DEVELOPMENT OF COTTON FIBERS IN THE PIMA AND ACALA VARIETIES[1]

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INTRODUCTION

The spinning value of cotton fibers is dependent in large measure on their length and degree of maturity. The thickness of fiber walls is closely correlated with degree of maturity and fiber strength. Other fiber characters influence the spinning quality of cotton, but those mentioned are of major importance and are the ones which were studied in this particular investigation.

The extent to which factors external to the cotton plant, such as soil and climatic conditions, influence fiber length and maturity is not well understood. A knowledge of the life history of cotton fibers from the flowering of the plants, at which time fiber growth begins, to the maturity of the fibers is necessary in order to establish the degree to which external factors influence the length of fibers and the thickness of the fiber walls. The only published information relative to the development of cotton fibers which has come to the author's attention is the work of Balls [2] in Egypt. His material was taken from a single series in which the flowers opened near the beginning of the flowering period. The variety used was a pure strain of Egyptian No. 77 which has a fiber length of about 30 mm. as determined by measurements taken on combed fibers attached to the seed. Balls found that the fibers increased in length until the twenty-fifth day after flowering. The maximum rate of growth in length occured near the fifteenth day after flowering. Thickening of the fiber walls began about 21 days after flowering, reached its maximum rate of increase in 36 to 39 days, and was practically completed 45 days after flowering.

The data included in the present publication relate to the life history of two types of cotton fibers developing in successive periods during the growing season of 1926.

MATERIAL AND METHODS

Pima, the only variety of American-Egyptian cotton now grown in the Southwest, has a fiber length of approximately 40 mm. (1 9/16 to 1 5/8 inches). Acala cotton is the upland variety most widely grown in the Southwest, and has a fiber length of 28 to 30 mm. (1 1/8 inches). These two varieties were chosen for the work on fiber development because they are representative of the two types of cotton grown commercially in the Southwest.

The fiber material studied was obtained from Acala and Pima plants growing on adjacent plots at the Salt River Valley Experiment Station. The plants were irrigated with sufficient frequency to prevent

[1] Received for publication Aug. 6, 1929; issued May, 1930.
[2] BALLS, W. L. THE DEVELOPMENT AND PROPERTIES OF RAW COTTON, p. 73–85, illus. London, 1915.

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abnormal water stress but not so frequently as to produce overgrown plants. The soil in these plots is a fertile clay loam with a moisture equivalent of approximately 19.

Several hundred flowers of each variety were tagged on July 13, August 3, August 24, and September 14, making four series at 3-week intervals. A study of Figure 1 shows that the July 13 series began near the fore part of the flowering period and the September 14 series near the close of the flowering period. The August 3 and August 24 series flowered during mid season when flowering was at its height. Six bolls were collected from each series at 3-day intervals from flowering to maturity and stored in 5 per cent formalin for later study.

DEVELOPMENT OF FIBER LENGTH

Three measurements were made of the length of the wet fibers in each boll immediately after the bolls were taken from the preserving

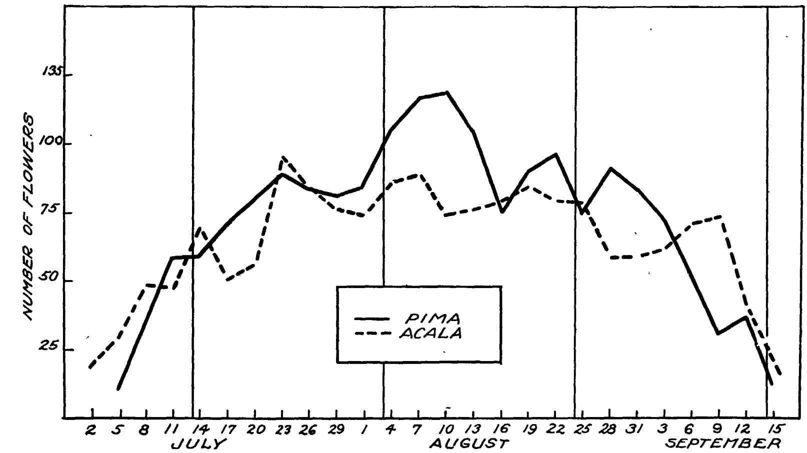

FIGURE 1.—Rate of flowering on 25 plants of the two cotton varieties studied

solution. Thus 18 measurements were made for each 6-boll collection. The fibers in the 3-day-old bolls were too short to measure satisfactorily without the aid of a microscope, but succeeding measurements were made without one.

INCREASE IN FIBER-WALL THICKNESS

Several hundred fibers were taken from each boll and infiltrated and embedded in paraffin in preparation for sectioning. (Celloidin and gelatin are also used for the infiltration of textile fibers with certain advantages over the paraffin method.) The embedded material was sectioned with a microtome having a drawing cut. Considerable difficulty was experienced in cutting the young fibers before the walls began to thicken, but as the walls thickened the fibers were more easily sectioned. The sections were mounted with albumen glycerin and stained with gentian violet.

The rate of wall thickening is relatively slower than the increase in fiber length, and it was soon found that measurements taken on material collected at 6-day intervals furnished dependable information on this development.

RESULTS

Cotton fibers are unicellular elongations from the epidermal layer of the ovule. The fibers begin to extend beyond the epidermis almost immediately after fertilization and are plainly visible under proper magnification 24 hours later. A comparison of Figures 2, 3, and 4 shows the rapidity of fiber growth following fertilization. Some fiber growth occurs even in ovules in which fertilization has been prevented by the removal of the anthers before the flower has opened. Fiber growth in unfertilized ovules is much slower for the first three

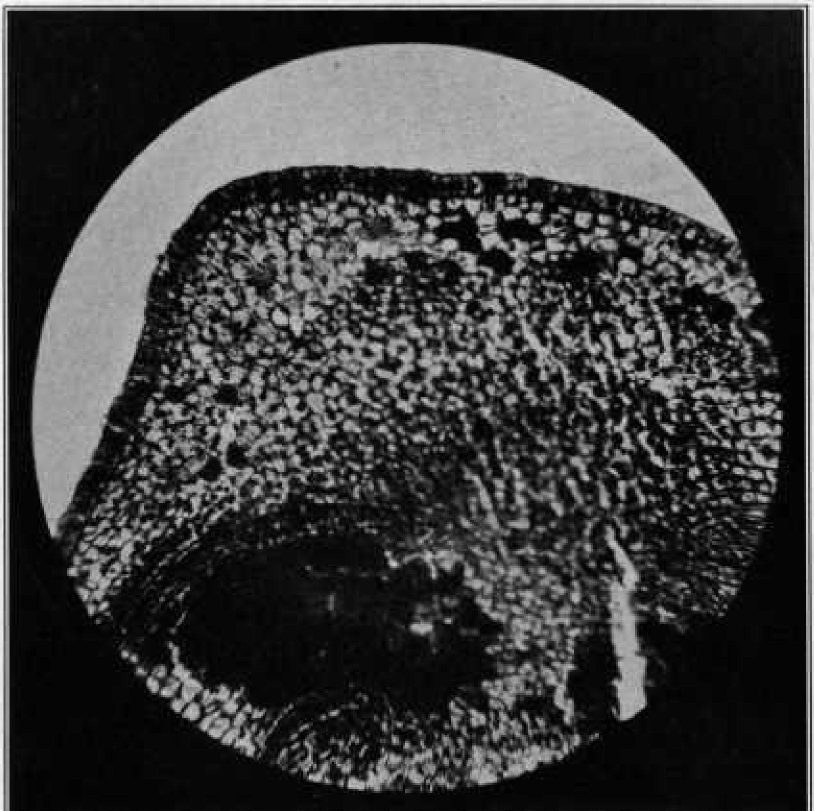

FIGURE 2.—Cross section of cotton ovule showing appearance of epidermis on day of fertilization. No transformation of epidermal cells into fibers is evident. Highly magnified

days than in fertilized ovules, and very little if any growth takes place after the third day, abscission of the boll usually occurring within seven or eight days after flowering.

The cumulative increase in fiber length of both Acala and Pima cotton is shown in Figure 5 and in Tables 1 and 2. Increase in length was practically completed in the first three series of Acala fibers in 21 days and in the corresponding series of Pima fibers in 27 days after flowering. The September 14 series of each variety required three days longer for the completion of fiber elongation, or 24 and 30 days for Acala and Pima, respectively. It will be noted that the temperatures were declining rapidly during the time when the September 14 series of Acala and Pima fibers were developing length. The minimum temperatures had dropped considerably below 60° F., and the maximum temperatures had declined at least 10°. Pima cotton required about six days longer than Acala to complete growth in fiber length due largely to the fact that the Pima fibers were 10 mm. longer than the Acala. Dry fibers from mature bolls were used for the final measurements in each series; wet fibers from immature green bolls were used for all other measurements. This accounts for the drop at the end of each curve.

The curves showing the cumulative increase in fiber length in each series of Pima cotton have been superimposed in Figure 6 and those

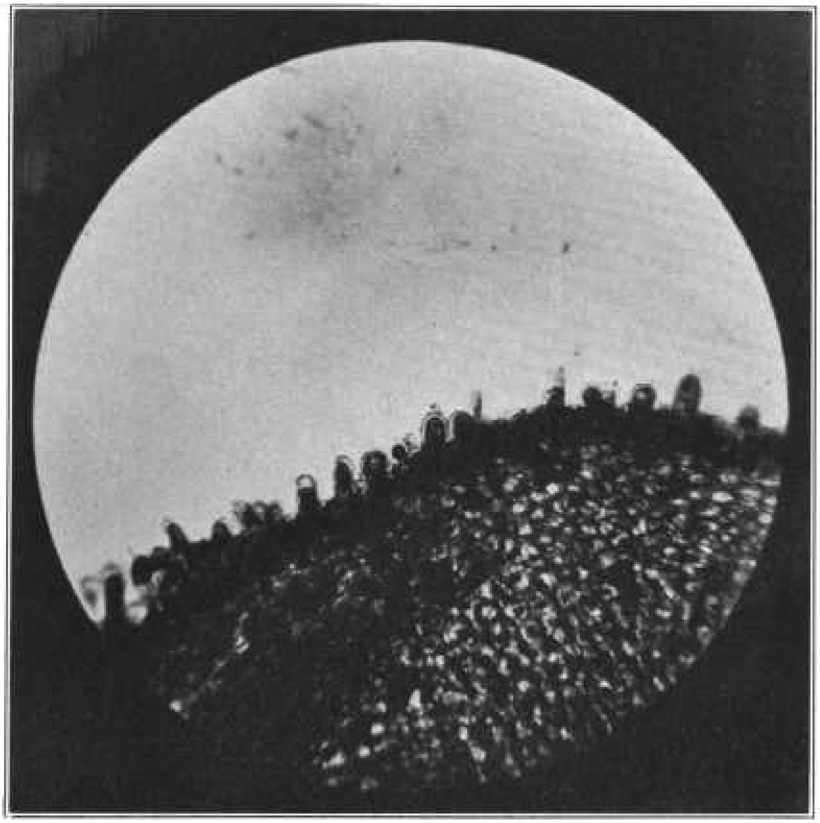

FIGURE 3.—Cross section of cotton ovule showing beginning of fiber growth from epidermal layer 24 hours after fertilization. Highly magnified

of Acala in Figure 7. These figures show that prevailing conditions did not create any great differences between either the Acala or the Pima series in the increase in length.

The rate of increase in fiber length is shown in Figure 8. The rate of fiber elongation was materially greater with Acala fibers than with Pima fibers after the ninth day from the flowering period. The most rapid increase occurred three days earlier with the Acala fibers than with the Pima in the first two series and six days earlier in the last two series. The greatest increase in fiber length was about 8 mm. in three days, the Pima fibers making slightly more rapid growth than the Acala in the first three series and a full millimeter more in the September 14 series. This means that these cotton fibers were making a daily growth in length of from three-thirty-seconds to one-eighth inch at the time of their most rapid growth. The temperatures which prevailed during the development in fiber length did not appear to cause any material differences in the rate of growth in the first three series but prolonged the period of growth in the September 14 series.

The curves showing the rate of fiber elongation have been superimposed in Figures 9 and 10. The most rapid increase in length of

FIGURE 4.—Cross section of cotton ovule showing development of fibers 48 hours after fertilization. Highly magnified

the Pima fibers occurred during the 3-day period ending on the twenty-first day after the flowering period in all series, as shown in Figure 9, while the most rapid increase in length of the Acala fibers occurred during the 3-day period ending on the fifteenth day in the August 24 and September 14 series and during the period preceding the eighteenth day in the July 13 and August 3 series, as shown in Figure 10. Present data do not indicate the factors which caused the retardation in the rate of fiber elongation from about the ninth to the fifteenth day in all of the Pima series and also in the Acala series to a lesser degree from the ninth to the twelfth day.

TABLE 1.—*Development of fiber length in Pima cotton from flowering to maturity*

Age of bolls (days)	Mean length of lint with ±σ in—			
	July 13 series	Aug. 3 series	Aug. 24 series	Sept. 14 series
	Mm.	*Mm.*	*Mm.*	*Mm.*
3	0. 4±0. 041	0. 4±0. 050	0. 3±0. 047	0. 3±0. 028
6	2. 9± . 543	3. 0± . 159	2. 7± . 222	2. 4± . 960
9	7. 1± . 667	6. 7± . 299	6. 1± . 331	5. 8± . 455
12	11. 9± . 597	11. 0± . 704	10. 9± . 554	10. 0± . 450
15	17. 0± . 959	16. 4± . 712	15. 2± . 471	13. 3± . 654
18	24. 4±1. 635	23. 2± . 424	22. 8± . 361	19. 8± . 705
21	32. 4± . 880	31. 7±1. 043	31. 1± . 390	28. 8± . 575
24	39. 1± . 882	37. 5± . 915	37. 8± . 522	35. 6±1. 204
27	40. 5±1. 355	39. 7± . 829	39. 2± . 876	38. 5±1. 140
30	40. 4± . 782	40. 1± . 527	39. 7± . 533	39. 9± . 312
33	40. 6± . 749	40. 3± . 657	39. 8± . 719	39. 9± . 470
36	40. 8± . 875	40. 1± . 524	39. 9± . 314	39. 9± . 805
39	41. 4± . 518	40. 0± . 566	39. 9± . 555	40. 2± . 500
42	40. 4± . 676	40. 2± . 601	40. 0± . 471	40. 4± . 755
45	40. 9±1. 053	40. 2± . 381	40. 3± . 463	40. 0± . 666
48	41. 0± . 499	40. 2± . 533	40. 0± . 745	40. 1± . 424
51	40. 7± . 650	40. 2± . 533	40. 1± . 705	40. 1± . 458
54	37. 5± . 590	40. 4± . 558	40. 1± . 705	40. 3± . 443
57		37. 9± . 741	40. 3± . 666	40. 1± . 458
60			39. 9± . 404	40. 1± . 404
63			36. 9±1. 282	40. 5± . 678
66				40. 1± . 229
69				40. 3± . 652
72				40. 1± . 458
75				40. 1± . 566
78				40. 1± . 404
81				40. 3± . 471
84				38. 7±1. 609
Average ratio of mean length to standard deviation	40. 50	51. 73	57. 35	63. 60

TABLE 2.—*Development of fiber length in Acala cotton from flowering to maturity*

Age of balls (days)	Mean length of lint with ±σ in —			
	July 13 series	Aug. 3 series	Aug. 24 series	Sept. 14 series
	Mm.	*Mm.*	*Mm.*	*Mm.*
3	0. 6±0. 033	0. 7±0. 048	0. 6±0. 065	0. 6±0. 055
6	3. 5± . 236	3. 2± . 818	3. 2± . 206	3. 0± . 348
9	7. 8± . 500	6. 5± . 579	7. 3± . 883	7. 2± . 499
12	13. 3± . 628	13. 2± . 858	11. 5± . 833	12. 2± . 533
15	20. 7± . 943	19. 5± . 490	19. 6± . 755	20. 2± . 785
18	28. 3± . 926	27. 9± . 432	26. 9± . 911	25. 3± . 458
21	30. 0± . 705	30. 1± . 681	29. 7± . 533	28. 5± . 500
24	30. 0± . 779	29. 8± . 552	29. 8± . 415	30. 1± . 524
27	29. 9± . 657	29. 9± . 755	29. 9± . 524	30. 1± . 404
30	29. 7± . 448	29. 9± . 547	29. 7± . 577	29. 7± . 558
33	30. 1± . 524	29. 7± . 496	29. 9± . 737	29. 7± . 779
36	30. 0± . 624	29. 9± . 585	29. 7± . 658	29. 9± . 524
39	30. 0± . 577	29. 9± . 514	29. 7± . 869	30. 3± . 810
42	30. 1± . 737	29. 9± . 657	29. 8± . 533	29. 8± . 566
45	30. 0± . 823	30. 0± . 666	30. 0± . 471	19. 3± . 816
48	26. 0±1. 328	30. 1± . 458	29. 9± . 657	30. 2± . 415
51		29. 9± . 566	29. 7± . 309	30. 3± . 833
54		27. 8±1. 771	27. 5±1. 300	29. 9± . 810
57				29. 8± . 975
60				30. 0± . 745
63				30. 1± . 524
66				30. 1± . 565
69				30. 2± . 500
72				29. 8± . 785
75				28. 4±1. 458
Average ratio of mean length to standard deviation	36. 53	40. 89	39. 47	41. 86

The standard deviation from the mean fiber length was exceptionally small with both varieties, as indicated in Tables 1 and 2. Deviations were much greater with the young fibers from 3 to 18 days old, probably due to the greater likelihood of error in measurements taken on short fibers as compared with those taken on the longer and older

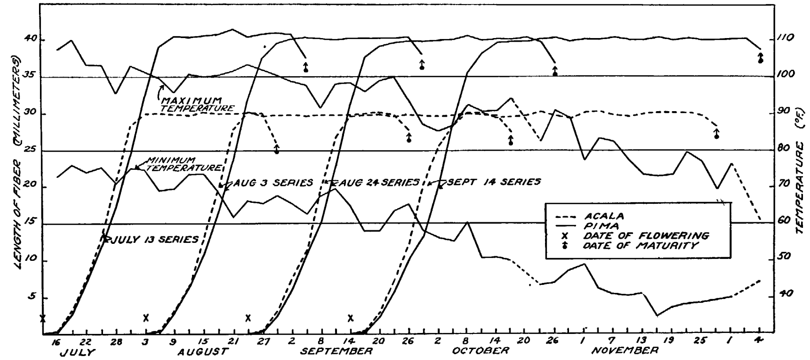

Figure 5.—Cumulative increase in fiber length in Acala and Pima cotton

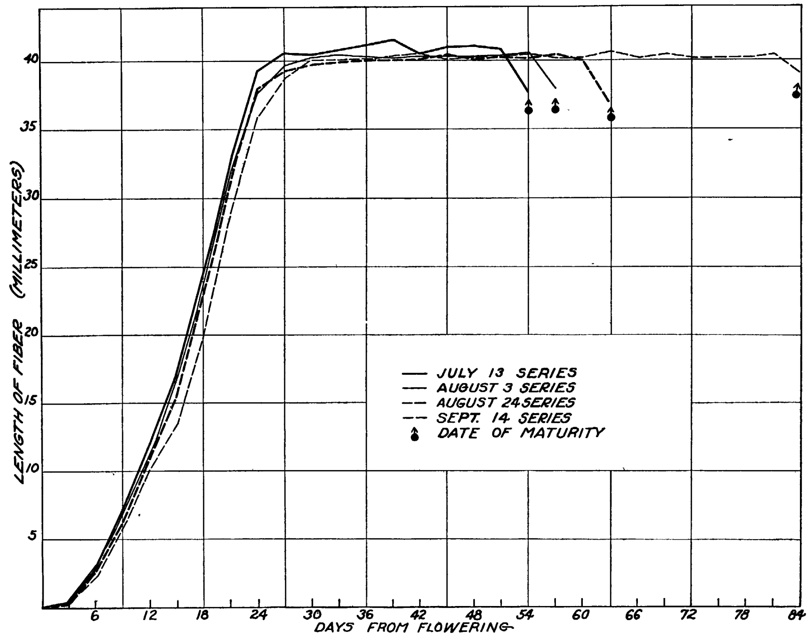

Figure 6.—Superimposed curves showing cumulative increase in length of Pima cotton fibers

fibers. The Pima fibers were more regular in length than were the Acala fibers, as indicated by the smaller deviations in length measurements in the former variety. This greater regularity of the Pima fibers became more pronounced as the season advanced, which is evidenced by the wider ratios between mean fiber lengths and the standard deviations in each successive series of the two varieties.

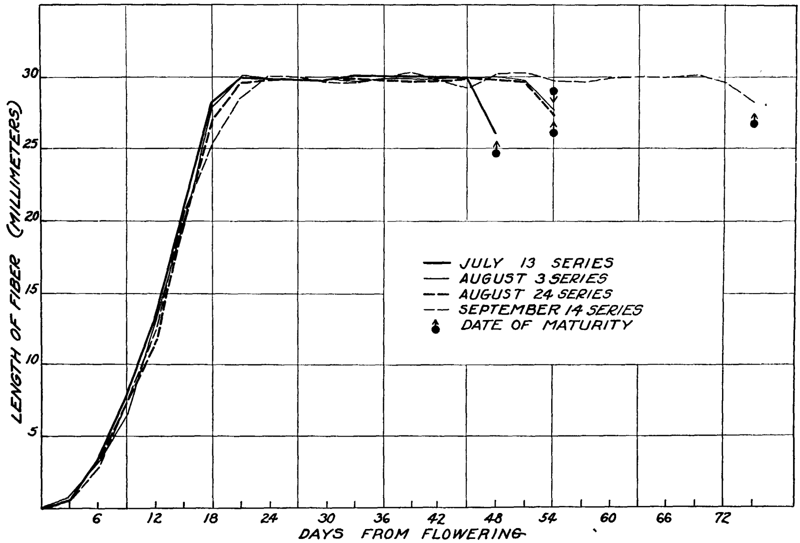

FIGURE 7.—Superimposed curves showing cumulative increase in length of Acala cotton fibers

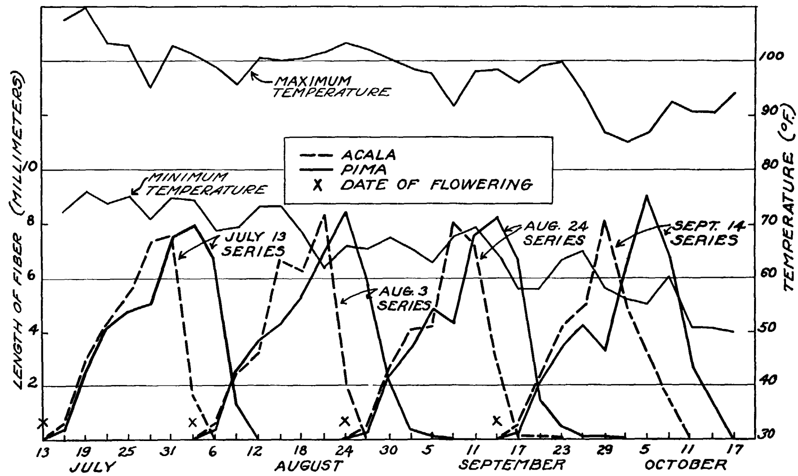

FIGURE 8.—The rate of increase in cotton fiber length as affected by temperature

TABLE 3.—*Development of fiber-wall thickness in Pima cotton from flowering to maturity*

Age of bolls (days)	Thickness of fiber wall in— July 13 series	Aug. 3 series	Aug. 24 series	Sept. 14 series
	Microns	*Microns*	*Microns*	*Microns*
6	0.30	0.35	0.35	0.40
12	.32	.35	.35	.40
18	.35	.35	.36	.40
24	.90	.70	.43	.40
30	1.85	1.02	.86	.51
36	2.40	1.90	1.70	.81
42	2.75	2.55	2.00	1.55
48	2.80	2.90	2.37	1.80
54	3.10	2.80	2.35	2.56
57		2.80		
60			2.50	2.51
63			2.40	
66				2.79
72				2.65
75				
78				2.80
84				2.80

TABLE 4.—*Development of fiber-wall thickness in Acala cotton from flowering to maturity*

Age of bolls (days)	Thickness of fiber wall in— July 13 series	Aug. 3 series	Aug. 24 series	Sept. 14 series	Age of bolls (days)	Thickness of fiber wall in— July 13 series	Aug. 3 series	Aug. 24 series	Sept. 14 series
	Microns	*Microns*	*Microns*	*Microns*		*Microns*	*Microns*	*Microns*	*Microns*
6	0.36	0.40	0.35	0.40	57				
12	.35	.35	.35	.40	60				2.82
18	.36	.40	.35	.40	63				
24	.63	.70	.52	.52	66				2.83
30	1.64	1.02	1.22	1.12	72				3.18
36	2.28	2.25	1.65	1.43	75				3.20
42	2.58	2.50	2.00	1.82	78				
48	2.75	2.80	2.70	2.10	84				
54		3.12	2.40	2.76					

The cumulative increase in fiber-wall thickness is shown in Tables 3 and 4 and Figure 11. Measurements were taken on material collected at 6-day intervals beginning six days after flowering and continuing until maturity. No appreciable thickening occurred during the first 18 days after flowering with either variety of cotton in any series. The fiber walls began to thicken sometime between the eighteenth and twenty-fourth day in the first two series and to a somewhat lesser extent in the third series. A small amount of thickening also took place in the September 14 series of Acala between the eighteenth and twenty-fourth day, but the walls of the pima fibers did not thicken until after the twenty-fourth day in this last series. The temperatures were declining rapidly during the time the fiber walls were thickening in the August 24 and September 14 series, the maximum temperatures dropping below 75° and the minimum below 40° before thickening was completed in the last series. These temperatures were evidently sufficiently low to inhibit the rapid thickening of the fiber walls. A comparison of Figure 5 with Figure 11 shows that during the period immediately succeeding flowering, elongation of the fibers was proceeding rapidly, but thickening of the fiber walls did not begin until elongation was almost completed. The rate of thickening was slow at first, but became considerably accelerated after elongation had been completed.

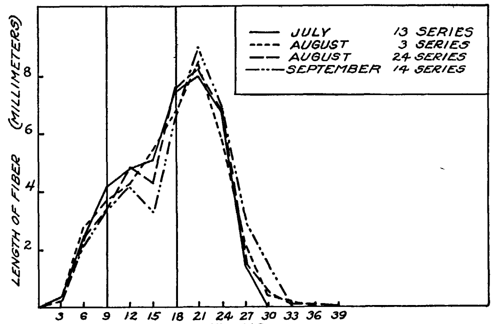

FIGURE 9.—Superimposed curves showing the rate of increase in length of Pima cotton fibers

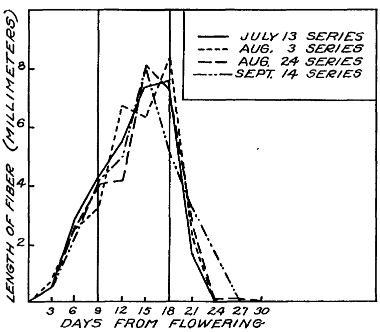

FIGURE 10.—Superimposed curves showing the rate of increase in length of Acala cotton fibers

The curves showing the development in thickness of fiber walls have been superimposed in Figures 12 and 13. Maximum fiber-wall

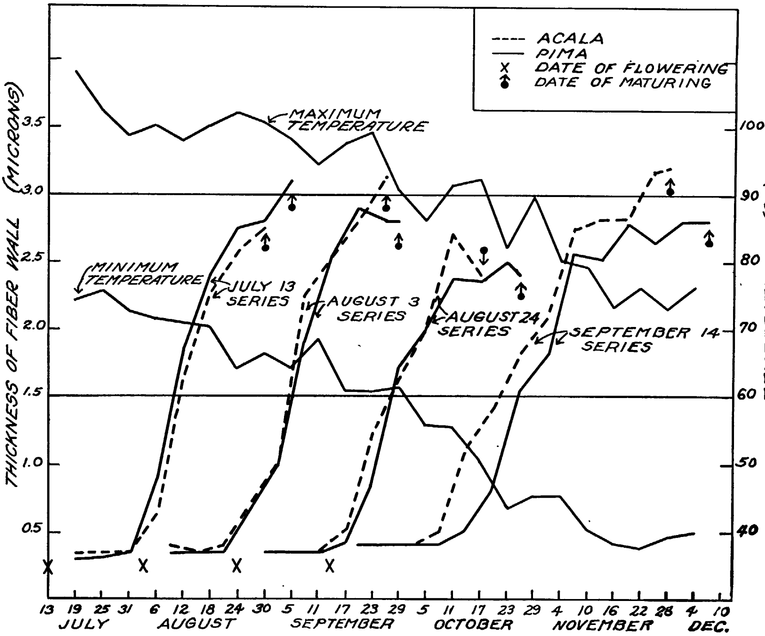

FIGURE 11.—Cumulative increase in fiber-wall thickness in Acala and Pima cotton

thickness was attained in the Pima variety 54, 48, 60, and 78 days after the flowering period in the July 13, August 3, August 24, and September 14 series, respectively. Acala cotton required 48, 54, 48, and 75 days for maximum fiber-wall thickening in these respective series. With the exception of the August 3 series, the Pima fibers required from 3 to 12 days longer for wall thickening than did the Acala fibers.

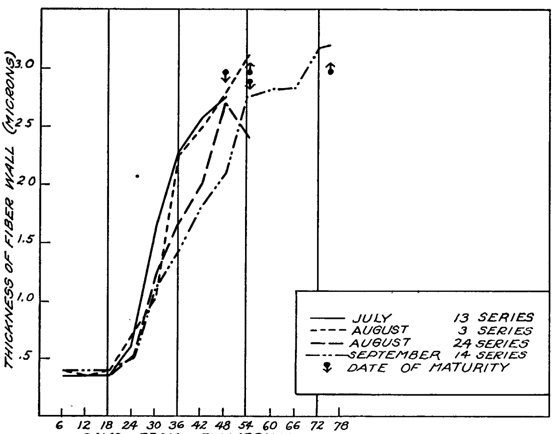

FIGURE 12.—Superimposed curves showing the cumulative increase in fiber-wall thickness of Pima cotton

The effect of temperature on the rate of increase in fiber-wall thickness is well shown in Figure 14. The rate of increase in thickness dropped as the temperatures declined with each successive series with the one exception of the August 3 series of Acala fibers. No explanation will be advanced as to why two high peaks with an intervening low rate of thickening occurred with the Pima fibers in the

September 14 series and also in the August 24 and September 14 series of Acala fibers.

More than one-third of the total wall thickening of the first two series of Acala fibers was acquired during the 3-day period of most rapid thickening. Considerably less than this amount of wall thickening was acquired during the corresponding periods of the last two Acala series. The amount of wall thickening in the Pima fibers during the time of their most rapid thickening was somewhat less than for the Acala in the first two series and more than the Acala in the last two series.

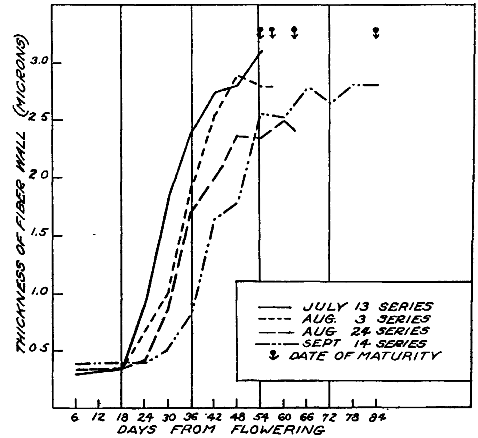

FIGURE 13.—Superimposed curves showing the cumulative increase in fiber-wall thickness of Acala cotton

The superimposed curves in Figures 15 and 16 emphasize differences in the rate of increase in fiber-wall thickness which prevailed between the various series. A comparison of these two figures with Figures 9 and 10 shows that differences between series in the rate of increase in fiber-wall thickness were much more pronounced than were

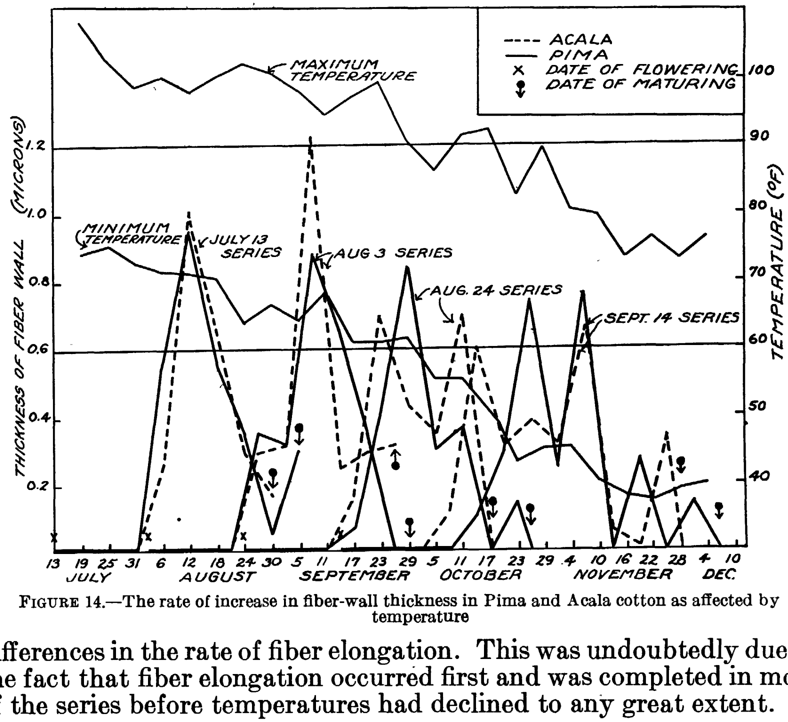

FIGURE 14.—The rate of increase in fiber-wall thickness in Pima and Acala cotton as affected by temperature

differences in the rate of fiber elongation. This was undoubtedly due to the fact that fiber elongation occurred first and was completed in most of the series before temperatures had declined to any great extent.

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Fiber-wall thickening was completed at the date of maturity of the bolls in three of the Acala series and in one of the Pima series, while wall thickening was completed in the remaining series from three to nine days before the bolls opened. These differences were due in part to the difficulty in deciding when a boll is mature. The tendency toward delayed opening of the bolls was greater during the latter part of the season and was probably due to the general slowing up of plant activity.

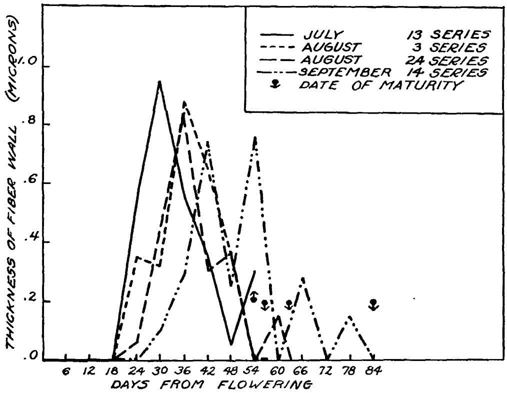

FIGURE 15.—Superimposed curves showing the rate of increase in fiber-wall thickness of Pima cotton

SUMMARY AND CONCLUSIONS

Fiber growth begins at the time of flowering irrespective of fertilization and proceeds rapidly after fertilization but ceases within a few days in unfertilized bolls.

Elongation of Acala fibers was completed 21 days after flowering in the series which flowered July 13, August 3, and August 24; and 24 days after flowering in the series which flowered September 14.

Pima cotton required 27 days for the elongation of the fibers in the first three series and 30 days for those in the September 14 series.

Lower temperatures probably caused the prolongation of the time needed for completion of fiber length in the September 14 series of both varieties.

The fibers of both varieties made a daily increase in length of from three thirty-seconds to one-eighth inch at the time of their most rapid growth.

The greatest increase in fiber length occurred about the twenty-first day after flowering in the Pima series and from the fifteenth to the eighteenth day in the Acala series.

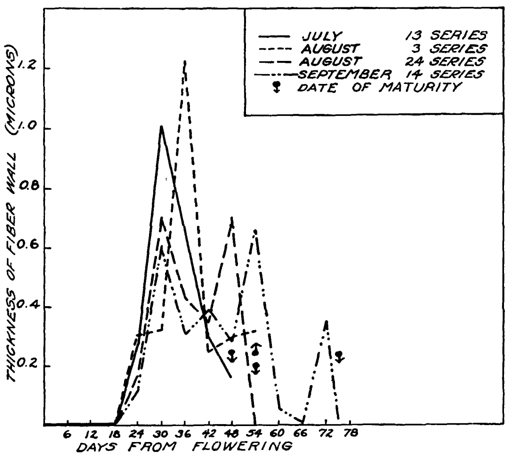

FIGURE 16.—Superimposed curves showing the rate of increase in fiber-wall thickness of Acala cotton

No appreciable thickening of fiber walls began until fiber elongation was almost completed.

The rate of fiber-wall thickening became less, with one exception, in each successive series as the temperatures declined.

Fiber-wall thickening was completed in the Pima fibers 54, 48, 60, and 78 days after the flowering period in the July 13, August 3, August 24, and September 14 series. Acala cotton required 48, 54, 48, and 75 days for maximum fiber-wall thickening in these series.

Fiber-wall thickening was completed in some instances at the time of boll maturity and in others a few days before maturity.

The time of the season during which cotton fibers are developing affects the rate of fiber-wall thickening greatly but does not influence the rate of fiber growth in length to any appreciable extent until late in the season.

Prevailing temperatures contribute to the rate of fiber development, and when lower than necessary for optimum plant growth, have a retarding effect on both fiber elongation and fiber-wall thickening.

Varietal differences in the development of length and wall thickness of cotton fibers as unlike as Acala and Pima are noteworthy.