

COTTON PHYSIOLOGY TODAY

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Cotton Fruit Development - The Square

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Cotton fields go from a pile of leaves and stems to a sea of bolls in what seems like overnight. The last 2 years in particular have been excellent examples of just how rapidly a crop can be set and matured. Part of this rapid crop development has come from the enhanced management producers have employed in the last few years. Stress in particular has been minimized wherever possible. Gone, to a large extent, are those dull gray, irrigated cotton fields where the water was started too late, those dense cotton jungles that chug a pint of Pix without even burping, those plant bug havens that celebrate the 4th of July without pinhead squares, and those "perfect sites" for next year's test plot on potassium or disease resistance. In their place are more compact, efficient plants where sunlight reaches down to healthy leaves that feed the early bolls.

Other parts of this rapid crop development are the many unseen steps in boll development. As soon as the first true leaf appears, the cotton plant is starting to form squares. Even though the plant appears to "make cotton" overnight, it really has been forming fruit for an extended period that starts shortly after emergence.

Prebloom

Meristems and Square Anatomy

Cotton plants grow in an orderly manner, producing new parts such as nodes or squares from growing tips (meristems). Within each growing tip, cells divide into daughter cells that either continue to replicate or start the slow change into recognizable plant parts.

The fruiting branch meristems (a 40x magnification pictured at right), responsible for the development of fruit, are located in the axils of mainstem leaves, above node 5 or 6. Once a plant starts to produce fruiting branches, it is very rare that it will revert to producing vegetative branches. Below node 5 to 6, the meristem in the leaf axil is vegetative and can produce a vegetative branch or a new mainstem. Vegetative meristems are under the control of apical dominance that flows from the young tissue in the terminal. Hormones produced in the terminal — a vegetative meristem — prevent other vegetative meristems from growing. If the plant terminal is damaged by insects or hail, one or more of the lower vegetative meristems begins to grow to produce new mainstems. In this way, early damaged plants can recover a capacity to produce a crop even though it will be late maturing.

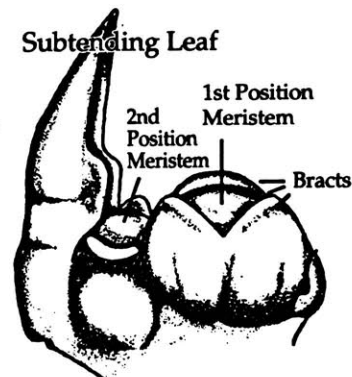
Square Initiation

The time-line in the figure below, displays the bud height and development of the first square on the plant. Other squares develop at a slightly faster speed due to warmer temperatures later in the year.

Days Before Bloom	Bud Height (25 mm = 1 inch)	Comments
40	Microscopic, bracts only	Square initiation can occur, as early as 2nd true leaf expansion. Hot spring weather induces 4-bract squares, cool or very hot weather delays square initiation.
32	Microscopic	Lock number determined, carbohydrate stress decreases number from 5 to 4.
23	2 mm Pin-head	Ovule number determined, carbohydrate stress decreases potential seed number.
22	2 mm Pin-head	Pollen cells divide.
19	3 mm Match-head	Pollen viability reduced by hot night temps, >80°F.
5	13 mm	Square starts to expand rapidly
3	17 mm	Fibers begin to form
0	Flower opens	Pollen sheds and fibers start to elongate. Extremes of humidity or water disrupt pollen function.

+1 Fertilization of ovule, now called seed

A fruiting branch is fundamentally different from a vegetative branch. A fruiting branch is independent of control by the terminal meristem, i.e. not affected by apical dominance. The fruiting branch meristem, instead of maintaining itself, produces an internode that terminates in a flower. The parts of the flower are produced in a set order — first the subtending leaf, then the bracts, sepals, petals, anthers and finally the carpels (immature locks). The last formation of a fruiting branch meristem is the carpels; further growth of the fruiting branch requires another meristem to grow, which is located at the base of the square (just outside the bracts) giving rise to the characteristic zig-zag shape of the fruiting branch. Because the cells divide in the center of the meristem and turn (differentiate) into specific plant parts near the meristems edge, the oldest parts are outside of the younger parts in the flower.



Abnormal Squares and Bolls

Although many of the abnormal squares and bolls are caused by physical damage from insects, some are caused by adverse weather disturbing the meristem's normal function. The High Plains of Texas, where adverse weather is experienced just about every year, has a preponderance of odd and misshapen bolls; other regions can also experience extremes of weather that disrupt the meristems. Two of these, 4-bract squares and super numery carpels, are discussed below.

After the fruiting branch meristem forms the subtending leaf, it starts to form the bracts. High spring temperatures (average day/night temperature above 80°F) can cause this meristem to attempt to produce another leaf after the subtending leaf, but before the bracts are formed. This extra leaf forms a fourth "bract", and is located just outside the normal 3 bracts. The lowest fruiting branches appear most susceptible to 4-bract squares, because high temperatures later in the season do not have the same effect. Four-bract squares are more susceptible to shed and thrips injury — the fourth bract provides an opening for thrips to enter the young square — than well-developed 3-bract (normal) squares.

Within 10 days after a square starts to form, the meristem completes its production of floral parts, ending with the carpels or locks in the center the square. If the meristem growth doesn't terminate with the carpels, a boll abnormality called "super numery carpel" results. This is a small, skinny boll at the center of the first boll. It forms when the meristem keeps on making new parts — in this case another set of carpels — after the first carpels are formed. In 1992, Alabama Cotton Specialist, Charles Burmeister, reported that super numery carpels were common in the bottom bolls of early-planted, northern fields. Extreme cold weather occurred very late in the seedling stage and may have been responsible for disrupting the meristem's normal development. Meristems are hardy parts of the plant and function despite severe temperature, nutrient or drought stress, up to a limit. Pima cotton appears more susceptible to bottom boll abnormalities, especially when fields are planted early and experience cold weather after emergence.

Locks per Boll

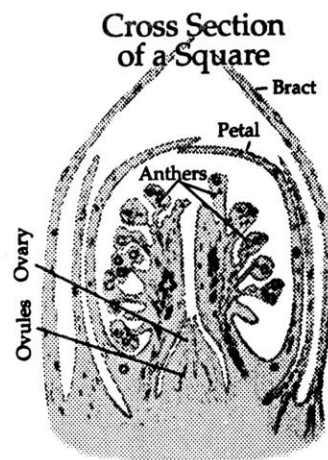
When the meristem is producing carpels, the number of locks is determined. Whether an upland boll produces a 4- or 5-lock boll, is influenced by the health of the plant. If an ample supply of carbohydrate is available (usually just before and after early bloom), the microscopic squares will produce more 5-lock bolls. Plant health is usually reduced early in the square period (from cool temperatures) and from mid to late bloom (heavy boll load), and thus squares initiated at this time result in a higher proportion of 4-lock bolls.

Pollen and Ovule Formation

One of the fortuitous developments in evolution was genetic recombination. The recombining of parental genes to make a novel genetic offspring allowed evo-

lution to proceed at an explosive pace and species to adapt to changing conditions. Genetic recombination starts with the production of pollen cells in the anthers, approximately 22 days prior to bloom. A pollen cell has half the genetic material of the mother plant, but when combined via fertilization with an ovule (which also has half the genes) the result is a normal seed with a full set of genetic material. Shortly after pollen formation, approximately 17 to 19 days before bloom, pollen is vulnerable to high nighttime temperatures. Pollen sterility is primarily a problem of the Southern Deserts when night temperatures remain above 80°F, which results in anthers that fail to shed pollen and retain a smooth appearance the day of bloom.

Another event that occurs approximately 22 days prior to bloom is the formation of ovules. When plants experience stress (cold or hot temperatures), the number of ovules per lock in pinhead squares is reduced. Although by 22 days prior to bloom the upper limit of seeds per boll has already been set (locks per boll X ovules per lock), up to half of the ovules fail to develop into a seed and terminate development as a mote.



Square Growth

When the square is 5 days away from bloom, it starts an explosive growth in size, as the petals expand readying themselves for bloom. Large squares are now firmly attached to the plant and drawing some nutrients from nearby leaves. Young squares, on the other hand, are almost entirely fed by their own bracts, which are better adapted than leaves to either low light, cool weather or N deficiency. Large squares are also less likely to shed. Work in Arkansas indicates that insects must injure more than 30% of the square for shedding to occur. Physiological shed of large squares is rare.

Bloom

Pollination

Early in the morning, when a flower opens, pollen is shed as the pollen sacks rupture. Some pollen lands on the stigma where each grain starts to grow a thin microscopic tube down toward the ovules. Cotton pollen is sticky, and thus insects, not wind, are the primary mode for pollen transfer from one plant to another. In areas where insects are controlled by frequent sprays, cotton is 95-99% self-pollinated, meaning flowers are primarily fertilized by pollen from the same plant. However, where bumble bee and other

wild bee populations are high, individual plants may have as much as 50 to 60% outcrossing. Cotton's high self-pollinated percent allows seedsmen to maintain genetic purity of varieties, despite only limited isolation. Experience with colored cottons in California indicates that contamination in the gin or warehouse is much more likely than by pollen from colored fields. As non-pesticide methods of insect control are developed (for example genetically engineered resistance), out-crossing may become more commonplace.

Cotton pollen is extremely sensitive to moisture and ruptures within 5 seconds upon contact with liquid water, such as occurs with rain or irrigation. As a result, rain or irrigation during the morning hours can completely eliminate boll set for that day. Some varieties do not flower or produce viable pollen under high temperatures (98°F). This has been observed mostly in those varieties adapted to cooler climates like the High Plains.

Fiber Initiation

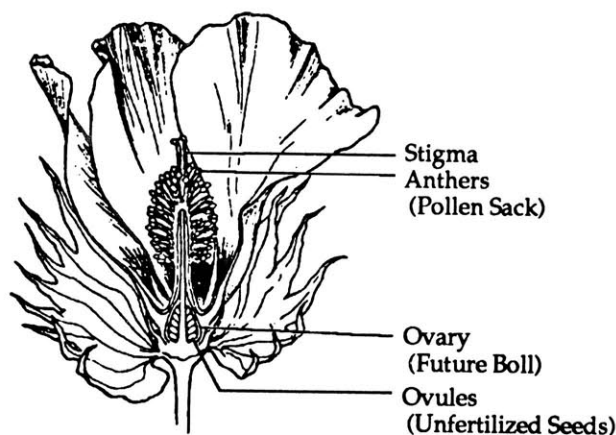
Fibers start to elongate from the surface of the ovule on the day of bloom and can continue to elongate for a few days even if the ovule is not fertilized. These unfertilized ovules end up as motes. Because of their small size and short fibers, modern ginning equipment removes motes at the lint cleaning stage. On average, 25 to 30 lbs of motes are produced per bale of cotton, which sells for 8 to 15 cents per pound and ends up in batting, mattresses and paper. Since the fibers develop from the surface of ovules, they are strictly maternal tissue. For example, pollen that may be transported in from a nearby colored cotton field will not contaminate that season's lint because the lint is determined strictly by the maternal plant, but if the field is grown for planting seed, in the following year an off-type plant with colored cotton could result.

Fiber initiation appears to be very temperature sensitive, too hot or too cold, and short fibers result. Severely cold temperatures, 50°F, delay fiber initiation for 1 to 2 days, but even moderately cool temperatures, 60°F, during fiber initiation result in shorter fiber. Hot temperatures during initiation also result in shorter fiber, along with fewer seeds per boll, smaller seeds and bolls. During fiber initiation, the cells on the surface of the ovule balloon. This ballooning stage is critical in the determination of both fiber length and diameter (fineness). Based on indirect estimates, the number of fibers per seed varies widely from field to field. Approximately 20% of the cells on the ovule surface, at bloom, form fibers. The other cells continue to divide and about a week after bloom some produce fuzz fibers. The number of fibers per seed can be estimated by dividing the lint per seed in micrograms by the micronaire and staple length in inches. Fibers per seed vary between 13,000 to 21,000 depending on location. Little is known about the causes of low or high fiber counts per seed.

Fertilization

As the pollen tube begins to grow down into the flower, the pollen nucleus divides. Upon reaching the egg sack in the ovule, one pollen nucleus combines with the egg cell to start a new embryo. The second nucleus enters another cell that then develops into a nutritional tissue called endosperm that supports the new embryo. Fertilization is like a complex square-dance of cells moving about, dividing and changing; if any part gets out of step, the likely result is a mote and not a viable seed. With fertilization, the genetic cycle is now completed as the fertilized embryo contains a full complement of genetic material.

Young seeds produce hormones that increase the flow of nutrients and carbohydrates to them, thus if a boll fails to set more than 10 to 15 seeds, it cannot pull in sufficient nutrients and ultimately sheds. For this reason, unless insects damage the seeds, mature bolls with less than 10 to 15 seeds are rare. High temperature is a major cause of low seed counts. Drought and moisture in open blooms are other less significant causes. The following diagram depicts a cotton flower with its young boll on the day of bloom.



Understanding the inner workings of a square gives us a good idea of how a square responds to stress. Young squares undergo a complex and delicate formation of flower parts and when stressed either shed or form abnormalities. Flower buds during their late development are in an expansion phase, both by cell division and cell enlargement, thus large squares are fairly resistant to stress. Blooms are just expansion for show. During bloom, cells enlarge rapidly as water is pumped into the flower causing the petals to unfurl. The unfurling is almost resistant to stress, as severely wilted plants can still have a normal looking bloom. This simple task of a bloom makes it resistant to shed. However, the day after bloom, in the young boll pollen fertilizes the egg and starts the complex process of seed development; sensitivity to stress is at the all-time highest. As the boll gets larger and completes the complex seed formation, it gains greater and greater resistance to shed.

About the Authors

James McD. Stewart is a Plant Physiologist at the University of Arkansas, currently focusing on genetic tools for cotton breeders. He co-edited and wrote major parts of the Cotton Foundation book "Cotton Physiology". This book has recently been reprinted and is now available along with the latest in the series "Weeds of Cotton".

Tom Kerby serves California cotton growers as Extension Cotton Specialist. In addition, many of his ideas and results have been adopted by producers Belt-wide.

Jack Mauney is the other co-editor of the "Cotton Physiology" book and author of numerous scientific and popular articles on cotton physiology.

Derrick Oosterhuis is a Cotton Physiologist at the University of Arkansas. He and his research team have pioneered many areas of cotton physiology and production, such as PGR's, Foliar Potassium and Leaf Function.

Judy Timpa is a Research Chemist with the USDA at the Southern Regional Research Center in New Orleans. Judy's research focuses on understanding the chemical and physiological nature of cotton quality.

Narrow-Row Handbook Now Available.

A producer handbook that utilizes figures and charts to explain the principles of narrow-row cotton is now available. For a free copy write the NCC.

New Editor for Cotton Physiology Today

Starting with the next issue of Cotton Physiology Today, Dave Guthrie will take over responsibility for this newsletter and other activities of the Cotton Physiology Education Program. Dave comes to the NCC from North Carolina where he served producers as Extension Cotton Specialist. Dave received his PhD in cotton physiology from the University of Arkansas in 1983. Dave combines a strong cotton physiology background with a broad knowledge of production practices, having worked with cotton in California, Arkansas and North Carolina.

I have accepted a position with Texas A&M University as Extension Cotton Specialist for the Texas High Plains. Over the last 3 years, my work at NCC with the many producers, research, extension and industry personnel has provided me the opportunity to learn from cotton people all across the Belt. I thank you for all of your input and time that has made this program such a success and look forward to working with you in the future. (Kater Hake)

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