BREEDING OF COTTON

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Cotton Breeding

- Plant breeding is the art and science of changing and improving the heredity (genetic abilities) and performance of plants.
- Breeding can also be defined as the use of techniques involving crossing plants to produce varieties with particular characteristics (traits), which are carried in the genes of the plants and passed on to future generations.
- Breeding can also be defined in many other ways. Breeding is an application of genetic principles for the improvement of plants and other organisms.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Cotton Breeding

- Conventional plant breeding refers to techniques other than modern biotechnology, in particular cross-breeding, back-crossing, etc.
- In practice, breeding in cotton and other crops generally refers to development of new, superior varieties.
- Other and more recent techniques used in breeding include state-of-the-art breeding methods such as genomics, marker assisted breeding (MAB), biochemistry and cell biology.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Cotton Breeding

- Cotton is generally self-pollinating, but in the presence of suitable insect pollinators can exhibit some cross-pollination.
- Cotton is classified as an often cross-pollinated crop but for breeding purposes, it is treated as a self-pollinated crop, which is true for all cultivated species.
- Cotton, in spite of being an often cross-pollinated crop, does not suffer from in-breeding depression.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Cotton Breeding

- The extent of natural out-crossing in cotton depends on the climatic conditions where cotton is grown.
- The extent of natural cross-pollination varies even within a country.
- The cotton pollen grains cannot be carried by wind, and only insects carry pollen from one flower to another.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Cotton Breeding

- *Genetics* is a science of heredity.
- It is also a science of similarities and differences.
- This is a science that tells how traits are inherited and why an offspring is similar or different from the parents.
- Gregor Mendel published his work, *Experiments with Plant Hybrids*, in 1856.
- His work was so brilliant and unprecedented at the time it appeared that it took 34 years for the rest of the scientific community to catch up to it.
- Mendel's work was rediscovered in 1900 and the science of genetics was born.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Objectives

Principal objectives in breeding cotton are;

- high production of lint fiber,
- improvement in fiber and seed quality.
- early maturity,
- adaptation to mechanical harvesting,
- resistance to stress environments,
- resistance to disease and insect injury,

Other considerations are important in local areas.

Breeding Objectives

Yield of Fiber

- High yield of high-quality lint fiber is the ultimate objective in the breeding of cotton.
- The yield of a cotton plant is determined by
  - number of bolls,
  - size of the bolls, and
  - percentage of lint.
- The characteristic contributing most to yield is number of bolls.
- For plants to be high-yielding, they must be prolific and set a large number of bolls.

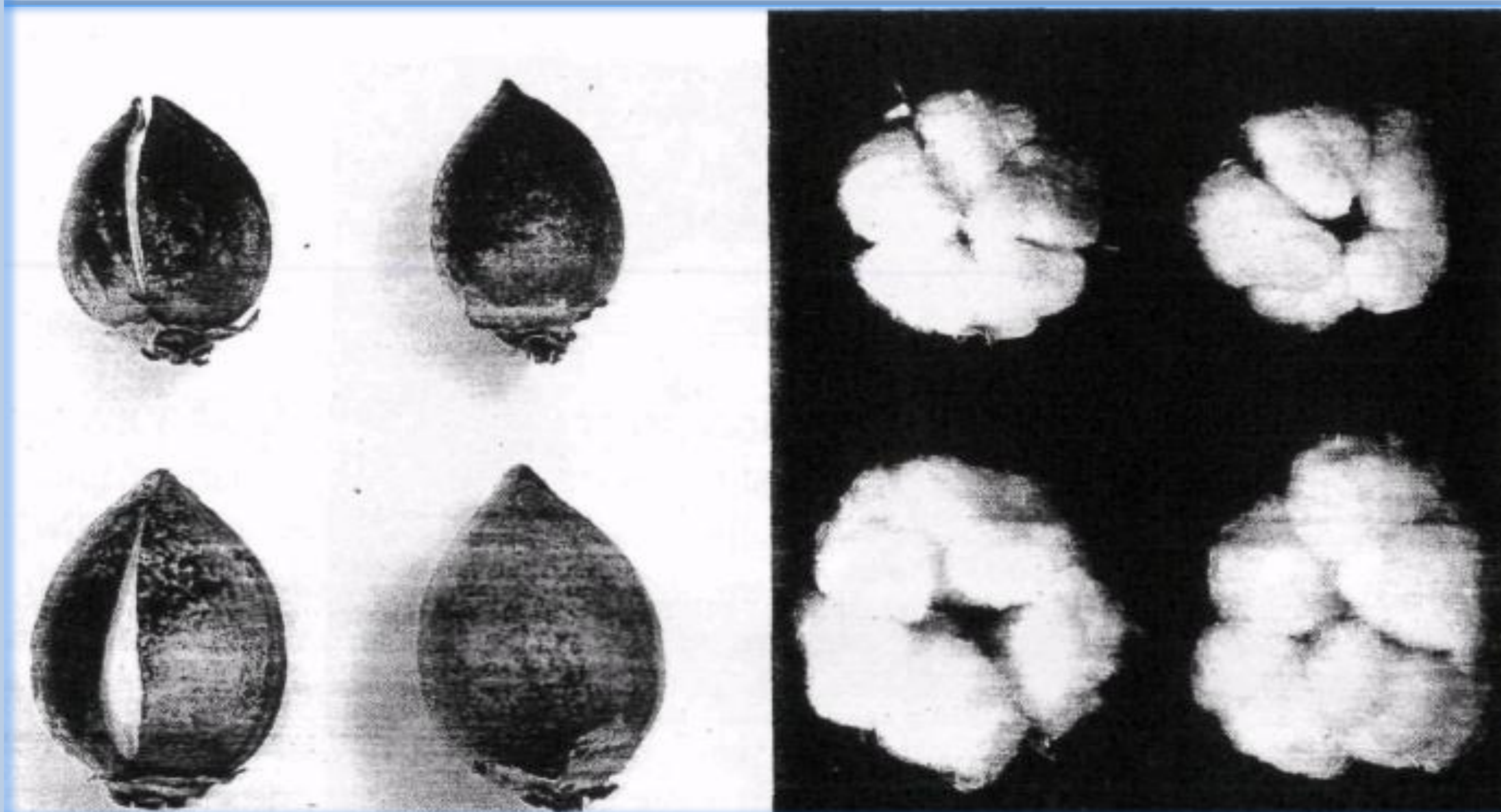
Poehlman and Sleper (1995)

Breeding Objectives

- Cotton cultivars differ in size of bolls.

Small boll - Delta type

Unopened bolls



Mature bolls

Large boll - Acala type

Poehlman and Sleper (1995)

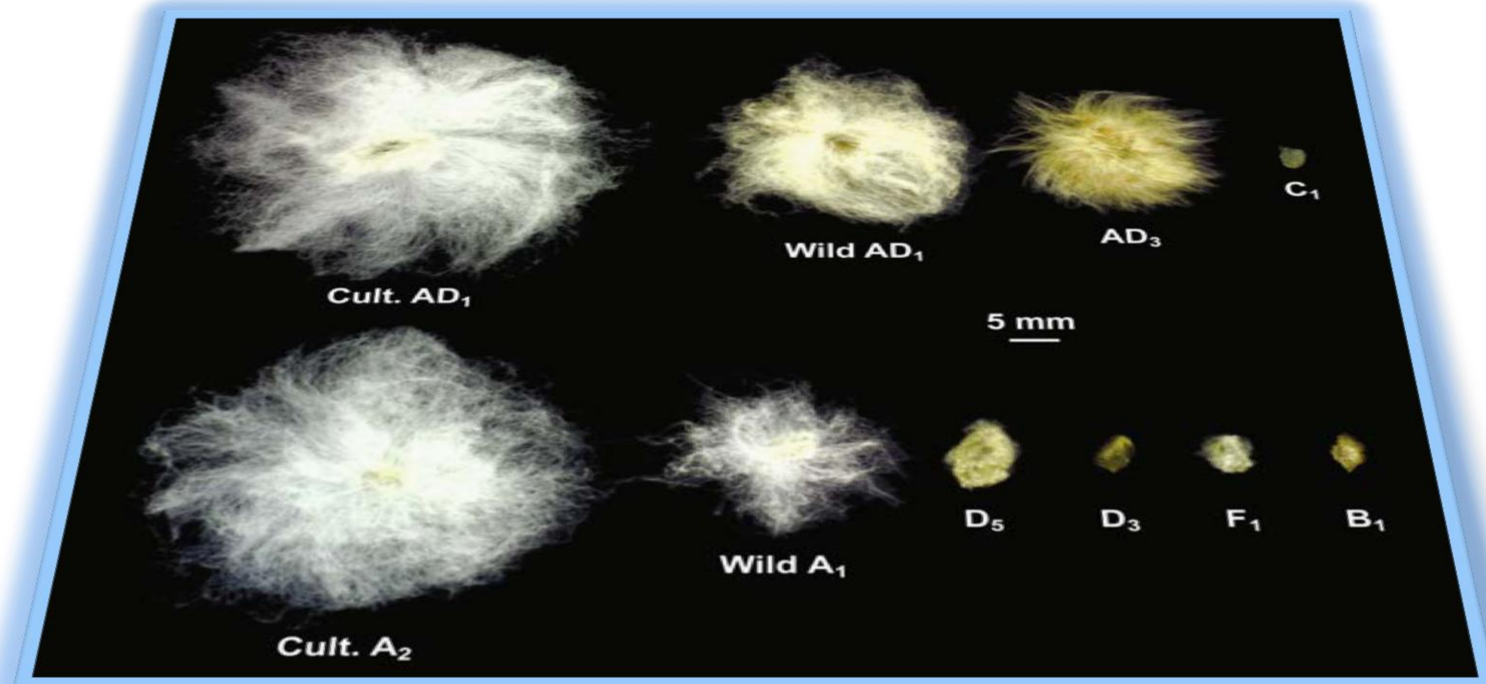
Breeding Objectives

Yield of Fiber

- Boll size is expressed as the weight in grams of seedcotton (lint + seeds) per boll.
- Normally, cultivars that set a high percentage of five-lock bolls are superior in yielding ability to cultivars with four-lock bolls.

Breeding Objectives

- Lint production is affected by seed-set because lint is produced on the surface of the seed and by the density of the lint on the seed.
- The percentage of lint is determined from the weight of the lint cotton that may be obtained from a given weight of seed cotton.



Poehlman and Sleper (1995); Kulkarni et al (2009); Wendel et.al.(2009)

Breeding Objectives

Yield of Fiber

- Selection for improved yield of lint often results in a reduction in fiber quality.
- In temperate climates it is important that the bolls be set early enough that most will mature and that few immature bolls remain on the plant when it is killed by frost.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

- Cotton fiber is the major commercial product from cotton.
- Cottonseed oil and cake are secondary products, yet cottonseed is the second-most important oilseed in the world.
- The fiber develops in bolls consisting of three to five locks.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

- The cotton fibers are borne on the seeds, each fiber being an outgrowth of a single epidermal cell.
- Cotton fibers are separated into two groups according to length.
- The outer and longer layer, called lint, contains long fibers separated from the seed in ginning.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

- An inner and shorter layer, called linters, or fuzz, contains short fibers that remain attached to the seed after ginning.
- The lint fibers are used in spinning cotton yam, and the linters or fuzz fibers are used in making rayon and cellulose products.
- The cotton fiber cell is a thin-walled tubular structure that elongates until it reaches its maximum length.

Poehlman and Sleper (1995)

Breeding Objectives

- The tubular fiber cell is thickened by the deposition of cellulose in successive layers on the inner wall, and the hollow core inside, or lumen, becomes smaller.
- Fiber maturity refers to the thickness of the fiber wail; mature fibers have thick inner cell walls.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

- The spinning performance of cotton fiber is associated with the length, strength, and fineness of the fibers.
- Cotton types vary in these characteristics.
- Special instruments are available that accurately measure each of these qualities in samples of cotton fiber.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

Fiber Lenght

- Fiber length is important because it contributes to the quality of the yarn.
- Variation in the length of the cotton fibers are found within a cultivar and even within a single boll.
- Uniformity in staple length improves spinning performance, increases the utility of the cotton, and reduces waste.
- Improvement in the quality of cotton fiber has been made by breeding cultivars with increased staple length and greater uniformity in fiber length.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

Fiber Strenght

- Fiber strength is important in determining yarn strength.
- Cotton from cultivars that produce weak fibers is difficult to handle in manufacturing processes.
- The structure of the inner layers of the cotton fibers affects its tensile strength.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

Fiber Strenght

- Cotton types and cultivars differ in fiber strength, and high fiber strength is difficult to obtain without sacrificing yield. Pima cotton has greater fiber strength than Upland cotton; among Upland types, the Acala cultivars have the strongest fibers.
- The storm-proof cultivars traditionally produce the weakest fibers, but fiber strength has been improved in recently released cultivars.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

Fiber Fineness

- Cotton fibers from some cultivars feel soft and silky; fibers from other cultivars feel coarse and harsh.
- The difference in the way they feel is determined by the fineness or coarseness of the fibers.
- Fiber fineness is associated with perimeter, or diameter, of the fiber and with the thickness of the fiber wall.

Poehlman and Sleper (1995)

Breeding Objectives

Fiber Quality

Fiber Fineness

- Extra-long-staple Pima cultivars produce fibers with small perimeters and fine texture.
- Storm-proof cultivars produce fibers with large perimeters and coarse texture.
- Eastern, Delta, and Acala types have fibers that are intermediate in fineness.
- Within a cultivar, fiber perimeter is relatively constant, variations in fineness being associated with fiber wall thickness.

Poehlman and Sleper (1995)

Breeding Objectives

Rapid Fruiting and Early Maturing

- Flowering of the cotton plant is indeterminate with bolls set over a period of time.
- Earliness is influenced by
- how early the cotton plant begins to set squares and to flower,
- how rapidly the new flowers develop,
- the length of time required for the bolls to mature.

Poehlman and Sleper (1995)

Breeding Objectives

Rapid Fruiting and Early Maturing

- Rapid fruiting and early maturity reduce losses to disease and insects, facilitates harvesting with a mechanical picker, and increases production efficiency by reducing inputs of fertilizer, protective chemicals, or irrigation water.
- Small compact plants and small bolls and seeds are generally associated with earliness in a cotton cultivar.

Poehlman and Sleper (1995)

Breeding Objectives

Adaptation to Mechanical Harvesting

- Boll size and opening are indexes of picking efficiency. Bolls need to open sufficiently to permit the cotton to fluff and be caught by the spindles.
- Yet they must have sufficient storm resistance for the fiber to remain in the burr and not be blown or rained out and lost before harvest.

Poehlman and Sleper (1995)

Breeding Objectives

Adaptation to Mechanical Harvesting

- A compact, rapid-fruiting plant that does not lodge on fertile soils, with bolls spaced along the main stems and set high enough off the ground that they are not lost in spindle harvesting, is desired.
- A natural tendency to shed leaves upon maturation of the bolls, or ease of defoliation; small or deciduous bracts; and smooth leaves free of hairs will reduce the amount of leaves and trash in the seed cotton.

Poehlman and Sleper (1995)

Adaptation to Mechanical Harvesting

The storm-proof cotton is harvested by stripping whole bolls from the plant.

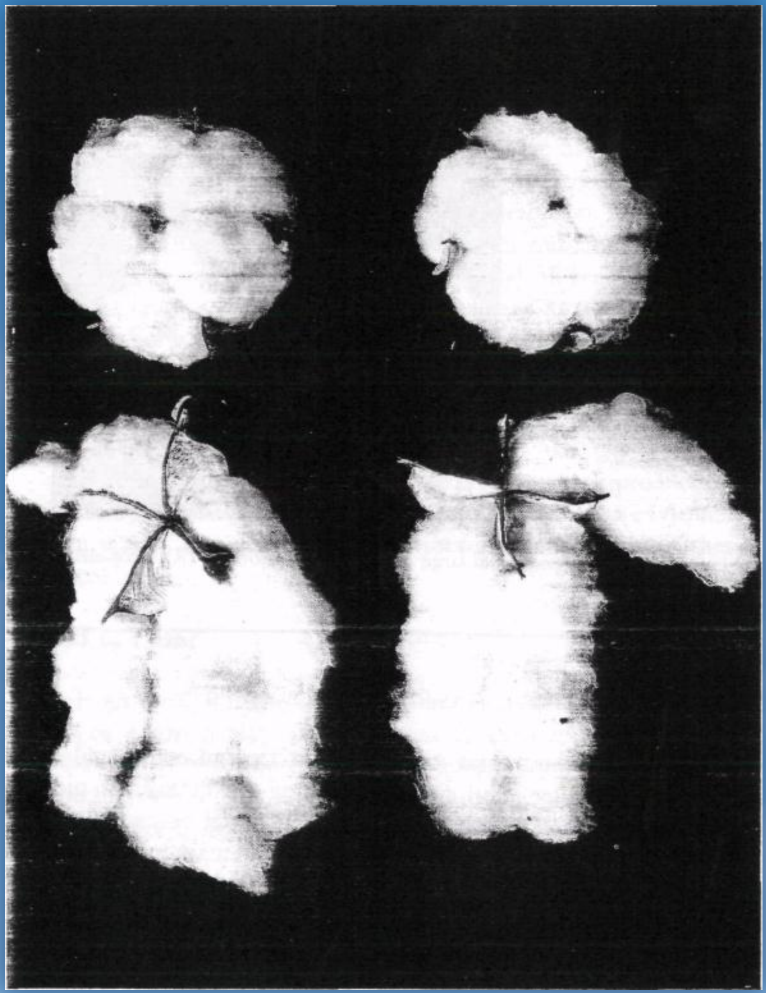
- Short plants with short fruiting branches,
- bolls borne singly,
- early fruiting and early maturity,
- seedcotton that adheres tightly in the boll at maturity

are characteristics desired in storm-proof cotton cultivars.

Poehlman and Sleper (1995)

Breeding Objectives

Stormproof Boll



Comparison of mature bolls of stormproof (upper) and open boll cottons (lower).

In the storm-proof type:

- the cotton remains in the boll and is harvested by stripping bolls from the plant.

In the open boll type:

- the cotton is harvested by mechanical pickers using spindles.
- When open boll cottons are subjected to high winds, the lint strings out and some of the lint being lost.

Poehlman and Sleper (1995)

Breeding Objectives

Resistance to Stress Environments

Drought and Heat Tolerance

- Water is often a limiting resource for cotton production in dry areas of the world.
- Limited sources of irrigation water and higher fuel costs for pumping is causing breeders to look for cotton strains with more efficient water use under drought conditions.
- Genetic variability for root growth and dry matter accumulation has been demonstrated among exotic strains and selections from breeding populations growing in drought environments.

Poehlman and Sleper (1995)

Breeding Objectives

Resistance to Stress Environments

Drought and Heat Tolerance

- Recurrent selection to improve drought tolerance would involve crossing among drought-tolerant strains to form a source population from which selections are made under drought stress conditions.
- The superior selections are crossed in all combinations to start the next selection cycle.
- Selection of *G. barbadense* strains in periods of high temperature at low elevations resulted in development of Pima strains with greater heat tolerance.

Poehlman and Sleper (1995)

Resistance to Stress Environments

Salt Tolerance

- Genetic differences to salt tolerance during late growth stages have been observed in cotton strains grown in saline soils.
- Salt tolerance during germination, early growth, and during late vegetative growth has been observed in a strain of Acala cotton.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

- Many disease problems are associated with the cotton plant.
- Breeding for host-plant resistance has been an effective method of control of the major disease pathogens.
- Development of multidisease resistance has received much attention in the breeding of resistant cultivars.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Seedling Disease Complex

- Several soil fungi, including Fusarium spp., Pythium spp., *Rhizoctonia solani* Kuehn., and *Thielaviopsis basicola* (Berk. & Br.), reduce the potential yield of cotton by causing seed rotting and damping-off of cotton seedlings.
- Cotton is particularly vulnerable to seedling disease when planted in cold, wet soil.
- Progress in breeding for resistance to seedling disease may be attained by selecting for rapid germination and seedling vigor in cold wet soils, combined with seedling disease resistance.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Fusarium Wilt & Root Knot Nematode Complex

- Fusarium wilt is caused by a soil-inhabiting fungus, *Fusarium oxysporum,* Schlect. f. sp. *vasinfectum* (Atk.) Snyd. and Hans.
- Fusarium wilt is most severe on light, sandy soils.
- The disease damages the water-conducting tissues of the plant, causing wilting and premature killing.
- The disease is associated with injury caused by the root knot nematode *Meloidogyne* incognita (Kofoid & White) Chitwood, which provides openings through which the wilt fungus enters the root.

Poehlman and Sleper (1995)

Fusarium Wilt & Root Knot Nematode Complex

- Both nematode and wilt resistance are required to give a cultivar maximum protection.
- The principles of survival and progeny testing were introduced to cotton breeding before 1900 by selection of surviving plants on wilt-infested soils, followed by progeny-row testing.
- Highly resistant cultivars did not become available until the 1950s.
- High resistance to root knot nematode is essential for high resistance to fusarium wilt.
- Resistance to the fusarium wilt-root knot nematode complex is quantitatively inherited.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Verticillium Wilt

- The fungus causing verticillium wilt, *Verticillium dahliae* Kleb., may persist in the soil for many years.
- The disease is widespread throughout in some cotton-growing areas around the world.
- The fungus attacks cotton plants at any stage of growth, but symptoms are most noticeable with the onset of fruiting.
- Affected plants ore stunted, shed leaves and young bolls, and have stems with vascular discoloration.
- Sources of tolerance were found in *G. barbadense.*
- Screening for resistance may be conducted on wilt-infested soils or by artificial inoculation techniques.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Bacterial Blight

- Bacterial blight (also called blackarm, angular leaf spot, and boll blight) is a bacterial disease caused by *Xanthomonas campestris pv. malvacearum* (Smith) Dye.
- The disease is found almost everywhere that cotton is grown.
- Symptoms are angular water-soaked leaf spots, elongated black lesions on the stems, blighted spots on the bolls, and failure of bolls to open.
- The bacterial blight pathogen is spread by hard, driving rains or sprinkler irrigation.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Bacterial Blight

- The organism is pathologically specialized, and numerous genes conferring race-specific resistance have been identified.
- Combinations of two or more major genes, combined with minor or modifier genes, are required for a high level of resistance.
- Genes for resistance have been identified from 11 diploid and two tetraploid species of *Gossypium*.

Poehlman and Sleper (1995)

- Boll rots may be caused by several primary pathogens and saprophytic pathogens which enter the boll through cracks, insect injury, or other access points.
- Boll rots reduce yield, weaken and stain the lint, and infect the seeds.
- One breeding approach has been to utilize a mutant narrow-leaf type, known as *okra-leaf*, to produce open canopies so that sunlight and wind will dry the bolls rapidly.

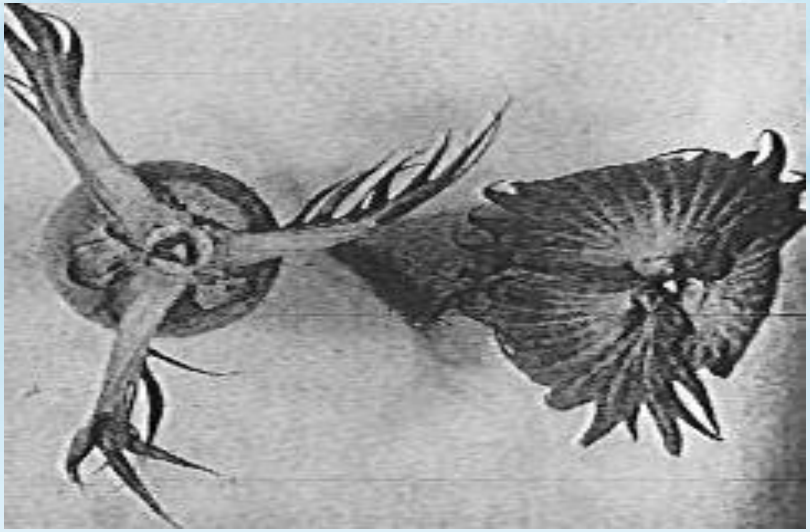
Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Boll Rots

- A mutant bract type, known as *frego bract,* in which the bracts curl outward leaving the flower buds and bolls well exposed, also facilitates rapid boll drying.
- A mutant strain known as *nectariless* removes extra floral nectaries, which may be points of pathogen invasion.



Barut (2004); Poehlman and Sleper (1995)

Multiple Disease Resistance

- Cotton seedlings may be simultaneously evaluated for resistance to several common disease pathogens.
- The procedure consists of sequential inoculation of cotton seedlings growing in controlled environments with different disease pathogens.
- A sequential inoculation and selection procedure for evaluating cotton seedlings for resistance to root knot nematodes, bacterial blight, fusarium wilt, and verticillium wilt consists of the following steps:

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Multiple Disease Resistance

- Germinate cotton seeds from a genetically mixed population in soil heavily infested with root knot nematodes *(Meloidogyne incognita).*
- Inoculate cotyledons of 10- to 12-day-old seedling plants with races of the bacterial wilt pathogen *(X. campestris pv. malvacearum)* by scratching the cotyledon with a bacterial-laden toothpick.
- Inoculate four-week-old nematode-tolerant and bacterial-wilt-resistant plants with a virulent culture of *F. oxysporium,* discarding susceptible plants after 12 to 14 days.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Multiple Disease Resistance

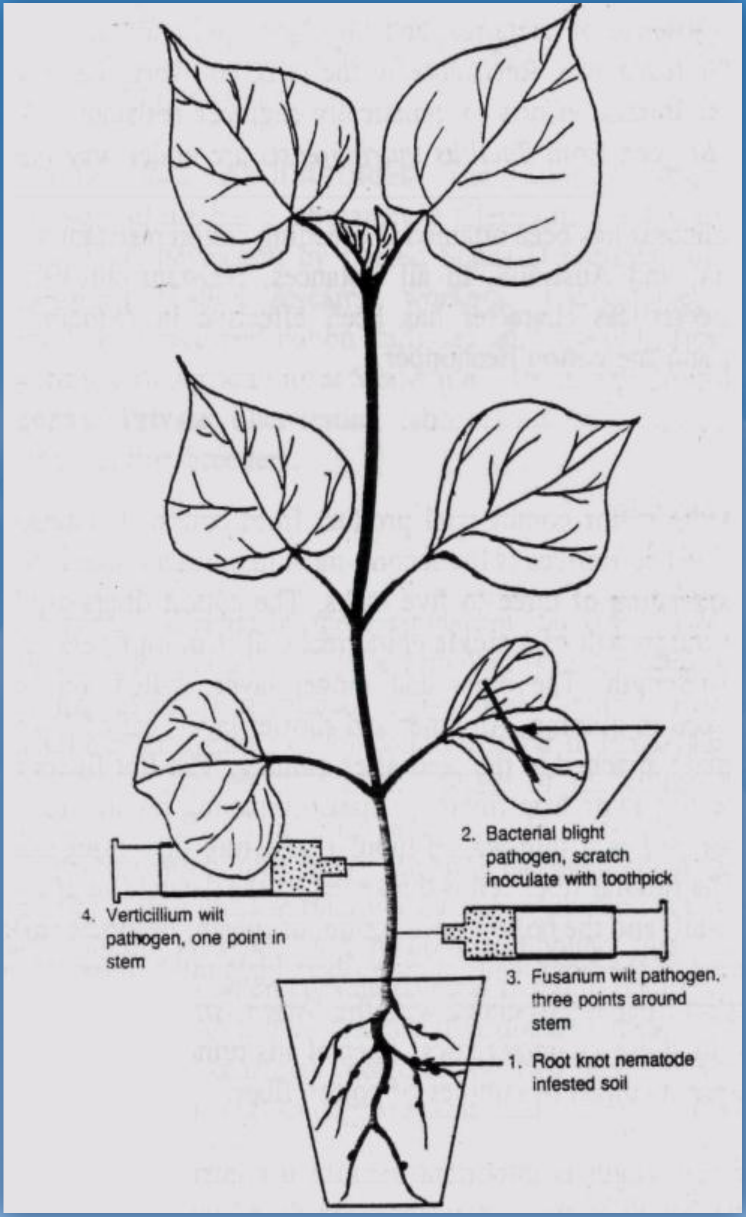
- Inoculate surviving plants from previous disease infections at age of 8 to 10 weeks with a culture of *Verticillium dahliae* and grow resistant plants to maturity.
- The breeding populations to be evaluated are generated by crossing among cultivars resistant to the various diseases.
- During the test periods, temperatures are adjusted to give optimum symptom expression for each disease.

Poehlman and Sleper (1995)

Breeding Objectives

Disease Resistance

Multiple Disease Resistance



Steps in sequential inoculation of cotton seedlings in breeding for multiple disease resistance.

- **Germinate seeds in root knot nematode-infested soil.**
- **Inoculate seedling with bacterial blight pathogen by scratching the cotyledon with a bacterial-laden toothpick.**
- **Inject fusarium wilt pathogen into stem.**
- **Inject verticillium wilt pathogen into stem. Discard susceptible plants after each step and inoculate only resistant plants in next step.**

Poehlman and Sleper (1995)

Breeding Objectives

Insect Resistance

- Insect pests cause serious losses in cotton each year.
- Development of tolerance by cotton insects to chemical insecticides, the high cost of insecticidal control, and environmental concerns and legal restrictions on use of chemicals suggest that a greater effort must be devoted to development of insect-resistant cotton cultivars.

Poehlman and Sleper (1995)

Breeding Objectives

Insect Resistance

Cotton Bollworms

- The cotton bollworm (Helicoverpa zeaj-tobacco budworm (Heliothis virescens) complex and pink bollworm (Pectinophora gossypiella) are serious cotton insect pests in many areas of the world.

Breeding Objectives

Insect Resistance

Cotton Bollworms

- Resistance to the pink bollworm has been reported in some diploid wild species.
- Intense efforts to genetically engineer resistance to Lepidoptera insects by insertion of the Bt gene from Bacillus thuringiensis are under way.
- Characters that suppress insect population development, such as glabrous leaves, absence of nectaries, and high gossypol content in the square, have been used in breeding for resistance.

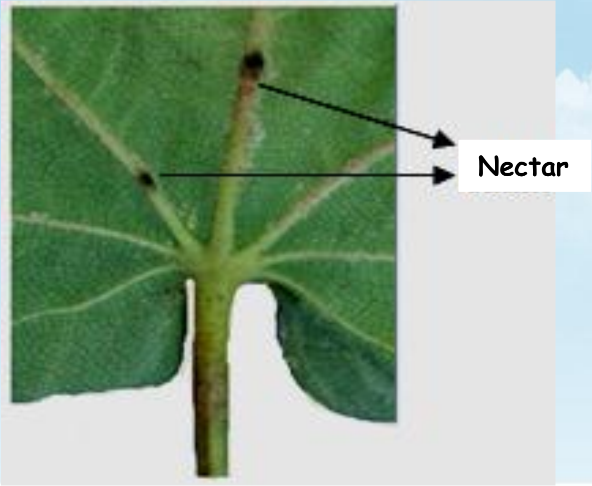
Poehlman and Sleper (1995)

Breeding Objectives

Insect Resistance

Other Insects

- Success has been attained in breeding cotton resistant to leafhoppers (jassids)
- In all instances, resistant cultivars possessed a heavy pubescence.
- The nectariless character has been effective in reducing populations of the tarnished plant bug and the cotton fleahopper.



Nectariless

Seed Quality

- Stand establishment is affected by the germination and vigor of the seed planted.
- To be mechanically planted, all fuzz and lint must be removed from the seed, either by flame or acid treatment.
- Genetic improvement in seedling vigor, cold tolerance, and resistance to seedling disease would permit earlier planting of the cotton cultivar in temperate climates.

Poehlman and Sleper (1995)

Seed Quality

- Processing quality is affected by the oil content of the cotton seed and presence of undesirable pigments in the oil.
- While much emphasis has been given to breeding cotton seed free of undesirable pigmentation, only minor attention has been given to selecting cultivars for higher oil content.

Poehlman and Sleper (1995)

Seed Quality

- The cotton plant normally produces pigmented glands in the leaves, stems, and seeds, which contain *gossypol*, a terpenoid compound that causes discoloration in cottonseed oil and in egg yolks when cottonseed meal is fed to poultry, reduces availability of lysine in cottonseed protein, and causes toxicity if cottonseed meal is fed in excess to young swine or poultry.
- A glandless character controlled by two recessive genes, gl_2 and gl_3, was introduced into commercial cultivars to improve seed quality, but insects have a preference for glandless cotton.

Poehlman and Sleper (1995)

Breeding Methods

- The breeding methods are:
  - Introduction,
  - Selection,
  - Hybridization,
  - Mutation

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

Introduction

- Introduction is the direct adoption of native/developed germplasm from elsewhere.
- *Acclimatization* played a much greater role in the development of introduced cotton germplasm
- The early-introduced cotton stocks were largely mixed populations with varying amounts of cross-pollination and heterozygosity that gave them plasticity and potential for genetic change.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

Selection

- Selection, as a breeding procedure, involves identification and propagation of individual genotypes or groups of genotypes from mixed populations, or from segregating populations following hybridization.
- Unless genetic variation can be identified and distinguished from environmentally caused variability within the mixed population, selection may not be effective in isolating the desired genotypes.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

Selection

- Selection is the process of planned improvement in the performance of specific cultivars for certain traits through conscious choice.
- The sources of variation may be natural mutation, segregation within a population and natural out-crossing.
- Commonly used selection methods in handling the segregating population developed through hybridization are pedigree, bulk and mass selections.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

Mutation Breeding

- *Mutation breeding* is the use of mutagens, both physical and chemical or in combination, for realizing new variability.
- Ionizing radiations (radiation capable of creating ions) such as gamma rays have been used in cotton for inducing sudden and often drastic changes in many instances.
- Most mutations are recessive and lethal in nature.
- Cotton being an allotetraploid has less chance of mutation expression.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

Mutation Breeding

- Mutation breeding is not commonly used in cotton now, but varieties have been developed using mutation and adopted on a commercial scale in some countries.
- Mutation breeding was mostly tried in cotton during the 1960s and 1970s with the objective of creating non-existing characters.
- Chemicals and ionizing radiations were used to create permanent changes in the existing genomes in many countries.
- The most significant challenge in mutation breeding lies in the detection of a desirable mutation that is not linked to any negative effect.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Breeding Methods

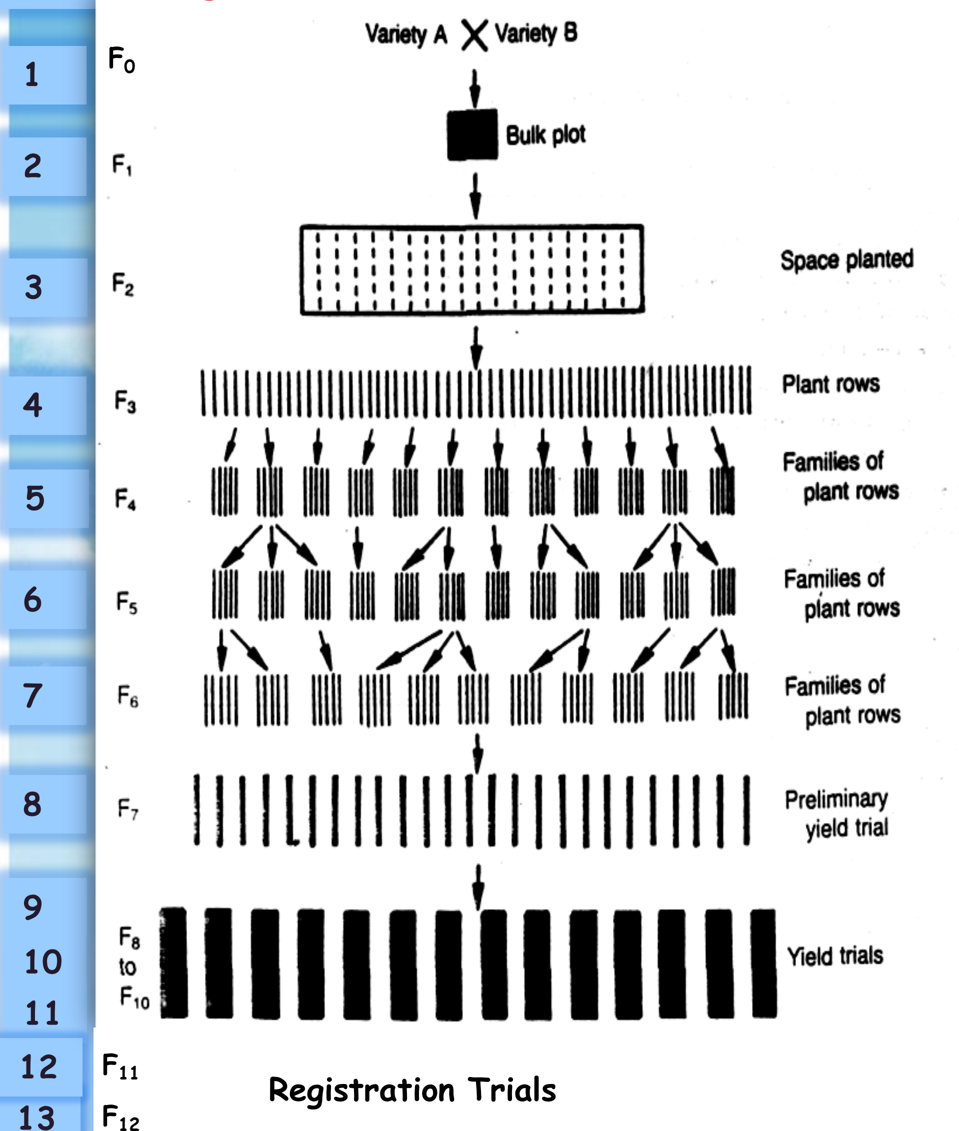
Hybridization

- Hybridization is the crossing of genetically different parents for the sake of creating variability, often with the purpose of obtaining genotypes with trans-gressive performance.
- Hybridization (crossing between two parents) results in new combinations, but drastic changes should not be expected.
- This is the most widely used method of developing new cotton varieties.
- Conventional Breeding/Traditional Breeding is the application of introduction, selection and hybridization methods for developing or improving genotypes/varieties.

Chaudry and Guitchounts (2003); Poehlman and Sleper (1995)

Pedigree Selection

Pedigree Selection Method



- F_0 Hybridization
- F_1 Bulk Plot
- F_2 Bulk Plot (2000-3000 plants), Selecting F_2 plants
- F_3 Plant Rows, from selected F_2 plants, progenies of 25 to 30 plants are grown in plant rows comparing the standart cultivars in F_3.
- F_4 Plant Rows, Superior plants from the best rows are selected and planted in families of plant rows comparing the standart cultivars in F_4 to F_6, with selection being made of best plants, in best rows.
- By F_7 genotypes should be relatively uniform.
- Preliminary yield trials are planted in F_7 and yield trials are continued through F_{10}.
- *After* plants are selected in F_3 and F_4, remaining plants in row should be bulked and preliminary yield tests started.

Pedigree Selection

- Pedigree breeding starts with the crossing of two genotypes, each of which have one or more desirable characters lacked by the other.
- If the two original parents do not provide all of the desired characters, a third parent can be included by crossing it to one of the hybrid progeny of the first generation (F1).
- In the pedigree method superior types are selected in successive generations, and a record is maintained of parent–progeny relationships.

Pedigree Selection

- The F2 generation (progeny of the crossing of two F1 individuals) affords the first opportunity for selection in pedigree programs.
- In this generation the emphasis is on the elimination of individuals carrying undesirable major genes.
- In the succeeding generations the hybrid condition gives way to pure breeding as a result of natural self-pollination, and families derived from different F2 plants begin to display their unique character.
- Usually one or two superior plants are selected within each superior family in these generations.

Pedigree Selection

- By the F5 generation the pure-breeding condition (homozygosity) is extensive, and emphasis shifts almost entirely to selection between families.
- The pedigree record is useful in making these eliminations.
- At this stage each selected family is usually harvested in mass to obtain the larger amounts of seed needed to evaluate families for quantitative characters.
- This evaluation is usually carried out in plots grown under conditions that simulate commercial planting practice as closely as possible.

Pedigree Selection

- When the number of families has been reduced to manageable proportions by visual selection, usually by the F7 or F8 generation, precise evaluation for performance and quality begins.
- The final evaluation of promising strains involves
- (1) observation, usually in a number of years and locations, to detect weaknesses that may not have appeared previously;
- (2) precise yield testing; and
- (3) quality testing.
- Many plant breeders test for five years at five representative locations before releasing a new variety for commercial production

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