The cultivated peanut, *Arachis hypogaea* L., is one of the most important crops in the world. India, China, and West Africa produce the largest quantities of peanuts, although extensive production occurs in the warmer regions of all continents. With the exception of North America, where peanuts are grown for consumption as a snack food, the crop is primarily used as a source of high quality vegetable oil and as livestock feed.

The cultivated peanut is presently divided into two subspecies and four varieties (Fig. 10-1). The subspecies *hypogaea* has no floral axes on the mainstem, and has alternate pairs of vegetative and floral axes along lateral branches. The variety *hypogaea*, also called Virginia, has less hairy and shorter branches than the variety *hirsuta*. The subspecies *fasciata* has floral axes on the main axis, and has continuous runs of one to many floral axes along lateral branches. The variety *fasciata*, also called Valencia, has fewer branches and more seeds per pod than the variety *vulgaris*, also called Spanish.

The three botanical varieties grown commercially in the United States—Spanish, Valencia and Virginia—have origins that trace back to South America. The Spanish (var. *vulgaris*) type originated from the Guarani area of northeastern Argentina, Paraguay, and southern Brazil. Records exist indicating that the Portuguese took the Spanish type from the Guarani region into Portugal and Rome, and that the Spanish took this type to Spain and France. The introduction of this small-podded, short-season peanut to the United States occurred in 1871 when a farmer from the state of Virginia procured some of the seed from Malaga, Spain.
**Arachis hypogaea L.**

<table>
<thead>
<tr>
<th>Sub-species</th>
<th>hypogaea</th>
<th>fastigiata</th>
</tr>
</thead>
<tbody>
<tr>
<td>VARIETY</td>
<td>hypogaea</td>
<td>fastigiata</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U.S. MKT. TYPE</th>
<th>hypogaea</th>
<th>fastigiata</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNNER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIRGINIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VALENCIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPANISH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Not grown commercially in the United States*

**Figure 10-1** Botanical classifications for the four market types of peanuts in the United States.

The Valencia type (var. *fastigiata*) originated in Paraguay and central Brazil. The name referred to an introduction from Valencia, Spain which came into the United States near the turn of the twentieth century.

The Virginia type (var. *hypogaea*) is divided in the United States into two categories based on pod size. The first peanuts grown in the southeastern United States had small pods and a spreading (runner) growth habit. In the early days, they were called 'Southeastern,' 'African,' 'Wilmington,' 'North Carolina,' 'Georgia,' or 'Florida' runners. These were the types that probably came to the United States on slave ships. The large-seeded form of the Virginia botanical type has an unclear beginning. Its origin could trace to any one of a number of locations within a large geographic area in the center of origin.

The botanical varieties form a rough basis for classification of peanuts into the four different market types grown in the United States. This classification primarily refers to pod and seed size characteristics (Fig. 10-1). Spanish and Valencia are terms used for two market classes, as well as designating botanical classifications of these varieties of the subspecies *fastigiata*. Within the variety *hypogaea* there are two market classifications, Virginia and runner. Virginia market-type peanuts are those with
large pods (≥40% of pods passing over rollers 13.5 mm apart), while runner market types are those with smaller pods (<40% large pods).

Although peanuts from any of the four market classes may be used for the various consumer products made from peanuts, there are relatively distinct uses for each market class. Virginia peanuts are used for salted peanuts and cocktail peanuts when shelled, or they are roasted and sold as in-shell peanuts. Runner and Spanish usually are used to make peanut butter, candy, and oil. Valencia peanuts are sold either roasted in the shell or boiled.

TYPES OF CULTIVARS

Mode of Propagation

The peanut plant of commerce is propagated by seed. The seeds are borne on the plant in a unique manner. The ovules are located at the base of a floral extension called the hypanthium, which can be as long as 10 cm (Fig. 10-2). Pollen tubes carrying the male gametes travel the length of the hypanthium to fertilize the female gamete. Peanuts are self-pollinated, with rates of outcrossing varying from 0 to a maximum of 10%, depending on the genotype of the plant and environmental conditions. After fertilization, the flower withers and the plant produces an ovarian structure called the gynophore, or peg, which is positively geotropic. The gynophore grows toward the soil and carries the embryo with it in a section behind the tip. The tip of the gynophore penetrates the soil where the embryo expands horizontally to produce the peanut fruit. The mature peanut seeds are found inside a lignified pod, which is maternal tissue. The pods, attached to the branches of the plant by the gynophore, develop and mature in the soil. Harvesting is accomplished by cutting the taproot and lifting the entire plant from the soil.

Several species of Arachis are grown as forage legumes. These species produce few seed and are propagated vegetatively, usually by rhizomes.

Past and Current Cultivar Types

Archaeological evidence has shown that the peanut had been used in Peru as early as 2500 B.C. Researchers feel the domestication of the peanut must have occurred before that time, probably by the predecessors of the modern Arawak-speaking peoples of the region.

Cultivation of the peanut was limited to the Western Hemisphere until its dispersal by European explorers. The Portuguese probably took peanuts to Africa and from there to India. Explorers also took peanuts from the western regions of South America to the western Pacific, China, and
Indonesia. It is believed that peanut seed came to North America with the transport of slaves from Africa because peanuts were used as food on slave ships (Hammons, 1982).

The types of peanut cultivars used in the early periods of commercial U. S. production were broadly defined on the basis of gross morphology. Plants with large pods were designated Virginians, which probably corresponds to the current Virginia market classification. Those with small pods were similar to the current runner market classification. By the
1890s, the Virginia types were classified into Virginia Bunch and Virginia Runner on the basis of plant growth habit. However, names given to peanut seed often embraced a range of types.

The Tennessee peanut was known to have a red seed, in contrast to the brown or tan of other common types. The Tennessee peanut was variously described as having large seed the size of the current Virginia market types or having seed smaller than runner types. Spanish and Valencia types were known with the same botanical characteristics as the current Spanish and Valencia types. Unlike the Virginia botanical type, the Spanish and Valencia types were not further subdivided on the basis of plant or pod characteristics (Beattie, 1911).

Before 1900, most cultivars in the United States were large seeded. Because peanut pods were picked from the vines and shelled by hand, much less work was required to pick and shell a bushel of large-seeded peanuts than was required for the smaller-seeded types. After equipment was invented that would both pick the peanuts from the plant and shell them, the smaller-seeded cultivars increased in popularity.

The earliest cultivar development process consisted of making selections out of the original plant material introduced from different parts of the world. After the rediscovery of Mendel’s work in 1900, it was realized that the variation in peanuts could be improved dramatically by artificial hybridization. The earliest known reports on peanut breeding are those of Van der Stok in the Netherlands East Indies in 1910. His work included attempts to develop new genotypes of peanuts for commercial use and the hybridization of peanuts for genetic studies.

The first peanut breeding program in the United States was reported at the Florida Agricultural Experiment Station in 1928. Programs began in North Carolina in 1929 and in Georgia in 1931. Sporadic and undocumented reports of breeding efforts before this time have been suggested in the literature, but the major thrust of these earlier efforts seemed to be the selection of individual plants from peanut collections or from farmer stocks. The programs in Florida and Georgia were aimed at the development of new gene combinations through hybridization and the subsequent selection of these combinations in segregating generations. In Florida, pedigree selection of individual plants from segregating populations was practiced in the early days of the breeding program and is still the major breeding procedure used today (Norden et al., 1982).

The different types of peanut types of peanut cultivars currently grown in the United States are divided on the basis of both botanical and market-type characteristics. The Valencia type is a favorite for the production of peanuts that are sold in roadside stands in the southern United States as boiled peanuts. Because peanuts marketed in this fashion do not receive the government price support that is paid for peanuts marketed for most other purposes, information on the extent of their
production is difficult to obtain. The Valencia type also is grown and marketed as a dry, in-shell peanut which does receive the price support. Most of this production is in New Mexico and is a small fraction of the commercial peanuts grown in this country.

Growers in Texas and Oklahoma produce about 18% of the peanuts in the United States, and their production is currently split between Spanish and runner market types. Farmers often will grow the Spanish type if irrigation is not available, because the cultivars generally mature from 15 to 30 days earlier than runner and Virginia types. Because the Spanish type frequently produces less than the runner and Virginia types, the latter are more likely to be produced if a grower has irrigation. In the northern region of peanut production (Virginia and North Carolina), the large-seeded Virginia type predominates and provides 20% of the total peanut production in the United States. The remaining 62% are produced in the southeast, primarily Georgia, Alabama, and Florida, where the runner market type is most frequently grown. The runner type is used extensively in the manufacturing of peanut butter, which is the most important use of peanuts in the United States.

EXTENT AND NATURE OF BREEDING PROGRAMS IN NORTH AMERICA

The majority of the breeding efforts in North America are in agricultural experiment stations at land-grant institutions in the peanut-growing regions of the United States. There are several reasons for the small amount of peanut breeding being carried out by private companies. Most of the peanut production in the United States is concentrated in three environmentally diverse regions: Virginia-North Carolina, Georgia-Florida-Alabama, and Texas-Oklahoma. Total hectarage in each of these regions may not be large enough for a private company to consider cultivar development as an economically feasible venture. In addition, the hectarage in the United States is held static by the government, which prevents market expansion for a U.S. breeding company.

There are historic reasons for both the location of peanut production and the constant hectarage. In the years during and immediately after World War I, peanut production increased dramatically. In an attempt to help maintain a reasonable return to the farmers who grew peanuts, the U.S. government began to control prices and hectarage in 1938. With the exception of the years during World War II, when these restrictions were lifted to allow U.S. farmers to meet the demand for vegetable oil, the prices and production of peanuts were controlled by the government through 1981 (Table 10-I). Beginning in 1981, the government removed
hectarage controls and instituted a two-price system that would support only a limited production of peanuts. Peanuts that received government support were designated as quota peanuts, while all other peanuts were classified as nonquota or additional peanuts. The amount of quota peanuts a farmer can produce is a proportion of the peanuts grown on the hectare the farmer was allotted in 1978 (Sands, 1982).

Quota peanuts can be bought by the Commodity Credit Corporation of the U. S. Department of Agriculture (USDA) at a price set for the current growing season. This price is determined in such a way that a farmer with an average or better yield per hectare should make a reasonable profit on the quota peanuts. Additional peanuts can be sold to the Commodity Credit Corporation, but at the nonquota price which is set lower than normal production costs. The additionals also can be sold by the farmer on the open market. These policies have effectively kept the peanut hectare in the United States relatively constant for the last half century, with the exception of the World War II years (Table 10-1).

Table 10-1 Peanut Production Trends in the United States

<table>
<thead>
<tr>
<th>Year</th>
<th>Hectarage units of 1000 ha</th>
<th>Yield</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1889</td>
<td>82.6</td>
<td>474 kg/ha</td>
<td>N.A. *</td>
</tr>
<tr>
<td>1899</td>
<td>209.4</td>
<td>623</td>
<td>N.A.</td>
</tr>
<tr>
<td>1909</td>
<td>217.5</td>
<td>739</td>
<td>N.A.</td>
</tr>
<tr>
<td>1919</td>
<td>372.2</td>
<td>840</td>
<td>20.5 cents/kg</td>
</tr>
<tr>
<td>1929</td>
<td>511.1</td>
<td>798</td>
<td>8.1</td>
</tr>
<tr>
<td>1939</td>
<td>485.2</td>
<td>713</td>
<td>7.5</td>
</tr>
<tr>
<td>1943</td>
<td>1933.9</td>
<td>692</td>
<td>15.6</td>
</tr>
<tr>
<td>1949</td>
<td>1118.6</td>
<td>906</td>
<td>22.9</td>
</tr>
<tr>
<td>1959</td>
<td>581.2</td>
<td>1189</td>
<td>21.1</td>
</tr>
<tr>
<td>1969</td>
<td>587.7</td>
<td>1954</td>
<td>27.1</td>
</tr>
<tr>
<td>1979</td>
<td>615.2</td>
<td>2927</td>
<td>45.4</td>
</tr>
<tr>
<td>1984</td>
<td>618.0</td>
<td>3227</td>
<td>54.8</td>
</tr>
</tbody>
</table>

tions for yield until the end of the growing season. All selection work for yield or any characteristic associated with the pods must be done after harvest. These factors add cost to the development of new peanut cultivars.

In the United States, most peanut breeding and genetics programs are carried out at the state agricultural experiment stations in Florida, Georgia, New Mexico, North Carolina, Oklahoma, Texas, and Virginia. Three of these programs (Georgia, Oklahoma, and Virginia) are cooperative with the USDA Agricultural Research Service (USDA-ARS). All of the programs in these states include both basic and applied genetic research, as well as studies on breeding methodology. Therefore, the effort directed to the development of new peanut cultivars is only a portion of the actual research work done by these programs.

Research recently has been initiated in Ontario, Canada, for the development of a short-season peanut that may be adapted to the climatic conditions of southern Canada. Research efforts in peanut breeding in Latin America seem to be limited. United Fruit Company operated a breeding program for peanuts in Nicaragua and Honduras. However, the current status of this program is not known.

**BREEDING OBJECTIVES FOR CULTIVAR DEVELOPMENT**

**Yield**

The primary objective of most breeding programs is to improve peanut yields per unit land area. While this is being done, quality characteristics of the peanut that are desirable to the processors and the consumers must be maintained or improved. Because the process of cultivar development can take 15 to 20 years, it is important for the breeder to determine as accurately as possible the current and future needs of the grower, processor, and consumer. The price support currently received by growers of quota peanuts in the United States allows them to utilize intensive management during crop growth. If the quota price support is dropped, the price growers receive for peanuts may fall. This will increase the demand for peanut cultivars that are able to produce under a less intensive management system. This may include increased biological pressures of insects, diseases, and nematodes, as well as stress from drought and extremes of temperature. This situation is already encountered by farmers who grow additional peanuts.

Over the last 40 years, cultivar development has contributed to a doubling of the yield potential of peanuts. However, yield increases in recent cultivars have not been as pronounced as the increases noted earlier in this period. It may be that the less dramatic yield increases are the
result of greater emphasis on disease and insect resistance and ability to produce under drought conditions.

Studies on the inheritance of yield have produced a range of results, indicating that the genetic basis of pod yield is complex (Wynne and Gregory, 1981). Heritabilities ranging from near zero to over 0.75 have been reported, depending on the method of estimating heritability and the populations used. Direct studies on the type of gene action responsible for yield have been limited. Work on the proportion of the genetic variability due to general and specific combining ability has shown that general combining ability was highly significant and usually much greater than specific combining ability (Wynne and Coffelt, 1982). This would indicate that additive gene effects are important in the expression of pod yield in peanuts.

Breeding efforts usually are carried out at one location in a state, province, or region, but peanut production frequently occurs in environments that differ from the research station in soil type, fertility, water management, and pest control. In some cases, genotypes selected for good agronomic performance at a given research station will not perform as well at other locations. The industry needs cultivars that have the ability to yield well in a broad range of environments. The ability of peanut cultivars to maintain high production levels in different environments, called yield stability, is an important objective of any peanut breeding program.

At the Florida Agricultural Experiment Station, the objective of yield stability has been addressed by maintaining as much genetic diversity in released cultivars as possible. To accomplish this goal, cultivars are released that are composites of 3 to 10 related lines, rather than a single genotype (Norden et al. 1982). By including different genotypes in one cultivar, it should be adapted to a wider geographic area, with more yield stability over seasons and broader protection against biological and environmental stresses than cultivars that are a single genotype (Norden et al., 1986). These advantages are balanced by the increased difficulty of maintaining seed stocks, by the possible lowered uniformity compared with single-line cultivars, and by the generally lower yield of the composite in a given year and location compared with the best component line.

Pest Resistance

Growers throughout the United States currently spend a great deal of time, money, and energy on the control of various types of diseases, nematodes, and insects in peanuts. A reduction in the use of these pesticides would be economically and environmentally advantageous. Breeding programs around the world concentrate their efforts on the development of resistance to different biological pests because severity of infec-
tions or infestations differ among regions. There is currently more emphasis on disease resistance than any other class of pest resistance.

A number of breeding programs throughout the United States have worked to develop peanut genotypes with multiple pest resistance. Some lines, such as NC 3033, carry resistance to cylindrocladium black rot, pod breakdown, and leaf spot diseases. Tifton 8, a selection of PI 261976 made at the University of Georgia, has resistance to cylindrocladium black rot, leaf spots, southern corn rootworm, thrips, and velvetbean caterpillar, and is less susceptible to diplodia collar rot, corn earworm, and aflatoxin development than standard cultivars. However, these lines have unacceptable agronomic and/or processing characteristics.

Disease Resistance. Many programs concentrate on specific pest problems. Early and late leaf spots [Cercospora arachidicola Hori and Cercosporidium personatum (Berk. & Curt.) Deighton] cause serious yield losses throughout the world. Research at a number of locations has concentrated on the screening of germplasm for resistance, and a wide range of genetic material with resistance has been identified.

Many breeding programs throughout the world are focusing their efforts on the development of leaf spot resistant cultivars. In general, lines that show appreciable resistance to the leaf spots are agronomically unacceptable, either because of low yields when compared with standard cultivars under disease controlled conditions, or because of poor quality factors, such as shelling percentage, Blanchability, or flavor. However, researchers at the University of Florida have recently released a new cultivar, 'Southern Runner,' which has moderate resistance to leaf spots (especially late leaf spot), acceptable yields, and good chemical quality and flavor. Although the genetic basis of the leaf spot resistance is unclear, separate studies with different sources of resistance have shown that the trait, although quantitative, is controlled by relatively few genes. Recent research in Virginia has indicated that cytoplasmic factors also may be involved.

One disease of peanuts that has direct implications for the quality of the end-product and the health of the consumer throughout the world is Aspergillus flavus Link ex Fr. This fungus will grow on the peanut fruit, especially under moist conditions just before and during harvest, as well as in storage. The fungus produces aflatoxins that are highly toxic and can be carcinogenic. Peanut seed in the United States with at least 15 parts per billion (ppb) of aflatoxin cannot be used for direct edible purposes. Some of the aflatoxin can be removed in oil refining by treating the oil with an alkali. This causes the aflatoxin to sediment out with the alkali. When a grower sells peanuts for oil, however, the grower will receive the price for additional, rather than quota peanuts. The presence of aflatoxins
is of concern to everyone involved in the growing, processing, and marketing of peanuts in the United States and abroad.

A number of breeding programs have invested considerable effort in the development of *A. flavus* resistant peanut cultivars. Several peanut genotypes have been identified that have resistance to colonization by the *A. flavus* fungi on whole seed (Diener et al., 1982). Development of *A. flavus* resistant peanut cultivars will be difficult. The characteristic has a low heritability, and the amount of resistance a genotype shows will vary from season to season and location to location. In addition, screening efforts to find resistance in peanut germplasm have identified sources of resistance that are less colonized than commercial cultivars, but the screening methods are not yet sufficiently refined to make the incorporation of the resistance a feasible objective of breeding programs. Also, mechanical damage during harvesting and processing can contribute to loss of resistance.

Sclerotinia blight, caused by *Sclerotinia minor* Jagger, is present in most peanut-producing areas of the world. It is the most important disease problem in Virginia, and is becoming increasingly important in North Carolina, Texas and Oklahoma. There are sources of resistance to *Sclerotinia* blight, and the cultivar ‘Virginia 81B’ possesses some resistance. Reports of reciprocal cross differences suggests cytoplasmic factors may be important in determining resistance.

*Cylindrocladium* black rot (CBR), caused by *Cylindrocladium crotalariae* [(Loss) Bell and Sobers], is a soil-borne fungus-causing root and pod rot, especially in the Virginia-North Carolina production area. Screening for CBR resistance is difficult because of the lack of consistent field disease pressure. Screening is currently taking place in several breeding programs and resistance has been reported in Spanish and Virginia types. Inheritance studies with four parents having varying levels of resistance and susceptibility showed that the resistance had a heritability ranging from 0.48 to 0.65, depending on the method of calculation (Hadley et al., 1979). This information suggests that early-generation selection for resistance to CBR should be effective. North Carolina State University recently has released a Virginia-type cultivar named ‘NC8C’ with a moderate level of resistance to CBR.

*Rust* (*Puccinia arachidis* Speg.) is a fungal disease with airborne spores that occurs sporadically in the United States, but is one of the limiting factors in peanut production on a worldwide basis. Because of its sporadic severity in the United States and continual severity in areas of the Caribbean near the peanut-producing sections of the United States, researchers are interested in the development of rust-resistant, agronomically acceptable genotypes.

A group of 14 different rust-resistant germplasm lines, designated
Tifrust 1 through 14, were cooperatively released by the USDA-ARS, Georgia Experiment Station, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India. These lines are selections from plant introductions and are unacceptable for cultivar release because of low yield and poor quality.

Several reports have indicated that rust resistance is controlled by two recessive genes, both of which must be present for resistance. Other researchers, using different genetic backgrounds, have indicated that resistance is somewhat more complexly inherited. In most cases, selection of resistant phenotypes in early generations has been successful. Although some resistant genotypes have been selected and are being tested, no rust-resistant cultivars have yet been released.

Pythium pod rot (*Pythium myriotylum* Drechsler) can occasionally cause economic peanut losses due to fungal destruction of peanut pods. A high level of resistance has been reported in ‘Schwarz 21,’ a Spanish cultivar, but the use of this parent to confer resistance to other peanut genotypes is hampered by the lack of a reliable screening method. Until now, only field screening has been used to identify resistance, and this technique has limited usefulness because lack of uniform infestation causes frequent misclassification of susceptible plants into resistant categories. The trait seems to be controlled in a rather complex manner because early-generation selection has been reported to be ineffective (Boswell et al., 1979).

Disease caused by *Sclerotium rolfsii* Sacc., variously called white mold, southern blight, or stem rot, is one of the more important problems facing breeders in the United States. Although the disease is not as widespread as the leafspots, current pesticides do not control white mold as effectively as they control leafspots. Relatively few sources of genetic resistance have been reported in the cultivated peanut.

*Nematodes.* Root-knot nematode (*Meloidogyne arenaria* Chitwood) is a destructive pest of peanuts in all peanut-production areas in the United States. Although screening techniques have been developed and selection for this pest has taken place in a number of different locations in the United States, no usable levels of resistance have been found (Holbrook et al., 1983).

Lesion nematode (*Pratylenchus brachyurus* Goodfrey) has been reported to cause erratic but significant yield losses in some western areas of peanut production. Resistance has been identified in ‘Florunner,’ ‘Starr,’ PI 295233 and PI 290606. The inheritance of resistance has not been reported. Screening of segregating generations is ineffective because erratic nematode distributions and populations cause large experimental error.
Insects. A number of insect pests cause economic damage to peanuts, although the amount of damage varies from season to season and from location to location. One of the most economically destructive insect pests is the lesser cornstalk borer (*Elasmopalpus lignosellus* Zeller). Smith et al. (1980) developed a rapid screening technique that was used to identify genetic differences for resistance to this insect.

Researchers at the North Carolina Agricultural Experiment Station have released ‘NC 6,’ a peanut cultivar that has sufficient resistance to southern corn rootworm (*Diabrotica undecimpunctata howardi* Barber) to eliminate the need for insecticide application for this insect pest in many peanut soils.

Four peanut lines with resistance to the potato leafhopper, *Empoasca fabae*, have been released by the North Carolina Agricultural Experiment Station. Resistance seems to be controlled by a few major genes.

Genetic differences among peanut genotypes for resistance to thrips, *Frankliniella fusca*, and to aphids, *Aphis craccivora*, have been demonstrated. Little research has been done to elucidate the genetic mechanisms that control these differences.

Drought Resistance

Drought conditions can occur throughout most of the peanut growing regions of the world. Research to identify drought resistant genotypes and drought resistance mechanisms is still in the preliminary stage.

Earliness

The development of early-maturing peanut cultivars is an important objective for many breeding programs. Earlier cultivars could be less vulnerable to inclement weather, such as hurricanes or drought, require fewer fungicidal sprays, and may command premium prices for being early on the market. Early cultivars also have more potential to fit into multiple-cropping systems.

Breeding programs in Virginia, North Carolina, and Florida have released the early-maturing cultivars ‘VA 81B,’ ‘NC7,’ and ‘Early Bunch,’ respectively. Texas recently has released two germplasm lines for early maturity. The breeding program at Oklahoma State University has released an early-maturing Spanish peanut cultivar, ‘Pronto.’ Selection at Oklahoma for early maturity involved choosing parents that combined well, limiting the growing season to give stringent selection for the earliness trait, selection in early generations, rapid generation advance, and extensive field testing. Their success in selection of early-generation
material indicates that the trait may have a relatively large additive genetic component.

Quality

New peanut cultivars should possess a certain chemical composition and maintain certain processing and end-use characteristics to be acceptable to both manufacturers and consumers. The sum of these characteristics is called quality and is composed of a number of different traits. These include grade factors, protein, oil, and carbohydrate content and composition, flavor, and milling quality. All these characteristics must be considered by a breeder before a peanut line is released as a new cultivar.

*Market-grade Factors.* After peanuts have been harvested and dried by the grower, the unshelled pods are taken to market. At the market, the bulk lot of peanuts is sampled with a pneumatic sampler that takes cores at random locations. These samples are blended and subdivided so that approximately 2 kg are available for grade analysis. The sample peanuts are divided into several categories that are used for establishing the price for a lot of peanuts. Some of the categories, such as percentage foreign material and percentage loose shelled kernels, are a result of the harvesting process. Other categories are based on heritable characteristics that can be changed genetically, and are of interest to the breeder.

After the percentages of foreign material and loose shelled kernels are determined, a 500-g sample of in-shell peanuts is taken. The sample is evaluated for pod size, then shelled and analyzed for shell proportion and seed moisture content, screened for seed size, and examined visually for external seed damage. The seeds are split and examined visually for concealed damage.

For the first pod sizing, pods are placed over rollers that are 13.5 mm apart. Any pods remaining on the rollers are graded as fancy pods. If a lot has 40% or more fancy pods, it is considered a Virginia market-type peanut. The breeder will have difficulty with lines that have the genetic capacity to produce about 40% fancy pods. In some environments the line will be graded Virginia, and in other environments, if the percentage of fancy pods falls below 40%, it will be graded as a runner market-type. Such market inconsistencies for a cultivar are not acceptable.

After the initial pod sizing, the entire lot of pods are passed over counter-rotating rollers which separate the pods into three size categories. The separate categories are shelled in different compartments of a three-compartment sheller. The seeds are sized with screens that vary depending on the market type of peanut. Runner types are sized with screens having openings of 6.4 by 19.1 mm; screens for Spanish and Valencia
types have openings of 6.0 by 19.1 mm; Virginia type screens have 6.0 by 25.4-mm openings, and screens for Virginia extra large seed have 8.5- by 24.4-mm openings. Whole or broken seeds that fall through these openings (except the 8.5- by 24.4-mm opening) are called "other kernels." Any whole or split seed that remain on the screens are examined for damage. Whole seed are passed through a seed splitter that allows examination of the interior of the seed. Any seed with discoloration, sprouts, insect damage or mold are counted as damaged kernels. All seed without damage are designated as sound mature kernels (SMK) if they have passed through the shelling process without splitting. Those seed that are without damage, but split, are designated as sound splits (SS) (Davidson, et al., 1982).

The price received by the farmer for a lot of peanuts depends not only on the total yield of peanuts, but also on the percentage of sound mature kernels, sound splits, and other kernels. Extra large seed in Virginia market type lots also receive a premium. The price paid for a lot of seed will be reduced based on excessive percentages of damaged or split kernels or excessive moisture.

The peanut breeder uses the same equipment and procedures used by the industry to determine the grade factors for lines under consideration for release as cultivars (Fig. 10-3). Because these characteristics are genetically controlled, albeit in a complex manner, the lines to be released must satisfy the acceptable standards set by current cultivars to receive a place in the market. If a line under consideration deviates considerably from any one of these standards, that deviation may warrant the discarding of the line.

Oil Quality. Oil quality refers to oil content, fatty acid composition, iodine value, ratio of oleic to linoleic acid (o/l ratio) and stability or shelf life. The oil content of peanut seed in a diverse collection of germ plasm ranged from 46.5 to 63.1% in wild species and from 43.6 to 55.5% in cultivars (Norden et al., 1982). Research on peanut oil content and composition in the United States has been minimal.

Genetic manipulation of the proportion of different fatty acids in peanut oil has been reported by several workers and a great deal of variability is present in peanut germplasm (Table 10-2). The Virginia botanical types generally have a higher oleic acid content and lower linoleic acid content than Spanish or Valencia types. This results in a lower iodine value for peanut oil from the Virginia types and indicates that these types will become rancid through autooxidation more slowly than the Spanish or Valencia types. Crosses with all four of the market types of peanuts have shown that a wide range of iodine values can be obtained from recombination of genes from the different parents, and that the iodine
Figure 10-3 Equipment used in the grading of peanuts. (a) The sizer has counter rotating cylinders spaced on a taper to separate different size peanut pods. (b) The peanut sheller has three compartments (A) that receive three different size categories from the sizer. The sheller has spring-loaded bars (B) that move back and forth over the pods and crack the shell. The seeds fall through a screen and out the chute (C) while the shell material rides the screen or is aspirated out (D). (c) The seed splitter (A) splits seed as they fall from the hopper chute (B) and permits examination on a belt (C) of both sides of half kernels to detect visible and concealed damage.

value in peanuts is highly heritable. In spite of general trends, it is possible to have Spanish and Valencia types with oil having iodine values as low or lower than are present in the Virginia or runner types.

The peanut breeder is faced with a paradox when breeding for oil quality. Consumer preferences exist for an oil with a low iodine value and one with a high iodine value. Oil with a low iodine value is desirable because it can be stored for longer periods of time without going rancid. Oil with a high iodine value has a higher level of unsaturation and is desirable because it is considered by many to have human health benefits.
Table 10-2  Range of Fatty Acid Percentages

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic</td>
<td>8.0 – 15.0</td>
</tr>
<tr>
<td>Stearic</td>
<td>1.3 – 4.5</td>
</tr>
<tr>
<td>Oleic</td>
<td>41.1 – 80.0</td>
</tr>
<tr>
<td>Linoleic</td>
<td>3.8 – 41.9</td>
</tr>
<tr>
<td>Arachidic</td>
<td>0.4 – 2.0</td>
</tr>
<tr>
<td>Eicosenoic</td>
<td>0.8 – 1.8</td>
</tr>
<tr>
<td>Behenic</td>
<td>1.5 – 3.9</td>
</tr>
</tbody>
</table>

Data from Bovi (1982).

Protein quality. As with peanut oil, the quality of peanut protein is determined by a number of factors. Both the protein content and the amino acid balance of the protein can be important to the peanut breeder, although neither have received great attention (Wynne and Gregory, 1981). This is because the primary use of peanuts on a worldwide basis is as an oilseed crop. In those areas of the world where peanuts are used extensively for human food, consumption generally is in the form of snack foods, which are consumed in such small amounts that they have minimal consequence on human nutrition.

The protein content of peanut seed is influenced by both genotype of the plant and the environment in which the plant is grown. The range of protein content is usually around 25 to 30%. The protein has a typical amino acid spectrum seen in other legumes, with a methionine content about 67% of that found in whole eggs.

Carbohydrate Quality. Genetic differences have been found in peanut genotypes for proportions of the intestinal gas-forming sugars raffinose and stachyose, indicating that the sugar content and composition of peanut cultivars should also be an important component of the selection process in a breeding program. The lower levels of these sugars in the ‘Early Bunch’ cultivar (4.0%) compared with ‘Florigiant’ (5.2%) and ‘Florunner’ (5.5%) made ‘Early Bunch’ more desirable from the standpoint of consumer acceptance for that factor.

Milling Quality. A number of characteristics of the peanut fruit are important in the processing of peanuts. Milling quality is a term used to describe the ease with which whole peanut seed is removed from the shell.
(shelling percentage) and seed coat (blanching). It can be influenced by the environment in which the crop is grown and harvested, and by the shape, structure and tissue composition of the pod, seed coat and seed. Cultivar differences are known to exist. 'Starr,' 'Argentine,' and 'Tamnut 74' were found to have poorer milling quality than 'Florunner' and 'Florigiant.' The blanching quality of 'Early Bunch' is known to be inferior to that of 'Florigiant.' Information on the genetic control of these differences is not available.

The fact that most quality tests are costly and require several pounds of seed delays their use until the later stages of selection in a breeding program. An unacceptable quality level for any of these traits is sufficient reason to prevent a promising line from being released.

**STEPS IN CULTIVAR DEVELOPMENT**

Once the major objectives in a peanut breeding program have been determined, the next step is to choose parents that will allow the breeder to reach the desired objectives. The mathematical probability of obtaining the gene combination that will produce a plant with all the desired characteristics is extremely small. Breeders can improve the chances for such a combination by utilizing parents that already contain many of the genes in the desired combination. For this reason, one parent in most crosses will be a highly adapted genotype, either an already released cultivar or a promising germplasm line. The other parent will have the trait or traits the breeder wishes to add to the adapted genotype, but this second parent also should be as adapted as possible. Sometimes adaptation itself is more important than absolute levels of the missing trait carried by the other parent. For example, if a major goal of a breeding program is the development of a leafspot resistant cultivar, a resistant genotype with the potential for pod production of 3000 kg/ha will be more desirable as a parent than a genotype with the potential for only 1200 kg/ha, even if the second genotype has a higher level of leafspot resistance than the first.

The chosen parents are crossed to allow recombination. Plants in each successive generation after this artificial hybridization are allowed to self-pollinate. Beginning as early as the $F_2$ generation, the breeder will select plants that exhibit desired levels of characteristics required in a new cultivar. The breeding process will involve continued selection and testing of these plants until a single, highly homozygous line or a collection of related homozygous lines are found to be superior to cultivars currently being used by producers. The selection and testing of genetic material obtained from artificial hybridization is the major effort in peanut breeding programs.
SOURCES OF GENETIC VARIABILITY

There are between 40 and 70 species of *Arachis* found in South America. The genus as a whole has a center of diversity in Mato Grosso, Brazil, with species found in an area south of the Amazon River, bordered on the west by the Andes Mountains and on the east by the Atlantic Ocean (Fig. 10-4). Within this area, there are both perennial and annual species of *Arachis*. The perennial species generally are found in high rainfall areas, and the annuals are found in semiarid portions of the region.

There are six or seven sections within the genus. The section *Arachis*, which contains the cultivated peanut, consists of annual and perennial diploids (2n = 2x = 20), and two annual tetraploids, *A. monticola* and *A.*

Figure 10-4  Location of the six centers of diversity in South America for the genus *Arachis*. (1) Guarani region (Paraguay). (2) Goias and Mina Gerais region (Brazil). (3) Rondonia and northwest Mato Grosso (south Amazon). (4) Bolivian region (southwest Amazon). (5) Peruvian region (upper Amazon and west coast). (6) Northeastern Brazil. Center 4 is considered the center of origin of the cultivated peanut.
PEANUT

It is believed that *A. hypogaea*, the cultivated peanut, arose from a wild tetraploid, which may have been *A. monticola*. However, the status of *A. monticola* as a separate species is questionable. It may be more proper to consider it as a subspecies or a botanical variety of *A. hypogaea*. The wild diploid ancestors are not known with certainty, but cytological evidence suggests they may have been *A. batizocoi* and *A. cardenasi* (Smartt and Stalker, 1982).

While breeders obtain most of the variability in their programs from hybridization of different sources of *A. hypogaea*, research at several institutions around the world has led to introgression of genes from some of the diploid *Arachis* species. The most successful method for this introgression has been doubling of the diploid genome followed by crossing and subsequent backcrossing to *A. hypogaea*. New techniques in embryo rescue and tissue culture are making it possible to utilize genes from many of the different diploid species in peanut breeding programs.

Types of Parents and Populations

The germplasm used in making peanut crosses is usually highly homozygous genotypes. With the exception of certain conditions in breeding programs where the major goal is increased genetic recombination, highly heterozygous germplasm is avoided. The purpose of making crosses is to combine genes from both parents into new and better combinations. When highly homozygous parents are used, each of their gametes will contain the same sample of genetic information carried by the parent. The subsequent segregating generations after the cross will be managed to examine the recombining of that genetic information. If heterozygous germplasm is used, the gametes from a single parent will all be different. Because the artificial hybridization process is complex and time consuming, only a limited number of crosses can be made in peanut. This means that only a small sample of the genetic information from a heterozygous parent can be obtained.

The parental material used in breeding programs can be divided into three broad, but not mutually exclusive, categories. The first is plant introductions, or PIs. The PIs available in the United States from the USDA’s Regional Plant Introduction Center in Experiment, Georgia, are either lines contributed by researchers from around the world or germplasm obtained on plant collection trips to the centers of peanut diversity in South America and elsewhere. Other PIs have come from areas of the world where commercial peanut production occurs, such as India, western and southern Africa, and China and neighboring Asian countries. The bulk of this germplasm is frequently unadapted and unfit for mechanized agricultural production in the United States. It is also sometimes of inferi-
or chemical, flavor, and processing quality, although it may have a desirable plant type, or carry disease, insect, or nematode resistance.

Released cultivars make up the second major category of parental material. Because these genotypes will be agronomically adapted and generally have the quality desired by both processors and consumers, they provide an excellent genetic foundation on which to build future cultivars.

Advanced breeding lines from an established breeding program are included in the third major category. The lines may be promising ones that have not yet gone through all the evaluation procedures needed before cultivar release. Frequently within a breeding program, these lines are used as parents while they are still advanced lines, although later they may become new cultivars. Other lines are used that had the potential to be a new cultivar, but in the later stages of evaluation were found to be deficient in one or more traits. These lines may often have better expression of some characteristics, such as yield, than the current cultivars. Because they had unacceptable traits, such as an iodine value that was too high or a shelling percentage that was too low, they were not released. They frequently provide desirable parents in combination with other genotypes that can compensate for the problems present in the advanced, unreleased lines.

Population Development by Hybridization

*Procedures for Artificial Hybridization.* After parents have been chosen, their genes are recombined through the process of artificial hybridization. Because the peanut flower is a complete, naturally self-pollinated flower, human manipulation is necessary to combine the desired male and female gametes. Because reciprocal differences have been shown in a number of peanut crosses, each parent in a cross will be used as both a male and a female. The large number of flowers on the peanut plant allows some flowers to be emasculated and used as the female parent, while other flowers on the same plant can be used as sources of pollen.

The artificial hybridization process generally is carried out in flats or pots in the greenhouse to facilitate movement of plants and to place plants in a physical position to facilitate crossing. In some areas of the world, most notably at ICRISAT in Hyderabad, India, crossing takes place in the field. In more temperate areas of the world, greenhouse crossing can be carried out during times of the year when field work is not demanding of a breeder’s time. It is possible to grow peanuts in the greenhouse during the winter months and produce $F_1$ seed before field planting. However, the peanut plant flowers much more profusely with the higher temperatures and the brighter and longer days characteristic of the summer.
months. Because fewer flowers are produced per plant, crossing during the winter months is more difficult. Another disadvantage of winter crossing is the additional cost of heating the greenhouse.

Some breeders, especially those who do their crossing in the spring months, will use frost-free environments, such as south Florida or Puerto Rico, to grow F1 plants. This can give the advantage of providing one extra generation in a growing season, especially for breeders who make their crosses later in the year.

The process of artificial hybridization usually is performed on only one flower per inflorescence. Because the fertilized egg is buried in the soil through the growth of the gynophore, it is important to choose flowers located near the soil surface. Fertilized flowers that require extensive elongation of the gynophore to reach the soil surface are less likely to develop into fruits.

Flower buds appear in the leaf axils the day before the corolla is visible and dehiscence takes place. On warm, bright days, buds will be large enough to emasculate at approximately 1600 hours at the latitude of the United States. Cool, cloudy days reduce the number of flowers per plant and delay their development to the point that emasculation becomes inefficient unless carried out near 2100 or 2200 hours.

The sepal in front of the flower is pulled down, and the sepal on the side of the standard is folded back. The standard is teased open with a tweezers and also folded back. The two wings are removed, as is the keel, although some breeders move these floral parts to the side. Normal peanut flowers have 10 anthers, 6 with long filaments and 4 with short filaments. The anthers and as much of the filaments as possible are removed. Because emasculated flowers are rather inconspicuous, and because many flowers may exist on a plant, methods are used to identify these flowers. Generally string, often color coded, is attached to the hypanthium of the emasculated flower, or small tags are attached to branches directly above or below the emasculated flower. (Fig. 10-5).

Pollination is carried out the following morning between 0700 and 1000 hours. Flowers from the plant to be used as the male parent are removed and pollen is placed on the stigmatic surface of the filamentous pistil. Some breeders use tweezers or camel hair brushes to transfer the pollen, while others squeeze the pollen directly from the flower onto the stigma. Care must be taken to ensure that the pollen remains on the extremely small stigmatic surface and is not knocked off by other branches or pot movement. (Fig. 10-5).

At this point, some researchers employ methods to increase shade and relative humidity around the pollinated flowers. Several of these methods include placing moist paper towels around the flowers, putting small paper or polyethylene tubes over the flower, or placing large polyethylene tubes over the entire plant.
Figure 10-5 Stages in the artificial pollination and subsequent development of hybrid peanut seed. (1) A flower removed from the male parent plant. (2) Pollen that has been squeezed onto forceps and transferred to the stigma of the emasculated flower. (3) Cluster of pollen grains on the stigma. (4) Dampened paper towel (a) placed over the pollinated flower to provide a higher relative humidity for germination, and the wilted flower (b) 5 to 6 hours after pollination. (5) Color-coded wire looped around the developing peg (b), which is still attached to the withered flower and its identifying string (a). (6) Fruit which is generally harvested 55 to 65 days after the peg is identified. (Photographs by John Swearingen and line drawings by Ashley Wood, University of Florida, Gainesville.) (From Hybridization of Crop Plants, p. 451, by permission of the Crop Science Society of America and American Society of Agronomy.)
After pollination is completed, all remaining flowers are removed daily for 10 to 20 days by breaking off the hypanthium near the point of attachment to the branch. Successful fertilization will be followed by peg formation, usually within 7 to 10 days from pollination. Marking of pegs that have resulted from artificial hybridization is advantageous. A number of techniques can be used, including marking with metal tags, string, or multi-colored wire from telephone cables. In the case of Virginia botanical types, the fruit will mature approximately 70 days after pollination.

Success rates vary with technique and location, but frequently over 70% of greenhouse pollinations result in seed production. Peanut pods produced from artificial hybridization will often contain fewer seed than the plants would produce by natural self-pollination (Norden, 1980).

**Induced Mutations**

Because peanut breeding in the United States has been conducted for a relatively short period of time and has not had the concentrated effort that crops such as corn and soybeans have had, the variability within the species for most traits is extensive. For characteristics that are now either unknown or are present in inadequate levels in the cultivated species, such as acceptable resistance to the root knot nematode or improved protein quality, recent research on interspecific hybridization holds promise for the transfer of these characteristics to *A. hypogaea* germplasm. For these reasons, relatively little work has been conducted on the use of induced mutations for the production of increased variability.

The majority of the work on induced mutations in the United States has taken place at North Carolina State University. Most of that research has been of a more fundamental nature, examining the genetics of the induced changes and the nature of the change itself. The cultivar ‘NC-4x’ was released from this work but had little commercial success.

Researchers in India have used mutagenesis more frequently than have workers in other countries. Several cultivars have been released from programs that have used mutagenesis to obtain improved characteristics, such as large seed size or increased shelling percentage.

**BREEDING PROCEDURES**

**Breeding Strategies**

The first step to consider in the development of a new cultivar is the identification of the most important objectives. In many cases, limited time,
land, money, and personnel prevent all but the most important peanut characteristics from being used as selection criteria in a breeding program. These objectives generally will be the improvement of several characteristics that are less than desirable in a standard cultivar that is being utilized by growers in a given area. Once these objectives have been defined, the search begins for a genotype that carries the traits missing in the standard cultivar. If there is a single genotype that carries all of the desired traits, it is crossed directly to the standard cultivar and selection follows. If the desired traits are found only in different genotypes, some scheme for crossing, selection, and additional crossing is necessary.

Because the peanut plant is self-pollinated, most cultivars or genotypes used in a crossing program will be highly homozygous. Gametes from an inbred parent will be relatively uniform, and F₁ seeds and plants from a particular cross will be uniform and highly heterozygous. Genetic segregation will take place in the F₂ generation. Because this generation will have an extensive amount of genetic variability, it is important to obtain a large number of F₂ seed. Therefore, F₁ plants are grown in conditions as ideal as possible and are planted much further apart than commercial planting to maximize seed production. F₁ plants frequently are grown 45 to 90 cm apart in rows that are at least 90 cm apart.

The method for handling the F₂ seed depends on the procedures adopted by the breeder. Several different techniques are used by peanut breeders, and these are outlined in the following sections. From approximately the F₂ generation, the different breeding procedures use similar approaches in evaluating the relatively homozygous material for yield, quality and other important traits. The discussion will focus on the differences in the early generations of the breeding programs and then will describe the procedures common to all the programs that are carried out in later generations.

**Pedigree Method**

In the pedigree method, accurate records are kept of the line of descent or pedigree of each plant. Individual F₂ seeds are space-planted at least 30 cm apart in a standard row width of 90 cm. Seeds from each cross usually are planted together in the field for better comparison and selection. The number of plants grown will vary among programs depending on the number of crosses made each year and the support available for the program. Each plant is examined visually in the field and notes are taken throughout the growing season for vegetative characteristics of importance to the breeder. At harvest, the plants are dug and inverted and the pods are examined for disease, size, shape, pubescence, amount of constriction in the middle of the pods, reticulation or netting on the pod sur-
face, color, and number. A decision is made whether to discard a plant or save its seed to grow the F₃ generation the following year.

Individual F₃ plants that are saved are given an identification number. A minimum of 30 F₃ progeny from each F₂ selection are space-planted the following growing season. The best F₃ plants are chosen within selected rows (Table 10-3). F₄ progeny rows are grown from selected F₃ plants the following season. Although single F₃ plants usually will be selected from F₂-derived lines and advanced to F₄ progeny rows, occasionally uniform F₂-derived lines in the F₃ will be harvested in bulk and the progeny grown the following season as an F₃-derived line in the F₄. The selection procedure in the F₄ generation is similar to that used in the F₃.

Table 10-3  Pedigree Method for Segregating Generations for a Single-Cross Population of Peanut

<table>
<thead>
<tr>
<th>Season</th>
<th>Breeding Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Artificial hybridization of two parental lines.</td>
</tr>
<tr>
<td>2</td>
<td>F₁ seeds are sown in widely spaced plantings to produce F₂ seed.</td>
</tr>
<tr>
<td>3</td>
<td>Selection of individual F₂ plants is made on the basis of leaf size, shape, and color, length of internode, branching pattern and coarseness of branches, seedling vigor, plant size, ground cover, foliar and pod disease resistance, plant growth habit, pod pubescence, pod size, seed size and color, pod placement on the plant, pod shape, and pod fill.</td>
</tr>
<tr>
<td>4</td>
<td>F₃ progeny of selected F₂ plants are grown in individual rows. Selection of individual F₃ plants from the rows is based on the same characteristics used the previous season. Each plant selected will be grown as a separate plot the next season. Although rare, in some crosses, plants within a progeny row may be sufficiently uniform to bulk.</td>
</tr>
<tr>
<td>5</td>
<td>F₃₄ and F₃₅ lines are sown in rows. Selection of individual plants or entire lines may take place at this stage, depending on the uniformity of plants within a progeny row.</td>
</tr>
<tr>
<td>6</td>
<td>F₄₃, F₅₃, and F₆₃ lines are sown in individual progeny rows. At this stage, plants within a progeny row are sufficiently uniform that plot yield and grading data may be measured. Selection will be based on plot performance rather than individual plant performance. Off-type plants within a progeny row will be removed.</td>
</tr>
<tr>
<td>7 and 8</td>
<td>Plots in the F₄ or F₅ generation may be derived from any of the four or five preceding generations. Selection will be based on plot performance for the same characteristics used for selection in the sixth season.</td>
</tr>
<tr>
<td>9 to 12</td>
<td>Plots will be grown in multiple locations. Selection will continue for the characteristics examined in the preceding generations, but will now include stability of yield and grading data. Tests for flavor, iodine value, oil content, fatty acid spectrum, protein content, amino acid proportions, soluble sugars and milling quality will be conducted.</td>
</tr>
</tbody>
</table>
With each generation of self-pollination, the homozygosity at a single locus increases. When the progeny of a single plant are adequately uniform, they are harvested together in bulk to form an experimental line. Subsequent evaluations will be made on the entire line rather than individual plants.

Many peanut cultivars developed by pedigree selection are F₅-derived lines. Some breeders prefer to evaluate F₃-derived or F₄-derived lines as potential cultivars. Rarely are F₅-derived lines uniform enough to be considered for extensive evaluation as potential cultivars.

Bulk Method

When the bulk method is used by peanut breeders, F₁ seeds are sown in spaced plantings to produce as much F₂ seed as possible. The F₂ seed is planted en masse the next generation and the F₃ seed is harvested in bulk. Limited selection for easily identified traits, such as seed size or plant type, may be made on the F₂ plants. This is the only type of selection a breeder will perform until approximately the F₅ generation (Table 10-4). At or near this generation, a portion of the seed will be spaced planted so that the characteristics of individual plants can be readily evaluated. Individual plants that are selected will be evaluated in a progeny test for desirable characteristics. The entire F₅-derived line may be selected, although undesirable plants frequently will be removed from the line. If a plot is not uniform, plants with similar phenotypes will be bulked to constitute the next generation. After selection, the material will be handled the same way as material coming from the pedigree program.

Relatively little time and effort is required to advance populations by the bulk method from the F₂ to the F₅, especially compared with the extensive amount of work required in the pedigree method. However, proponents of the pedigree method feel that the selection made in early generations is worthwhile. They are concerned about carrying along large amounts of undesirable germplasm and about the elimination of desired genotypes from the bulks by natural selection.

Single-Seed Descent Method

The single-seed descent method (SSD) is a modification of the bulk method that can be used to inbreed populations in a shorter length of time. It requires handling less material in early generations and, under certain conditions, may lessen undue loss of desirable genotypes in a bulk from natural selection. In the SSD procedure, the F₁ seed obtained from the crosses made in the greenhouse are either planted in pots or flats in the
Table 10-4  Bulk Method for a Single-cross Population of Peanut

<table>
<thead>
<tr>
<th>Season</th>
<th>Breeding Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Artificial hybridization of two parental lines.</td>
</tr>
<tr>
<td>2</td>
<td>F₁ plants are grown in widely spaced plantings to produce F₂ seed.</td>
</tr>
<tr>
<td>3</td>
<td>F₂ seeds from the F₂ population are harvested in bulk. No selection is made, unless it is for a characteristic that can be mass selected, such as seed size or some easily identified plant trait.</td>
</tr>
<tr>
<td>4 to 6</td>
<td>A sample of seed from the previous generation is used to plant the next generation. Seeds of each generation are harvested in bulk, and only mass selection will take place in the population.</td>
</tr>
<tr>
<td>7</td>
<td>F₄ plants will be grown in spaced plantings (frequently 30 to 45 cm between plants in rows 90 cm apart). Individual plants will be selected on the basis of plant growth habit, leaf size, shape, and color, internode length, branching number and pattern, coarseness of branches, seedling vigor, plant size, ground cover, pod size, pod shape, seed size and color, pod fill, foliar and pod disease resistance, and pod number.</td>
</tr>
<tr>
<td>8</td>
<td>F₇ progeny of selected F₄ plants are sown in progeny rows. Desirable F₇-derived lines are selected on the basis of the same characteristics used for selection in season 7, as well as for plot yield and grading data.</td>
</tr>
<tr>
<td>9</td>
<td>Adequate seed of the F₈-derived lines will be available to plant replicated yield tests. Selection of lines will be based on the characteristics used in the previous season, as well as stability of yield and grading data, tests for flavor, iodine value, oil and protein content, fatty acid and amino acid spectrum, soluble sugars and milling quality.</td>
</tr>
<tr>
<td>10 to 12</td>
<td>Selection among lines in replicated tests will be based on the same characteristics used in season 9.</td>
</tr>
</tbody>
</table>

greenhouse or space planted in the field. The F₂ seeds from F₁ plants are harvested and planted in a greenhouse in a dense arrangement. A single seed or small quantity of F₂ seed is selected from each F₂ plant. These seed are planted in the greenhouse in the same dense arrangement (Table 10-5). It is possible to obtain three generations in about 14 months with this procedure (Isleib and Wynne, 1981). The number of seed selected, as well as the generations of dense planting, will vary among programs. After the desired number of inbreeding generations has been completed, the procedure for SSD is the same as for the bulk method. Seeds of a population are sown in the field in spaced plantings for selection purposes. This frequently occurs in the F₆ generation. Individual plants are selected on the basis of phenotype, and their progeny are grown the following generation. Selected lines are harvested in bulk to obtain seed for replicated field evaluation.
Table 10-5  Single-seed Descent Method for a Single-cross Population of Peanut

<table>
<thead>
<tr>
<th>Season</th>
<th>Breeding Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Artificial hybridization of two parental lines.</td>
</tr>
<tr>
<td>1</td>
<td>F₁ seeds are sown in widely spaced plantings of at least 30 cm between plants and 90 cm between rows to produce F₂ seed.</td>
</tr>
<tr>
<td>2</td>
<td>F₂ seeds are planted in pots in a greenhouse immediately after harvest if the plants are Valencia or Spanish botanical varieties. Seed from Virginia botanical varieties must have seed dormancy broken, usually by treating with ethylene or heat. Dense planting will be made in the greenhouse to produce only a few seeds per plant. Densities average 5 to 30 seeds in pots with a 30-cm diameter. One to 3 seeds per F₂ plant are harvested.</td>
</tr>
<tr>
<td>2</td>
<td>The F₂ generation is grown in the greenhouse under conditions similar to those used in the F₁ generation.</td>
</tr>
<tr>
<td>2 to 3</td>
<td>F₃ seeds are sown in greenhouse pots as in previous generations.</td>
</tr>
<tr>
<td>3</td>
<td>F₃ seeds are sown in widely spaced field plantings spacing similar to that used for F₁ seed. Evaluation and selection for desirable characteristics and subsequent handling of plants and lines will be similar to that used in the bulk method for the same generations (Table 10-4).</td>
</tr>
</tbody>
</table>

With the SSD method, more generations are grown in a shorter period of time than with the other methods. The time required to obtain the three generations that took 14 months with the SSD would usually take 3 years with the pedigree or bulk methods. However, some breeders feel that this method reduces the genetic variability available from a cross. The SSD has been used to only a limited extent by peanut breeders.

Recurrent Selection

Diálele selective mating (DSM) is a form of recurrent selection proposed by Jensen (1970). A number of selected parents are crossed in as many combinations as possible. The offspring of two-way crosses can be crossed to each other, or the offspring can be grown out and examined for important characteristics, and only the selected plants intercrossed. At any stage in the program, material can be intercrossed or carried through a pedigree, bulk, or SSD selection program to obtain potential new cultivars. The purpose behind the DSM is to obtain more genetic recombination than can be obtained in standard breeding programs. In a standard program, a cross is made and the population is self-pollinated, which limits the formation of new gene combinations. With DSM, the genes from different plants have an increased opportunity to recombine due to the extra number of generations of intermating.
In spite of the advantages of creating possible new gene combinations, DSM requires a large amount of labor in peanuts. Crossing is rather time consuming, especially considering the number of seed produced for the time invested. Another problem is that crossing in early generations gives little or no opportunity for selection. Several peanut breeding programs are now using DSM, but whether this method is better than any of the conventional methods of cultivar development has not been determined.

**Modifications of Breeding Systems**

The pedigree and bulk systems are used more commonly by peanut breeders than SSD or recurrent selection. Many breeders use a combination of systems or will make modifications of conventional systems.

The University of Florida peanut breeding program uses a modified pedigree system. Single plants are selected and progeny tested by the pedigree method during inbreeding. By the F3 to F5 generation, seeds of individual plants or lines derived from them are mixed to form multilines (Norden et al., 1984). Plants or lines are chosen for a multiline on the basis of their phenotypic similarities. Vegetative characters, which can be seen throughout the growing season, and reproductive characters, which can only be examined after harvest, must both be considered in selecting genotypes for a multiline. Vegetative characters will include plant height, branching patterns and branching angles from the main stem, leaf size and color, and numbers of branches. Reproductive characters will include all aspects of pod shape and size, as well as kernel size, shape, and color. Disease resistance levels and chemical composition differences may be large among the genotypes in a multiline.

This breeding procedure results in cultivars with as much genetic diversity as possible, while obtaining a fairly uniform phenotype. This is in contrast to the standard pedigree method, which results in a cultivar that is essentially genetically uniform.

The design of a breeding system is determined by the philosophy of the peanut breeder and by the mode of inheritance of the major characters. If several important characteristics are controlled by a few genes and the environment has relatively little effect on their expression, the pedigree method offers the advantage of early elimination of undesirable material. Table 10-6 outlines the selection scheme used in the development of ‘Southern Runner,’ a peanut cultivar released by the Florida Agricultural Experiment Station that has moderate leafspot resistance. In the development of ‘Southern Runner,’ the major character, leafspot resistance, was selected in early generations because of the relatively high heritability of the trait.

If the traits of major importance are influenced by the environment to
Table 10-6  Selection Scheme Used in the Development of ‘Southern Runner’

‘Southern Runner’ was derived by pedigree selection from a cross made in 1972 between PI 203396 and ‘Florunner.’ The primary objective of this cross was to combine the leafspot resistance of PI 203396 with the high yield and market quality of the popular runner-type cultivar ‘Florunner.’

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
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<tbody>
<tr>
<td>1971</td>
<td>PI 203396 was selected as a parent from an unsprayed field breeding nursery based on its leafspot resistance. ‘Florunner,’ the male parent, was the most productive and popular runner-type cultivar at the time.</td>
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<tr>
<td>1972</td>
<td>The parents were planted in the greenhouse in March and crosses were made in May. F₁ seeds were harvested in July.</td>
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<tr>
<td>1973</td>
<td>F₁ seeds were space planted 45 cm apart in the field, and plants were sprayed with fungicide for leafspot control to maximize seed production.</td>
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<tr>
<td>1974—1977</td>
<td>For the F₂ to F₄ generations, pedigree selections were made under space planted field conditions without leafspot control. The F₂ population was grown in six rows 6.7 m long with plants spaced 23 cm in rows 90 cm apart. F₃₃, F₃₄, and F₄₈ lines were grown in two-row plots with the same spacings used for the F₂ population. Selections emphasized leafspot resistance and good agronomic runner market-type characteristics.</td>
</tr>
<tr>
<td>1978</td>
<td>F₄ seeds from three F₃ plant selections were bulked to form a multiline. The multiline was evaluated at Marianna, Florida in three replications of a yield test with two-row plots 6.1 m long with 60 seed planted per row. The multiline was evaluated for uniformity, growth habit, maturity, disease resistance, especially to leaf-spot, pod characteristics, and other pertinent information, such as digging conditions and pod loss. Each plot was harvested in bulk to obtain yield and grading data.</td>
</tr>
<tr>
<td>1979—1984</td>
<td>The multiline, identified as UF 80202 beginning in 1980, was evaluated in a total of 33 in-state yield tests through 1983. These included 19 tests that received no fungicide for leaf-spot control; 8 tests in which leafspot was controlled with a fungicide; and 6 tests in which fungicide treatment was a variable. The plot size in all tests was the same as in 1978. The number of replications at each test site varied from 3 to 9. Some tests initiated in 1981 included multiple harvest dates. Vegetative and reproductive uniformity, leafspot resistance, maturity, pod yield and grades were the primary factors evaluated. More detailed leafspot disease assessments of lesion counts, defoliation, leaf necrosis and other readings were made by a pathologist in all tests in which fungicide treatments were a variable and in some of the unsprayed tests, beginning in 1980. In 1981, UF 80202 was placed in the National Uniform Peanut Performance Test and was evaluated in the seven major peanut-producing states. These tests were sprayed with a fungicide at all locations to control leafspot. Seed samples were sent to laboratories for various chemical quality analyses, including iodine value, fatty acid per-</td>
</tr>
</tbody>
</table>
a large extent, it may be more desirable to delay selection until plants have reached a relatively high degree of homozygosity. The bulk or single-seed descent methods may be more desirable selection methods in such instances. If a breeder feels that linkage has an undesirable effect on the development of desirable genotypes, multiple generations of intermat- ing may be appropriate in a population before selection is initiated.

FIELD- PLOT TECHNIQUES FOR GENOTYPE EVALUATION

The pedigree, bulk and single-seed descent methods differ in the procedures used to handle segregating populations in early generations. Regardless of the method of inbreeding, the breeder will develop lines that must be evaluated as potential cultivars in replicated tests. The lines must be compared with one another and with cultivars that have been accepted by the growers. Comparisons must be made under different growing conditions for all traits important to the producer, processor and consumer.

Procedures for Yield Evaluation

Yield evaluation begins when adequate seed of uniform lines has been generated. F₅- or F₆-derived lines commonly are used for yield tests.

Production Practices. The first measurement of yield usually is done with a single, unreplicated plot at the main research location of the breeding program. These plots are frequently composed of two rows 90 cm apart and 6 m long. Unless selection among the genotypes is being made for characters with unique environmental requirements, such as nematode or
disease resistance, the lines will be grown with production practices similar to those used by growers.

Because new cultivars will be grown under many different management programs and in environmental conditions different from those found at the main research location, promising genotypes selected from the first yield test must be examined in as many different environments as possible in subsequent years. To evaluate genotypes at different locations, breeders must have cooperators that will grow and evaluate the tests, or the breeder must take on this responsibility. If cooperators do not exist, the cost involved in travel, land procurement, fertilizer, pesticides, and harvesting can easily consume a large portion of the breeder’s budget.

Because cultivars released from breeding programs in the United States are frequently grown in locations other than the state of origin, peanut breeders have developed the national Uniform Peanut Performance Test (UPPT). Breeders in seven states enter cultivars and advanced breeding lines in the test which is currently grown at 10 sites. Although general procedures for testing are similar among locations, a cooperator may adopt specific techniques used for growing peanuts in the state or region. In general, two-row plots 6 m long with a row spacing of 90 cm are used for yield evaluation, giving a total plot area of 10.8 m². The lines in a test usually are planted in a randomized complete-block design with six replications. Individual seeds usually are planted 5 to 10 cm apart within the row.

Although peanuts will grow well with residual fertility from a previous crop, phosphorus and potassium fertilizers are usually added before planting. Some researchers will add nitrogen as a starter fertilizer at the time of planting. Gypsum (CaSO₄) is applied over the row of the medium- and large-podded genotypes as the plants begin to peg to provide the required high level of calcium needed in the pegging zone. Irrigation water is provided, if needed. Pesticide use will depend on the prevalence of pests in a particular environment. Herbicides are used for weed control because cultivation can reduce yields, especially after the pegs begin to form. Leafspot diseases are a problem in all growing regions of the United States and a fungicide is used for its control. If the government price support system is discontinued, a wider range of commercial production practices will undoubtedly emerge, and the breeder will change the range of production inputs utilized for selection.

For yield evaluations within breeding programs and through the UPPT, Spanish and Virginia botanical types usually are grown separately for ease of harvest. In Florida, the Spanish types generally mature in 100 to 125 days compared with 125 to 150 days for Virginia types. The exact number of days to maturity will vary among regions and among seasons.

Studies have shown that growth habit differences among genotypes of the Virginia type rarely are of sufficient magnitude to cause major yield
bias among plots due to intergenotypic competition. This competition is even less of a problem for plants of the Spanish type which are more compact and upright than the Virginia type. Thus, the two-row plots grown for yield evaluations are considered sufficient to minimize intergenotypic competition in yield tests, especially when lines of similar maturity are grouped together. It is not necessary to end trim plots before harvest because any differential border effects caused by the alley between plots is of little consequence in ranking peanut genotypes for yield.

*Harvesting Procedure.* Determining the appropriate date of harvest in commercial peanut production is difficult. Not only does the peanut plant tend to be indeterminate, but the product of most importance to the grower develops underground. One method that can be used to approximate the harvest date is based on knowledge of the number of days required for a cultivar to reach maximum yield, assuming optimum growing conditions.

The standard technique used by most growers is called the shell-out method. Several representative plants are pulled from various places in a field. All but the obviously immature pods are picked and shelled. If the inside of the pod is tan to brown and the mature seed-coat color is detectable on the seeds, the pod is considered mature. If 60 to 80% of the pods are mature, harvesting should begin. Although this method is widely used, it is inexact. If a grower underestimates or overestimates the amount of time a crop should be in the field, valuable yield and quality may be lost through an excessive percentage of immature or overmature pods.

A relatively new technique for determining the time for harvest is called the hull-scrape method. The hull-scrape method is considered to be more accurate than the shell-out method. The hulls of pods from representative plants in the field are scraped on the outside. Color differences in the middle layer of the peanut hull correspond closely with the maturity of the pod. A profile of representative plants can be read on a profile-layout board, which will give the grower a more exact indication of the maturity level of the peanut crop (Henning, 1983).

Regardless of the system used to determine harvest date, the plants are dug when the proportion of mature pods has reached a predetermined level set by the grower. A tractor-drawn peanut digger-inverter severs the taproot of the plant just below the fruit, lifts the plant out of the soil, shakes off the soil, inverts the plant, and lays it on the top of the soil so that the roots and pods are exposed for drying (Fig. 10-6). The plants usually are left in a windrow to dry for several days, then are picked from the soil with a combine which separates the pods from the plant. In most cases, the moisture percentage of the pods at the time of combining is too high to place them directly in storage, so they are dried artificially in bins or trailers to an acceptable storage moisture level of 7 to 10%. 


The commercial harvesting procedure is a difficult one to emulate in a breeding program. The determination of separate maturity dates by the shell-out or hull-scare methods for all the genotypes in a breeding nursery is not practical because such a determination will destroy a substantial part of the small plots. The general appearance of the plant above ground can aid in deciding when to dig. Plant foliage often tends to fade or become lighter green as maturity approaches. Plant stress from soil-borne diseases, insects, or nematodes may require early harvest.

Because breeders dig entire groups of plots on the same date, segregating germplasm from crosses involving parents differing in maturity date will be penalized. Both yield and grading data will be determined inaccuracy for segregants that mature earlier or later than the date they are dug. Breeders must keep these penalty assessments in mind during selection. Selection for maturity is not done until plot size can be increased to sufficient size to allow proper evaluation of maturity dates. Advanced breeding lines in a program are harvested as close as possible to optimum maturity dates.

A peanut breeder cannot visually select for yield before harvest. All decisions regarding seed yield must be made after plants have been dug.
and inverted. At that time, individual plants may be selected and dried separately, or entire plots may be harvested in bulk. If entire plots are to be saved, they are generally left in the field to dry before being combined. Commercial combines are too large and cumbersome to be used for threshing the selected plots. Instead, plants of a plot are brought to small threshers which separate the pods from the plants. These threshers can be easily cleaned between plots to avoid mixing seed from different genotypes. Pods from the individual plots are bagged in mesh or burlap bags and further dried until their moisture percentage is low enough to permit safe storage. Before weighing the pods from a plot, the samples are passed over a stemmer which removes stems or sand clinging to the pods, and separates stems, sticks and other foreign matter from the pods. Because peanuts retain their viability much better when stored in pods rather than as shelled seed, the unshelled pods of individual plots are placed in storage. A subsample of pods from each plot is removed to obtain grading data.

PROCEDURES FOR SEED PRODUCTION

Seed production is the final step in cultivar development. It is important to have proper preservation and maintenance of the end product for the grower. The end product can be a single pure line, an early-generation composite of phenotypically similar plants or lines, a blend of isogenic lines, or a mixture of two or more relatively homozygous but not closely related lines. Even so-called pure lines might contain genotypes which, although morphologically alike, may differ in yielding ability or other traits. To retain genotypic diversity within the end product, it is important to be sure that an adequate number of plants are grown when increasing a pure-line cultivar.

If the cultivar is a multiline, each subline is increased and maintained separately by the breeder. Seeds of the sublines are mixed in equal quantities by weight to obtain breeder seed for increase of the cultivar. For the first few years after cultivar release, breeder seed of a multiline is supplied on an annual basis for the production of foundation seed. After experience with the cultivar is obtained by growers, it may be possible to refine the multiline by dropping one or two sublines. This is not done, however, unless several years of evaluation and refinement indicate that such a change in the genetic makeup of the cultivar will improve its performance.

Peanuts have low rates of natural outcrossing, varying from 0 to about 10%, depending on the genotype and environmental conditions. Even low rates of outcrossing can cause contamination. Seed production fields of different cultivars must be maintained at adequate distances to lessen the chance of outcrossing. In Florida and Georgia, a field of one cultivar must
not be closer than 15 m from fields of other cultivars to be eligible for certification. Certified seed standards in Florida permit a maximum of 0.5% of other cultivars. This standard is reduced to 0.2% for the foundation and registered seed classes. Other states with seed certification programs may have slightly different standards for purity. For example, Georgia has a zero tolerance for seeds of other cultivars. In some cases, the standards seem unnecessarily stringent because they prevent the use of seed with a rare mutation or outcrossing event. Problems can occur if foundation or registered seed is purchased from a state with different certification standards.

The genetic variation within a new cultivar makes it necessary for the seed industry to avoid practices that may favor one genotype more than another. Seed sizing was detrimental to the longevity of the ‘NC 2’ cultivar in North Carolina. The larger seed of ‘NC 2’ were sold on the edible market for a premium, while the smaller seed were sold as seed stock. Because the cultivar had genetic variability for seed size, this practice actually removed genes for larger seed size. Eventually, the cultivar, which was released as a Virginia market type, had to be sold as a runner market type because of a reduction in seed size.

FUTURE PROSPECTS FOR CULTIVAR DEVELOPMENT

Peanut breeders remain optimistic that much variability remains to be exploited in the genus *Arachis*. The variability for many traits is only beginning to be explored, and techniques of interspecific hybridization are beginning to allow breeders to utilize genes from species other than *A. hypogaea* in the development of new peanut cultivars.

Current peanut cultivars are complex combinations of the many genes required to obtain high levels of pod yield while, at the same time, producing a peanut that is acceptable to growers, processors and consumers. Any new cultivar released by a peanut breeder must maintain the high standards of milling and market quality and consumer acceptance, while at the same time improve yield. The combinations of genes necessary for the expression of these characteristics in a single cultivar are extremely rare. Detection of such combinations requires the screening of large populations of plants under field conditions to ensure that all traits are present in a given genotype. In addition to this complex combination of genes necessary for the release of new peanut cultivar, the conditions under which peanut cultivars are now grown may change in the near future if the current price support program is abolished. If the government support program is discontinued, the combination of genes required in a new cultivar will be even more complex because traits for adaptability to less desirable
environmental conditions will need to be considered along with the current emphasis on yield and quality.

Peanut breeders are well aware that the genotype with maximum potential for expression of all desirable traits has not yet been selected. Co-operation with the peanut industry and with other disciplines related to plant breeding, such as plant pathology, entomology, plant physiology, and molecular genetics, will be essential to increase the chances of success. Because genetic variability is only now being explored intensively in peanuts, a great deal of opportunity remains for improving the combinations of genes currently available in commercial cultivars.

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