Cotton

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The cultivated cottons comprise four species in the genus *Gossypium*, tribe *Gossypieae*, family *Malvaceae*. Two species were domesticated in Africa and/or India, one in South America, and one in Mesoamerica.

Cotton is cultivated virtually around the world in tropical and subtropical regions, both under irrigation and as a rainfed crop. Important areas of production are the southern United States westward to California, Mesoamerica and South America, Egypt, the Sudan, the Soviet Union, India, and the People's Republic of China. Lesser amounts are grown in the savannas of Africa, southern Europe, the Near East, and Australia.

Cotton is grown mainly for its lint (seed floss) which is used in spinning yarns for textiles, industrial cloths, and toweling. Smaller amounts are used in the production of sewing thread and for stuffing. The seeds are an important by-product. The refined oil is used in cooking, and the oil-cake residue as a protein feed for ruminant livestock. Linters, the short fibers removed from seed before crushing, are an important source of industrial cellulose.

I. PARENTAL MATERIAL

The Old World cultivated cottons are classified as *Gossypium arboreum* L. and *Gossypium herbaceum* L. Both are diploids with a haploid chromosome number of 13, the basic number for the genus. *Gossypium herbaceum* grows wild in Africa where the plant might have been domesticated. *Gossypium arboreum* is known only in cultivation, or as a ruderal plant, and might have been derived from *G. herbaceum* after that species was domesticated (Hutchinson et al., 1947). *Gossypium arboreum* remains an important crop in India today, whereas *G. herbaceum* is today a minor crop grown for local use in the drier areas of Africa and Asia.
Table 1—Species of *Gossypium* listed according to genomic formula and characters contributed for actual, or potential, improvement of the cultivated tetraploid species.

<table>
<thead>
<tr>
<th><em>Gossypium</em> species</th>
<th>Genomic formula</th>
<th>Character and authority</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>herbaceum</em></td>
<td>A$_1$</td>
<td>Resistance to leafhopper (Knight, 1954).</td>
</tr>
<tr>
<td><em>arboreum</em></td>
<td>A$_2$</td>
<td>Resistance to bacterial blight (Knight, 1953).</td>
</tr>
<tr>
<td><em>thurberi</em> Tod.</td>
<td>D$_1$</td>
<td>Increased fiber strength in <em>G. hirsutum</em> (Lewis, 1957).</td>
</tr>
<tr>
<td><em>armourianum</em> Kearney</td>
<td>D$_{2111}$</td>
<td>Glabrous leaf (Meyer, 1957).</td>
</tr>
<tr>
<td><em>harknessii</em> Brandg.</td>
<td>D$_{2112}$</td>
<td>Cytoplasmic male sterility (Meyer, 1975).</td>
</tr>
<tr>
<td><em>klotzschianum</em> Anderss.</td>
<td>D$_1$</td>
<td>Gossypol in foliage (Bell and Stipanovic, 1977)</td>
</tr>
<tr>
<td><em>raimondii</em> Urb.</td>
<td>D$_3$</td>
<td>Unusual terpenoids aldehydes in foliage (Bell and Stipanovic, 1977).</td>
</tr>
</tbody>
</table>

*Gossypium hirsutum* L. is native to Mesoamerica and *Gossypium barbadense* to South America. The species are closely related tetraploids with a diploid-like meiosis, the haploid chromosome number being 26. *Gossypium hirsutum* accounts for about 90% of the current world’s production of cotton. In addition to the cultivated forms, wild and ruderal races of the two species exist in tropical regions.

Cultivated *G. hirsutum* is commonly called short-stapled cotton, and is most often grown as an annual, the so-called Upland form. *Gossypium barbadense* is classified as a long-stapled cotton. Its strong, fine fibers are favored for the production of sewing thread and luxury fabrics.

In addition to the cultivated cottons, there are at least 31 wild taxa distributed in dry tropical and subtropical latitudes around the world (Fryxell, 1969). These, along with wild stocks and obsolete cultivars of the cultivated species, represent germ plasm sources of actual or potential use in improving cultivated cottons. Beasley (1942) classified *Gossypium* species according to chromosomal size and affinity at meiosis, assigning capital letters to various genomic groups, A, B, C, D, etc. Beasley’s classification is convenient when discussing interrelationships within the genus.

Although at least one Soviet worker (Vysotski, 1958) has reported introgression of germplasm from a *Malva* species into *G. hirsutum*, workers elsewhere have not reported crosses between *Gossypium* and related genera. Many diploid and tetraploid species can be crossed with the cultivated diploid species (A) and the cultivated tetraploid species (AD). Table 1 lists some of the species that have been crossed with the cultivated tetraploids with notations on the characters contributed for actual or potential improvement.

All of the tetraploid species intercross readily, although there is frequently genetic breakdown in ensuing progenies. Crossability among *Gossypium* species does not always follow closely known phylogenetic affinities. The Old World cultivated species, the contributors of genome A to the cultivated tetraploids (Beasley, 1942), are difficult to cross with AD species. Pundir (1972) implicated endosperm degeneration in embryo sacs bearing hybrid embryos as the main cause.

Most American D diploids cross well with each other and with AD species. Crosses between *G. klotzschianum* and *G. davidsonii* (both D$_1$) and other D and AD species usually fail because of a lethal interaction in hybrid
embryos. The D1 species produce viable hybrid plants with certain selections of AD cottons (Lee and Smith, 1970).

The African B diploid, *Gossypium anomalum* Wawr. & Peyr., crosses readily with Old and New World cultivated cottons, and is one of the few species that produces viable hybrids with D1. The Australian C diploid, *Gossypium sturtianum* J. H. Willis, crosses readily with *G. hirsutum*, however, little exchange of germplasm occurs among the genomes of the derived hexaploid.

A collection of obsolete cultivars of *G. hirsutum* is maintained at the U.S. Cotton Physiology and Genetics Laboratory, Stoneville, Miss., a collection of *G. barbadense* at the U.S. Cotton Research Laboratory, Phoenix, Ariz., and a collection of diploid cottons and race stocks of *G. hirsutum* at Texas A&M University, College Station. Seeds of various cottons are on deposit at the National Seed Storage Facility, Fort Collins, Colo.

**II. PLANT CULTURE**

**A. Field**

Cottons are grown on various soils, including sandy loams, lateritic clays, calcareous soils, and valley alluviums. Soils should be well drained. Cotton performs best on fertile soils, but excess nitrogen can lead to vegetative development at the expense of fruit production (Brown, 1938). The North Carolina Extension Service recommends 110 kg of N, 70 kg of K, and 50 kg of P per ha for satisfactory cropping. On sandy soils subject to leaching, the N and K can be applied in split applications. Boron deficiency inhibits fruit set in some areas of the U.S. cotton belt. Boron can be applied in fertilizers, or as a foliar spray at the rate of 5.5 kg/ha in split applications. Soil pH should not be below 6.2.

R. E. Sneed (personal communication, 1972) found that cotton in North Carolina requires about 2.5 cm of rainfall per week to maintain a good rate of growth and fruitation during July and August. Water requirements fluctuate with temperature and the depths to which roots penetrate. Mauney and Phillips (1963) expressed the opinion that moisture levels optimal for vegetative develop in wild stocks of *Gossypium* inhibit flower retention and development. Although cultivated cottons seem less sensitive to high soil moisture level than such primitive kinds, fruition proceeds more uniformly under adequate than with excessive moisture.

Plant density preferences vary among locations. Some stocks of *G. hirsutum* and *G. barbadense* maintained for home use in tropical America often grow into small trees. Cotton grown for annual production is commonly sown at a seeding rate of 9 to 12 seeds per m of row. Lesser densities tend to extend the fruiting season and denser planting leads to a high proportion of unproductive plants.

Cotton seed germinate in 5 days when soil temperature reaches 22 C, and seed should not be planted in soil colder than 16 C. Optimum temperatures for growth of seedling cotton are in the range of 27 C for a daily maximum and 11 C for a nightly minimum. Mauney (1966) showed that high night temperatures in the range of 27 C delay fruition and promote vegeta-
tive growth in cultivated *G. hirsutum*. A warm, dry regime is best for the last stages of fruit maturation and harvest.

Herbicides and tillage usually are used for weed control. A preplant herbicide is incorporated in the upper 5 cm of the soil surface or a post-plant herbicide is sprayed on the surface. Later applications of herbicides may be applied as a directed spray. Control of insect pests is usually organized and performed on a community-wide basis, with a strong emphasis on field scouting for monitoring pest populations.

Defoliants are applied when approximately one-half to three-fourths of the mature bolls have opened. A desiccant is frequently applied before the defoliant to promote better leaf drop. Seed cotton is harvested with a spindle picker, or with one of various types of stripping machines. Seeds are separated from lint on commercial gins and the lint packed into bales averaging about 227 kg each.

### B. Growth Chamber and Greenhouse

Greenhouses are commonly used to grow cotton for crossing and selfing. Growth chambers are not used for such purposes. For most work in the greenhouse, the intent is to simulate conditions for optimal growth in the field. Greenhouses are used mostly for producing cotton during the cool months. A cultivar of *G. hirsutum* can mature a crop of bolls in the greenhouse at Raleigh in about 120 days. A crop can be grown from seed harvested in September in time to provide mature seeds for field planting the following May.

Culture conditions in ground beds in greenhouses do not differ from those in the field. Most of the fertilizer can be applied as a preplant dressing, and water is usually applied in furrows. As in the field, soil pH should not be below 6.2. Greenhouse soils should be sterilized before planting, and methyl bromide is most commonly used. Potting medium should consist of three parts of soil to one part of vermiculite, or other such soil conditioner. About 25 g of complete fertilizer (equals parts of N, P, and K) should be applied to a 32-cm diam pot before planting. Additional N and K can be applied at biweekly intervals at the rate of 8 to 10 g per application. Watering of pots is best done by a time-clock monitoring system. Frequency of watering can be increased as the plants mature. Greenhouse temperatures are controlled by automated systems of heating and cooling, and turbulating devices are used for distributing air. Heating during cool weather should be programmed at 27 °C for a daily maximum, and 19 °C for a nightly minimum. On sunny days, ambient greenhouse temperature can approach 36 °C before cooling is applied.

Cottons sensitive to short days are frequently grown in greenhouses for crossing. Such cottons require careful management to ensure flowering and fruiting (Mauney and Phillips, 1963). Maturing plants should not be exposed to more than 10 hours of light per day, and soil moisture should be limited to the point of stress. The temperature regime described for cultivated cottons is adequate to promote flowering in primitive kinds, as long as the day-night temperature differential does not fall below 8 to 10 °C.
III. FLORAL CHARACTERISTICS

Cultivated cottons are generally self-pollinated (Brown, 1938). The stigmas of most cultivars are not exerted clear of the uppermost anthers, so that selfing usually occurs immediately after anther dehiscence (Fig. 1). Some primitive forms of *G. hirsutum* and *G. barbadense* have the stigma exerted well above the anthers. Such separation of anthers and stigma should promote cross-pollination by insect vectors.

A flower bud (square) of *G. hirsutum* grows from the pinhead stage to anthesis in from 21 to 25 days (Brown, 1938). Once in bloom, a cotton flower is receptive to pollination for 8 hours or less.

Cottons normally have perfect flowers. The developing bud is enclosed in three, rarely four, bractioles called the epicalyx (Fig. 1). A five-lobed calyx cups the base of the flower. The mature, unopened flower is tubular, consisting of five petals united at their bases and continuous with an anther column clasping the ovary and style. Petal length can vary from 9 cm in some stocks of *G. barbadense* to 2.5 cm in some cultivars of *G. arboreum*. Corolla color can be creamy white or various shades of yellow. White is most common in *G. hirsutum* and *G. arboreum*, and yellow predominates in *G. barbadense* and *G. herbaceum*. The diploid species and most cultivars of *G. barbadense* display a red spot at the base of each petal, a phenotype rarely observed in cultivars of *G. hirsutum*. The corollas of most species of *Gossypium* flare widely at anthesis, whereas those of *G. barbadense* and the wild species, *G. raimondii*, retain a tubular form.

![Cotton (G. hirsutum L.) flowers at three stages of development. Left to right: bud 48 hours from anthesis; 24 hours from anthesis (whitebud stage); and a cutaway view of flower at anthesis.](image)
The anther column bears anthers (approximately 100 per flower in cultivated *G. hirsutum*) on filaments of variable length. The tip of the stigma is exerted above the anther column. It is divided into three to five parts, each continuous with a locule of the ovary. The ovules are borne at the central axis of the ovary, and can number as high as 10 per locule in *G. hirsutum*, but fewer in most cultivars of the other domesticated species. The ovary, after fertilization, develops into a valvate capsule (boll); the maturation process requiring from 40 to 80 days. The capsule can be round, ovate, or top-shaped, depending upon the species or cultivar, and can bear from 3 to 10 g of seed and adhering lint.

IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION

A. Equipment

Equipment needed for hand-crossing and selfing of cotton is neither elaborate nor costly. Items used for self-pollination include paper clips, malleable wire, cardboard cylinders, and shellac and ethyl acetate for sealing the ends of buds (Fig. 3). Selfed or cross-pollinated flowers can be marked in various ways. Varicolored merchandize tags can be adapted by color code for various operations, such as one color for selfed flowers and another for crossing, or various colors can denote different crosses. Miravalle (1965) recommended a rectangular tag with a circular eye large enough to slip over a flower bud. Information concerning the flower can be code-punched into the tag for cross reference with a field book, or informa-

Fig. 2—Emasculated flowers of cotton (*G. hirsutum* L.). Left, anthers and petals removed showing the elongated style and stigma; right, a section of soda straw in place to protect stigma.
tion can be written on the tag in permanent ink. Emasculated flowers can be protected with a length of soda straw (Fig. 2), a cardboard cylinder (Fig. 3), or by placing a paper or a cloth bag over the flower.

Flowers to be pollinated are marked in various ways. Wooden stakes or white flags on heavy wire staffs may be placed in rows near plants bearing emasculated flowers. White cloth strips tied to plants are sometimes used.

B. Preparation of the Female

Progress of floral development in cotton follows a rigid and predictable schedule, provided that the temperature regime is favorable. Flowers approaching maturity are at the whitebud stage, the stage for emasculation, by 1200 hours the day before anthesis (Fig. 1). An experienced observer can predict the onset of anthesis as early as 48 hours before a flower is due to shed pollen. White buds are usually emasculated the afternoon before anthesis.

Some workers emasculate cotton flowers with the fingers, removing the epicalyx, corolla, and anther column in one deft operation. Cutting the petals away with an emasculating device, followed by stripping the anthers, is less injurious to flowers and improves fruit set. Some cottons, notably certain strains of *G. barbadense*, do not tolerate loss of petals before pollination. With such stocks, anthers may be removed through a slit in the corolla, or, if petals are removed, a drop of gibberellic acid solution (100 ppm aqueous) applied at the base of the anther column at emasculation improves fruit set (Brown and Lee, 1976). Treating stigmas of emasculated

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Fig. 3—Three methods of selfing in cotton (*G. hirsutum* L.). Left to right, paper clip attached to end of corolla, corolla wrapped with copper wire, cardboard cylinder over flower. All flowers are at anthesis.
flowers with a 30% ethanol solution destroys extraneous pollen. Stigmas of emasculated flowers are protected by covering with a length of soda straw, a cardboard tube, or a bag.

C. Pollination

Emasculated flowers are pollinated the day following emasculation, usually beginning around 1000 hours. The pollen in whitebuds can effect fertilization if held overnight under refrigeration. Stigmas are not fully receptive to pollination until the morning of anthesis. Pollen does not survive in the field for more than a few hours.

Flowers to be used as pollen sources are prepared the day before anthesis by sealing the corolla with any one of several devices (Fig. 3). With the exception of bags, none of the devices cited forestall the efforts of determined bumblebees; therefore, selfed flowers should be inspected for bee damage before use as pollen sources.

Flowers should be shedding abundant pollen at the time of use. In North Carolina during July, pollen shed in *G. hirsutum* usually commences when shade temperature reaches 27°C, most often around 0900 hours. Some cultivars of *G. barbadense* shed pollen earlier.

For most hand pollinations, the pollen is applied directly from the anthers to the stigma, usually within minutes after the male flower is collected. If pollen shed is tardy, as when temperature is low, heating will promote it. Stigmas are protected by replacing the shielding device, and the flowers are tagged according to some preplanned system of identification.

Pundir (1972) found that the elapsed time between pollination and fertilization in cultivars of *G. hirsutum* and *G. arboreum* ranged from 24 to 48 hours. Diurnal temperatures in Pundir’s experiments ranged between 9 and 38°C.

Research on freeze-drying of cotton pollen for future use is lacking. Small lots can be stored in a refrigerator (2 to 3°C) for at least 24 hours without loss of viability.

Rate of fruit set after pollination of emasculated flowers varies with location, season, and cultivar. R. J. Kohel (personal communication, 1977) reported about 50% success with *G. hirsutum* at College Station, Texas, with the rate falling as the season progressed. At Raleigh, North Carolina, I have recorded as high as 90% success in the field and greenhouse with *G. hirsutum*, but less (70 to 80%) with *G. barbadense* (Brown and Lee, 1976).

D. Factors Affecting Efficiency

Cotton nurseries are rarely elaborate. At Raleigh I commonly use blocks 15 m in length made up of rows 1 m wide. Two-meter alleys are left at the end of the blocks to facilitate access to the rows. Plots for crossing and for selfing are laid out in similar patterns. Often crossing and selfing are attempted in the same row.

Cotton plants commonly bloom over periods ranging from 3 weeks to more than a month. Matching flowering dates for most cultivars is rarely a problem, provided that such is taken into account at planting time. Most
cultivars of *G. barbadense* begin flowering 1 to 2 weeks later than *G. hirsutum*, if the two are planted on the same date. There is usually enough overlap in the flowering periods to ensure crossing, particularly when *G. barbadense* is used as the female parent.

Matching the flowering sequences of annual cultivars and cottons sensitive to short days presents a problem requiring careful management. Such cottons must be grown in tropical winter nurseries or in greenhouses under the proper regimes of temperature, moisture, and light duration. Most primitive cottons require the development of 15 or more nodes along the main plant axis before there can be flowering under any environment (Mauney and Phillips, 1963). Two-year-old plants of primitive cottons are commonly used for crossing with cultivated cottons, and the cultivar is most often used as the female parent. Pruning of flower buds delays flowering indefinitely, and can be used to promote synchronous flowering.

Many genetic markers are available for identifying F₁ plants in cotton, but few have been used. The most common is *R₁*, a dominant allele in *G. hirsutum* that imparts wine-red plant color (Pope et al., 1944). *R₁* does not weaken plants, and is readily transferred from one background to another. Alleles with similar effects are present in other cultivated species.

Glandless (*gl₁gl₁-gl₁gl₁*) has been proposed as a seed marker (Cross and Richmond, 1959). Normal cultivars of cotton have conspicuous pigment glands in most plant parts, including embryos. The glandless strains of *G. hirsutum* and *G. barbadense* are devoid of these pigment bodies. The glandless stock is used as the female parent and the amount of hybridization is assessed by cutting and inspecting seeds.

Turcotte and Feaster (1967) described a stock of Pima cotton (*G. barbadense*) that exhibited semigamy, a condition wherein the egg and sperm fail to unite after fertilization, each subsequently giving rise to an independent tissue line in the embryo. Such tissues are often haploid. Making a semigamous stock homozygous for a conspicuous marker affords ready identification of sectored F₁ plants, thus providing material for the production of homozygous lines.

**V. NATURAL HYBRIDIZATION**

Cottons are predominantly self-pollinated with the amount of outcrossing variable among locations. Interplanting of genetically marked stocks is used to assess rate of natural hybridization. Simpson and Duncan (1956) recorded from 29 to 60% outcrossing among 79 cultivars of *G. hirsutum* at Knoxville, Tenn. in an unsprayed field. Although self-incompatibility systems have not been documented for cotton, they found that cultivar rank was highly repeatable over two seasons. In the Mississippi Valley, the San Joaquin Valley, and the High Plains of Texas, outcrossing rarely exceeds 5%.

Bees of various genera serve as pollen vectors in cotton, with the genus *Bombus* being prominent. Hive bees, *Apis mellifera* L., have been used with success in cross-pollinating cotton (McGregor, 1976).

Mass crossing of cotton in the field requires the use of induced or genetic male-sterility. Eaton (1957) induced male sterility in *G. hirsutum* through foliar applications of alpha-dichloroisobutrate (FW-450). Fruits set
well on treated plants, but seed yield was sharply reduced because of damage to the growing plant. Chemosterilization remains as a tool of potential worth in the production of hybrid cottons.

Several recessive male-sterile alleles are known in *G. hirsutum*, some imparting complete pollen abortion (Weaver, 1968; Richmond and Kohel, 1961). These have potential use in promoting mass crossing in genetic and breeding programs and have been used in the production of commercial hybrids in India (J. B. Weaver, Jr., personal communication, 1976). Cytoplasmic-genetic male sterility (CMS) is recoverable when the genomes of *G. hirsutum* are transferred to the cytoplasms of various diploid species. The most dependable source of CMS made available to date employs the cytoplasm of *G. harknessii* (Meyer, 1975). This species has also contributed fertility restorer genes.

The chief potential use of CMS is in the production of single-cross hybrids for commercial production. A problem at present is the need to control insect pests in cotton fields while simultaneously preserving pollen vectors. There is evidence that if such vectors are preserved, satisfactory amounts of F1 seed can be produced. Lee Stith (personal communication, 1977), working in Arizona, used a system of eight rows of CMS to two rows of pollinators and obtained good seed set on the CMS rows. Wild bees served as pollen vectors.

Isolation requirements for intercrossing experiments in subtropical latitudes vary among locations, and perhaps also from year to year. Miller and Rawlings (1967) in an intermating experiment with *G. hirsutum* in North Carolina found a distance of 0.8 km from the nearest cotton to be adequate for isolating their material. Green and Jones (1953) found a buffer strip of 9 rows of cotton effective as a screen for experimental plots in Oklahoma. Pope et al. (1944), working in Tennessee, used strips of corn as barriers to pollen transport.

**VI. SEED DEVELOPMENT, HARVEST, AND STORAGE**

Cotton plants in the field at Raleigh commence blooming about 65 days after emergence, usually around 4 July, and continue flowering until the plants are loaded with fruit, commonly around 15 August. Bolls set in mid-July are expected to mature in 45 days on a typical *G. hirsutum* cultivar, such as 'Coker 310'. Maturation rates for *G. barbadense* are usually slower than those of *G. hirsutum*, the boll period commonly extended 10 days longer. Late fruits of all cottons take longer to mature, sometimes up to 80 days for *G. barbadense*. Mauney (1961) showed that embryos of *G. hirsutum* ('Coker 100W') from early flowers grew to maximum length in about 30 days.

Hand-crossed and selfed cotton are usually harvested by hand and the lint and seeds separated on a micro-gin. Larger lots are harvested with spindle pickers, or stripping machines, and the lint removed from seeds at commercial ginneries.

The fuzz on cotton planting seed is commonly removed with concentrated sulfuric acid, and the seed dried at 43°C preparatory to storage. Cottonseed with germination of 80% or better can remain viable in well-
ventilated storage facilities for at least 2 years. Storage pests, insects and rodents, are rarely a problem with cottonseed. Seed viability can be retained for longer periods under refrigeration. Pate and Duncan (1964) showed that *G. hirsutum* seeds containing 11% moisture remained fully viable for 25 years after storage at 0.5°C, but seeds stored at 13% moisture had only 16% germination. Bockholt et al. (1969) showed that Acala cotton (*G. hirsutum*) seed with 6.2% moisture stored at 10°C retained 51% viability after 26 years. In genetic and breeding programs, small quantities of seed are stored at subfreezing temperatures in cloth bags or in wire-top envelopes.

**VII. TECHNIQUES FOR SPECIAL SITUATIONS**

Special techniques for facilitating hybridization in cotton include the use of regulatory hormones, and embryo culture using excised embryos or intact ovules. Gibberellic acid (GA) promotes fruit set in cotton. Walhood (1957) reported that GA (100 ppm aqueous) promoted 100% boll set in Acala cotton; however, there was a dramatic increase in the level of seed abortion. Mathur and Mittal (1964) found that GA applied to prebloom cotton at rates ranging from 50 to 200 mg/liter increased flowering, but only the highest rate increased fruit set. Brown and Lee (1976) used GA to promote fruit set after emasculation in *G. barbadense*.

Culture of excised embryos has been used to produce interspecific hybrids in cottons, particularly crosses between Old and New World cultivars. The techniques for such culture as developed by Mauney (1961) have become standard for cotton.

Because yield of normal plants from embryo culture is low, techniques of ovular culture as developed by Beasley (1974) have come into favor for production of difficult hybrids. James McD. Stewart (personal communication, 1977) has used ovular culture to mass produce hybrids between AD (New World cultivar) and A (Old World cultivar) species, thus increasing the availability of diploid germplasm for the improvement of the tetraploid forms.

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