# GROWTH AND PRODUCTION OF COTTON

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## Contents





## Summary

Cotton is a soft, staple fiber that grows in a form known as a boll around the seeds of the cotton plant (*Gossypium sp*.), a shrub native to tropical and subtropical regions around the world, including the Americas, India and Africa. With ideal conditions, cotton seeds germinate in about five to ten days. The first two leaves are seedling leaves called cotyledons. In about two to four weeks they turn over to true leaves which continue the feeding process for the duration of the plants life. The plant continues to grow, adding leaves and height, and in approximately five to seven weeks, small flower buds called squares will appear on the cotton plant. As this square develops, the bud swells until it opens into an attractive flower. Within three days, the flower will pollinate itself, change color to a pinkish red, and then wither and fall, exposing a small, green,

immature cotton boll which is considered a fruit because it contains seeds. The fibers grow and thicken around the seeds within the segmented boll which enlarges in size. Finally, the cotton fibers become mature and thickened and the boll opens.

Successful cultivation of cotton requires a long frost-free period, plenty of sunshine, and a moderate rainfall, usually from 600 to 1200mm. Soils usually need to be fairly heavy, although the level of nutrients does not need to be exceptional. In general, these conditions are met within the seasonally dry tropics and subtropics in the Northern and Southern hemispheres, but a large proportion of the cotton grown today is cultivated in areas with less rainfall that meet their moisture requirements from irrigation.

## 1. Introduction

As the leading natural fiber crop, cotton is an important agricultural commodity, providing income to millions of farmers worldwide**.** Commercial cotton is grown in more than 80 countries, including Australia, China, Egypt, India, Pakistan, the USA and Uzbekistan; more than 150 countries are involved in import and export of cotton. Cotton fibers can be used for producing a wide range of commodities, ranging from textile fabrics and computer screens to automobile brakes.

The cotton genus *Gossypium* L. occurs naturally throughout the tropics and subtropics and consists of about 49 species that form a monophyletic group. Cultivated cotton includes four diploid and five tetraploid species. The geographical place of origin of the genus has not been identified, but DNA sequence data for extant *Gossypium* species suggest that the genus arose about 10-20 million years ago, after the break-up of Gondwana. Early in the evolution of the genus, three primary centers of diversity developed: Australia, northeast Africa and Arabia, and west-central and southern Mexico (Table 1). This global radiation was accompanied by an impressive diversification in morphology, ecology and physiology.

| **Genomes** | **Number of species** | ***Geographic location*** |
|---|---|---|
| A | 2 | *Africa/Asia* |
| B | 4 | *Africa* |
| C | 2 | *Australia* |
| D | 13 | *New World* |
| E | 7 | *Arabia* |
| F | 1 | *Africa* |
| G | 3 | *Australia* |
| K | 12 | *Australia* |
| *AD* | *5* | *New World* |

Table 1. Geographic distribution of *Gossypium* genomes (Smith and Cothren, 1999).

## 2. Taxonomy

Eight diploid genomes (A–G and K), each with $2n = 2x = 26$ chromosomes, have been

identified. The native distribution of all five tetraploid cottons ($2n = 4x = 52$, AD) is restricted to the New World, although its emergence involves a combination of an Old World A-genome (derived from an ancestor of *G. arboreum* L. and *G. herbaceum* L.) and a New World D-genome (derived from an ancestor of *G. raimondii* Ulbrich). The underlying trans-oceanic dispersal of the A-genome donor and the timing of the polyploidization event have been controversial, but the current view is that a single Mid-Pleistocene (1–2 mya) polyploidization event has occurred.

It is further assumed, that the emergence of tetraploid cotton was followed by long-distance dispersion and modification into five species, three of which are still truly wild: *G. mustelinum* Miers ex Watt (limited distribution in northeast Brazil), *G. darwinii* Watt (endemic to the Galapagos Islands), and *G. tomentosum* Nutall ex Seemann (endemic to the Hawaiian Islands). The other two species have undergone domestication, i.e. *G. hirsutum* L. (predominantly distributed in Meso America and the Caribbean) and *G. barbadense* L. (main distribution in South America and the Caribbean).

Cotton is unique among crop plants in that four separate species have been independently domesticated for their seed lint. The elongated epidermal seed trichomes of *G. herbaceum*, *G. arboreum*, *G. hirsutum*, and *G. barbadense* were recognized by humans as useful spinnable fibers and led to four independent domestication events. The cotton *G. hirsutum* has received much attention in this matter due to its prime economic importance in modern cotton production. It is presently responsible for 95% of the cotton produced internationally, having spread from its original home in Mesoamerica to numerous countries in both hemispheres. Pima or Egyptian cotton (*G. barbadense*) and Asian cotton (*G. arboretum*) together represent the remaining 5%.

The cotton plant is a perennial with reputedly the most complex structure of any major field crop. Its indeterminate growth habit and sympodial fruiting branches result in a four-dimensional occupation of space and time that is difficult to describe and analyze. A general division of the phenological growth stages of cotton into nine categories, according to BBCH scale, from the germination phase (stage 0) to the time of senescence (stage 9) was described by Munger *et al.* (1998) (Table 2). An understanding of cotton growth and development is important in the continuing efforts of growers to produce lint and seed more efficiently and profitably.



| Code | Definition |
|---|---|
| 0 | Germination |
| 1 | Leaf Development (main shoot) |
| 2 | Formation of side shoots |
| 3 | Stem elongation (main shoot) |
| 4 | Development of harvestable vegetative plant parts |
| 5 | Inflorescence emergence |
| 6 | Flowering |
| 7 | Development of fruits and seeds |
| 8 | Ripening of fruits and seeds |
| 9 | Senescence |

Table 2. Definition of the principal growth stages in the BBCH scale (Munger *et al.*,

1998)

## 3. Morphology and Physiology

### 3.1. Seeds and Germination

Seed offers a convenient base line in ontogenetic studies of plants. A mature cotton seed contains all of the organs necessary to produce a small seedling. The cotton seed is an ovoid, pointed, dark brown structure that consists of a seed coat (testa), an embryo with two-well developed cotyledons, and remnants of the endosperm. Before ginning and delinting, the epidermal layer of the seed coat bears fibers or lint of two types: long lint fibers and short linters. The embryo consists of a radicle, hypocotyls, the two cotyledons, and poorly developed epicotyls (Figure 1).

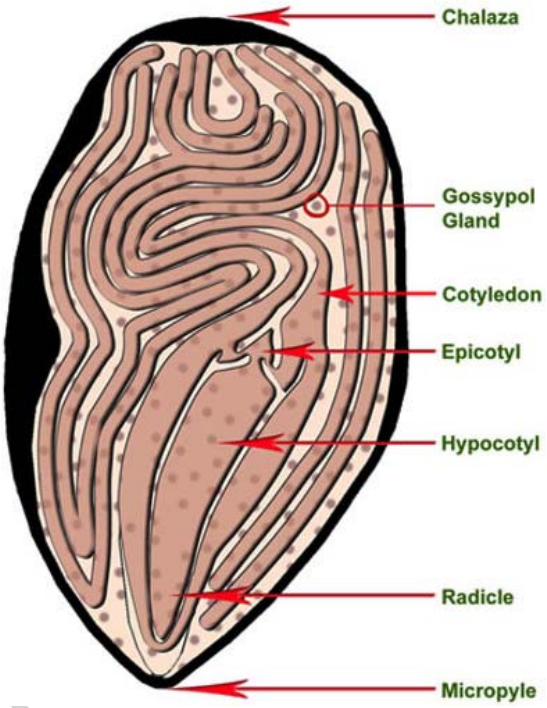


Figure 1. Inside the cotton seed (Ritchie *et al*., 2007).

One of the main traits of *Gossypium L*. seeds is the presence of pigment glands. Gossypol, a triterpenoid aldehyde, and its derivatives are predominant secondary metabolites in cotton glands. These compounds have insecticidal, anti-microbial, anti-fertility and toxic properties. Gossypol's concentration varies from zero in the seed kernel of some Australian wild diploid species to more than 9% in *G. davidsonii* Kell. Upland cotton seeds usually contain from 0.6% to 2% gossypol. As this triterpenoid is very toxic to humans and monogastric animals its rate in all food and feed products made with cotton flour must be very low and has to be systematically controlled.

Also, cotton seeds contain approximately 73% of unsaturated fatty acids and 26% of saturated ones. It has been reported that seeds of cotton contain one of the highest levels

of vitamin E, reported as alpha, α (5, 7, 9-tromethyltocol) and gamma, γ (7, 8-dimethylcotol) forms only, of 13 plant and animal sources of fats and oils. Vitamin E (tocopherol) is a lipid soluble strong anti-oxidant that occurs most frequently in vegetable oils and has been implicated in decreased risk of cardiovascular disease, some forms of cancer, improved immune functions, and in slowing the progress of some degenerative diseases in humans.

Prior to germination, the mature seed is dehydrated and metabolically inactive. The germination process begins with the passive transport of water through the seed coat (imbibition), following an initial softening of the chalazal "plug". Water moves from the chalaza by capillary action around the internal periphery to the radicle of the embryo where it is taken up. There is no direct uptake by the cotyledons. Oxygen uptake occurs and respiration increases as the stored food reserves are utilized for energy, and for building new cells and tissues.

The seed/embryo swells as water is absorbed, causing the seed coat to split at a pointed micro-pylar end. The radicle that emerges through the micro-pyle within 2-3 days, forms the primary root that grows downward into the soil. The tissues between the radicle and cotyledons, the hypocotyl, grow rapidly, arching near $180^{o}$ to form the "*hypocotyl hook*" near the cotyledons. With continued expansion of the hypocotyl, the cotyledons and epicotyl are pulled up through the soil surface whereupon the hypocotyl straightens. Typically, the seed coat is shed and remains in the soil.

Cotyledons contain stored food which supplies the energy for germination and early development, and they form the first green leaves. The cotyledons are carried 5-8cm above the soil by the elongating hypocotyls before unfolding and expanding. During this phase the developing seedling is anchored in the soil by the rapidly expanding root system. After emergence and exposure to the light, the cotyledons become green due to chlorophyll and are capable of photosynthesis. Prior to this stage, the developing aerial portion of the seedling and the rapidly growing radicle have been dependent on assimilate stored in the embryonic axis and cotyledons. More of early development of the cotton plant is focused on the development of a substantial root system, while growth of the above-ground portion (first 4-5 true leaves) is relatively slow.

Imbibition is responsible for activating the metabolic processes of germination due to the number of hydrolytic enzymes involved. Although the precise signal for the initiation of germination is unknown, studies of biochemical changes in seeds which have initiated germination processes show a dramatic rise in activity of many enzymes within a very short time; these occur quite rapidly in seeds after the imbibition of water. The composition of the free amino acid pool in embryonic cotton cotyledons is quite distinct from that of endosperm, and that of germinated, greened cotyledons is quite distinct from that of leaves. During germination (including the precocious germination of immature seeds), the pool expands considerably, showing a pronounced accumulation of asparagine.

The high level of asparagine found in seedling roots and in the cotyledon vascular exudate indicates that this is the major transported amino acid in germination. There is no pool expansion in the presence of abscisic acid which inhibits germination.

Gibberilic acid, kinetin or 2-chloroethyl-phosphonic acid partially overcome the inhibitory action of abscisic acid. Anaerobiosis leads to an accumulation of aspartate, alanine and glycine at the expense of asparagine; however, desiccation does not result in an accumulation of praline. Also, high levels of arginine are maintained through germination.

Germination efficiency and development are seriously affected by exposure to low temperatures. Cotton seedlings are damaged by temperatures below $15^{o}$C during germination; seedlings of upland cotton (*G. hirsutum*) are extremely sensitive to chilling damage during critical phases in the germination period. Other possible problems that may hinder germination and emergence include poor seed quality, pre-emergence seedling disease, flooding, soil crusting, salinity, and herbicide residue.

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**Biographical Sketches**

**Dr. Stella K. Kantartzi** is a graduate of Aristotle University of Thessaloniki in Greece, earning her bachelor's in Biology in 2000, her master's in Plant Breeding, Agronomy and Weed Science in 2003 and her doctorate in Genetics and Plant Breeding in 2006. Concurrently with her Ph.D. studies, she conducted research on cotton cytogenetics and molecular fingerprinting in the Dept. of Soil and Crop Sciences at Texas A&M University in College Station, TX as a visitor scientist. She subsequently spent two years as a post-doctoral associate, in the laboratory of Prof. James McD. Stewart at the University of Arkansas, investigating diploid cotton germplasm.

Since 2008, Stella Kantartzi has been on the faculty at Southern Illinois University in Carbondale, IL, as an assistant professor of plant breeding in the Department of Plant, Soil and Agricultural Systems. Her research in cotton has been focused on the development of partial inter-specific hybrids, *in-vitro* gynogenesis, assessment of molecular diversity, and gene mapping. She received a State Foundation Graduate Scholarship for 4 years from 2001 to 2005. Her professional memberships include the Agriculture Honor Society Gamma Sigma Delta, the Crop Science Society of America and the International Cotton Genome Initiative.

**Professor James (Mac) McD. Stewart** received his BS in Botany in 1963 and his PhD in Botany with emphasis in Plant Physiology and Biochemistry in 1968 from Oklahoma State University. He joined

USDA, ARS in 1968 at Knoxville, TN where he developed a research program in cotton fiber biology. In 1986 he joined the University of Arkansas as Professor and holder of the Ben J. Altheimer Chair for Cotton Research and Development. Professor Mac Stewart is noted for his research on fiber initiation, his contributions in ovule and embryo culture, and his publications on cotton biotechnology. He co-edited the Cotton Foundation's first reference book, Cotton Physiology, and wrote a major review of cotton biotechnology for the international audience, and is the lead editor on Handbook of Cotton Physiology.

Prof. McD. Stewart is recognized for his contributions on numerous plant explorations (Australia, Mexico and South America) he has made to cotton germplasm including 8 new species, and his strategies for enhancement of exotic germplasm. He served as a member of the International Cotton Advisory Committee's First, and Second Expert Panel on Cotton Biotechnology. He received both the Genetics Research Award in 2000, and the Cotton Physiology Research Award in 2003, the two highest awards given by the respective disciplines.

Currently the main focus of Dr. Stewart's cotton research is concerned with evaluation for and introgression of genetic diversity into cotton. This research is a continuation of a career-long interest in the *Gossypium* species, and ranges from basic taxonomy and cytogenetics, to strategies for hybridization, to development of molecular markers to follow introgression of selected traits.