Chapter 5

TEMPERATURE EFFECTS ON GROWTH, DEVELOPMENT, AND FIBER PROPERTIES

Jack R. Gipson
Texas Tech University
Lubbock, Texas

INTRODUCTION

Cotton in its native state grows as a perennial shrub in a semi-desert habitat, and as such requires warm days and relatively warm nights. The cultivated species grown throughout the world today are classic examples of plant domestication, but even so, the requirement for high temperatures has probably not been altered appreciably in well over a hundred years of breeding and selection.

In the classic work of Balls (1919a), he stated that cotton in the field seemed to grow best around 32C in Egypt, while prolonged temperatures above 35C were harmful. During the following decade a number of other researchers working with cotton in the field made observations that drew attention to the possible role of temperature in cotton growth, development, and production (Martin, Ballard and Simpson, 1923; Ballard, 1925; Loomis, 1927; Buie, 1929; Hawkins and Serviss, 1930; Hubbard, 1931). Later as the commercial production of cotton gradually moved into areas where temperatures were not optimal, interest in the role of temperature in all phases of cotton production steadily increased. During the last quarter-century a substantial body of definitive information relating to the influence of temperature on cotton growth and development, fruiting, and quality parameters have been accumulated.

GERMINATION AND EMERGENCE

In many areas of the Cotton Belt, cotton planted in early season is subjected to unstable weather conditions with extreme temperature fluctuations common, particularly in the northern regions of the Belt. As a consequence, many investigators have studied the influence of temperature on the germination and emergence of cotton. Ludwig (1932) found the minimum temperature for germination to be about 12C. Arndt (1945) grew cotton seedlings in darkness on agar at temperatures ranging from 18 to 39C and concluded that minimal temperatures for germination were below 18C, that the optimum was 33 to 36C, and that the maximum was above 39C. Marani and Dag (1962b) noted a pronounced difference in the ability of different cotton varieties to germinate at low temperature. Generally *G. barbadense* varieties germinated better than *G. hirsutum* at 12C (Marani and Dag, 1962a).

With regard to seedling emergence in the field, rate of emergence is generally a function of temperature. Holekamp *et al.* (1960) reported a higher correlation between emergence percentage and the 10-day average minimum temperature at 20 cm (8 inches) in the soil, than between emergence percentage and planting date. A rule-of-thumb recommendation was derived from this research to describe the earliest practical planting date on the Texas High Plains. The "rule" specifies that soil temperature should average 15.5C for a 10 day period at the 20cm depth before planting is initiated. It has been used successfully for almost 25 years. Similar "rule-of-thumb" recommendations have resulted from studies in other areas. Riley *et al.* (1964) determined the relationships between minimum, maximum, and average seed level temperatures, and days from planting to first emergence for the Mid-South. They recommended soil temperatures should average 20C or higher during germination and emergence. McQuigg and Calvert (1966) studied time and average soil temperature effects at planting depth on cotton emergence in growth chambers. From their data they plotted a graph which provided an estimate of the amount of emergence to expect under various soil temperature-duration patterns (See also Chapters 34 and 36).

Low soil temperatures during cotton seed germination has both immediate and long-term effects. The immediate effects were described by Christiansen (1963, 1964) and consist of two types; A) radicle tip abortion induced by chilling at the onset of seed hydration and B) root cortex disintegration induced by chilling the seedling after elongation of the embryonic axis has commenced. These effects are manifest at temperatures below 10C (Christiansen, 1963, 1964, 1967), and there are apparently two periods of chilling hypersensitivity during germination. These are discussed by Christiansen and Rowland in Chapter 34.

The effect of chilling temperatures on germinating cotton can have far-reaching effects. In addition to the immediate effect on emergence rate and stand development, chilling may also alter growth and the fruiting pattern throughout the season (Christiansen and Thomas, 1969). It appears that, in the final analyses, total yield could be significantly affected. Wanjura *et al.* (1969) have determined that the first plants emerging have the highest survival rates, and the emergence time exerts a dominant influence on yield. For example, their data showed that relative yield averaged 100, 46, and 29 percent for plants with 5, 8, and 12-day emergence dates.

VEGETATIVE GROWTH AND FRUITING

In some areas of the Cotton Belt, earliness is considered a desirable characteristic. It provides one mechanism by which the detrimental effects of low temperature on boll development in late season may be avoided. The degree of earliness of a given cultivar is associated with the length of the prefruiting period and the nodal position of the first sympodium (fruiting limb). Ray and Richmond (1966) found these two characters to be highly correlated, which implies that the nodal position of the first fruiting branch may be used as a criterion for selection in breeding for earliness. Both characters are influenced by temperature.

FRUITING LIMB INITIATION AND FLOWERING

The first scientific investigations relating temperature to cotton growth, development, and fruiting were initiated early in the 20th century. One of the first was a study by Ewing (1918) on certain environmental factors influencing the fruiting of cotton. His data showed a 2-day lag period between the application of low temperature (below 18.3C) and a subsequent reduction in the opening of flowers. This suggested that temperature had a modifying effect on flowering. Martin *et al.* (1923) then noted a lengthening in the interval between appearance of squares as the season advanced. Four years later, Loomis (1927) reported the same observations. In each case the effect was probably due to lower temperature. At about the same time McNamara *et al.* (1927) reported that the number of days from planting to first square was reduced by delaying planting until warm weather. Several years later Waddle and his coworkers (Waddle, 1954; Waddle *et. al.*, 1961) noted that a certain strain of *Gossypium hirsutum* race *latifolium* flowered and set fruit in the field at Shafter, California, but would not flower at College Station, Texas. Day lengths were slightly longer at Shafter, but temperatures were also cooler. Mean monthly minimums at Shafter were 8C lower for May and June and mean monthly maximums were 1 to 5C lower. Based on these differences at the two locations they correctly surmised that temperature was interacting with photoperiod to induce flowering at Shafter. Moraghan *et al.* (1968) studied 11 cotton strains under 7 different day-night temperature regimes. They found that the earliest squares were produced at the intermediate ranges of 27/22 and 30/25C. Squares were formed significantly later under extremely high (36/32C) and extremely low (18/13C) day-night temperature regimes. They also found variation among diverse cotton strains in the effects of both temperature and day length on the time of squaring.

Gipson (1974) studied the effect of temperature and methyl parathion on vegetative development and fruiting of two varieties of cotton. He maintained night temperatures at 10, 15, 20 and 25C with day temperatures ambient. Plants grown under 20 and 25C nights were not significantly different in days to first square or days to first bloom, indicating night temperature above 20C was not a limiting factor. As temperature was decreased below 20C, however, there was an appreciable increase in both time periods. Depending on the cultivar and treatment, the date of first square was increased by 2 to 5 days under 15C nights and by 11 to 15 days under 10C nights, as compared to the time required at 20 or 25C. Using 20 and 25C as the basis of comparison, the increase in days to first bloom ranged from 12 to 17 days under 15C nights to 28 to 34 days under 10C nights.

NODAL POSITION OF THE FIRST FRUITING LIMB

The first definitive studies conducted under controlled conditions on the role of temperature in determining the nodal position of the first floral bud was by Mauney and Phillips (1963). They studied the effects of both temperature and photoperiod on flowering, and on the nodal position of the first square in several *Gossypium* species, including a number of cultivars within the *G. hirsutum* and *G. barbadense* species. They noted an interaction between temperature and daylength in some species and cultivars, but not in others. With one exception, the *G. hirsutum* strains observed were classified under short-day flower control groups. Cool nights (15C) enhanced flowering in these types. Warm nights increased bud abscission in three strains, and no effect of either temperature or daylength on flower development was noted in the other seven *G. hirsutum* accessions. Mauney (1966) later studied floral initiation in a cultivar of *G. hirsutum* L., M-8, and found that in general, night temperatures above 28C resulted in a higher nodal position. The effect was greatly enhanced by high (28-32C) day temperatures. The converse was true with low night temperatures (20-22C). In conjunction with low night temperatures, high day temperatures resulted in a lower nodal position of the first sympodium. The enhancement of flowering by high day and low night temperatures was manifested not only in the lower nodal position of the first floral branch, but also in a shorter time from planting to floral initiation (See Chapter 2).

Low *et al.* (1969) obtained an increase of several nodes between the day-night temperature regimes of 24/19 and 33/28C. They found that *G. hirsutum* varieties responded to only one week of 24/19C, suggesting that earliness can be induced at a very early stage.

Studies by Gipson(1974) and Gipson and Ray (1974) lend credence to the idea that temperatures prevailing during the period between emergence and visual appearance of the first true leaf exert a modifying influence on the nodal position of the first fruiting limb. In the first study, conducted during the 1971 growing season (Gipson, 1974), night temperature treatments of 10, 15, 20 and 25C were initiated at emergence, with day temperatures ambient. The nodal positions of the first squares were essentially the same under 15 and 20C nights, but either a reduction of night temperature to 10C or an increase to 25C resulted in significantly higher nodal positions. In the second study, however, (Gipson and Ray, 1974) which was conducted during the 1972 and 1973 growing seasons with night temperatures of 13, 25 and 37C initiated at the first true leaf stage and day temperatures ambient, the night temperature treatments had no effect on the node of first square. Apparently nodal position of the first sympodium had already been determined between emergence and the appearance of the first true leaf.

Gipson (1974) also studied the influence of night temperature on number of fruiting and vegetative limbs per plant, utilizing two cultivars, Gregg 35 and Deltapine 16. Of the two, Gregg 35 was the more determinate. Total number of limbs per plant was relatively constant across cultivars and temperature treatments (10, 15, 20 and 25C nights), but the ratio changed between fruiting and vegetative limbs. At 10 and 25C the number of vegetative limbs increased at the expense of fruiting limbs. Gregg 35 produced the maximum number of fruiting limbs at 15C and Deltapine 16 produced the maximum at 20C. There was also a positive relationship between the number of vegetative limbs and the total nodal position of the first fruiting forms. The treatments that raised the nodal position of the first forms increased the number of vegetative limbs.

BOLL DEVELOPMENT

Both fiber and seed development proceeds simultaneously during the boll growth and maturation period, or between anthesis and boll (capsule) dehiscence. This time interval is referred to as the "boll period." It is initiated at anthesis and terminates with dehiscence which is manifest by desiccation and subsequent "cracking" of the boll at carpel sutures.

The fiber cells are differentiated from epidermal cells of the seedcoat, and their subsequent growth and development occurs in two distinct phases. The first is a period of cell elongation, and the second a period of secondary cell wall thickening (Balls, 1919b). The details of these two phases are given in Chapters 23 and 26.

FIBER ELONGATION

Both temperature and variety influence the rate of fiber elongation. Hawkins and Serviss (1930) noted that temperatures which were suboptimum for plant growth also retarded fiber elongation. O'Kelley and Carr (1953) obtained a marked decrease in rate of fiber elongation as temperature was decreased from 21.8 to 14.7C. They concluded 14.7C was approaching the minimum temperature required for elongation. Hessler *et al.* (1959) found that fiber length decreased as the season progressed, indicating a temperature deficiency for elongation. In Uganda, Morris (1962) found the time required for fiber cells to attain maximum length varied only slightly from season to season, despite marked differences in rainfall and temperature. He did note, however, that the maximum length obtained was reduced under the cool temperatures. Stockton and Walhood (1960), in a study of boll temperatures, found that as boll temperature increased above 32C fiber length was reduced.

Gipson and Joham (1969a) studied the influence of four different night temperature regimes on two varieties of field grown cotton during two consecutive seasons. Elongation of fiber was found to be closely associated with both temperature and variety. As night temperatures were lowered from 26.6 to 12.8C the first season and from 27.2 to 10.0C the second season, fiber elongation rates decreased and fiber elongation periods increased for both varieties. Rate of elongation was not uniform over the entire elongation period, but was dependent upon fiber age and night temperature. Maximum growth rates were obtained between 10 and 15 days after anthesis with night temperature levels of 21.1C or above. Temperature coefficients of elongation decreased with increased fiber age and night temperature, indicating the initial stages of fiber elongation (up to 15 days age) was extremely sensitive to temperature, whereas after 15 days age, fibers tended to become temperature independent. Gipson and Ray (1969a) then studied fiber elongation rates in five varieties of cotton as influenced by night temperature. Temperatures below 20C reduced fiber length; and generally the reduction was greater in varieties having the longer fibers. Lowering the night temperature also slowed the fiber growth rate and increased the fiber elongation period (Table 1). Temperature coefficients of elongation were in agreement with the previous study (Gipson and Joham, 1969a), indicating extreme temperature sensitivity up to 15 days age, at which time the coefficients of elongation quickly approached one, indicating temperature independence.

Table 1. Effect of night temperature on fiber elongation periods and on mean elongation rates.

Variety	Temperature, C							
	10	15	20	25	10	15	20	25
	Days				*mm/day*			
Acala 1517 BR-2	35	30	30	28	.71	.87	.93	1.00
Stoneville 7A	35	30	26	25	.66	.80	.96	1.00
Lankart 57	31	27	27	23	.77	.83	.85	.92
Stripper 31	30	26	26	22	.70	.81	.85	.88
C.A. 491	38	35	26	21	.53	.60	.81	.95

Source: Gipson, J.R. and L.L. Ray (1969a).

SECONDARY WALL THICKENING

In the second phase of fiber development, i.e., secondary wall thickening, cellulose is deposited layer on layer, one inside the other, within the primary wall at the expense of the lumen. This layering was first shown to correspond to number of days of growth by Balls (1919b). Later Kerr (1937b) confirmed the findings of Balls and showed that each layer (fiber growth ring) was actually made up of two layers: one compact and the other porous; the first associated with warm periods of growth during daylight and the second with growth during cool night hours. With night temperatures below 20C the porous zones were distinct from the dense lamella; whereas, with night temperatures above 22C, the porous zones were not well differentiated. Anderson and Kerr (1938) later indicated that the distribution and thickness of growth rings could be manipulated by varying temperature and light. They also found that walls of cotton fiber maturing early in the season were generally thicker than late maturing fibers, but the late maturing fibers possessed the greater number of growth rings. They attributed the differences to cooler temperatures in late season. Grant *et al.* (1966) later found the diurnal ring structure within the fiber was related entirely to fluctuations in temperature, and was not associated with alternating periods of light and darkness.

Gipson and Joham (1968b) studied the rate of cellulose synthesis as reflected by the increase in fiber weight per boll per day under four night temperature regimes. They found rate of cellulose synthesis was directly related to night temperature. As mean night temperature increased between the interval of 8.1 and 25.3C, gain per boll per day increased by 64 percent for the variety Acala 1517 BR-2, and by 46 percent for the variety Paymaster 101. In a study of five

Table 2. Effect of night temperature on the boll maturation period, the rate of cellulose production, and the micronaire value of five cultivars grown under four night temperature regimes (data reflects seasonal means).

Night temperature, °C	Acala 1517 BR-2	Stoneville 7A	Lankart 57	Stripper 31	C.A. 491
	Number of days of boll period				
27	50.5	53.3	55.3	53.6	50.8
21	66.2	66.0	62.3	64.6	56.3
15	87.3	88.5	84.2	79.5	68.5
11	95.9	94.6	92.6	86.4	81.8
S.E.[1]	+1.16	+1.37	+1.59	+1.68	+1.70
Cellulose production, mg. per boll per day (excluding fiber elongation period)					
27	45.4	31.6	49.9	30.1	27.6
21	39.8	30.4	39.9	30.8	27.1
15	22.6	19.4	24.6	22.6	19.4
11	18.8	11.5	22.4	17.7	14.4
S.E.[1]	+1.81	+1.63	+2.25	+1.26	+0.94
	Micronaire values				
27	4.08	4.28	4.44	5.33	3.88
21	4.08	3.89	3.71	5.70	3.46
15	3.13	2.94	3.65	4.57	3.57
11	2.51	2.44	3.08	3.36	2.85
S.E.[1]	+0.13	+0.13	+0.19	+0.20	+0.10

[1] Standard error of the mean calculated from a minimum of 5 samples per mean.

Source: Gipson, J.R. and L.L. Ray (1970).

cultivars grown under four night temperature regimes, Gipson and Ray (1970) also obtained pronounced differences in the rate of cellulose synthesis among cultivars and across temperatures. Data on cellulose production from their study is shown in Table 2.

BOLL MATURATION PERIOD

Length of the boll period is a function of both the rate of fiber elongation and the rate of cellulose deposition on the secondary wall. Since both phases are temperature dependent, one might expect temperature to be the overriding factor in controlling length of the boll maturation period. In practice, this appears to be the case. A number of early cotton researchers noted that the maturation period of bolls lengthened with the advance of the growing season (Martin *et al.* 1923; Buie, 1929; Hawkins and Serviss, 1930).

Gipson and Joham (1968b) found the rate of boll development to be inversely related to both day and night temperature. Night temperature was the dominant factor. They concluded that high day temperatures could not compensate for low night temperatures in the boll development process. Gipson and Ray (1970) studied the effect of four night temperature regimes on five cultivars and obtained pronounced increases in boll periods with decreasing night temperatures. Their data exemplifies the influence of temperature on boll periods and is shown in Table 1.

More recently, Young *et al.* (1980) in a field study at El Paso, Texas involving five planting dates found that number of days from planting required to produce open bolls decreased as planting temperatures approached an optimum, then increased for the last planting date as maturity was forced into the cooler days of fall. They noted that numbers of day-degree units (daily maximum minus 12.8C) and heat units (average daily temperature minus 12.8C) were negatively correlated with length of the boll period. The number of day-degree units gave a better estimate of boll period by harvest week than the number of heat units.

FIBER PROPERTIES

The effect of environment on the fiber properties and spinning performance of cotton was well documented in the mid 40's (USDA, Bureau of Plant Industry, 1947; see also Chapter 24) but the only research conducted on the topic was inspired by academic interest. By the mid 50's, the cotton trade recognized that more rigid standards must be set for official spot cotton market values. So, the New York and New Orleans Cotton Exchanges added a requirement that contract cotton would have micronaire readings incorporated, and that the base staple length would be increased to one inch in future contracts. Shortly thereafter, interest began to increase in the role of environment in cotton quality parameters. In the mid 60's micronaire readings were incorporated on the "green" (loan cards) and producers became aware of the importance of quality.

Over the years a number of physical and chemical properties have been found to be associated with the temperature prevailing during the fiber development period. Physical properties implicated include length, strength, and micronaire. Chemical properties affected are percent cellulose, degree of crystallinity, and degree of polymerization.

Hessler *et al.* (1957) studied a number of these properties utilizing cotton fiber grown under progressively lower seasonal temperatures on the Texas High Plains. From earlier to later blooms, or from blooms on August 8 to blooms on September 5, they found: micronaire decreased from 4.1 to 2.6; percent cellulose from 94.8 to 90.0; degree of polymerization from 7564 to 6090; crystallinity from 86.3 to 78.6; and strength (Pressley Index) from 74.7 to 68.7 (X 1000). This was a strong indictment on the role of temperature in fiber quality. Hessler *et al.* (1959) then studied fiber properties under increasing temperature deficiency as the season progressed. As the temperature deficiency increased in the colder late season, cellulose synthesis decreased, and sugars increased, indicating temperature dependence for cellulose synthesis. They obtained high correlations between cellulose and crystallinity and between crystallinity and strength.

Gipson and Joham (1968b) found night temperatures exerted a very significant influence on both physical and chemical properties of cotton fiber. Of the physical properties measured, micronaire was affected to the greatest extent by low night temperatures. Gipson and Ray (1970) obtained similar results. Their data on micronaire values for five cultivars grown under four different night temperature regimes are shown in Table 2. Within a given cotton cultivar, a trend toward finer fibers is characteristic of under-development and results from insufficient cellulose deposition on the secondary wall. Thus, low micronaire values obtained under low temperatures indicate a reduction in fiber development under these conditions. This is substantiated by the rate of cellulose synthesis for these same cultivars (Table 2).

In both studies (Gipson and Joham, 1968b; Gipson and Ray, 1970) fiber length was curvilinear within the temperature limits studied. In each case, maximum length was achieved with night temperature levels of about 19 or 20C (fitted curves). It was apparent, however, that the optimum varied with cultivar.

Strength (Pressley Index) was determined in both the previous studies, but the differences obtained due to temperature was minimal. This was probably due to the "bundle principle." The Pressley tester measures the breaking load of a bundle of fibers in arbitrary units divided by the weight in milligrams of a constant length of that bundle. Since there are more fine fibers than coarse fibers in a bundle of the same weight, the weakness of individual immature fibers cannot be detected by this method.

The data presented in this review implicates temperature as a primary component in the control of plant emergence, growth, development, fruiting, and boll development. It is obvious that low temperature is one of the greatest deterrents to optimum fiber development. Depending on the degree of development achieved, the spinning utility of fibers produced under suboptimal temperature conditions may be impaired.

SUMMARY

Cotton requires warm days and relatively warm nights for optimum growth and development. In many areas of the Cotton Belt, however, suboptimum temperatures may occur in both early and late season. As a consequence plant germination, emergence, growth, and development may be retarded in early season, and fiber development, maturity, and quality reduced in late season.

Minimum, optimum and maximum temperatures vary with the stage of plant development, the physiological process in question, and the cultivar concerned. The role of temperature has been defined and limits established for many phases of plant growth and fiber maturity, but a number of questions remain unresolved.

Some progress has been achieved in the development of cold tolerance, particularly in early season, but other areas are open for exploitation.

ACKNOWLEDGEMENTS

Personal research cited by the author was conducted under the auspices of the Texas Agricultural Experiment Station and was funded in the initial stages by Plains Cotton Growers; Lubbock, Texas, and the Cotton Producers Institute (now Cotton Incorporated). Later funding was provided entirely by Cotton Incorporated.

The author extends thanks to these fine organizations and to the many individuals with whom he worked at the TAES, at Cotton Incorporated, and at Plains Cotton Growers.