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Chapter 4

BREEDING OF THE CULTIVATED PEANUT

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Peanuts (*Arachis hypogaea* L.) are the most widespread and potentially the most important food legume in the world. The object of peanut breeding is to develop this potential by creating cultivars which meet the demands of the peanut grower, processor, and consumer.

Branch (1979), with the aid of several U. S. peanut breeders, recently compiled a list of peanut breeding goals. These, classified according to needs of differing industry segments, included: for growers - higher yields, pest resistance, and environmental stress-tolerance; for processors - more uniform maturity and more favorable shelling and blanching characteristics; and for the consumer - improved nutritional seed properties with fruit and seed of preferred shape, size, texture, color, flavor, and aroma.

An extensive explanation of the peanut breeding process and the progress which has been made towards achieving these goals has been written in the book "Peanuts: Culture and Uses" (Norden, 1973). This chapter reports current progress in peanut breeding programs and examines the problems facing these programs in the future.

GENETIC VARIABILITY

As Gregory (1962) pointed out, the basic resources upon which a plant breeder must draw for genetic material are finite and exhaustible. These basic sources are: 1) the hereditary differences among cultivars of cultivated peanuts; 2) the differences that may be created artificially by the use of mutagens; and 3) differences which occur among the wild relatives of the cultivated species. The genus *Arachis* originated in South America (Krapovickas, 1973; Smartt et al., 1978) and extends over more than 2.6 million km² of the continent (Banks, 1976). This genus includes 50 or more species from 7 clearly differentiated taxonomic sections. The cultivated peanut is thought to have originated as a wild allotetraploid between the quasi-annual *A. batizocoi* and the perennial *A. cardenasii* nom. nud. (Gregory et al., 1980).

Plant Introduction

Collections of peanut germplasm in the USA are fairly extensive. The bulk of the present collection was obtained through collection expeditions sponsored by the USDA with the cooperation of state experiment stations and foreign countries. Further explorations in South America are needed before this valuable germplasm is lost.

The most complete catalogued collection in the USA which is accessible to plant breeders is the one maintained by the Southern Regional Plant Introduction Station at Experiment, Georgia. Approximately 4,000 accessions are

catalogued by the Plant Introduction (PI) numbers along with useful information as cultivar name, vine, pod and seed characteristics, and information on disease, insect and nematode resistance (Norden, 1980a). Considerable genetic variability is available to breeders. Cultivars from the South American and African centers of diversity reportedly "exhibit" tolerance to aluminum, disease, drought, frost, fungi, high pH, heat, insects, laterite, limestone, low pH, sand, smog, savanna, ultraviolet light and viruses (Duke, 1981). A number of cultivars possessing some of these traits will be referred to later in this chapter.

A near duplicate of the Southern Regional collection is stored at the National Seed Laboratory at Fort Collins, Colorado. This collection is not a working collection but is reserved for extended storage. Several state experiment stations, notably Florida (Gainesville and Marianna), Georgia (Tifton), New Mexico (Clovis), North Carolina (Raleigh), Oklahoma (Stillwater), Texas (College Station and Stephenville), and Virginia (Suffolk), are good sources of genetic material (Banks, 1976; Rao, 1980). These collections contain much of the same basic parental material (PI's) as the Southern Regional collection but are greatly enhanced by the addition of breeding lines from various crosses made over the years.

Germlasm collections are being assembled in several countries, including Brazil (Pompeu, 1975), Argentina (Pietrarelli, 1975), Taiwan (Hsing, 1975), Venezuela (Mazzani, 1975), South Africa (Van der Merwe, 1975) and at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India (Rao, 1980). Up to mid-1980, about 8,500 accessions had been assembled at ICRISAT. ICRISAT also has a special interest in the wild species of *Arachis* which are being maintained jointly by the Genetic Resources Unit and the Cytogenetics Program.

Several wild species promise to play an important role in the genetic improvement of the peanut cultigen. Smartt and Stalker deal with this subject in Chapter 2.

Natural and Artificial Hybrids

The peanut is essentially self-pollinating, but as in most self-pollinating species some outcrossing usually occurs. This natural hybridization provides genetic variability but also affects the breeder's management in preserving the genetic purity of developing lines. Stone (1973) measured the natural crossing of peanuts in Puerto Rico by making alternate hill plantings of 7 cultivars using the dominant marker line, *krinkle*, and counting the hybrids in the progeny from the various plants on an individual basis. Total natural outcrossing was measured at 0.27 and 0.99% for 1969 and 1970, respectively. These results agree with those of previous workers where natural cross-pollination percentages of 0 to 2.56% were reported (Norden, 1980b).

Hammons (1973) discussed the utilization of natural crosses as a technique he termed pedigree natural crossing. This technique permits the production of larger numbers of F_1 hybrids than is possible with the same expenditure of time using manual procedures. A disadvantage of the technique is that the marker stock must have the characteristics desirable for cultivar improvement.

Both the genotype and environment, expressed as season and location, af-

fects the natural cross-pollination percentage. Most of the peanut cultivars grown commercially in the U.S. today were developed through artificial hybridization. The variability created through artificial cross-pollination, both among and within species of *Arachis*, is expected to be the prime means of peanut cultivar improvement in the future.

Mutations

Genetic diversity in peanuts resulting from the use of mutagenic agents has been frequently reported. Most of the genetic alterations are deleterious, but useful mutants have been reported in low frequency.

X-Rays. Extensive research on mutation breeding of peanuts has been conducted by a group of investigators in North Carolina since 1949. The results obtained, largely of a fundamental nature, have been reviewed (Gregory, 1968). Gustafsson and Gadd (1965) have also reviewed the literature on mutation breeding of peanuts.

To satisfy preferential demand on the international market for larger peanut kernels in India, TG-1, released as Vikram in 1973, was developed after treating seed of Spanish Improved cultivar with 75 Kr X-rays and by repeated selection for improved seed weight (Patil, 1977). More recent selections were made from crosses between TG-1 and a semisterile mutant which was also induced by X-ray radiation. Shelling percentages suggest that some of these selections are thin-shelled and even higher yielding than TG-1.

Gamma-Rays. Reddy et al. (1977) examined the effects of irradiation with 40 Kr gamma-rays on 6 peanut genotypes. Virginia bunch and runner type cultivars showed a dramatic decrease in seed germination and seedling survival rate, while spanish and valencia genotypes suffered much less damage. In the M_2 generation, mutant plants which fell into 7 different morphological groups were observed.

Mouli and Patil (1976) examined a suppressed branching mutant induced by gamma radiation. The mutant, discovered in the M_4 progeny after gamma radiation, was found to be true breeding and the inheritance was reported.

Chemicals. The effectiveness and efficiency of ethidium bromide as a mutagen for the treatment of mature peanut seeds were examined by Levy et al. (1979). Seeds of 2 cultivars were treated for 6 time intervals ranging from 3 to 48 hours. The mutagen uptake by the seeds increased with treatment duration up to 36 hours, and the bulk of the mutagen concentrated in the seed coat. They concluded that mutagenic effectiveness and efficiency were increased by short treatment periods sufficient only for the mutagen to penetrate the embryo.

Genetic variability in plasmon alone or in interaction with nuclear genes can affect the phenotypes in peanuts (Ashri and Levy, 1976). Differences were noted in the numbers of total, nuclear, and plasmon mutations induced by gamma-rays, acridines and alkylating agents (Ashri et al., 1977).

Ploidy Alteration

The sterility of triploid hybrids produced from crosses between cultivated peanuts (tetraploid) and wild species, which are mostly diploids, can be over-

come by doubling the chromosome complement using colchicine. Spielman and Moss (1976) compared 3 different techniques for the application of colchicine to *Arachis* hybrids to double the chromosome complement. They concluded that the most successful method involved treating the vegetative shoots and discussed the advantages of this method over the other 2 methods of treating seeds and cuttings. Smartt et al. (1978), working towards the improvement of the cultivated peanut by induced gene introgression from wild species, discuss the progress and problems encountered in polyploid development. One of the major problems is the incompatibility between some of the wild species and *A. hypogaea*.

Germplasm Maintenance

Procedures employed in establishing and evaluating local germplasm collections are similar throughout the world. Each accession is registered and undergoes phytosanitary certification. The botanical and agronomic characteristics are evaluated over a 2 to 3 year period. Germplasm which has suitable plant type and maturity characteristics is selected for further trials and evaluation.

Germplasm collections are stored either in seed storage rooms with ambient conditions, coolers or refrigerators, or, whenever possible, in facilities with both temperature and humidity control. Small samples of the accumulated seed stocks are grown at intervals to assure the maintenance of viable and vigorous seed. Maintaining viable seed of each accession is a very time-consuming task especially if seed storage conditions are sub-optimal. Norden (1981) reported that hand-shelled peanut seed can be stored successfully for at least 10 years if conditions are favorable. The temperature should be slightly above freezing (2 to 5 C) and seed moisture below 6% to maintain viability, prevent insect damage and retain longevity.

There is a general agreement among breeders that much work needs to be done to make collections of *A. hypogaea* germplasm more useful. Because the objectives of most plant breeding programs are essentially the same (i.e., high yields, major disease resistance, drought tolerance, high protein and oil content and quality, and early maturity with dormant seed), a properly organized germplasm system would facilitate the acquisition of material for a specific breeding objective and alleviate duplication of breeding programs or crosses. Current work is underway to organize germplasm collections systematically. Documented accessions (PI) have an internationally known number adaptable to a computerized record system. Advanced breeding lines and commercial cultivars could be coded in a similar manner; however, numerous lines and hybrid progeny selections comprise a very significant proportion of the material in most peanut breeding programs. Breeders need to agree on a method for writing pedigrees and the definition of terms before a workable computerized system can be formulated.

Peanut breeders from 16 countries participated in an international workshop on germplasm preservation and genotype evaluation in July 1975 in an effort to remedy some of the problems encountered in developing effective germplasm collections and exchange programs. As a result of this conference, efforts are being made to establish international peanut germplasm centers, set

up further collection explorations, establish a computerized system for data storage and retrieval and establish cooperative international cultivar evaluation (Varnell and McCloud, 1975). Funds have been very limited, however, for implementing these recommendations.

BREEDING SYSTEMS

Peanut breeders throughout the world have come to rely on breeding systems involving the use of introductions, hybridization and pure line selection. A description of the actual procedures involved in such systems is available (Norden, 1973, 1980a). The pressure on plant breeders to produce new cultivars which have pest resistance and other economically important traits, has forced breeders to scrutinize breeding systems carefully in order to speed up cultivar development. Although breeding systems developed over the past 25 years have provided peanut producers with many improved cultivars, progress has been slow. Simpson et al. (1975) cite the lack of genetic and cytological information, the complex genetic nature of the species, limited genetic variability and the necessity for peanut cultivars to fit specific standards for commercial acceptance as the major stumbling blocks preventing rapid progress by breeders.

In the last few years, USA producers have come to rely on increasingly fewer cultivars. Over 80% of the USA peanut production is accounted for by 3 cultivars, Florunner, Florigiant and Starr (Hammons, 1976a). This narrow genetic base predisposes the USA peanut crop to major damage from pests for which resistance is lacking and burdens the producer with the ever rising cost of petrochemicals necessary for pest protection. In many peanut producing areas of the world, such protection is not economically possible.

Several studies have been conducted to aid the plant breeder in developing breeding systems. Hammons (1973) has suggested that many of the important traits within the *Arachis* genus are probably based upon epistatic gene interactions which might be of advantage if hybrid peanuts were developed; however, this possibility seems very remote at the present time. Therefore, the major tool available to the plant breeder is hybridization. Estimates of genetic variance are needed to provide information on the inheritance of quantitative characters. These include not only the genetic variance for crosses among cultivars but also the type and magnitude of genetic variance for important traits of both adapted and exotic intersubspecific crosses.

Wynne and Rawlings (1978) emphasized the importance of variance component estimation for quantitative characters to facilitate the development of breeding procedures for the effective use of the diversity within *A. hypogaea*. They estimated the additive and additive x additive genetic variances for a cross of 2 virginia cultivars. Their data showed that additive genetic variance was important and that the additive x additive epistatic variance was of minor importance for the cross of these cultivars. Estimates of narrow sense heritability were high for all traits including yield, indicating that selection among the progeny of this intercultivar cross should be effective.

In a diallel cross, F_1 hybrids between subspecies [var. *hypogaea* (Bolivian), var. *fastigiata* (Guanian), and var. *vulgaris*] showed significant general and specific combining ability and hybrid vigor. The F_2 hybrid means were gener-

ally intermediate, but both exceptionally large and small means suggest the presence of dominance and non-allelic interactions (Gregory et al., 1980).

The relative importance of additive and epistatic effects on yield and several fruiting characters were also examined by Isleib et al. (1978) in progeny of a 6-parent half-diallel cross among spanish, valencia, and virginia type cultivars from differing geographic areas of South America. The general combining ability (GCA), a function primarily of additive variance, was not significant for yield or percent sound mature kernels (SMK) during any of the first 5 filial generations. The specific combining ability (SCA) was significant at the 1% probability level for both of these traits through the F_4 and at the 5% level for SMK % in the F_5 . They concluded that the epistatic effects must be important since the level of homozygosity expected in the later generations would preclude dominance from accounting for the non-additive variance.

Serry (1975) reported several genetic studies helpful in developing better breeding systems. These studies were concerned with a number of vegetative and reproductive characteristics of the plant and their relationship with yield. Hammons (1973) and Wynne and Coffelt (Chapter 3 of this book) have summarized the literature that presents our base of knowledge on the inheritance of genetically controlled characters in peanuts.

Pure Line and Mass Selection

The selection and subsequent increase for release as cultivars of single plants (pure line) or groups of plants (mass) from introductions continue to be important methods of peanut improvement. Makulu Red (Smartt, 1978), Apollo and Egret (Hildebrand and Smartt, 1980) and New Mexico Valencia C (Hsi, 1980) are a few examples of recent cultivars resulting from pure line selection. In Argentina (Pietrarelli, 1975) 3 cultivars have been released using pure line selection from a population of 40 introductions. Three of the 4 currently recommended cultivars in Malawi, Chalimbana, Mani Pintar and Malimba were derived by mass selection from introductions (Sibale and Kisyombe, 1980).

Perhaps the major current use of mass selection in peanut breeding has been for seed increase and maintenance. Mass selection is employed by most breeders either by roguing seed increases or by compositing seed derived from random plant increases.

Hybridization or Recombination

The breeder usually is confronted with the problem of combining the desirable traits of an existing cultivar with other beneficial traits. Thus, hybridization and selection among and within hybrid lines is currently the most widely used method of obtaining improved peanut cultivars.

Artificial Hybridization Techniques. Although the peanut is difficult to hybridize, making the cross is the least time consuming phase of the breeding program. The basic crossing techniques and numerous aids and modifications have been reviewed (Norden and Rodriguez, 1971; Norden, 1980b).

Hybridization of the cultivated peanut is commonly done in pots or flats in greenhouses so the plants can be moved around. However, in some countries, hybridization is done in field nurseries. During 1979 and 1980, 30,000 polli-

nations were made in the field at ICRISAT, India (Nigam et al. 1980). By the use of good insect control and an irrigation system to maintain high humidity at the time of pollination, success rates averaging 50% and 67% were obtained.

Crossing success may be strongly affected by environmental conditions and parental management as well as by the expertise of the breeder. Careful observation and consciousness of the growing conditions and plant health are particularly important in off-season greenhouse operations. High humidity favors pollen survival and growth during anthesis and following pollination.

The cultivated species has been taxonomically classified into 2 subspecies and 4 interfertile varieties: (i) subspecies *hypogaea*; variety *hypogaea* (includes the U.S. market types virginia and runner), and variety *hirsuta*; (ii) subspecies *fastigiata*; variety *fastigiata* (valencia market type) and variety *vulgaris* (spanish market type).

Although many interspecific crosses in the genus *Arachis* have failed, successful crosses have been reported (Banks, 1977; Gregory and Gregory, 1979; Gregory et al., 1980; and Singh et al., 1980). Singh et al. (1980) stated that the 2 major constraints to utilization of wild species are differences in ploidy level and incompatibility between some wild species and *A. hypogaea*. The subject of cross compatibility of interspecific crosses in the genus *Arachis* is covered by Smartt and Stalker in Chapter 2.

Hybrid Progeny Management. Optimum plant spacing in breeding nurseries depends mainly on the purpose of the planting and secondarily on the subspecies involved. F_1 plants should be spaced from 45 to 90 cm apart in rows 90 to 180 cm apart to produce sufficient quantities of seed. Spacings from 30 to 45 cm apart in rows 91 cm apart are recommended for segregating populations to permit uniform opportunity for the expression of each plant's potential, and permit visual evaluation and manual separation at harvest by the breeder. The closer spacings are satisfactory with erect or semierect growing types. Results of a study by Norden and Lipscomb (1974) indicated that superior yielding genotypes selected in conventionally spaced rows (91 cm) would also be superior in close-row (46 cm) spacings, and that the confounding effects of seasons is a greater problem in isolating superior yielding genotypes than effects of variations in growth habit or row width.

Harkness and Wright (1980) studied the effect of branching pattern variation on yield of 6 virginia peanut cultivars and found that the lines with abnormal branching patterns had no yield advantage over the lines with normal alternate branching patterns. Wynne et al. (1975), investigating the breeding potential of crosses among diverse peanut lines, concluded that data from space planted tests can provide useful information on the performance of crosses in early generations.

Selection Methods

Bulk population selection, pure line selection, and modifications of the 2 procedures are used to sort out the desirable genotypes in breeding programs.

Bulk Population Selection. In South Africa the progeny of 15 to 20 peanut crosses per year are increased in mass through F_3 generation, and single-plant selections are made beginning in the F_4 with the main objective of

increasing yield and kernal quality for confectionary purposes (Snyman, 1975). Hammons (1976b) successfully utilized a mechanical pod sizer in the F_2 - F_5 generations of a composite cross to select phenotypes meeting U.S. market requirements.

Pure Line Selection. In Argentina, breeders are trying to combine the early maturity and facility of picking and shelling of the widely grown Colorado de Cordoba cultivar with other cultivars and eliminate such defects as lack of seed dormancy, which produces sprouting; fragility of the peg, which causes separation at harvest; low oil content; and susceptibility to leafspot. Using pure-line selection on the progeny of cultivar and interspecific crosses, 1 cultivar was released (Pietrarello, 1975).

Modified Pedigree Selection. One of the major limiting factors in making progress in peanut breeding is the time required for cultivar development. After hybridization, it usually takes from 10 to 20 years to develop a new cultivar. A modified pedigree method of selection using single seed descent, proposed by Goulden (1941) and described by Brim (1966), has been utilized by Wynne (1976b). Using this method each F_2 plant in the population is advanced by a single seed. The main advantages of this procedure are that the genetic variance for characters with low heritability can be easily maintained, less space is utilized, and more than 1 generation can be obtained per year. This method was successfully used to transfer southern corn rootworm (*Diabrotica undecimpunctata howardi*) resistance to lines with desirable agronomic qualities.

Accelerated Programs. To increase the efficiency of the cultivar development program in North Carolina, Wynne (1976b) utilizes a recurrent selection program that combines the use of a greenhouse, a phytotron unit, and winter increase nurseries in a tropical climate. This system makes possible the growth of 5 generations in a 24-month period.

Early generation yield trials were used by Coffelt and Hammons (1974) to evaluate progenies of reciprocal intraspecific crosses between Argentine and Early Runner. F_2 plants were yield tested in the F_3 and the F_3 lines yielding more than the parents were advanced to the F_4 . Nine of 12 F_5 breeding lines yielded more than the parents and 7 produced more than the highest yielding commercial check. Results from the F_5 and F_6 yield trials showed that desirable characters were transferred from each parent to the breeding lines, and that selection on the basis of early generation yield evaluations can be effective in breeding peanuts.

Wynne (1976a) concluded from a test similar to that of Coffelt and Hammons (1974) that early generation tests of selections from crosses of different botanical cultivars are useful for fruit length, % sound mature kernels, and % fancy size pods; but of limited value when selecting for yield. Other methods of accelerating progress in peanut breeding utilize methods to break the dormancy in unripened seeds (Takeuchi et al., 1977) and by growing multiple crops per year (Nigam et al., 1980):

Backcross Breeding

Backcrossing is one of the major tools of peanut breeding programs. It is being used in Texas for the transfer of leafspot disease tolerance from a runner-

type peanut to a spanish peanut (Simpson et al., 1975). Six backcrosses have been made to the recurrent spanish parent and selections are being evaluated for yield. In Malawi, backcrossing was used to incorporate peanut rosette virus resistance from low yielding cultivars from the Upper Volta and Ivory Coast area of West Africa into rosette-susceptible, but high yielding Chalimbana. Rosette virus resistant RG-1 was recently released from this program (Sibale and Kisiyombe, 1980).

Mutation Breeding

Several induced mutation studies have been conducted to incorporate this useful tool into peanut breeding systems. Ashri and Levy (1976) conducted mutation studies in which developing embryos of several bunch and runner cultivars were treated with the alkylating agents ethylmethanesulphonate (EMS) and diethyl sulfate (DES) and other chemical mutagens not previously used on higher plants. A breeding test was developed to distinguish between nuclear and plasmon mutations affecting growth habit (Levy and Ashri, 1978). Ethidium bromide was shown to be a very effective mutagen. Chronic and acute treatments of developing embryos produced very high mutation rates.

Emery et al. (1972) studied the quantitative genetic effects of 9 independently mutated backgrounds of the macromutant 'cup' in which the leaves curl up in a cup shape. Estimates of the additive and additive x additive components of genetic variance were made within 3 specific 'cup' backgrounds. From this study they concluded that selection potential within backgrounds of independent mutations at the same locus is comparable to that within backgrounds of mutations at different loci.

A small mutant peanut with only 4-5 primary branches, but all with flowering nodes, was isolated from a cross between two radiation-induced mutants. Though the overall vegetative growth was less than that of non-irradiated spanish, the number of pegs and pods per plant were similar, indicating better plant efficiency (Patil and Mouli, 1978).

SPECIFIC BREEDING OBJECTIVES AND PROGRESS

Higher Yields

A larger yield per unit land area is one of the ways that a grower has to counteract the continually escalating costs of production. Although development of new peanut cultivars has more than doubled the yielding potential over the last 40 years, yields are not rising as rapidly as they were earlier in the period. Frank McGill, Extension Peanut Specialist for Georgia, was quoted (Shelton, 1980) as saying that higher yields will result when: (1) a greater % of the flowers produced pods, (2) we discover how to utilize the heterosis of the F_1 generation, (3) lines resistant to soil-borne disease are developed and (4) the fertilizer/physiology problem is solved, particularly the poor response to direct fertilization and how to increase fruiting without also increasing plant growth.

Duncan et al. (1978) evaluated the physiological changes in peanut plants from cultivars released during the past 40 years to determine which physiolog-

ical changes are responsible for the yield increases. Weekly harvests of 4 virginia type cultivars, Dixie Runner, Florunner, Early Runner, Early Bunch and a spanish type, Spancross, supplied information on changes in dry weight of all of the plant parts. The number of pegs, flowers, fruit weight, root length, shoot length and leaf areas were also calculated each week. The partitioning of assimilate between vegetative and reproductive parts, the length of the filling period, and the rate of fruit establishment were concluded to be the 3 physiological processes which explained most of the yield variation. Finding that estimates of partitioning to fruit ranged from 41% for the first cultivar released (Dixie Runner), to 98% for the most recently released cultivar, Early Bunch, they concluded that selection for yield has resulted in the development of peanut cultivars that partition more of their daily assimilate to fruit, and that this improvement is largely responsible for gains in yield potential.

The photosynthetic rates of attached leaves of 31 peanut genotypes, including 6 wild *Arachis* species and 24 genotypes of *A. hypogaea*, were compared by Bhagsari and Brown (1976). The photosynthetic rates for Florunner were consistently higher than for most of the other genotypes. The wild species generally had lower photosynthetic rates than did *A. hypogaea*. Photosynthetic rate was positively but weakly correlated with % nitrogen and chlorophyll content of leaves in 2 out of 3 experiments.

Manipulation of the host genotypes has been proposed as a method of increasing biological nitrogen fixation by rhizobia in symbiosis with the peanut. However, Isleib et al. (1980) obtained non-significant correlations between parental and general combining ability effects for traits related to nitrogen fixation. They concluded that simple evaluation of lines for nitrogen-fixing capacity may not identify superior parents for use in breeding programs.

Dholaria et al. (1972) computed the phenotypic, genotypic, and environmental correlation coefficients between yield and yield-contributory characters in 20 spreading and 20 bunch peanut cultivars under high and low fertility levels. Observations were made on the weight of pods per plant, number of pods per plant, number of branches per plant, shelling output and weight of kernels per plant. Under both fertility levels, pod weight per plant of spreading type cultivars was positively correlated with all other characters except shelling output. This relationship was explained by the fact that pods in the spreading type are formed alternately on the branches, and higher yields result because more branches bear more pods. In the bunch group, the pod yields were positively correlated with all other characters studied, with stronger relationships under high fertility levels. Results of this study also indicate that yield of kernels per plant is largely dependent on the weight of pods per plant. Seed size could not be related to seed yield. The weight of pods per plant, shelling percentage and seed weight together gave highly significant multiple correlation coefficients with yield under both fertility levels, and were considered important characters whenever yield selection is practiced.

Serry (1975) reported results of peanut research in Egypt in which highly significant positive correlations were consistently found among yield per plant, stem length, number of branches, number of flowers, number of pods, number of seeds and total seed weight per plant.

Shell and seed characteristics of peanuts are not only important in yield but also in handling and processing, resistance to pests, and general appearance.

Breeders must be aware of the fact that cotyledonary and embryonic tissues of peanut seeds are 1 generation ahead of the seed coat (testa) and the pericarp (shell) which are maternal tissue. Thus, when material is not completely homozygous, testa and pericarp can have a different genotype from the cotyledons and mask the genetic behavior of the seeds and shell/seed relationship. Godoy and Norden (1981) studied shell and seed size relationships in 3 crosses and their reciprocals among genotypes differing in pod and seed sizes. The larger the difference in fruit and seed size between the parents, the more pronounced was the skewness of the size distributions of the progeny toward the smaller parent. Estimates of phenotypic correlations for fruit and seed volume were high and positive in most cases. However, correlations of fruit density with fruit volume were negative, suggesting that seeds grown inside pods with genetically smaller cavities may be compacted by the shell.

Yield Stability and Genotype x Environment Interactions

Stability of yield between seasons and throughout a wide geographical area are important attributes of a commercial peanut cultivar. The objectives of the peanut breeding program in Florida have been to produce cultivars which fit the somewhat specific and restrictive marketing system without the depletion of genetic versatility. Nearly all of the cultivars released by the Florida Agricultural Experiment Station could be classified as multiline strains or early generation composites of 4 to 10 sister lines in the F_4 to F_8 generations. The stability of production over years and locations of the cultivars Dixie Runner, Early Runner, Florispan, Florigiant, and Florunner is well known (Norden et al., 1969, 1977). The advantages of multiline cultivars are: (1) adaptation to wide geographical areas, (2) more stable yields over seasons, and (3) broader protection against disease. The disadvantages are: (1) less uniform than pure line cultivars, (2) more difficult to maintain seed stock and identify in seed certification programs, and (3) generally lower yielding in a given year or location than the best line within it.

A theoretical genetic basis for the utilization of early generation multiline cultivars draws upon the fact that yield control is multigenic and that the cultivated peanut is an allotetraploid. Heterotic effects between alleles within a locus of a given genome are lost rapidly with selfing. However, with multiple genes controlling a trait and final selection of lines in the early generations, a moderate level of residual heterosis could be retained for several generations. Heterosis, due to the interaction of genes at similar loci on different genomes, could also be utilized and would be retained if the genes are in the homozygous condition when the lines are selected and composited (Norden, 1977). Thus, both the genetic diversity of multilines and heterosis available through early generation selection might contribute significantly to stability of yield.

In a 4-year study with 17 peanut genotypes, Yadava and Kumar (1979) concluded that yield stability parameters were governed by independent genetic systems, but stated that more studies are required on the genetic systems governing the different parameters of genotype x environment interaction.

The importance of genotype x environment interactions on yield and grade were evaluated by Tai and Hammons (1978) for entries in the 1976 Georgia variety tests. Short and long season cultivars were included in irrigated and

non-irrigated tests at each of 2 locations. The cultivar component significantly exceeded the first and second order interactions for pod yield and the percentages of sound mature kernels, sound splits, damaged kernels, other kernels, and total kernels. The cultivar effects were consistently evident, especially for pod yield and size factors.

Peanut genotypes differ in their ability to compensate for poor stands. Knauff et al. (1981) examined the yield and grading data over a 7-year period for 6 genotypes of peanuts in rows 91 cm apart; while within row spacings were 10, 15, and 30 cm. Widely spaced (30 cm) plants of Florunner, Florigiant and Early Bunch were less able to maintain the yields of closely spaced (10 cm) plants than were Dixie Runner or 2 experimental lines.

Pest Resistance

Currently, even where effective, acceptable pesticides (environmentally and healthfully) are available, their usage is increasingly costly and being questioned economically. Thus, some of the more important aspects of most peanut breeding programs throughout the world are aimed at developing cultivars with resistance to the major disease and insect pests. Resistance is the safest, most economical, and most satisfactory method of pest control.

McDonald and Raheja (1980) in a recent review of the literature on peanut pests, diseases, resistance and crop protection indicated that research programs in many countries now emphasize the integration of chemical control with cultural practices and the use of resistant cultivars. They stressed that the greatest benefit for the traditional peanut farmer would be the availability of pest resistant cultivars.

A review of literature prior to 1972 on breeding for pest resistance in peanuts has been published (Norden, 1973). The literature since then is extensive, and space would not permit a detailed coverage in this chapter.

Diseases

Multiple pest resistance is a much sought objective of new cultivars and a number of studies are being conducted toward this end. The reaction of 45 peanut breeding lines and plant introductions to rust, cylindrocladium black rot (CBR), pod breakdown (PB), leafspot (LS) and thrips under natural field infestations was reported by Coffelt et al. (1977). Visual ratings of pod and root damage by CBR indicated that root and pod resistance may be controlled by different genetic mechanisms. All lines tested were susceptible to rust, but 2 lines from Nigeria (PI 372263 and PI 372303) had less damage than the others. Seven lines had less PB than Florigiant, the most resistant check. None of the lines tested for thrips damage were resistant, although significant differences were observed among lines. Multiple pest resistance was found in some lines, such as NC3033 which showed resistance to CBR, PB, and LS pathogens.

Cercospora Leafspots. (*Cercospora arachidicola* Hori and *Cercosporidium personatum* [Berk. and Curt.] Deighton). Melouk and Banks (1978) have devised a detached leaf technique to screen for resistance of peanut genotypes to these fungi. Detached compound leaves of various genotypes with petioles

were immersed in Hoagland's solution, inoculated with a spore suspension and placed on racks in a clear plastic, humid chamber in a greenhouse. With temperatures maintained at 27-30°C and 80-90% relative humidity (using cheesecloth on both sides of the chamber), necrotic spots appeared on leaves of susceptible genotypes within 12 days. Most non-inoculated leaves of susceptible and inoculated leaves of resistant genotypes remained free of disease during the entire screening process. This reproducible screening technique requires only a small amount of leaf tissue, space, and fungal inoculum.

Monasterios (1980) evaluated the reaction of 180 peanut genotypes for resistance to leafspot caused by both *C. arachidicola* and *C. personatum*. The disease progress was monitored by taking weekly lesion counts and the prevalence of lesions caused by each of the fungi were made twice during the season. Of the genotypes screened, 14 had very few lesions caused by *C. arachidicola*, 10 had very few caused by *C. personatum*, and 15 had low readings for both. The genotypes FESR-5-1-B-b4, FESR-5-2-B-b4 and NC 3033 showed the fewest number of lesions caused by *C. arachidicola*, while PI 203395, PI 203397, PI 261893-2-1-1-B, PI 261893-1-3-B, PI 261893-2-1-4-1-2B and PI 2619061-1-1-1-2-B-B showed the fewest number of lesions caused by *C. personatum*.

A total of 1,400 peanut introductions were screened for resistance to *C. arachidicola* in greenhouse tests by Sowell et al. (1976) and the more promising lines were subsequently evaluated in the field. PI 109839 was selected and recommended for use as a source of resistance to early leafspot although 6 other plant introductions were as resistant as PI 109839 in the field tests.

Hassan and Beute (1977) evaluated the *C. arachidicola* resistance of 16 peanut lines in the field and greenhouse. In greenhouse tests, Spantex and Starr developed fewer lesions than NC 3033 and AC 3139 following leaf inoculation, while in the field, with naturally occurring inoculum, the reverse was true. They concluded that visual estimation of % leaves infected was a rapid, efficient method for evaluation when large numbers of plants per entry are available.

A study was conducted to determine the structural features of leafspot tolerant and susceptible peanut genotypes to aid in the development of a foliar disease resistance screening program (Taber et al., 1977). Leaflet sections from 8 genotypes, including Florunner, were examined with the scanning electron microscope and compound microscope. Although stomatal distribution patterns were similar on leaves of all genotypes, stomatal size varied among genotypes. Smaller stomatal size was found in PI 269685, a disease tolerant introduction. Differences were also noted in the number of tannin cells which may be of use in screening for leafspot tolerance.

Parent, F₁, and F₂ progenies of 3 *Arachis* species were inoculated with spore suspensions from *C. arachidicola* and *C. personatum* by Sharief et al. (1978). The reactions of the host to the pathogens were measured by the number of lesions/cm² of leaf, area of leaflet diseased, and % of defoliation. The study indicated that the variation in disease tolerance resulted from multifactorial genetic differences in the host. It was also concluded that introgression of genetic factors from the 2 resistant *Arachis* species (*A. chacoense* and *A. cardenasii*) into the genomes of *A. hypogaea* should result in increased host resistance to both pathogens.

At Reading, England, Moss (1977) has produced hexaploids with *A. hypogaea* using *A. chacoense* and *A. cardenasii* and other diploid species. *A. chacoense* is immune to *C. arachidicola* and *A. cardenasii* is resistant to *C. personatum*. These hexaploids have been exposed in field trials to *C. personatum* in India and to *C. arachidicola* in Malawi. Hexaploids from *A. hypogaea* x *A. cardenasii* were unexpectedly found to be resistant to both pathogens. Selected lines are now being used in additional crosses with both diploid and tetraploid parents.

Kornegay et al. (1980) studied the inheritance of resistance to *C. arachidicola* and *C. personatum* in 6 virginia type peanut lines and indicated that resistance to both fungi and tolerance to infection, i.e., minimal leaf defoliation, were primarily due to additive genetic effects. NC 3033 was ranked among the most resistant of the lines and considered among the most useful in a Cercospora leafspot resistance breeding program. A similar statement concerning NC 3033 was made earlier by Hassan and Beute (1977).

Over the years, peanut breeders have observed apparent negative relationships between leafspot resistance and both yield and early maturity. The recently released PI 109839 as *C. arachidicola* resistant germplasm is an example of this. The yield of PI 109839 averages about one-half that of Florunner, and the growth period extends 25 or more days longer (Hammons et al., 1980). Miller and Norden (1980) examined these relationships by comparing the amount of leafspot that developed on 3 peanut cultivars differing in yield and maturity. Fruit production of the cultivars was regulated by removing floral buds for varying periods depending on the maturity of the genotype. The results showed that reducing the yield decreased the severity of leafspot disease symptoms and, based on leaf retention, delayed plant maturity. Peanut breeders should consider this factor as they examine sources, both old and new, of resistance to leafspot diseases.

Web Blotch (*Phoma arachidicola* Marasas, Pauer and Boerema). Smith et al. (1979) compared the reactions of 17 spanish, runner and virginia genotypes to web blotch in 2 yield tests. Reactions were measured as the % infected attached leaflets and the % defoliation. Entries of the virginia and runner market types were generally more resistant to web blotch than the spanish entries. Definitive yield and grade effects were not detectable, but indications were that yield and kernel size were affected. Florunner was among the most resistant and Florigiant and GK-3 were intermediate.

Rust (*Puccinia arachidis* Spegazzini). Peanut rust has occurred with increasing frequency in the United States in recent years and has become established throughout Asia, Australia, and much of Africa. Three genotypes are known to be resistant; Tarapota, Israel line 136, and DHT 200. Resistance is physiological, bigenic, and recessive (Hammons, 1977). Rust resistant lines with acceptable agronomic traits are being developed in several breeding programs. In India, Subrahmanyam et al. (1980) are using 3 rust screening methods to test breeding material and germplasm for rust resistance. Natural infection is used during the rainy season, an infector row system with irrigation is used during the dry season, and a greenhouse method using detached leaves can be used at any time.

Collar Rot (*Diplodia gossypina* Cooke). Florigiant, Florispan and 4 breeding lines were compared for susceptibility to *D. gossypina* at 2 inoculum concentra-

tion levels by Porter and Hammons (1975) to establish the relationship between seedborne inoculum and disease severity. Florispan and the breeding line F 334A-B-14 were the most resistant. Genes for resistance seemed to have been inherited through a parent of Florida cross 334A. The resistance derived from line F334A-B-14 may be valuable in the development of agronomically acceptable resistant cultivars, because it is already a highly productive breeding line.

Sclerotinia Blight (*Sclerotinia sclerotiorum* DeBary). Several peanut cultivars, breeder lines and introductions were screened in a field study for susceptibility to Sclerotinia blight (Porter et al., 1975a). Of the cultivars screened Florigiant appeared to be the most resistant and together with NC 17165 gave the highest pod yields. Some spanish and valencia breeding lines were more resistant than Florigiant and offer sources of greater resistance to *S. sclerotiorum* in breeding programs.

CBR-Black Rot (*Cylindrocladium crotalariae* Loos, Bell and Sobers). Cofelt (1980) compared the reaction of 12 spanish cultivars and 2 valencia plant introductions for reaction to CBR. Highly resistant disease reactions resulted from some spanish genotypes but the author emphasized that critical progeny selection for both pod and root resistance might be necessary in a resistance breeding program.

Hadley et al. (1979) studied the F₁, F₂ and parental generations from a 4-parent diallel cross to determine the heritability of CBR resistance. The progenies of the 4 parents differed in levels of resistance. NC 3033, Argentine and NC2 produced progeny from which resistant selections could be made, while Florigiant produced susceptible progenies in all crosses. Estimates of heritability ranged from 0.48 to 0.65 depending on the method of calculation. Based on these estimates, early generation selection for CBR-resistance in the greenhouse should be effective.

Pythium Pod Rot (*Pythium myriotylum* Drechsler). Erratic but economic peanut losses occur in temperate, sub-tropical and semi-arid regions, where irrigation is practiced, as a result of pod rot caused by *Pythium myriotylum*. Schwarz 21, a somewhat variable spanish cultivar, was reported to be highly resistant to the Pythium pod rot complex in Israel (Frank and Krikun, 1969). Rehovot 121, a resistant selection from Schwarz 21 accessioned into the U.S. as PI 341885, was among the most resistant genotypes tested in Virginia (Porter et al., 1975b).

No rapid, reliable laboratory method of screening for Pythium pod rot resistance, applicable for a breeding program, has been developed. Thus, selection is dependent upon screening populations in soils heavily infested with the pathogen. Repeated evaluations are usually required to reduce misclassifications resulting from escape and non-uniform disease pressure.

PI 341885, Toalson, and PI 365553 showed less pod deterioration than most commercial cultivars in South Texas field tests where pod rot incidence was high (Smith et al., 1976; Boswell et al., 1979). Smith and Boswell (1979) reported some success in combining pod rot resistance and agronomic acceptability, including yield, using field screening on a plant row basis in the F₄ and F₅ generation. Early generation (F₂ progeny row) selection was ineffective (Boswell et al., 1979). Pettit et al. (1975) examined pod tissue for the mechanism(s) of pod rot resistance. They reported that dense sclerenchyma

bands occur within the shells of PI 341885, Toalson, and PI 365553; and that these contain considerable lignin which has considerable antifungal properties. PI 365553 also has thickened cells compactly arranged on the pod surface which was proposed to provide an additional fungal barrier.

Verticillium Wilt (*Verticillium* spp.). Khan et al. (1973) evaluated peanut germplasm for resistance to *Verticillium* wilt and the inheritance patterns of resistance. After screening 152 accessions in the field, promising accessions were further examined in a greenhouse and a growth chamber with artificial inoculation procedures. Twenty-one accessions were selected for having less than 40% wilt. Crosses among the 2 most tolerant and 2 of the most susceptible accessions were used to perform the genetic studies. Susceptibility seemed to be controlled by a single dominant gene, but crosses between the 2 tolerant parents intensified the tolerance levels.

Aflatoxin (*Aspergillus flavus* Link ex Fries and *A. parasiticus* Speare). Extensive research has been under way in recent years to seek ways to eliminate aflatoxin in peanuts which could be the major problem facing the industry. Much of the breeding research has involved the screening of germplasm for resistance to toxin-producing strains (Mixon, 1976, 1980; Amaya et al., 1977, 1980; Bartz et al., 1978; Kushalappa et al., 1979; Zambettakis, 1979) and has sought to identify the mechanisms of resistance (Zambettakis, 1975; Pettit et al., 1977).

Bartz et al. (1978) examined harvesting procedures combined with hand-shelling of various genotypes to test for tolerance to members of the *Aspergillus flavus* group of fungi. Of 15 cultivars tested, Florunner was found to be the most tolerant. Kushalappa et al. (1979) tested 17 peanut genotypes for resistance to colonization by *Aspergillus parasiticus* after 2 growing seasons. They found invaded seeds in pods that appeared free from the *A. flavus* group and seeds free of the test fungus in colonized pods. The study indicated that resistance of pods to *A. parasiticus* is of low heritability, because genotypes that were relatively resistant 1 year were susceptible in the next.

Wilson et al. (1977) compared 2 introductions, PI 337409 and PI 337394F, which were reported to be resistant to *Aspergillus* spp. penetration and colonization, with an easily colonized genotype, PI 343360, and a commercial cultivar, Florunner. They found that although these reportedly resistant introductions may have an advantage in the field, there were no differences between resistant and susceptible genotypes when stored in high relative humidity and temperatures favorable for fungal development.

Tissue of pods and seed coats from reportedly resistant genotypes from the world peanut collection were examined histochemically and morphologically to determine the biochemical and structural differences associated with the ability to resist fungal penetration (Pettit et al., 1977). It was found that the most resistant pods contained sclerenchyma bands within the mesocarpic tissue. The size and shape of the hila and the amount and type of cuticular wax deposition on the exterior surface of the seed coat was also important. Zambettakis (1975) had earlier reported similar results. Of 24 cultivars studied by Zambettakis, Florunner, Darou IV and Shulamit had the slowest spread of infection by *A. flavus* on the surface of the pods and also had pods with the highest proportion of sclerenchyma.

Rosette Virus. *Aphis craccivora* Koch is the only known vector of peanut rosette virus which is of particular concern to peanut breeders in Africa. Although heavy and consistent rainfall and the buildup of predators usually combine to prevent extensive damage from virus, irregular weather patterns in some years can produce conditions for extensive damage in susceptible cultivars. Harkness (1977) used introductions from Senegal to produce resistant cultivars adaptable for both the northern and southern regions of Nigeria. RG-1 is a rosette resistant cultivar developed in Malawi by the backcross breeding of Chalimbana with rosette resistant lines from West Africa (Sibale and Kisyombe, 1980).

Necrotic-Etch Leaf Disease. Hammons (1980) investigated a necrotic-etch leaf disease, which, although it lacks distinctiveness or uniformity of affected areas, is easily identifiable in peanuts. Research indicates that the disease is not transmitted mechanically, but the causal agent is as yet unknown. Using the multicross testing procedure, Hammons determined that it is inherited as a qualitatively controlled recessive characteristic. F₂ data from 5 cross combinations gave good fits to the digenic 15:1 model, indicating duplicate loci. The parental line Jenkins Jumbo has qualitatively controlled resistance to necrotic-etch disease.

Insects

Lesser Cornstalk Borer (*Elasmopalpus lignosellus* Zeller). The lesser cornstalk borer is 1 of the most economically destructive insect pests of peanuts in the U.S. Smith et al. (1980a) reported the development of an objective, rapid technique for greenhouse screening of germplasm. Seedlings planted 1 per container were infested with first instar larvae. Twenty-one days after infestation the plants were scored for damage visible above the soil surface, damage concealed by the soil surface, and survival. Larvae were scored for developmental stage and survival. Entries were screened in groups of 16 including the cultivar Starr as a standard. Evaluations were made of 490 cultivars, introductions and selections. Eighty-one cultivars scored significantly lower ($p < .05$) than Starr in 1 or more rating categories. Re-evaluations were made of some genotypes and the cultivars Early Runner, Florunner and Virginia Bunch scored significantly better than Starr (Smith et al., 1980b). These 3 cultivars also had less larval survival than Comet in field trials reported by Schuster et al. (1975).

Southern Corn Rootworm (*Diabrotica undecimpunctata howardi* Barber). The North Carolina Agricultural Experiment Station recently developed and released NC 6, a peanut cultivar which has sufficient resistance to southern corn rootworm to eliminate the need for insecticide application in many peanut soils (Smith, 1976). Development of NC 6 required 6 years of counting rootworm punctures which resulted in the selection of 4 lines with high rootworm resistance, but they had undesirable agronomic qualities. Work began in 1960, and after years of crossing and screening, this resistant cultivar is now available. Yield and value per hectare show that NC 6 is equal to Florigiant.

Fall Armyworm (*Spodoptera frugiperda* Smith). Noting that the nutrition of the host plant can influence the expression of resistance to insect attack, Leuck and Hammons (1974b) conducted a study using 3 growth media and various

fertilizer combinations. They found that fall armyworm preferred foliage of peanuts grown in Tifton loamy sand field soil over that of peanuts grown in washed sand or vermiculite. The data also showed that fall armyworm resistance varied with the types of fertilizer, vigor, and condition of the cultivar utilized in the study. It was recommended that care must be exercised in designating relative insect resistance to a given peanut cultivar unless very narrow limits of edaphic conditions are observed during testing. Additional testing with fall armyworms showed that inorganic compounds affect plant resistance to this pest, and it was suggested that this information may be used to manipulate it (Leuck and Hammons, 1974a).

Thrips (*Frankliniella fusca* Hinds). Thrips is a pest on seedling peanut plants throughout all production areas of the United States. Young et al. (1972) screened 872 peanut entries for resistance. Slight to moderate resistance was found in 50 entries. Non-preference and antibiosis were suggested as resistance mechanisms.

Kinzer et al. (1973) evaluated 350 cultivars for thrips resistance in the field and made laboratory investigations on those rated as putatively resistant. An Oklahoma selection from PI 280688, identified previously as resistant by Young et al. (1972), demonstrated the most consistent resistance. Larval survival on this selection was only 30% and non-preference for this genotype was marked in both the larval and adult stages of the insect.

Smith (1980) concluded that thrips resistance is available in spanish, valencia, and virginia type peanuts with resistance being more prevalent in the spanish. Thrips injury to peanuts in the U.S. is considered more cosmetic than injurious (Smith and Sams, 1977; Tappan and Gorbett, 1979), but the results from this research may be useful where economic losses result because of insect transmission of viruses.

Pompeu (1975) in Brazil conducted field tests for resistance to thrips, *Enneothrips flavens* Moulton, which is reported to be the most important pest of peanuts in that area. No resistance was revealed in *A. hypogaea* but *A. repens*, *A. macedoi*, and *A. benthamii* were found to be resistant.

Potato Leafhopper (*Empoasca fabae* Harris). More than 700 peanut lines, mostly of the virginia botanical type, were field screened for leafhopper damage in North Carolina during the years 1961 to 1972 (Campbell et al., 1976). Twelve lines, all of the subspecies *hypogaea*, were selected as being highly resistant to the insect. Anatomical studies on leafhopper susceptible and resistant selections revealed that the abaxial epidermis and the length and shape of the trichomes may be related to resistance. The susceptible types had a thinner abaxial epidermis and more appressed trichomes than the resistant. The authors suggested that trichome characteristics may be an effective criterion for selection in a leafhopper resistance breeding program.

Nematodes

Lesion Nematode (*Pratylenchus brachyurus* Godfrey). Resistance to the lesion nematode by 2 unadapted peanut introductions has been reported by Smith et al. (1978). This nematode causes erratic but significant losses of yield and grade on an estimated 20% of the Texas peanut acreage.

Six introductions, selected after a preliminary evaluation of 40 entries, and

2 spanish checks were compared for pod discoloration, and nematode recovery from shell and root tissue. The 2 PI's, 295233 and 290606, had significantly less pod discoloration than Starr and Spangcross in the replicated field test on naturally infested soil. Fewer nematodes were found in the effluent from mist chamber extractions of both the root and hull tissue of the PI's than for the checks.

Florunner, Starr, and the 2 introductions were compared for nematode response in a subsequent test and more nematodes were recovered from pod tissue of Florunner than of the PI's, but the counts were similar for the root tissue. The nematode recovery from the Starr effluent was again higher than for the introductions. Both PI's have been used as parents in the Texas breeding program. Although erratic nematode distribution and population increase confounds resistance with escape, progress has been made in selecting more adapted resistant lines.

Root-Knot Nematode (*Meloidogyne arenaria* Chitwood). Minton and Hammons (1975) conducted greenhouse tests for resistance to root-knot nematodes, a major parasite of peanuts in the southeastern United States. A total of 512 entries including cultivars, breeding lines, and plant introductions were tested but none possessed resistance to *M. arenaria*. These results concur with the report of Banks (1969) that over 4,500 *A. hypogaea* accessions have been screened for resistance to this nematode without finding high levels of resistance.

Genotype x Pesticide Interactions. It is generally assumed that insecticide performance is independent of the peanut cultivar; however, several years of tests by Campbell et al. (1976) indicate that insecticide performance is influenced by the peanut cultivar. Systemic insecticides used for thrip and leafhopper control on bunch type peanuts exhibit the most significant cultivar x insecticide interaction. Thus, insecticidal recommendations should reflect cultivar differences if they occur.

Drought Resistance

Drought conditions are known to reduce yields, cause poor peanut quality and germination, and increase the incidence of aflatoxin. However, information on the effects of drought during various periods in the peanut growing cycle is very limited. Pallas et al. (1979) studied the effects of 5 drought treatments on peanut leaf diffusive resistance, yield, and quality characteristics on rainfall protected plots of Tifton loamy sand. Treatments consisted of early, middle, and late season short drought periods of 35 days and longer early and late drought conditions for 70 days. They found that much of the plant-water stress that developed during drought was relieved 1 day after irrigation. The general trend was progressive decreases in yield as duration and lateness of drought in the season increased. Thus, if full season irrigation is not possible, irrigation in the latter part of the growing season should be considered.

Following recent work which dramatically increased drought resistance in barley and rye grass after moderate gamma-ray irradiation, Gautreau (1976) conducted a study to see if the same results were possible with peanuts. However, drought resistance was not improved in the Senegalese cultivar tested.

Earliness

Early maturity is a priority objective of many peanut breeding programs, especially in areas where the growing season may be shortened by freezing temperatures, a dry season, diseases and pests, and where there is a need to fit peanut production into double cropping or other farming schemes.

Banks and Kirby (1977) are breeding earlier maturing spanish peanuts in Oklahoma to escape the danger of fall frost damage and because such cultivars may allow for double cropping. At ICRISAT, Nigam et al. (1980) stress early maturing cultivars for the semi-arid tropics which have short growing seasons due to a lack of rainfall and to fit peanuts into relay or sequential cropping systems. The sources of earliness being utilized in the breeding program at ICRISAT are Chico, AC 91176 and 91776, which are spanish types that mature in 75-85 days; and a virginia type, Robut 33-1, which matures in 100 days.

One of the major advantages of the new NC7 cultivar is the fact that it matures up to 10 days earlier than Florigiant, the predominant cultivar in North Carolina and Virginia (Wynne and Mozingo, 1979). Frost damage can at times be a problem during harvest in the Virginia-North Carolina area. In Florida, the Early Bunch cultivar matures up to 10 days earlier than Florunner and Florigiant (Norden et al., 1977), which is an advantage in that the crop is less exposed to the vagaries of the weather and pests than with longer season cultivars. Earliness coupled with a high genetic yield potential however, results in moisture and nutritional requirements being more critical during the pod filling period of growth.

Mohammed et al. (1978) used the F_2 and F_3 generations of 2 crosses of a virginia and 2 spanish lines to investigate the selection potential of large fruit, high yield and early maturity. Additive and non-additive genetic effects, heritability, and phenotypic and genotypic correlations were estimated. From this study they concluded that desirable early maturing, large fruited, and high yielding genotypes could probably be extracted from the F_2 and F_3 populations, but selection for maturity and yield would be more efficient in later generations.

Quality

Oil. Analyses were performed on the oil content of 37 selected wild species and 21 selected *Arachis hypogaea* L. cultivars (Cherry, 1977). Oil percentage in seed ranged from 46.5 to 63.1% for wild species and from 43.6 to 55.5% for cultivars. Oil quantities were distributed among wild species and cultivars so a chemotaxonomic relationship could not be established in *Arachis*.

Yang et al. (1979) developed a cultivar Tainan 10 which has an oil content as high as 57.1%. Tainan 10 was derived from the cross Tainan 6 x Florispan Runner.

Oil from seed of different botanical types of peanuts differ in their tendency to develop oxidative rancidity or undesirable odors and flavors. Virginia botanical-type peanuts produce oil with a lower linoleic percentage and therefore tend to have greater oil stability than spanish or valencia botanical types. Hybrids from infraspecific crosses vary in the chemical composition of the oil (Tai, 1972). The oil of Jenkins Jumbo, a virginia type peanut, has unusual biochem-

ical properties. Based on 7 years of tests at Tifton, GA, Jenkins Jumbo averaged 29.8% protein and 48.2% oil. The oil has an iodine value of 82 which is lower, and the mean autoxidation induction period for the freshly expressed oil is longer than for most other peanut genotypes (Hammons and Norden, 1979).

Khan et al. (1974) examined the possible use of refractive indices to assess the fatty acid composition of hybrid and segregating populations of 6 crosses of peanuts. The crosses involved 2 subspecies (*hypogaea* and *fastigiata*), 3 botanical types (virginia, spanish and valencia), and 4 market types, represented by Florigiant, Florunner, Spanhoma and Valencia cultivars. The refractometer proved to be a practical, rapid, inexpensive, and accurate tool for the assessment of the fatty acid composition of peanut oil. A wide range of genetic variability in iodine values was noted in F_2 populations from these infraspecific crosses, indicating that there is selection potential for the improvement of quality and stability of seed oil within specific botanical plant types. Iodine values were determined to be highly heritable and under the control of only a few genes.

Protein. Although peanuts are more popular in the world today for oil, they are also an important protein-rich food. However, peanut protein, like other plant proteins, is low in sulfur-containing amino acids, especially methionine. Heinis (1978) analyzed a total of 239 peanut cultivars and breeding lines and found that the average peanut cultivar has only 67% of the methionine content of whole eggs. No cultivar was very outstanding in methionine levels, although a few, including the parental line, Jenkins Jumbo and the cultivar, NC-Fla 14 were above average. With the exception of methionine, amino acids were positively correlated with % protein. Methionine had a small but significant (5% level) negative correlation with % protein. The NC-Fla 14 cultivar, however, is slightly above average in both protein content and in methionine. The 32% average protein content of NC-Fla 14 (Emery et al., 1974) places this cultivar slightly above the others in the North Carolina-Virginia area. Frank McGill, as quoted by Shelton (1980), stated "if the protein quality can be improved, the demand for peanuts in the world market should be greatly enhanced." Young (1979) reported variety, location, and variety location interaction effects on the amino acid composition of 31 cultivars and breeding lines from uniform variety performance tests in 7 states.

Milling. Milling quality, as defined by Davidson and McIntosh (1973), is a measure of the ability of the seed to resist splitting and skinning by commercial shelling and processing equipment. The amount of splitting is important since it is a major factor in determining market value. However, reliable methods have been unavailable until recently for determining the milling quality of small seed lots. Davidson and McIntosh (1973) developed a small, relatively simple, laboratory sheller for determining the milling quality of small (1 to 2 kg) lots of seed that is useful to the breeder for evaluating milling quality as well as the shelling efficiency of experimental peanut lines. The best index of milling quality is the summation of bald (seeds with seed coats removed) and split seed. For all 3 market types tested (spanish, runner and virginia) the regression equations for correlating the bald plus split seed outturns of the laboratory sheller (Model 3) and commercial type shellers were essentially the same ($y = 0.9x + 2$).

Another method of determining the milling quality of peanuts is by evaluating the tensile strength of individual seeds. This method was designed and utilized by Woodward (1973). His studies showed a high degree of correlation between the milling quality determined by the separation force (tensile strength) of individual seeds and milling quality determined by mechanical shellers. Seeds with seedcoats carefully separated at the interface of the 2 cotyledons offered less than one-tenth the resistance than that of similar seed with seedcoats intact, indicating that the seedcoat is the major resistance to splitting. The cotyledons showed very little bond strength anywhere except where the embryo attaches.

In addition to the direct effects on market quality, seedcoat splitting can have an effect on the germination and susceptibility of the seeds to invasion by fungi, including the toxin-producing *Aspergillus flavus*. Seedcoat splitting can be caused by differences in growth rates of the embryo, cotyledons and seedcoat as well as mechanically. Six peanut genotypes with differing degrees of seedcoat splitting were crossed with non-splitting genotypes and the F_1 , F_2 and F_3 seedcoat generations investigated (Bovi, 1980). The studies indicated that seedcoat splitting is heritable but can be masked or confounded by seed size. In the seedcoat splitting genotypes the heavier seed were more prone to splitting. The F_1 populations showed splitting percentages intermediate between that of the parents. The F_2 populations revealed monogenic inheritance with additive effects in 1 cross and 2 unusual segregations suggesting duplicate additive and complementary gene action. Seed with split seedcoat germinated less than the non-split seed. As a consequence of the poorer germination, the population means tended to be skewed toward the smaller seed weight which was represented to a greater degree by the non-split seed.

Cultivar differences in the testa integrity of peanuts subjected to high drying temperatures was reported by Glueck et al. (1977). Starr and Florunner had a twofold increase in sound split kernels when dried at 49 C as compared to 35 C while the increase in New Mexico Valencia A was insignificant. The percentage of sound splits for NC Fla 14 was similar to that of New Mexico Valencia A at 35 C but testa slippage increased at the high drying temperature. Microscopic examination revealed that mature testae of New Mexico Valencia A were less compacted and more flexible than those of Starr and Florunner.

CULTIVAR MAINTENANCE

With the large expenditure of time (10 to 20 years) and effort involved in peanut cultivar development, it is proper for the breeder to place emphasis on the preservation, maintenance and improvement, if possible, of the new cultivar in order to extend its useful life for as long as possible. Procedures utilized by breeders to maintain the genetic purity and seed viability of new cultivars have been reviewed (Norden, 1973). However, breeders are continually seeking ways of improving the methods and making the task less difficult.

Coffelt et al. (1978) conducted a study to determine which harvesting and curing techniques would be best for the production of breeder's seed in Virginia. The major objectives were to reduce the labor requirement, preserve high germination levels, maintain complete cultivar purity, and prevent loss from frost damage. Three methods were studied. The stack pole-stationary

picker method failed to satisfy the first objective. The windrow-combine method failed to satisfy the last 2 objectives. A new green harvesting method satisfied all objectives. The equipment and curing procedures for this method have been developed but have not yet been tested on a large scale for seed production.

The procedures utilized in the maintenance of breeders seed depend on whether the cultivar is a single pure line, a blend of isogenic lines, a mixture or blend of cultivars or an early generation composite. Where the cultivar is an early generation composite, the breeder must be especially careful to avoid shifting the genetic base. Gorbet (1977) conducted a study to determine the performance of various seed sizes of Florunner peanuts. Traits studied included rate of emergence, seedling vigor, yield, grade, and size distribution of seed harvested from these plantings under field conditions. The rate of emergence and seedling vigor data was positively associated with increased seed size. In 2 of the 3 years studied, higher yields were obtained from larger seeds. However, when data was combined across years, yield differences were only significant between the smallest seed planted (5.16 mm) and the others. Gorbet (1977) concluded that differences in seed size of Florunner were probably due to the stage of maturity and environmental conditions, but because this cultivar is composed of 3 breeding lines, genetic factors could be involved and he cautioned against sizing Florunner seed over a period of years or selection cycles.

THE DILEMMA OF PEANUT BREEDING

The dilemma that peanut breeders are continuously faced with is associated largely with the widely different needs of the various segments of the industry: seed producers, shellers, processors and consumers.

Whereas seed producers desire a peanut with thick, tough hulls to protect the seed within from insects, diseases and damage during harvest and handling, the shelling of such a line would be slower, seed damage higher and sheller turn-out lower. The sheller prefers a thin-shelled peanut that shells rapidly and in which the seeds are encased in tough seedcoats that remain intact and prevent the cotyledons from splitting. However, a line possessing seedcoats of this nature would most likely blanch poorly and be unacceptable by end-use product manufacturers.

Whereas the end-use product manufacturer desires a peanut with oil having a low iodine value and a long shelf-life, consumers generally prefer a peanut with a higher iodine value and oil with a high ratio of unsaturated to saturated fatty acids. Since the 4 U.S. market types of peanuts are completely cross compatible, the breeder has at his disposal a continuous array of plant, pod and seed characteristics, but he is restricted in the material he selects to the artificial standards of these 4 types. Whereas the grower desires a high yielding, early maturing peanut with good leafspot resistance, the lines with the best leafspot resistance are generally later maturing and lower yielding. Because market demands change rather rapidly, end-use manufacturers hesitate to define for the breeder the characteristics that they would like in a peanut 5 or 10 years in the future. Despite the fact that this list could be expanded considerably, much progress has been made in the improvement of peanut cultivars over the years

largely due to the assistance of many people in both the private and public sectors.

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