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Growth and Development of Fiber and Seed in Upland Cotton[1]

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ABSTRACT

Three environments and four cultivars of upland cotton (*Gossypium hirsutum* L.) were used to evaluate the affect of environment on the growth and development of cotton fiber and seed. The environments were a College Station planting, an early Lubbock planting, and a late Lubbock planting. These environments were quantified by conversion of the daily average temperatures from each environment into heat units. The College Station planting had the most and the late Lubbock planting the least number of available heat units. 'TM-1,' 'CA 491,' 'Acala 1517 Br-2,' and 'Western Stormproof,' were planted in replicated tests in each environment. Tagged bolls were harvested weekly to give estimates of the rates of fiber elongation and fiber dry-weight accumulation. After boll maturity, fiber length, fiber elongation periods, fiber/seed, fiber fineness, seed size, and number of seeds/boll, were determined. Linear correlation and regression analyses between heat units and the characters measured after boll maturity were used to evaluate the relationships between environments and cultivars.

Environment influenced the rate of fiber elongation and fiber dry weight accumulation. Fiber elongated and accumulated dry weight faster in the College Station environment than in the two Lubbock environments. Correlation and regression coefficients from the simple linear regressions of heat units on the characters measured after boll maturity revealed that all of the cultivars responded to a reduction in the number of available heat units. However, CA 491 and Acala 1517 Br-2 appeared to be somewhat better adapted to growth and development of fiber and seed in a cooler environment than were TM-1 and Western Stormproof.

Additional index words: **Fiber elongation, Fiber growth and development, Heat units.**

TWO types of fibers, cover the seed surface of most cultivars of upland cotton (*Gossypium hirsutum* L.): the long lint fibers that are used in the manufacture of fabrics and the short fuzz fibers that form a dense mat near the surface of the seed. Both lint and fuzz fibers are single-cell, tubular outgrowths that arise from the epidermal cells of the seed coat at or soon after anthesis (Lang, 1938).

The growth and development of the cotton fiber consists of two phases. The first phase is a period of fiber elongation, or lengthening, and the second is a period of fiber thickening, or secondary-wall development. After fiber initiation, the primary cell membrane of the long lint fibers, and to a lesser extent that of the short fuzz fibers, elongates until final fiber length is reached. Early studies on the period of fiber elongation suggested that fiber thickening did not begin until after final fiber length was reached (Balls, 1915; Anderson and Kerr, 1938). However, recent studies have shown that fibers can begin to thicken before the completion of fiber elongation (Benedict, Smith, and Kohel, 1973; Schubert and Benedict, 1973; Shubert et al., 1973; Kohel, Quisenberry, and Benedict, 1974).

Balls (1915), who reported some of the earliest work on the growth of the cotton fiber, found that the lint fibers of a strain of *G. barbadense* L. had reached maximum fiber length by the 24th day after anthesis. Thickening of the fiber walls then began about 21 days after flowering, reached its maximum rate of increase in 36 to 39 days, and was practically completed 45 days after anthesis. Hawkins and Serviss (1930) microscopically studied the development of lint fibers in two cultivated species of cotton, *G. barbadense* (Pima) and *G. hirsutum* (Acala). They recorded some species and intraseasonal differences in the time required for the fiber to achieve its maximum length and to complete secondary wall development. They found that the period of fiber elongation and secondary wall thickening increased slightly during the latter part of the growing season. In Uganda, the time required for a fiber to reach maximum length varied only slightly from season to season, despite marked differences in rainfall and temperature (Evenson, 1960; Morris, 1962). Hessler, Lane, and Young (1959) have noted that at Lubbock, Tex., fiber length and fineness (micronaire) decreased as the season progressed and suggested that low temperature was the causative agent.

In field studies in which night temperatures were controlled by the use of portable growth chambers, the growth and development of cotton fiber and seed were closely associated with night temperatures (Gipson and Joham, 1968a, 1968b, 1969; Gipson and Ray, 1969, 1970). Studies at the Canberra phytotron have shown that low temperatures can markedly affect fiber length and fineness (Hesketh and Low, 1968). O'Kelly and Carr (1953) suggested that decreasing temperatures from 21.8 to 14.7 C reduced the rate of fiber elongation and that 14.7 C was the minimum temperature at which fibers will elongate.

Our purpose was to study the growth and development of cotton fiber and seed under varied field environments and to evaluate cultivar responses to these environments.

MATERIALS AND METHODS

The cultivars used were 'Texas Marker-1' (TM-1), 'CA 491,' 'Acala 1517 Br-2,' and 'Western Stormproof.' TM-1 is a highly inbred line that was developed from 'Deltapine 14' in the cotton genetics program at College Station, Tex. (Kohel, Richmond, and Lewis, 1970). This line has been used often as a standard in genetic studies. CA 491 was a selection from a cross between a Yugoslavian strain ('CB 3051') and the commercial cultivar ('Stormrider'). This experimental strain has been used extensively in studies on the earliness of crop maturity in cotton. Acala 1517 Br-2 is a cultivar developed in the high-altitude, irrigated areas of New Mexico and is characterized by large bolls and long, strong fiber. Western Stormproof was developed and is grown in the semiarid, nonirrigated areas of the Rolling Plains of Texas.

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Table 1. Effect of environments on growth.

Days after anthesis	CSD1		LD1		LD2	
	Rate of fiber elongation	Accumulation of fiber dry-wt	Rate of fiber elongation	Accumulation of fiber dry-wt	Rate of fiber elongation	Accumulation of fiber dry-wt
	mm/day	mg/day	mm/day	mg/day	mm/day	mg/day
7*	1.10	0.34	0.47	0.39	0.23	0.34
14†	1.49	0.94	0.70	0.44	0.58	0.37
21	1.23	1.58	0.80	0.50	0.77	0.38
28	0.94	2.02	0.94	0.92	0.83	0.61
35	0.75	2.15	0.77	1.05	0.72	0.83
42	--	2.04	--	1.15	--	0.95
49			--	1.16	--	1.01
56			--	1.07	--	0.98
63			--	0.93	frost	
70			--	0.84		

* Rates at 7 days after anthesis estimated by fiber length and weight divided by seven.

† Rates 14 days after anthesis to boll maturity are regression coefficients (b_1) from regression of fiber length or weight on days after anthesis.

Although our entries were inbred lines, experimental strains, and commercial cultivars, all will be referred to as cultivars in the text. We selected these to represent diverse upland cotton cultivar types, but they may not represent a random sample of all upland cotton germplasm. The applicability of conclusions drawn from studies with these cultivars to all upland cotton germplasm is unknown.

The cultivars were planted in two locations (College Station and Lubbock, Tex.) and on two planting dates at Lubbock, Tex. Each location and planting date was defined as an environment. The environments were designated as: i) CSD1, the cultivars were planted on May 15, 1972, at College Station, Tex.; ii) LD1, the cultivars were planted on May 20, 1972, at Lubbock, Tex.; and iii) LD2, the cultivars were planted on June 20, 1972, at Lubbock, Tex.

In each environment, the cultivars were planted in a randomized, complete block design with three replications. Each cultivar was planted in single-row plots 10-m long with 1 m between plots in each replication. The CSD1 and LD1 environments each received a 10-cm summer irrigation. Because of the late planting date (June 20) and timely rainfall, the LD2 environment was not irrigated. Routine cultural practices and insect control were followed throughout the season for each environment.

The bolls used in this study were tagged on July 20, 1972, in the CSD1 environment; on Aug. 2, 1972, in the LD1 environment; and on Sept. 1, 1972, in the LD2 environment (a killing freeze occurred 63 days after anthesis in the LD2 environment). All flowers that developed before these taggings were removed so that the bolls used would not be stressed from competition for available photosynthate. Five bolls were harvested from each cultivar in each replication every 7 days, after they were tagged. These samples were taken into the laboratory, and the boll walls were separated from the seedcotton. One locule from each of these samples was used to determine fiber length. This locule was placed in boiling water for 2 to 5 min to allow the seeds to separate. As the seeds separated, an individual seed was placed on the convex side of a watch glass, the individual fibers were streamed out with a jet of water, and the length of the fibers was measured (Morris, 1962; Gipson and Joham, 1969).

The seedcotton from the remaining five bolls, less the one locule used to determine fiber length, was dried and weighed. After the weight was recorded, the fiber was removed from the seeds by dissolution in sulfuric acid. The seeds that remained after the fiber was removed were dried, reweighed, and counted. The weight of the fiber removed was determined by subtracting the weight of the seeds from the weight of the seedcotton. The weight of fiber/seed was calculated by dividing the weight of fiber by the number of seeds/boll. Although this technique was probably not as accurate as physically removing the fiber from the seed (Schubert et al., 1973), it was faster and thereby allowed more material to be processed and evaluated.

To aid in evaluation and to clarify the results reported in this paper, we divided the growth and development of seedcotton into three parts: i) fiber length, ii) fiber thickening, and iii) seed development. The characters used to evaluate the development of fiber length were: i) *rate of fiber elongation,* ii) *fiber length,* and iii) *elongation periods.* The rate of fiber elongation was estimated from a linear regression of fiber length on days after anthesis. The slope of the regression line (b_1) from the regression equations was used as the average rate of fiber elongation, measured in mm/day. Elongation rates were estimated 14, 21, 28, and 35 days after anthesis. At the end of 35 days, significant increases in the rate of elongation had ceased in all environments.

Fiber length was measured from the mature fiber of tagged bolls at the end of the boll maturation period from saw-ginned lint samples. Fiber length was estimated as the length (mm) of the longest 2.5% of the fibers as measured on the digital fibrograph instrument. The elongation period was the number of days required to complete fiber elongation and was determined by dividing the fiber length by the average rate of fiber elongation.

Characters used to evaluate the development of fiber thickening were: i) *the rate of fiber dry-weight accumulation,* ii) *dry weight of fiber/seed* at boll or fruit maturity, and iii) *fiber fineness.* The rate of fiber dry-weight accumulation was estimated from a linear regression of fiber dry weight/seed on days after anthesis. Fiber dry-weight accumulation was estimated from 14 days after anthesis until boll maturity, or for the LD2 environment, until frost. The weight of fiber/seed at boll maturity was taken from the same bolls that were used for fiber length measurements. Fiber fineness was measured on the micronaire instrument in micronaire units and was the resistance of a given quantity of fiber to air flow. The smaller the value, the finer the fiber. Fine fiber can be an inherent property of a cultivar or a measure of fiber immaturity due to the environment.

The characters used to evaluate seed development were: i) *dry-weight of individual seed* and ii) *the numbers of seeds/boll.* The dry weight of individual seed at boll maturity was determined from the same bolls used to obtain estimates of fiber length, fiber/seed, and fiber fineness. The number of seeds/boll was an average of the seed counts made from each weekly sample.

To quantify the relationships between environments and cultivars, the association between accumulated heat units and fiber length, fiber elongation period, fiber/seed, fiber fineness, seed weight, and the number of seed/boll was determined by simple linear regression and correlation analyses. Heat units during the period of boll development were calculated for each environment (CSD1, LD1, and LD2). These heat-unit values were determined from the daily average temperatures of each environment by the following formula:

$$\text{Heat units (HU)} = (T_1 - C + T_2 - C + \ldots + T_M - C)$$

where T_M = the daily average temperature within an environment and C = a constant temperature below which the cotton plant, theoretically, ceases to make effective plant growth and development. The constant temperature used in this study was 18.3 C. This value was chosen after a range of constant temperatures was applied to the data. The 18.3 C value provided the best fit of the environmental data to the biological plant responses as measured by the size and significance of the correlation coefficients.

During boll growth and development, the number of heat units accumulated in the CSD1 environment was 584; in the LD1 environment, 476; and in the LD2 environment, 275. Heat units, as used in this study, do not necessarily imply that temperature was the only factor that affected plant growth and development, but instead represents only a method of quantifying the environments. However, meteorological data from the College Station and Lubbock locations and from the early and late Lubbock plantings suggested that daily average temperatures were an environmental variable that significantly differed between these locations and planting dates.

Table 2. Analyses of variance and mean separation for growth factors.

Source of variation	df	Mean squares: Fiber length	Elongation period	Fiber dry wt	Fiber fineness	Seed dry wt	Seeds/boll
		mm	days	g	micronaire	g	no.
Environment	2	0.0194**	360.90**	1,755.44**	19.39**	1,516.44**	249.88**
Reps/environment	6	0.0007	11.39**	4.83	0.02	8.80	7.30
Cultivars	3	0.0464**	11.42**	925.52**	0.56**	737.52**	11.59
Env. × Cult.	6	0.0015	2.04	111.07*	0.52**	159.74**	12.51*
Error	18	0.0010	2.57	37.23	0.05	27.25	4.18
Cultivar				Mean separation†			
TM-1		26.7 b	31 a	65 b	3.4 b	80 ab	34 a
CA 491		24.7 c	28 b	53 c	3.4 b	77 b	32 a
Acala 1517 Br-2		28.3 a	30 a	72 a	3.7 a	94 a	35 a
Western Stormproof		24.7 c	30 a	53 c	3.1 c	73 b	34 a

*, ** Statistically significant at the 0.05 and 0.01 levels, respectively.

† Means within columns followed by different letters are significantly different at the 0.05 level; according to a Duncan's new multiple range test.

RESULTS AND DISCUSSION

The rate of fiber elongation was significantly influenced by environments (Table 1). In the College Station environment (CSD1), the rate of fiber elongation peaked 14 days after anthesis, whereas the peak rate of elongation occurred 28 days after anthesis in the LD1 and LD2 environments. The primary difference between the first and second planting at Lubbock (LD1 and LD2) appeared to be in the rate of fiber elongation that occurred during the time of peak elongation. The fiber in the LD1 environment elongated at a rate of 0.94 mm/day during peak elongation, whereas fiber in the LD2 environment elongated at 0.83 mm/day during this period. This slower fiber elongation rate in the LD2 environment resulted in a significantly shorter fiber in this environment than in the LD1 environment. Fiber length was approximately the same in the CSD1 and LD1 environments, although fewer days were required to complete elongation in the CSD1 environment than in the LD1 and LD2 environments.

In the CSD1 environment, the rate of fiber dry-weight accumulation was two to three times as rapid as in the two Lubbock environments (Table 1). Fiber dry-weight accumulated faster in the LD1 environment than in the LD2 environment. The rate of fiber dry weight accumulation peaked 35 days after anthesis in the CSD1 environment and 49 days after anthesis in both the LD1 and LD2 environments. All three environments produced different values of fiber/seed and fiber fineness. The extremely fine fiber associated with the LD2 environment was probably partly caused by fiber immaturity related to the killing freeze that occurred prior to the completion of the boll maturation period.

A comparison between the rates of fiber elongation and fiber dryweight accumulation for the three environments suggested that fiber elongation (lengthening) and dry-weight accumulation (fiber thickening) overlapped during their occurrence (Table 1). In the CDS1 environment, fiber elongation was completed 24 days after anthesis, whereas the rate of dry-weight accumulation began approximately 14 days after anthesis. In the LD1 environment, fiber elongation was completed 32 days after anthesis, and fiber dry-weight accumulation began 28 days after anthesis. In the LD2 environment, fiber elongation was completed 34 days after anthesis, and fiber dry-weight accumulation began about 28 days after anthesis.

Cultivars differed somewhat in the rate of fiber elongation and dry-weight accumulation; however, these differences appeared to be associated with fiber length and seed size. Cultivars that produced longer fibers (TM-1 and Acala 1517 Br-2) elongated faster and for a longer period of time than did cultivars that produced shorter fibers (CA 491 and Western Stormproof). Likewise the large-seeded cultivars (Acala 1517 Br-2 and TM-1) accumulated fiber dry-weight faster and produced more fiber/seed than did the small-seeded cultivars (CA 491 and Western Stormproof).

Analyses of variance and mean separations were conducted on those characters that were measured after boll maturity (Table 2). Environments significantly affected all characters. The cultivars differed significantly for all characters with the exception of the number of seeds/boll. Acala 1517 Br-2 had the longest fiber, the most fiber/seed, the coarsest fiber, and the largest seeds. CA 491 and Western Stormproof had the shortest fiber, the least fiber/seed, and the smallest seeds. CA 491 required the fewest days to complete fiber elongation, the Western Stormproof had the finest fiber. Environment × cultivar interactions were significant for fiber dry weight/seed, fiber fineness, seed dry weight, and seeds/boll.

We quantified the relationship between environments and cultivars by calculating correlation (r) and regression (b_1) coefficients from a linear regression of the accumulated heat units of an environment on the different characters that were measured after boll maturity. A significant correlation coefficient showed that, for the character being measured, a cultivar responded to the accumulation of additional heat units. The regression coefficient (b_1) of a cultivar indicated the magnitude or degree of these responses. A small regression coefficient associated with a cultivar suggested that the response was small, whereas a large regression coefficient indicated that the response was large.

The fiber length of only one cultivar (TM-1), was significantly associated with an increase in accumulated heat units (Table 3). All cultivars showed an association between the amount of accumulated heat units and elongation period. The regression coefficients between accumulated heat units and the elongation period suggested that those cultivars which produced longer fibers (TM-1 and Acala 1517 Br-2) were more responsive to available heat units than

Table 3. Influence on fiber length and elongation period.

Character	Cultivar	Environments CSD1	LD1	LD2	b_1	r
		mm			mm/HU	
Length	TM-1	28	27	25	0.0075	0.82**
	CA 491	25	25	24	0.0025	0.45
	Acala 1517 Br-2	28	29	28	0.0012	0.25
	Western Stormproof	25	26	23	0.0053	0.58
Environmental means*		26 a	27 a	25 b		
		days			days/HU	
Elongation	TM-1	24	33	36	-0.1189	-0.93**
	CA 491	23	31	31	-0.0879	-0.92**
	Acala 1517 Br-2	24	33	34	-0.1107	-0.92**
	Western Stormproof	24	32	34	-0.1005	-0.94**
Environmental means*		24 a	32 b	34 b		

* Means followed by a different letter were significantly different at the 0.05 level according to Duncan's new multiple range test.

Table 4. Influences on fiber dry weight/seed and on fiber fineness.

Character	Cultivar	Environments CSD1	LD1	LD2	b_1	r
		mg			mg/HU	
Fiber/seed	TM-1	79	66	51	0.0744	0.92**
	CA 491	66	50	43	0.0609	0.90**
	Acala 1517 Br-2	77	71	68	0.0241	0.67*
	Western Stormproof	71	49	37	0.0895	0.85**
Environmental means†		73 a	59 b	50 c		
		micronaire			mic/HU	
Fiber fineness	TM-1	4.9	3.2	2.4	0.0078	0.94**
	CA 491	4.8	2.9	2.5	0.0057	0.81**
	Acala 1517 Br-2	4.6	4.1	2.4	0.0068	0.97**
	Western Stormproof	4.5	2.6	2.4	0.0064	0.87**
Environmental means†		4.7 a	3.2 b	2.4 c		

*, ** Significantly different from zero at the 0105 and 0.01 levels of probability, respectively. † Means followed by a different letter were significantly different at the 0.05 level according to Duncan's new multiple range test.

Table 5. Influences on seed size and on the number of seeds/boll.

Character	Cultivar	Environments CSD1	LD1	LD2	b_1	r
		mg			mg/HU	
Seed size	TM-1	90	90	58	0.0982	0.92**
	CA 491	87	73	70	0.0429	0.74*
	Acala 1517 Br-2	97	98	87	0.0325	0.79*
	Western Stormproof	80	82	57	0.0714	0.86**
Environmental means†		89 a	86 a	68 b		
		no.			no./HU	
Seeds/boll	TM-1	37	33	31	0.0152	0.76*
	CA 491	34	35	27	0.0241	0.85**
	Acala 1517 Br-2	38	36	30	0.0239	0.82**
	Western Stormproof	40	36	27	0.0378	0.98**
Environmental means†		37 a	35 b	29 c		

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively. † Means followed by a different letter were significantly different at the 0.05 level according to Duncna's new multiple range test.

were those cultivars which produced shorter fibers (CA 491 and Western Stormproof).

An environment with fewer accumulated heat units significantly decreased the fiber dry weight/seed and increased the fiber fineness of all cultivars (Table 4). The effect on fiber dry weight/seed was greatest on Western Stormproof and least on Acala 1517 Br-2. The effect of fewer heat units on fiber fineness was most pronounced on TM-1 and least on CA 491.

Accumulation heat units significantly affected seed size and the number of seeds/boll on all cultivars (Table 5). The effect on seed size was greater in TM-1 and Western Stormproof than in CA 491 and Acala 1517 Br-2. A reduction in heat units decreased the number of seeds/boll the least in TM-1 and the most in Western Stormproof.

The results of this study showed that environment can significantly influence the rate of fiber elongation, the rate of fiber dry weight accumulation, fiber length, days required to complete elongation, dry weight of fiber/seed, fiber fineness, seed size, and the number of seeds/boll. The environments used in this study were quantified by conversion of daily average temperatures to heat units. We recognized that many environmental variables were associated with accumulated heat units and that the recorded responses of the cultivars were due to the total environment.

Our use of the two locations showed the desirability of conducting field studies on fiber growth and development in a near-optimum environment (College Station), as well as in a suboptimum environment (Lubbock), when attempting to elucidate the effect of environment. If the College Station environment had not been included and the test had been conducted on only two planting dates at Lubbock, the environmental effect on cultivar potential would have been masked by the heat unit deficiency of the Lubbock environments.

All of the cultivars that we studied responded in some degree to the available heat units associated with the environments (all grew and developed faster in the College Station environment). However, TM-1 and Western Stormproof were more affected by a cooler environment than were CA 491 and Acala 1517 Br-2. These latter cultivars may have the inherent ability to grow and develop in cooler environments, perhaps because of some adaptation to the areas where they were developed (Texas High Plains and New Mexico). Gipson and Ray (1969, 1970) suggested that CA 491 carries cold-tolerant genes that make this strain potentially useful in developing cotton cultivars that are tolerant to suboptimum temperatures. Hesketh and Low (1968) found that fiber development of Acala 1517 Br-2 was exceptionally stable over a wide range of temperatures.

If the differential cultivar responses that we have obtained in suboptimum heat unit environments are heritable and can be manipulated by traditional breeding techniques, then it may be possible to develop new genetic combinations that can produce more and better fiber when they are grown in a suboptimum environment.

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