## COTTON FRUIT DEVELOPMENT: THE BOLL

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The boll, or fruit, is the most important component of cotton production. Indeed, much of the anxiety producers experience during the season focuses on boll retention and protection from insects. If we can understand what is happening during boll growth and development, many potential problems in crop management can be avoided. The result will be increased yields and profits. This newsletter tracks the course of boll development from white flower to open boll.

Cotton bolls range in size from under 3 grams to over 6 grams per boll (Figure 1). Seed accounts for about 60% of this weight; the remainder is lint. This translates into about 200 to 400 bolls to produce a pound of lint, or 100,000 to 200,000 bolls per bale.

Figure 1
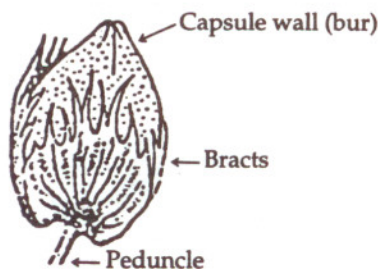
Typical cotton boll prior to opening

(Oosterhuis, 1990)

The yield and quality from a cotton field can be modified infinitely by genetic, environmental, cultural and chronological variables. Each variety has a unique complement of molecular templates that determine the onset and duration of individual physiological processes driving boll growth and development. Temperature, sunlight intensity, water and nutrient availability and internal hormonal balances will influence both boll retention and development.

EARLY STAGES OF BOLL DEVELOPMENT

Boll Components

The boll consists of three main components: the bur (capsule), the seeds and the lint. The leaf-like bracts are the most evident feature of a young boll, having attained their maximum size shortly after flowering. The bracts are photosynthetically active and can supply about 10 percent of the carbohydrates required by the boll. Current information suggests that the bracts are less sensitive than the leaves to stress, and their contribution is more important under these conditions. The bur serves to protect the developing seedcotton in addition to providing some carbon fixation during the

first ten days of boll development. According to Dr. Tugwell, University of Arkansas, the inner layer of the bur wall (endocarp) hardens about 350 DD60s after white flower providing a measure of protection against insect feeding. Upland cotton has 4 or 5 sections or locules that contain the individual locs. However, under low carbohydrate status 3-locule bolls will occur. Varietal differences influence the ratio of 4 to 5 locules. Pima cotton has 3 locules per boll. In upland cotton, a normal loc consists of 6 to 9 seeds with their fibers more or less intertwined.

Boll Size and Growth Rate

Boll growth begins with pollination of the white flower at early to mid-morning. This topic was covered in detail in *Cotton Physiology Today* (Vol 4, No. 1). The boll grows rapidly after fertilization following an S-shaped curve, with the most rapid growth occurring between 7 to 18 days, and full size reached in about 20 to 25 days (Figure 2). A similar pattern of increase occurs for boll length, diameter and volume but dry weight increases until the boll is mature. Boll development is often divided into three overlapping phases: the enlargement phase, the filling phase and the maturation phase.

Figure 2
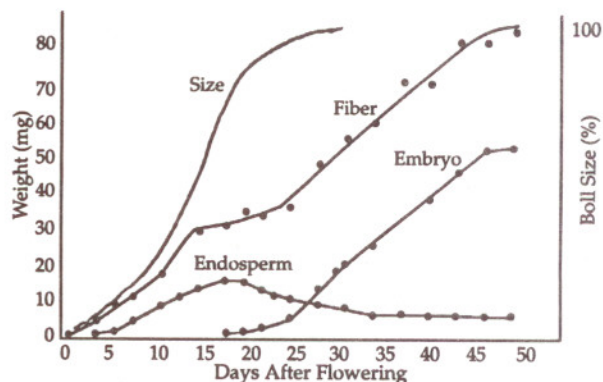
(Stewart, 1985)

During the first three weeks (the enlargement phase) maximum boll size, maximum seed size and maximum fiber length are established. The maturation period from white flower to open boll is influenced strongly by temperature. Approximately 750 DD60s are required for full maturity which might be accumulated in as few as 40 days or more than 70 days. The rapid achievement of full size followed by a lengthy maturation period during autumn is a source of confusion and potential management mishap. Pro-

ducers may delay harvest in the hope of realizing yields from top bolls that are full but immature. This tendency can be avoided if a realistic measure of physiological cutout and the end of the effective bloom period is noted. Refer to last month's newsletter for more information on phantom bolls. At maturity, the capsules crack and split along their sutures, and the fibers fluff as they dry, pushing out beyond the bur as open cotton.

Fiber Initiation

Many preparatory events occur leading up to the time the flower bud opens (anthesis). By this time the cells on the surface of the unfertilized seed (ovule), which will become fibers, already have been determined, although external changes may not be evident. Most of the cells destined to be lint fibers swell into small balloons above the surface on the day the flower opens; however, a few new fibers may initiate up to four or five days past white bloom(Figure 3). The number of lint fibers on a seed is between 12,000 and 18,000 for most varieties.

Figure 3
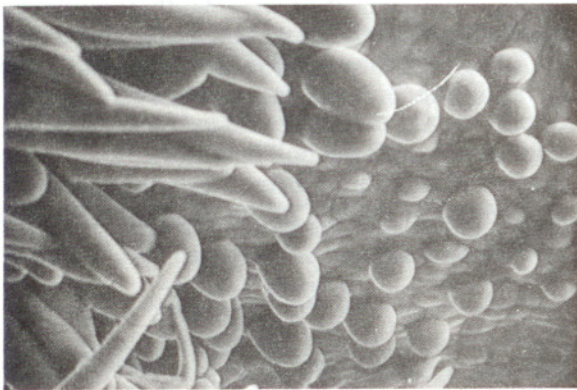
A second wave of fiber initiation occurs, typically around 6 days after bloom. The physiological environment of the seed has changed during this period so that the development of the new fibers is different. The major difference at initiation is in cell diameter. Ultimately, these later-developing fibers become the fuzz fibers that remain on the seed after saw ginning.

Elongation and Primary Wall Synthesis

During the elongation phase, the individual lint cells elongate to about 25,000 or more times their original length before the secondary wall forms. The fiber economizes on resources by filling the volume of the cell with a watery sac (vacuole). This requires only the formation of the membranes for the vacuole and cell surface rather than a large volume of synthesized compounds to fill the cell. The cell accumulates large amounts of potassium and an organic acid in the vacuole to create the low water potential required for expansion. Rapid primary wall formation also must occur as the fiber is expanding. Primary wall of the fiber is only about 30% cellulose. Since the primary wall

has a low cellulose content, it is very flexible and can be stretched more easily than walls with a high cellulose content. During elongation, a protein skeleton that is laid down inside the primary wall influences later stages of development.

Seed Expansion

At the same time the fibers are expanding, the seed also is increasing in size. While the seed expands, the embryo remains small, but the tissue that feeds the embryo (endosperm) and the cell layers that will become a seed coat increase in size. If the endosperm and embryo do not develop properly during this time, the young seed aborts and appears as a mote in the mature boll. Immature fibers from motes contribute to neps (white spots) in cotton fabric.

The periods of elongation of the fiber and expansion of the seed correspond to the enlargement of the boll wall, so maximum length of the fiber is reached in about 20 days. The fuzz fibers apparently grow much slower and cease elongation simultaneously with the lint fibers. Thus, maximum boll volume, seed size and fiber length are determined during the first three weeks of development. If potassium is limited during this period, boll size, seed size and fiber length can be affected. Severe water stress during expansion also can reduce size. The anatomy of a mature seed is shown in Figure 4.

Figure 4
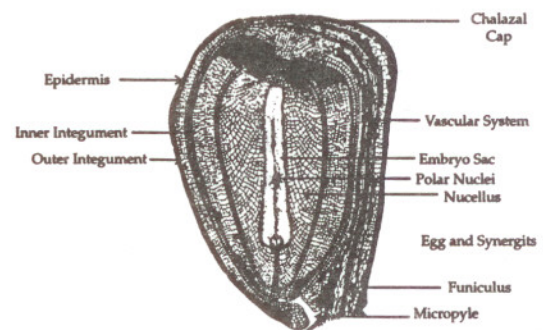
LATER STAGES OF BOLL DEVELOPMENT

The second half of boll development is characterized by accumulation of dry weight on the framework that developed during the first half. While fiber length, and to some extent uniformity, is determined during early boll development, micronaire, maturity and strength are determined primarily thereafter. Deposition of secondary wall begins in the fiber at about 16 days after flowering, but the tip of the fiber continues to elongate past 20 days. Only when secondary wall deposition reaches the tip of the fiber does it stop expanding. Thereafter, cellulose is laid down until the embryo reaches maturity and the boll opens.

The secondary wall of the fiber is almost pure cellulose laid down in winding sheets around the inside of the primary wall. Points along the length of a fiber where the direction of winding of the cellulose layers

changes are called reversals. Where and how often these occur is established during development of the primary wall. Reversals may represent weak points in single fiber, but they probably do not influence yarn strength. The thickness of the secondary wall determines the micronaire and maturity of the fiber, and it also has a strong influence on single fiber strength. Warm weather favors cellulose deposition, and cool weather inhibits it. Thus, during cool weather an embryo may mature and the lint still have low micronaire, fiber maturity and strength. It is well established that first pick cotton has better fiber quality than second pick, the difference being the less favorable temperatures during maturation of the latter. Premature defoliation and boll opening also can lower fiber maturity.

Fiber strength is related to the average length of the cellulose molecules that are deposited. Longer cellulose chains are associated with higher strength. Again, adequate potassium is important for cellulose synthesis, although the exact reasons are not clear. With today's high-speed harvesting and processing, fiber strength is related to uniformity. Strong fibers break less frequently than weak fibers during processing, thus the short fiber content is less and uniformity ratio higher.

Seed quality is determined during later development. Major changes are occurring in the tissues that become the seed coat during the same time that secondary walls are laid down in the fiber. Ultimately, these result in an outer pigmented layer, a thick palisade layer and an inner fringe layer. Young embryos begin developing cotyledons at about the time secondary deposition begins in the fiber. These reach their maximum size by the fourth week of development and in the process absorb a major part of the endosperm, so there is no outward sign of their development. From about 25 days of age, the embryo begins to accumulate protein and oil. There is a close relation between oil percent and micronaire. The same factors that decrease the maturity of fibers also negatively impact seed quality.

Boll Opening

Boll opening is a process under the control of hormones. Ethylene is primarily responsible for triggering the process of boll opening. Ethylene is the active ingredient in such crop management compounds as Prep. High auxin produced by the developing seeds counters the action of ethylene and prevents premature opening, but as the boll reaches maturity, auxin level drops and ethylene increases. Cells in a specialized layer in each suture of a boll enlarge and produce enzymes that dissolve their cell walls. Cracking along these sutures allows water to escape and the boll contents and bur wall begin to dry. A unique network of vascular strands causes the inner part of the bur wall to be more rigid than the outer part. Because of this, the outer part of the wall shrinks more than the inner upon drying, causing the wall to bend outward to give the characteristic bur of the open boll. Any factor that affects maturation of the capsule wall, such as boll age, carbohydrate stress or disease can lead to poor boll opening.

Drying

The final event in the development of cotton fiber occurs during drying after boll opening. The bonds between cellulose chains are not well established until water is removed. These bonds, the reversals and the uneven deposition of cellulose causes the fiber cell to collapse into a ribbon, twist and form crimps. The twists and crimps of adjacent fibers become intertwined and are important in the spinnability of the cotton fibers. The high cellulose content and the hollow central core of the fiber contribute to the excellent absorbency and "feel" of cotton.

BOLL SHEDDING

Cotton square and boll shedding (abscission) has received much attention and generated much controversy during the past 50 years. The attention stems from the concern that lost squares and bolls represent lost yield, such that if shedding were decreased, then productivity would be increased. On the other hand, there is evidence that boll shedding may be an important natural process by which the plant adjusts its fruit load to match the supply of inorganic and organic nutrients. This suggests that a limited amount of shedding is normal and perhaps necessary for good quality and yields. Shedding is generally attributed to physiological or insect causes.

Many theories have been put forward to explain abscission in cotton, most of them focusing either on the "nutritional" or "hormonal theories" or (more likely) a combination of both. If the production of carbohydrates cannot supply the demand, then the plant stops retaining (sheds) young bolls. Actually, nutritional stresses alter the hormone balance which in turn causes fruit abscission. Gene Guinn in Arizona reviewed the causes of boll shedding and concluded that the balance between auxin, ethylene and abscisic acid regulates growth, flowering, fruiting and abscission.

Boll Position

Fruiting site position within the canopy influences boll retention and development. Boll retention declines throughout the boll loading period as the nutrient sink size increases. Each additional boll must compete with a shrinking resource base. Although first position sites are physiologically favored, positions further removed from the main stalk can develop valuable bolls and quality lint. Plant spacing, pest pressure, light environment, and water and nutrient availability will help determine the contribution and quality of lint from these more distant bolls.

The importance of first position bolls is influenced by the regional and cultural system employed. Short-season management systems rely on high retention of first position bolls on 5-10 fruiting branches depending on season length. Long season or rainfed systems or regions with high insect pest pressure may depend on more fruiting branches and second or third position fruit. This may require an adjustment to lower plant

densities to allow improved light penetration for supporting less favored positions.

Size and Age of Fruit that Abscises

Insects may cause all ages of squares or small bolls to shed, but environmental problems result in the shed of only specific sizes of fruit. By knowing the size of fruit that abscises, we often can determine the cause. When large squares shed, insects usually are involved. Whereas heavy shedding of small 4-8 day-old bolls often is due to environmental/physiological causes. Large squares, flowers and medium size bolls are very resistant to environmentally-induced shed, possibly due to their high concentration of auxin, the retention-promoting hormone. Large bolls rarely shed, possibly due to the tough vascular connections that feed the growing boll. Therefore, under typical environmental stress, the plant will shed only small bolls and small-to-medium size squares.

Environmental Stress Factors

There are various management options to minimize shedding, including optimum planting dates to best utilize the season, adequate but not excessive N and other nutrients, efficient control of irrigation, good drainage to remove excess water, lower plant density to allow sunlight penetration, proper timing and rates of growth regulators and avoiding heavy insect, disease and weed pressures.

Wrap Up

This discussion has reviewed the intricate physiological process that creates the smallest unit of yield, repeated countless times prior to a successful harvest. Crop managers are challenged to maintain a favorable environment that will support this yield development. Appropriate management practices include soil selection, optimum plant population, stand uniformity, sufficient and timely water and fertility, plant growth regulators and adequate pest control. Season-long crop monitoring will provide warnings of inadequate boll load development. These diligent inspections will provide crucial data for making timely inputs to promote good boll development and high yields.

For additional reading on boll and fiber development refer to the following issues of *Cotton Physiology Today*:

- Causes of High and Low Micronaire, September 1990, Vol. 1, #12
- Fiber Development and HVI Quality, Nov-Dec 1990, Vol. 2, #2
- Boll Weathering, November 1992, Vol. 3, #10

To obtain copies of these issues, call or write the National Cotton Council, PO Box 12285, Memphis, TN 38182-0285, phone: 901-274-9030.