COTTON FIBER DEVELOPMENT: GROWTH AND ENERGY CONTENT OF DEVELOPING COTTON FRUITS

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Abstract

The quality of any agronomic product depends on the physiological performance of the crop, but limitations to optimal performance under the highly variable growth environment within a typical agricultural crop canopy are often not clear. Controlled-environment studies have demonstrated that the physiological factors important in cotton (*Gossypium* sps.) fiber synthesis depend on environmental constraints, especially temperature and available energy in the form of reduced carbohydrates from photosynthesis or stored reserves. In this study, we examined fiber development in two cotton species, *G. hirsutum* and *G. barbadense* under field growth conditions. The sensitivity of boll period to growth temperature indicate that a one degree shift in average daily temperature experienced during the boll development period would alter the duration of the maturation by 5 days. However, differences in average daily growth temperature also resulted in changes in dry weight accumulation and composition pattern of fruit components, particularly of the fiber and seed. Control of bur development was insensitive to growth environment and independent of fiber development. Lack of coordination between fiber growth factors and boll maturity (as indicated by bur opening) can result in substantial reductions from optimal fiber quality upon harvest, and indicates a need for a better measure of crop maturity than the rate of fruit dehiscence.

Introduction

While yield is of primary importance in most agricultural production systems, in cotton (*Gossypium* sps., L.) increasing demand is being placed on the quality of the product. Defects in cotton fabrics due to irregularities and imperfections are one of the biggest problems currently facing the cotton industry (Focus on Textile Research, 1992). With the demand for higher quality products, the textile industry places greater importance on fiber properties, requiring stronger, finer and cleaner cotton with greater uniformity (Deussen, 1992).

Environmental conditions result in limitations to optimal physiological performance of the cotton crop and affect the yield and quality of the product. Temperature in particular plays a significant role in the control of fruit development in cotton through the dependence of metabolic processes on temperature. In addition to the direct effects of temperature on physiological performance, the energy requirements for fruit development may limit optimal fiber quality. Moreover, the indeterminate growth habit of cotton results in fruit developing under very different environmental conditions throughout the growing season. Thus, the physiological changes in the cotton canopy together with the diurnal and seasonal changes in external environment result in non-uniformity of cotton fiber produced within a given field, reducing the overall quality.

In these studies, we report environmental conditions for two growing years and the corresponding developmental changes occurring within the cotton bolls. This initial report describes the requirements for energy during the fruit development period and the effects of the environment on boll components. Quantitative changes in fiber development for these same bolls are reported by Bradow *et al.* (1996).

Materials and Methods

Plant Growth and Maintenance

Cotton seeds (*G. hirsutum*, cv. DES 119, and *G. barbadense*, cv. Pima S-6) were planted in a well-drained sandy loam at 1 m row spacing in 18 m by 12 m plots on May 11, 1992. On May 19, 1993, *G. hirsutum*, cv. Delta & Pine Lands 5415 (DPL 5415) and *G. barbadense*, cv. Pima S-6, were planted in 12 m by 12 m plots with a 1 m row spacing using a Kenze dual-frame no-till cotton planter. Plants were thinned by hand to 10 plants per m row. Nitrogen was applied at 5.6 g/m^2 at planting, followed by 4.5 g/m^2 at lay-by. Potassium was broadcast 35 days prior to planting at 6.7 g/m^2. All plots were rainfed. One boll development period was followed in 1992, beginning at 73 days after planting (DAP), and two periods in 1993 beginning at 70 DAP (early) and 92 DAP (late).

Climatological conditions were collected with a Campbell Scientific weather station located 500 m from the test plots. Climatological information was sampled at 10 sec intervals, and 15 min averages were recorded automatically. Air temperature at a height of 2 m above sod was recorded with a copper/constantan thermocouple. Solar radiation was measured with a LiCor pyranometer. Daily rainfall was recorded manually.

Fruit Tagging and Harvest

Flowers on a minimum of 200 plants from each cultivar were tagged on day of anthesis with white jeweler's tags at 73 (1992), 70 (1993, early) and 92 (1993, late) days after planting. Only first-position fully opened flowers were chosen for tagging. On the earlier tagging dates, blooms were in the middle of the canopy (nodes 10-15), while blooms were on nodes above 15 on the late tagging date. Fruits were harvested at weekly intervals after anthesis. A minimum of twenty fruits were harvested from each plot at

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1247-1251 (1996)
National Cotton Council, Memphis TN

the earlier harvest dates, and that number was reduced to ten at the later harvest dates. Because of the limited number of fruits available for the late-season 1993, harvests were only taken at three time-points to compare to the earlier fruit development period. Only healthy fruits free of insect damage were chosen.

After harvesting, the stems and bracts were removed from the fruits, and fresh weights determined. The fruits were carefully sliced open, frozen thoroughly and freeze-dried for 48 h. After freeze-drying, the fruits were dissected into bur, seed and fiber, and dry weights determined. A portion of the fruits were used for determination of chemical composition (lipid, soluble and insoluble carbohydrates, protein, and ash) and energy content, as described below. The fiber from the remaining fruits was used to determine fiber properties with the Advanced Fiber Information System (AFIS) as described in following report (Bradow *et al.*, 1996).

Chemical Composition and Bomb Calorimetry

After dry-weight determinations, the fruit components were ground in a Wiley mill (1-mm screen) for determination of chemical composition by proximate analysis and energy content by bomb calorimetry. Proximate analysis was determined on 10 g samples of the ground fruit components at the Mississippi State Chemical Laboratory using AOAC Official Methods of Analysis (1990) as follows: moisture (930.15), ash (942.05), lipids (920.39B), insoluble carbohydrates (962.09), and protein (990.03). Soluble carbohydrate was determined as the nitrogen-free extract by difference.

The results of the proximate analysis were used to calculate the energy content of the developing fruits from average caloric values per gram as: protein = 5.6; crude fat = 9.3; insoluble carbohydrate = 4.3; and soluble carbohydrate = 4.3 (Crampton and Harris, 1969). Several of the harvest dates were chosen for bomb calorimetry, which was performed using the standard test method for heat of combustion (high precision method) (ASTM method D-2382-83). The energy content calculated from the results of the proximate analysis were compared to the measured energy contents determined from the bomb calorimetry. In all instances, the measured and calculated energy contents agreed within 5%.

Results and Discussion

Environment During the Boll Development Periods

Average daily temperature maxima and minima during the fruit development periods showed variability common to natural environmental conditions (Fig. 1). At several times during each of the fruiting periods, the minimal temperature fell below the permissive range (20 C). During the 1993-late growing season, bolls experienced chilling temperatures below 10 C.

The average daily temperatures ((maximum + minimum)/2) were used to estimate the fruit maturation period from published temperature-dependent fruit maturation rates determined as carpel dehiscence (Hesketh and Low, 1968; Reddy *et al.*, 1993) (Fig. 2). According to these models of boll maturation, the hotter 1993-early tagged fruits matured 9 days earlier in *G. hirsutum* and 5 days earlier in *G. barbadense* than the 1992 harvest. These models of fruit maturation developed under controlled environments predicted that the much cooler 1993-late season would have required nearly twice the time to reach maturity as either of the early-season harvests. However, the late-tagged 1993 fruits were open at final harvest (56 DPA), indicating physiological maturity. Based on the estimated maturity from date of boll opening, the *G. hirsutum* cultivars were past optimal maturity at final harvest, while the *G. barbadense* was very near optimal maturity.

The dependence of boll maturation period on canopy temperature was estimated from published correlations of boll maturation on temperature (Fig. 3, true temp), and 1 and 2 degree increases in average daily temperature, or 1 and 2 degree decreases (Fig. 3). For each change of 1 degree, there was approximately a 5 day change in the boll maturation period. Thus, increasing the temperature at the growing point by only an average of 1 degree would shorten the boll maturation period by 5 days.

Fruit Components During Development

The growth of the fruits was monitored by determination of dry weights of the individual components (Fig. 4). The outer section of the cotton fruit, the carpel, showed the most rapid initial rate of growth, reaching final size by 30 DPA. The growth of the cotton fiber continued until nearly 50 DPA, after which point there was a slight loss of fiber weight, possibly due to drying in the mature open fruits. The increase in seed weight continued until final harvest.

Among the three cultivars, the DES 119 had the largest fruit, mostly due to a larger carpel. This cultivar also tended to have more fiber and larger seed per fruit. Although the total dry weight of the Pima S-6 was not significantly different from the DPL 5415, the Pima S-6 had less fiber per fruit and slightly lower seed weight than did the DPL 5415. These differences were reflected in the relative energy content of the fruit components from the different cultivars. Part of this difference in seed and fiber weight per *G. barbadense* fruit arose from the significantly fewer seeds per fruit. The 17.5 $\pm$ 0.4 seeds per fruit for Pima S-6 was about half the number observed in both *G. hirsutum* cultivars (32.0 $\pm$ 0.5 for DPL 5415, and 36.9 $\pm$ 0.9 for DES 119). Although DES 119 had more seeds than either DPL 5415 or Pima S-6, it had more under-developed seeds (motes) (6.4 $\pm$ 0.6 for DES 119 versus 3.4 $\pm$ 0.5 for DPL 5415 and 2.8 $\pm$ 0.3 for Pima S-6), resulting in no difference in the number of developing seeds per fruit between DPL 5415 and DES 119. No significant

differences were observed between years in the number of seeds or motes per fruit for Pima S-6. Hence, on a per seed basis, *G. barbadense* had larger seeds with more fiber per seed.

Proximate analysis of the fruits allowed a more detailed examination of events during development (Fig. 5). The soluble carbohydrates, composed mostly of sugars, increased rapidly during the initial fruit development, and decreased slowly as the fruits matured. The decrease in soluble carbohydrates coincided with an increase in the lipid and insoluble carbohydrate fractions. The protein fraction showed a gradual increase throughout the fruit development period. The insoluble carbohydrates (mostly cellulose and lignin) showed an increase that corresponded to the development of the cotton fiber (Fig. 4).

Of the fruit components, fiber development appeared to be the most sensitive to growth environment. The absence of differences in carpel development rate under different growing environments indicated that the genetic control for carpel development was not dependent on temperature but rather on chronological age. Thus, carpel dehiscence does not provide an accurate indication of fruit maturation. After a given period of time the carpels opened, even though the fiber was still immature (*eg*. late season Pima). Seed development reflected some sensitivity to growth environment, particularly for Pima. To the extent that fiber development is dependent on seed development, the sensitivity of the seed development to growth temperature may limit fiber development. Additionally, control of fiber developmental processes independent of the successful completion of the previous step (*e.g.* secondary cell wall initiation prior to optimal fiber elongation) can greatly increase the variability of fiber and seriously limit the final fiber quality. Some degree of control of cotton fruit development most likely is determined by seed development and viability, a factor that is often overlooked in studies of fiber synthesis.

From a production viewpoint, fiber should develop to optimal uniform quality. Therefore, a more accurate determinant of fiber maturity is needed than carpel dehiscence. Seed development and seed viability may be important considerations in determining fruit maturity, as these factors may play a greater role in carpel dehiscence than fiber development. The trigger for carpel development appears to be decoupled from fiber maturation. It is either independent of the growth environment or depends on a factor of fruit maturity other than fiber development, such as seed viability. Although this lack of coordination between carpel dehiscence and fiber maturity can result in reduction in the quality of cotton fiber produced in a field, it can be used to advantage since it allows use of harvest aids that enhance carpel opening.

Acknowledgments

We would like to express our sincere appreciation to Mr. Wade Stewart from BASF for generous use of the Kenze dual frame no-till cotton planter.

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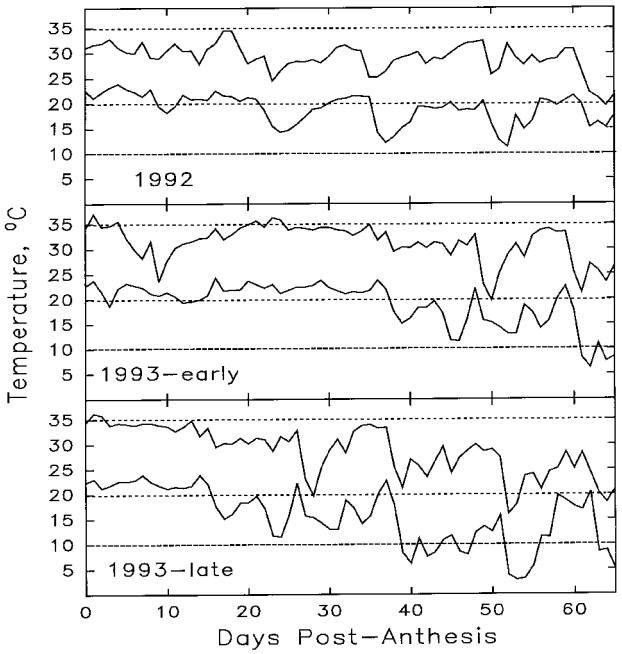

Figure 1. Daily temperatures. The daily maximum and minimum temperatures during the fruit development periods for 1992 (73 DAP), 1993 early (70 DAP), and 1993 late (92 DAP) were recorded at a weather station located 500 m from the field site.

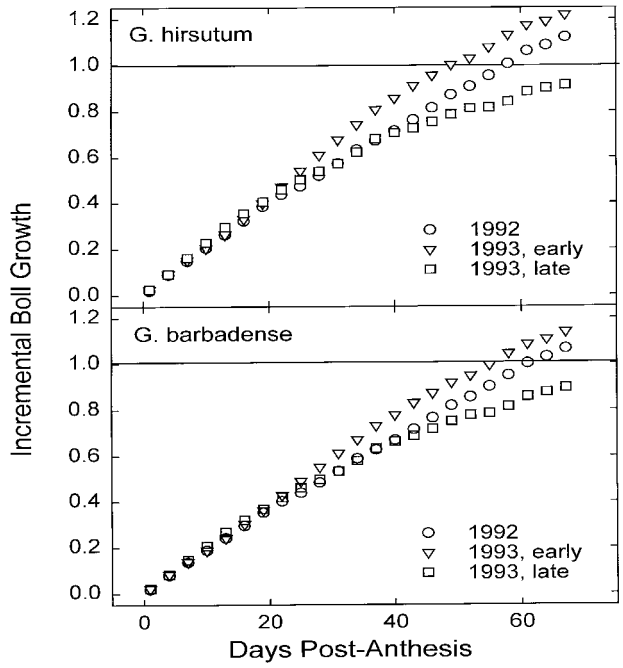

Figure 2. Incremental boll growth. The estimated boll growth during the three boll development periods was determined from the calculated cumulative degree days, using 60 F as a base temperature.

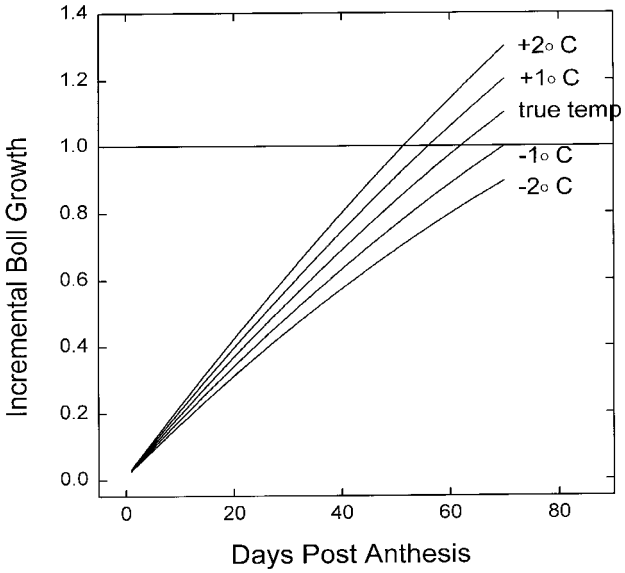

Figure 3. Dependence of boll growth on temperature. The dependence of boll maturation on temperature was determined for the 1992 weather data (true temp), and for average daily temperatures 1 and 2 degrees warmer (+1, +2), and 1 and 2 degrees cooler (-1, -2).

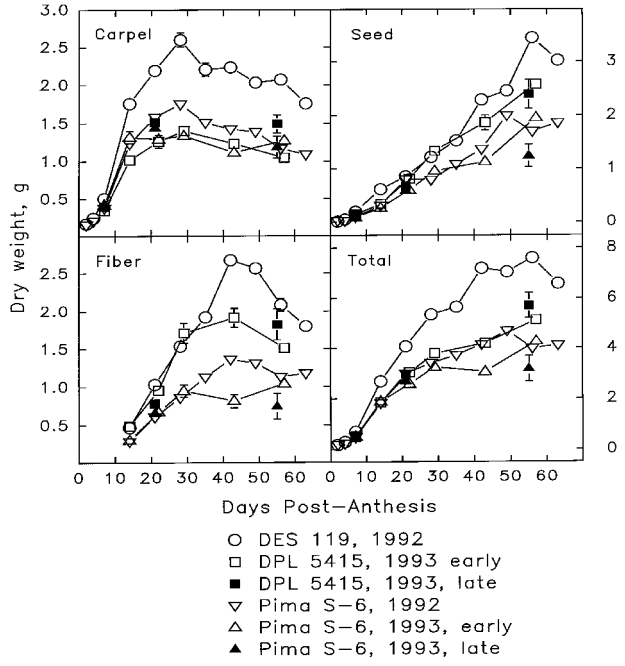

Figure 4. Dry weight of fruit components during development. The dry weight of the fruit components were determined during development for DES 119 (1992, ○); DPL 5415 (1993 early, □; 1993 late, ■); and Pima S-6 (1992, ▽; 1993 early, △; 1993 late, ▲). The fresh fruits were weighed, freeze-dried, and dissected into carpel, fiber and seed and the dry weights of the individual components determined. Reported values are means ± s.e. for a minimum of 10 separate fruits.

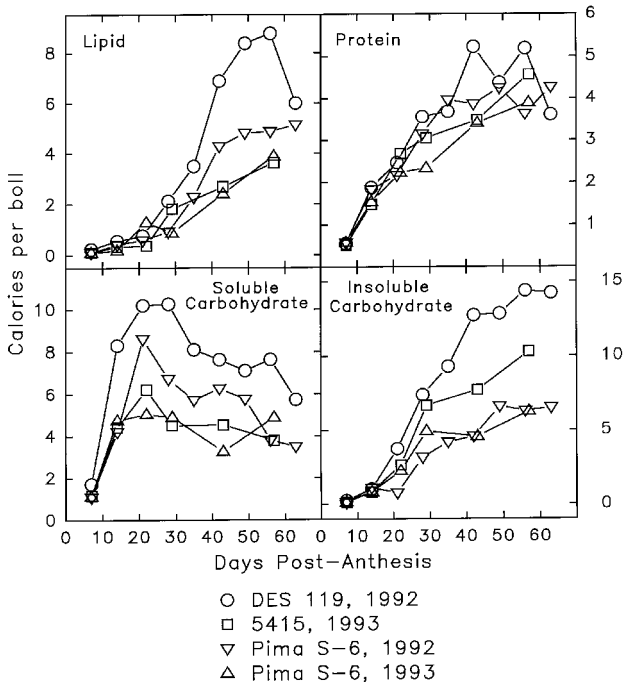

Figure 5. Caloric content of fruits during development. Caloric content of fruits was determined by proximate analysis of ground fruits and conversion based on an average caloric value per gram for: protein, 5.6; crude fat, 9.3; insoluble carbohydrate, 4.3; and soluble carbohydrate, 4.3 (Crampton and Harris, 1969). Calculation of energy content from proximate analysis agreed within 5% of energy contents measured directly by bomb calorimetry. Symbols are as given in Figure 3.

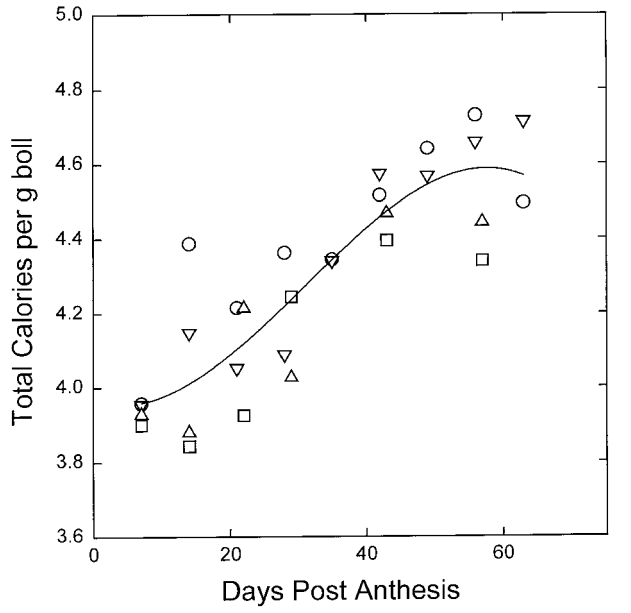

Figure 6. Total energy content of cotton fruits during development. Total energy content of cotton bolls during development was determined from the summation of boll components (Fig. 5). Symbols as in Figure 5.