the non-crystalline scatter background and peaks. A mixture of Gaussian and Cauchy functions were employed to achieve best curve-fitting. Crystallinity is calculated as the ratio of the summation of all resolved peaks to the total scatter under the unresolved trace including the background. The apparent crystallite sizes of the 101, $10\bar{1}$ and 002 reflections planes is based on the Sherrer equation. Further details on the experimental procedures and spectra analyses can be found in our previous paper [3].

Results and Discussion

The breaking forces of both hydrated and dried single Pima S7 and TM 1 fibers increase with fiber development. The work to break values of both the hydrated and dried fibers are similar. Hydrated fibers have higher breaking forces than the dried fibers whereas the breaking elongation values are higher for the dried fibers. The breaking forces of both Pima S7 and TM 1 fibers increase more between 20 and 30 dpa than in the later stages (Figure 1). Single fiber breaking forces are similar between Texas Marker 1 and Pima S7 varieties during the first 4 weeks of development. Between 30 and 50 dpa, both the forces required to break single fibers and the breaking tenacities of the Pima S7 fibers are higher than those of the TM 1 fibers.

When compared to our previous data on Maxxa and SJ-2 varieites, the single fiber breaking forces of developing fibers are in the descending order of Pima S7, Maxxa, TM 1, and SJ-2 (Figure 1). It should be noted that SJ-2 fiber strengths were measured using an Instron. Our earlier data show that the Instron data are lower than the Mantis data on the same Maxxa fibers. Single fiber tenacities among these fibers follow the same ranking order with TM 1 and SJ-2 being similar.

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Variations of single fiber properties have been further examined using fibers from bolls which were matured on plants. Fibers from three different regions of the ovules, i.e., the chalazal end, the medial section, and the micropylar end, were compared. All measurements were performed using only the middle sections of the fibers. Pima S7 fibers are generally stronger and thinner. However, the variations in their tensile properties follow the same trends between these two varieties. The fibers from the medial section of the ovules have the highest breaking forces, elongation, and works to break. The fibers from the micropylar ends tend to have higher breaking forces and works than those from the chalazal ends. Ribbon width and linear density data show that fibers from the micropylar ends of the ovules tend to be wider and to have thicker secondary cell walls. Fibers from the medial regions of the ovules have the highest strengths or tenacities. The tenacities of single fibers from the chalazal and micropylar ends are similar although fibers from the micropylar ends are wider and have thicker cell walls than those from the chalazal ends.

WAXD of the developing SJ-2 and Maxxa fibers shows four peaks located near 2θ angles of 14.7^o, 16.6^o, 22.7^o and 34.4^o, characteristic of the 101, 10$\bar{1}$, 002 and 040 reflections of cellulose I, respectively. The overall crystallinity and apparent crystallite sizes of fibers from both varieties increase with fiber development. Further investigation on the varietal differences and tenacity-structure relationships is underway.

Summary

- For both Texas Marker 1 and Pima S7 varieties, the single fiber breaking forces increase most significantly during the fourth week of fiber development.

- The forces required to break single fibers are similar between Texas Marker 1 and Pima S7 varieties through the end of the fourth week of development. Beyond 30 dpa, both the single fiber breaking forces and tenacities of the Maxxa cotton fibers are higher than those of the SJ-2 cotton fibers.

- The linear densities and average ribbon widths of Pima S7 fibers are lower than those of the TM 1 fibers.

- Among the four varieites of cottons we have studied, the single fiber breaking forces of developing fibers are in the descending order of Pima S7, Maxxa, TM 1, and SJ-2.

- Single fiber breaking forces are highest among fibers from the medial sections of the ovules, followed by those from the micropylar ends and those from the chalazal ends.

- Ribbon width and linear density data show that fibers from the micropylar ends of the ovules tend to be widest and to have thickest secondary cell wal followed by those from the medial sections and those from the chalazal ends.

- Single fiber strengths or tenacities of fibers from the medial regions of the ovules are the highest with those from the chalazal and micropylar ends being similar.

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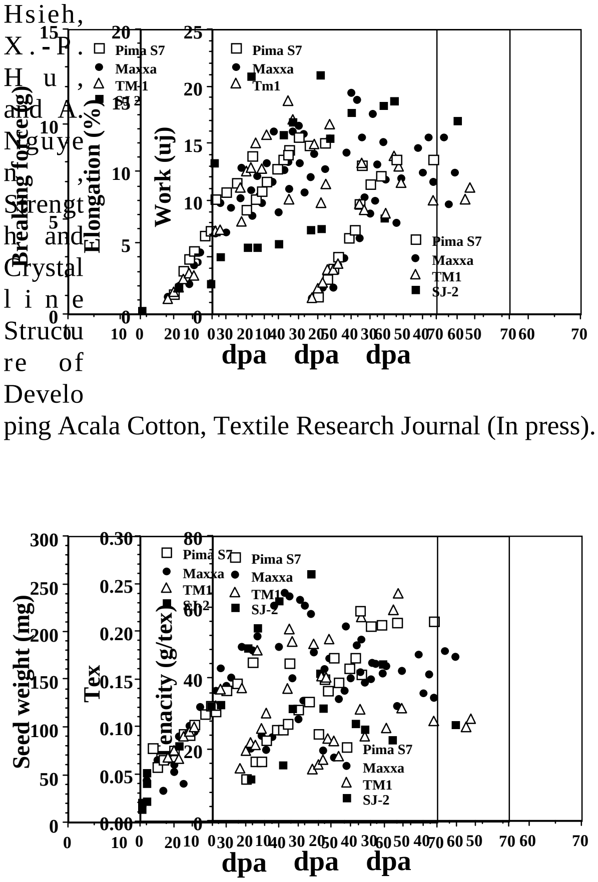

Figure 1. Single fiber breaking properties of Pima S7, Texas Marker 1, Maxxa, and SJ 2 cottons.

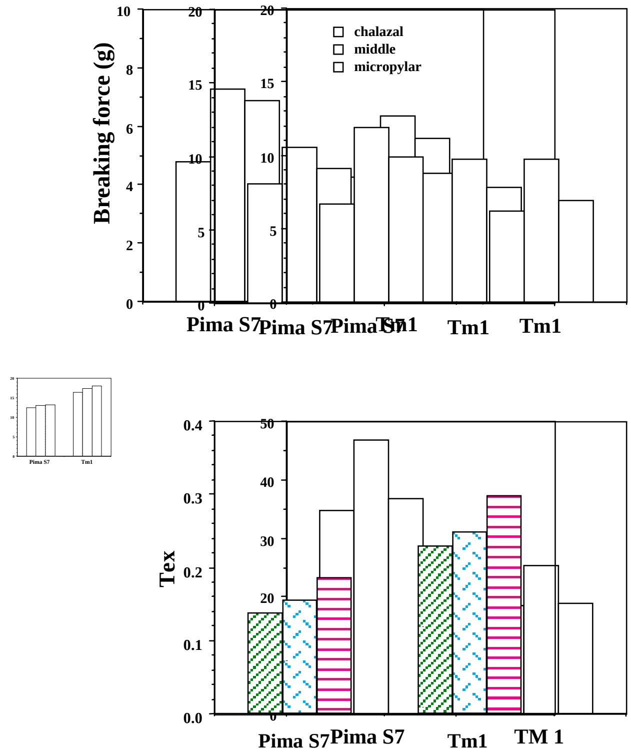

Figure 2. Tensile property variations of single fibers from the chalazal ends, medial sections, and micropylar ends of mature Pima S7 and TM 1 ovules.