INFLUENCE OF CELLULOSE SYNTHESIS AND DIFFERENCE OF ITS CONTENT ON THE STRENGTH OF COTTON FIBER

Jihua Liu
Shandong Agricultural University
Taian, Shandong, P. R. China.
Current address: Texas Tech University
Lubbock, TX

Abstract

Cotton fiber cellulose synthesis during development and cellulose content in mature fibers were investigated by using ^{3}H-labeling for 3 cultivated cotton species, *G. hirsutum*, *G. barbadense*, and *G. arboreum*. There was no significant correlation between fiber strength and cellulose content for the mature fiber of different species or varieties if cellulose content was higher than 80%. However, if cellulose content was lower than 80% for the same variety, there was a significant correlation between fiber strength and cellulose content. Therefore, for any one variety, increasing the cellulose content is valuable to enhance fiber strength and micronaire. In contrast, the mean rate of cellulose deposition had no significant influence on fiber strength, whereas dynamic changes in its deposition rate did have an effect. The species (*G. barbadense*) or variety (Xu-576) with higher fiber strength had only deposited less than 50% of their final cellulose content before 25 DPA, and they kept a higher stable deposition rate from 25 to 45 DPA. Other species (*G. hirsutum* and *G. arboreum*) or varieties (LM-1 and LM-6) had deposited nearly 70% of their final cellulose content by 25 DPA. Fiber strength is enhanced by high-rate cellulose deposition over a longer period as long as late-season growing conditions are not stressful. In contrast, stability of fiber strength and micronaire between growing seasons is enhanced in species or varieties with early-season, high-rate cellulose deposition when growing conditions are less likely to be stressful.

Introduction

The cotton fiber, which develops from the ovule epidermal cell, is one of the most important textile materials. Fiber quality has significant effects on the quality of textile products. Among all cotton fiber physical properties, fiber micronaire (including maturity and fineness) and strength mainly depend on the property of its secondary cell wall. The secondary wall is mainly composed of cellulose (90%-95%), and cellulose synthesis during fiber development and final cellulose content at fiber maturation have important influences on fiber strength (Liu, 1991, 1993; Haigler 1994). However, we still do not know exactly how cellulose deposition and content determine strength, which means that we do not know how to manipulate the process beneficially through genetic engineering or cultivation.

Numerous studies have been done of cellulose biosynthesis in cultured and plant-grown cotton fibers (Montezinos and Delmer, 1980; Delmer et al. 1991, 1993; Roberts et al 1992). These findings have included identification of different sensitivities to low temperature of different varieties. It has also been shown that the higher the fiber strength, the more sensitive is fiber development to lower temperature (Liu et al. 1994b). Previous work has shown that factors other than orientation of cellulose crystallites affect fiber strength (Liu et al. 1994a, 1994b; Liu 1998). The objective of this research was to determine: (1) the difference of cellulose content in mature fibers of different species and varieties that developed under different environments and its influence on fiber strength; and (2) differences in patterns of cellulose deposition during fiber development in different species and varieties and under different flowering times, including analysis of effects on fiber strength.

Materials and Methods

Species and Varieties

We used 3 cultivated species of cotton, *G. barbadense*, *G. hirsutum* and *G. arboreum* , to compare the difference between the species and 40 varieties of upland cotton and analyze the relationship between cellulose content and fiber strength in the normal mature fiber.

Sampling Developing Fiber

During fiber development, samples of 6-8 bolls were harvested every 5 days between 25 - 55 DPA (time of boll opening). We also harvested 8-10 mature bolls with the same blooming and maturity time from every species or variety between September 25-30 of each year.

Test of Fiber Strength

We used the Pressley fiber strength testing instrument to test the 0 gauge strength, the Stelometer fiber strength instrument to test the 3.2 mm gauge strength, and the Y162 Chinese fiber strength instrument to test the single fiber breaking force. Fiber samples were thoroughly mixed before testing. Strength measurements were made under the ISO 3060-74 international standard and the GB 6099-85, GB 6100-85 and GB 6101-85 Chinese national standard.

Analysis of Cellulose Content

Fibers were hydrolyzed with 98% H_2SO_4 to allow quantitation of cellulose by total sugars released.

Analysis of Cellulose Synthesis

From 25 to 45 DPA, we cultured the sample seed cotton 1 hour under 30¡C with ^{3}H-glucose as the sole carbon source followed by washing 5 times with 100% EtOH. Fibers were then counted, with increased radioactive signal indicating higher rate of cellulose synthesis.

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Results and Analysis

Difference of Fiber Strength and Cellulose Content in the Mature Fiber of Cultivated Species

Table 1 shows the relationship between fiber strength and cellulose content in the mature fiber. Although there is significant difference in fiber strength and cellulose weight per length of fiber between cultivated species, the cellulose content in the mature fiber is very similar (range of 85.59 - 92.95% with coefficient of variance = 3.21%). Therefore, there is no close correlation between fiber strength and cellulose content in the mature fiber. When cellulose content is $\geq$ 85%, it has no significant influence of fiber strength. Table 1 also shows that both cellulose content and weight have no significant influence on fiber strength because *G. barbadense* has the lowest cellulose content and weight but the highest fiber strength. Therefore, genetic engineering to increase fiber strength cannot be accomplished simply by increasing cellulose content.

Difference of Fiber Strength and Cellulose Content in the Mature Fiber of Upland Species

Cellulose content of 40 varieties of upland cotton differed very little (range of 83.2 - 98.04% with coefficient of variance = 3.56%). These results confirm that when cellulose content is higher than 80%, there is no further significant influence on fiber strength. The significant correlation between cellulose weight per fiber length and single fiber breaking force shows that cellulose weight impacts individual fiber strength.

Dynamic Change of Fiber Strength and Cellulose Content During Fiber Development

Table 2 shows the effect of dynamic change in cellulose content and fiber strength during fiber development. These results indicated that: (1) During fiber development, fiber strength increases with cellulose content only until 80% is reached. Therefore, optimum fiber strength could be more reliably attained under improved production conditions to speed up maturation to the 80% value. (2) At 25 DPA (just at the end of elongation), cellulose weight per fiber length had only reached 28.45%, 45.16%, 30.75% and 38.71% of their maturity value for XH-6, SXY-1, LM-1 and LM-6, respectively, whereas 47.09%, 84.90%, 82.90% and 87.70%, respectively, of final 3.2 mm gauge fiber strength had been reached. Note that XH-6 (*G. barbadense*) is the only one not attaining at least 80% final strength by 25 DPA. For *G. hirsutum* and *G. arboreum* species, development after 25 DPA influences only 12.3 - 17.1% of final fiber strength, although subsequent cellulose deposition would contribute substantially to maturity, fineness or micronaire. The early attainment of strength implies that this fiber property in these two species is more resistant to late-season environmental stress than in *G. barbadense* .

Cellulose Deposition During Fiber Development

Table 3 shows results from incorporation of ^{3}H-glucose into fibers. We conclude that: (1) There is no significant correlation between fiber strength and mean cellulose deposition rate during fiber development. Although there were significant differences of cellulose deposition rate between species, the species with the highest rate does not have the highest fiber strength. *G. hirsutum* had the highest cellulose deposition rate (M=638.0), whereas similar lower rates were observed in *G. arboreum* (M=353.5) and *G. barbadense* (M=352.9). Tables 1 and 3 show that *G. hirsutum* has the lowest fiber strength. (2) There are close correlations between fiber strength and the dynamics of cellulose deposition. Among six experimental species or varieties, we observed 3 types of cellulose deposition dynamics. The first is *G. barbadense* and Xu-576 (*G. hirsutum*), which have similar rates throughout development and maintain high rates at 25 - 40 DPA. In these cases, strength is enhanced by more cellulose laid down with lower orientation angle structure and higher crystallinity (Liu et al, 1994), but fiber strength and micronaire are more sensitive to late-season environmental stress. The second type of cellulose deposition dynamics is in LM-1 (*G. hirsutum*) and SXY-1 (*G. arboreum*), which have highest cellulose deposition rate at 25 DPA and 40 - 45 DPA. In these cases, fiber strength is depressed because less cellulose is laid down with lower orientation angle and higher crystallinity. Because substantial cellulose is deposited before 25 DPA, fiber properties are less affected by late-season environmental stress. The third type of cellulose deposition dynamics is in LM-6 (*G. hirsutum*), which has highest cellulose deposition rate at 25 DPA followed by a gradual decrease over time. Also in this case, fiber strength is depressed because less cellulose is laid down with lower orientation angle and higher crystallinity. However, strength and micronaire can be expected to be more stable in these fibers because of their primary dependence on early growing season conditions.

Conclusion

From the above results we can conclude that cellulose content above 80% in the mature fiber has no significant influence on the fiber strength, but below 80% cellulose content is important. Mean cellulose deposition rate also had no influence on fiber strength. Higher fiber strength is correlated with the dynamics of cellulose deposition: deposition of less than 50% cellulose before 25 DPA allows more cellulose to be deposited with lower orientation angle and higher crystallinity later in fiber development. However, fibers with this pattern of cellulose deposition are more likely to be affected by late-season environmental stress and to have variable fiber strength and micronaire. Stability of fiber strength and micronaire between growing seasons is likely favored by the deposition of more cellulose early in the growing season, although at a sacrifice of final strength attained.

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Table 1. Differences in fiber strength and cellulose content between cultivated species.

Species or Variety	*G. arboreum*	*G. hirsutum*			*G. barbadense*		C.V.(%)
	SXY-1	LM-1	LM-6	Xu-576	XH-2	XH-6	
3.2mm gauge strength (gf/tex)*	21.71	17.13	17.60	21.99	31.03	32.32	27.77
O gauge strength (psi)	92.63	75.84	86.24	90.65	105.44	107.51	10.00
Single fiber breaking force (gf)	6.25	3.11	2.93	3.43	4.28	3.97	32.21
Fiber fineness (m/g)	3503	5499	6065	6411	7260	8159	24.49
Fiber maturity coefficient	1.75	1.62	1.69	1.85	1.94	1.99	8.00
Cellulose content (%)	92.95	85.59	85.25	89.68	88.47	88.63	3.21
Cellulose weight (10^{-5}mg/cm)	264.31	156.44	140.88	139.57	122.14	108.63	35.95

* 3.2mm gauge strength was modified to the Stelemeter standard with standard sample.

Table 2. Dynamic changes in cellulose content and strength during cotton fiber development.

Species or Variety	Character	DPAs 25	30	35	40	45	50	55
LM-1 (*G. hirsutum*)	Cellulose content (%)	46.35	56.42	72.63	69.00	68.72	80.39	85.59 (53)
	Cellulose weight (10^{-5} mg/cm)	47.68	62.60	114.74	114.39	118.10	152.19	155.63
	3.2 mm gauge strength (gf/tex)	13.82	13.69	14.55	15.89	15.73	16.64	16.67
LM-6 (*G. hirsutum*)	Cellulose content (%)	60.03	62.29	64.92	74.40	82.82	84.40	85.25 (53)
	Cellulose weight (10^{-5} mg/cm)	53.63	78.85	89.87	113.19	136.62	138.36	138.54
	3.2 mm gauge strength (gf/tex)	15.05	15.10	15.15	15.56	16.55	16.19	17.16
XH-6 (*G. barbadense)*	Cellulose content (%)	46.78	70.64	70.19	79.68	82.87	90.67	88.67 (53)
	Cellulose weight (10^{-5} mg/cm)	30.91	71.47	75.45	90.31	97.87	107.43	108.63
	3.2 mm gauge strength (gf/tex)	14.63	24.80	25.87	27.07	29.71	31.45	31.07
SXY-1 (*G. arboreum)*	Cellulose content (%)	71.84	80.59	81.39	81.20	80.38	92.95 (49)	
	Cellulose weight (10^{-5} mg/cm)	118.4	196.55	219.74	217.09	217.88	260.45	
	3.2 mm gauge strength (gf/tex)	17.38	17.07	17.80	19.88	20.54	20.47	

* 3.2mm gauge strength was modified to the Stelometer standard with standard sample.

Table 3. Incorporation of ^{3}H-glucose into cotton fiber throughout development (dpm / 50mg).

Species or Variety	DPA 25	30	35	40	45	Mean (M)	C.V. %
SXY-1 (*G. arboreum*)	405	331	218	430		353.5	29.61
LM-1 (*G. hirsutum*)	711	726	514	258	828	607.4	37.20
LM-6 (*G. hirsutum*)	1656	1248	522	451	228	821.0	73.51
Xu-576 (*G. hirsutum*)	425	564	504	574	361	485.6	18.84
XH-6 (*G. barbadense*)	465	372	415	223	263	347.6	29.34
XH-2 (*G. barbadense*)	410	306	536	316	223	358.2	33.35