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THE GROUNDNUT CROP

A scientific basis for improvement

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CHAPTER 14

Groundnut breeding

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14.1 INTRODUCTION

Groundnuts (*Arachis hypogaea* L.) are grown throughout the tropical and warm temperate regions of the world, with commercial production principally between latitudes 40° N and 40° S. Leading producing nations are India (33.4% of global production), China (27.8%), USA (9.3%), Senegal (4.2%), Indonesia (4.2%), Nigeria (3.3%), Myanmar (3.0%), Sudan (2.7%) and Argentina (2.0%). Clearly, the crop is grown in several agroecological systems and under numerous socioeconomic environments. Yield of groundnuts is often low due to diseases and insects, unpredictable and variable rainfall, inability to apply improved agronomic practices and production technology, lack of cultivars adapted to local conditions, low financial inputs, lack of small-scale farm implements, and lack of the infrastructure required to supply quality seed of improved cultivars (Nigam *et al.*, 1991).

The primary objectives of groundnut breeders are to develop cultivars with high yield potential, adaptation to specific environments and production systems, resistance or tolerance to environmental stresses and resistance to diseases and insects. Because groundnuts are grown under many different cropping systems across a wide array of agroecological conditions, the specific objectives of breeding programmes vary considerably. Breeding is a continuing process as the crop is introduced to new environments and production systems, as market demands change, and as disease and insect pest populations shift in reaction to deployment of new cultivars. As the primary constraints to production are overcome by new cultivars and production practices, breeding for improved flavour and quality desired by processors and consumers becomes more important (Bunting *et al.*, 1985).

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TABLE 14.1 *Botanical division of* A. hypogaea *L.*

A. hypogaea L.	Characteristics	Secondary centres of diversity
subsp. *hypogaea*	No flowering on mainstem Alternate branching	
var. *hypogaea*	Two seeds per pod	Bolivian Amazonian
var. *hirsuta* Kohler	Long mainstem Three or more seeds per pod	Peruvian
subsp. *fastigiata* Waldron	Flowering on mainstem Sequential branching	
var. *fastigiata*	Limited vegetative branching Three or more seeds per pod	Goiás and Minas Gerais Guaranian Goiás and Minas Gerais Peruvian North-east Brazil
var. *vulgaris* Harz	Short runs of reproductive branches Two seeds per pod	Goiás and Minas Gerais Guaranian Peruvian

14.2 VARIABILITY IN GROUNDNUT GERMPLASM

In order to develop cultivars with traits that overcome the constraints peculiar to a specific environment, there must be sufficient genetic variation to allow selection for desired traits. Assertions by American researchers regarding the paucity of genetic variation in groundnut referred to specific economically important characters of the extant cultivars and breeding stocks within market classes in the USA (Gregory *et al.*, 1973). More recently, molecular analyses have not detected significant amounts of variability in allozymes (Grieshammer and Wynne, 1990), restriction fragment length polymorphisms (Kochert *et al.*, 1991) or DNA fragments amplified by polymerase chain reaction (Halward *et al.*, 1992) in cultivated germplasm of broadly diverse origin.

The most commonly used botanical division of *A. hypogaea* into subspecies and varieties is that of Krapovickas (1968), based on patterns of reproductive and vegetative branching and on pod morphology as summarized in Table 14.1.

Because of strong local preferences for particular pod and seed characteristics, early breeders of groundnut often worked with limited numbers of parents possessing attributes acceptable to local consumers or processors. In the USA, market classes of groundnut roughly follow the

botanical divisions of the cultivated species with the following exceptions. Firstly, the runner and virginia market classes are commonly equated with var. *hypogaea*, but do not have purely *hypogaea* ancestry. Both have had substantial introgression of fastigiate germplasm, primarily from spanish ancestors (var. *vulgaris*), in the course of plant improvement through breeding (Isleib and Wynne, 1992). Spanish parents were used to increase oil content, shorten maturity and increase the harvest index of the crop. The most common runner and virginia groundnut cultivars in the USA have 0–50% fastigiate ancestry (Table 14.2) and average 35%. Secondly, groundnuts of var. *hirsuta* are not represented in any market class, nor has *hirsuta* germplasm been used in the development of any released cultivars or registered germplasm to date. *Hirsuta* types are extremely rare in the USA national collection and in the global collection maintained at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Andhra Pradesh, India. Chinese scientists report that 'peruvian-type' groundnuts are grown commonly in their central production region, but it is not clear whether the peruvian type mentioned is *hirsuta* or *fastigiata* with the typical peruvian pod configuration. *Hirsuta* groundnuts remain a garden crop in north-western South America and in Mexico (D. Williams, personal communication), and collection efforts should be focused there.

It was not until the late 1970s that the extent of natural genetic variability available to groundnut breeders was fully appreciated and widely recognized (Norden, 1980). Collections of cultivated groundnuts were considered extensive by the mid 1970s (Banks, 1976). Many of these and other accessions in germplasm collections in the USA or at ICRISAT since 1976 were obtained from expeditions made to South America, the centre of origin and diversity for groundnuts, under the sponsorship of the US Department of Agriculture (USDA) and the International Board for Plant Genetic Resources (IBPGR) in co-operation with state experiment stations in the USA and several other countries. The most important expeditions were those of Archer in 1936; Stephens and Hartley in 1947–48; Gregory, Krapovickas, Pietrarelli and others in 1959, 1961, and 1967; Hammons, Langford, Krapovickas, Pietrarelli and others in 1968; and Gregory, Banks, Simpson, Krapovickas, Pietrarelli and others in 1976, 1977, 1979 and 1980 (Wynne and Gregory, 1981) as well as those of IBPGR/CENARGEN/ICRISAT teams made during 1989 (Simpson, 1990). Collection of South American genetic resources continues today with particular emphasis on the wild species native to areas of Brazil undergoing rapid development. Much of the germplasm from Africa, an important centre of secondary variation (Gibbons *et al.*, 1972), was introduced into the United States by Smartt in 1959 (Wynne and Gregory, 1981). These accessions are maintained by the Southern Regional Plant Introduction Station at Experiment, Georgia. The most extensive collection of cultivated groundnut germplasm is now maintained by ICRISAT.

The Genetic Resources Unit there maintains a global collection of more than 12 000 accessions (Nigam *et al.*, 1991). In addition to the cultivated germplasm, there are more than 70 wild species of *Arachis* (Stalker and Moss, 1987). Some of the wild species have direct value as forages (Prine *et al.*, 1981) but for the most part they constitute a genetic reservoir of useful characteristics for the improvement of the cultivated groundnut, notably with respect to host-plant resistance to diseases and insects but perhaps also for agronomic traits (Guok *et al.*, 1986).

Although it was widely recognized that there was tremendous morphological variation among the accessions of cultivated groundnuts, it has only been during the last decade that the extent of the desirable variation has been demonstrated (Wynne *et al.*; 1991). As late as 1973; the widely held view was that there were many defects, with respect to the requirements of man, in the genetic composition of groundnuts (Gregory *et al.*, 1973). This view resulted from inadequate collection and evaluation of the germplasm of groundnuts (Wynne and Halward, 1989b). Systematic and extensive screening of the cultivated germplasm was not practised until ICRISAT adopted groundnut as a mandate crop in 1976 (Nigam *et al.*, 1991).

Several groundnut breeders had large collections of groundnuts by the 1970s but these were inadequately evaluated due to limited funds and personnel (Norden, 1980). Although many of the efforts to evaluate groundnut germplasm have not been systematic or exhaustive, a large number of accessions of cultivated groundnuts have been identified that contain desirable variation for yield, fruit size, morphological traits, tolerance to environmental stresses, disease and insect resistances, and seed composition.

In many developing nations, groundnut's primary use is as an oilseed either for domestic use or for export. Other countries view groundnut primarily as a food crop. In either case, the composition of groundnut has become an issue of increasing importance in the past ten years. For use as an oilseed, the market demands groundnuts with high oil content and good storability. Where groundnut is used as a food, whether as whole or processed seeds, attributes important to the consumer such as flavour, protein quality and shelf life have long been primary concerns of the groundnut marketing and processing industries. Shelf life is largely a function of the time required for auto-oxidation of linoleic fatty acid in the oil fraction of the seed to produce a characteristic rancid flavour. Increased use of oxygen-permeable packaging materials by groundnut processors has increased the need to extend shelf life through genetic improvement of the seed itself. Oleic acid, the 18-carbon mono-unsaturated (18:1) precursor to linoleic acid (18:2), is less reactive with oxygen and is therefore more desirable in the fatty acid profile of groundnut oil. A commonly used index of the storability of groundnut is the ratio of oleic to linoleic fatty acids (O/L ratio). This ratio ranges in value from under 1 to over 2 in cultivars used in the USA (Brown *et al.*, 1975; Ahmed and Young, 1982). O/L ratio

TABLE 14.2 *Fastigiate ancestry of runner- and virginia-type groundnut cultivars currently or formerly grown in the United States*

Cultivar	Market class	Share of US certified area[1]	Specific fastigiate ancestry	Total fastigiate ancestry
Dixie Runner	Runner	0%	50% Small White Spanish 3x-1	50%
Early Runner	Runner	0%	50% Small White Spanish 3x-2	50%
Florunner	Runner	47.4% (61.8%)	37.5% Small White Spanish 3x-2 12.5% Spanish 18–38	50%
GK 7	Runner	7.0% (9.1%)	15.625% Small White Spanish 3x-2 15.625% Spanish 18–38	31.25%
MARC I	Runner	0% (New release)	1.5625% McSpan Spanish 3.125% Pearl 6.25% Small White Spanish 3x-1 21.875% Small White Spanish 3x-2 7.8125% Spanish 18–38	40.625%
Okrun	Runner	3.7% (4.8%)	50% Argentine 18.75% Small White Spanish 3x-2 6.25% Spanish 18–38	75%
Southern Runner	Runner	2.2% (2.9%)	18.75% Small White Spanish 3x-2 6.25% Spanish 18–38	25%
Sunrunner	Runner	3.5% (4.5%)	25% Small White Spanish 3x-2 12.5% Spanish 18–38	37.5%

TABLE 14.2 *Cont.*

Cultivar	Market class	Share of US certified area[1]	Specific fastigiate ancestry	Total fastigiate ancestry
Florigiant	Virginia	0.3% (1.9%)	25% Small White Spanish 3x-2 12.5% Spanish 18-38	37.5%
NC 2	Virginia	0%	25% Spanish 18–38	25%
NC 5	Virginia	0%	25% Improved Spanish 2B	25%
NC 6	Virginia	1.3% (8.0%)		0%
NC 7	Virginia	5.2% (33.4%)	6.25% Improved Spanish 2B 25% Small White Spanish 3x-2 12.5% Spanish 18–38	43.75%
NC 9	Virginia	3.6% (23.0%)	12.5% Small White Spanish 3x-2 18.75% Spanish 18–38	31.25%
NC 10C	Virginia	2.2% (13.9%)	6.25% Improved Spanish 2B 18.75% Small White Spanish 3x-2 12.5% Spanish 18–38	37.5%
NC-V11	Virginia	3.0% (19.1%)	6.25% Improved Spanish 2B 12.5% Small White Spanish 3x-2 6.25% Spanish 18–38 25% PI 337396 (var. *fastigiata*I)	50%
VA-C 92R	Virginia	0% (New release)	6.25% Improved Spanish 2B 12.5% Small White Spanish 3x-2 9.375% Spanish 18–38	28.125%

[1]Proportion of total area certified and (in parentheses) proportion of market class area certified.

is commonly used as a criterion for release of new cultivars in the USA with high values viewed as desirable by the groundnut industry. It is interesting to note that this demand for mono- rather than di-unsaturated fat in groundnut contradicts the general demand for less saturated oils in components of human diets. Norden *et al.* (1987) reported a groundnut variant with an extremely high O/L ratio greater than 30. Moore and Knauft (1989) determined that this trait was governed by two recessive genes and is therefore easily transferable to existing cultivars through backcrossing.

Recently, concern over the high contribution of fats to daily caloric intake by the populations of industrialized nations has created demand for low- or reduced-fat foods. The range of oil content in cultivars in the USA is 43.6–55.5% (Norden *et al.*, 1982). Among over 6000 groundnut accessions evaluated at ICRISAT, the range was 31.8–55.0% (ICRISAT, personal communication). This range is too high to permit reference to groundnut, even at the lower extreme of the distribution of fat contents, as a low-fat food, but it is clear that selection for reduced oil content should be effective.

14.2.1 Foliar fungal pathogens

Much of the screening of the groundnut germplasm for desirable variation during recent years has emphasized biotic stresses. This work was recently reviewed (Nigam *et al.*, 1991; Wynne *et al.*, 1991). Three foliar fungal diseases – late leaf spot [*Phaeoisariopsis personata* (*Mycosphaerella berkeleyi*)], early leaf spot [*Cercospora arachidicola* (*Mycosphaerella arachidis*)] and rust (*Puccinia arachidis*) – are the most widely distributed and economically important diseases of groundnut. They are common wherever groundnuts are grown but they vary in incidence and severity among locations and years. Each disease alone can cause severe damage but yield losses are generally increased when they occur together. For example, rust and late leaf spot together can cause up to 70% yield loss in India (Subrahmanyam *et al.*, 1984). These diseases also affect seed grade adversely and they markedly reduce haulm yields – an effect that is of particular importance in those regions of the semi-arid tropics where small farmers maintain significant numbers of livestock.

Effective field screening methods have been developed for use in areas where natural disease pressure is high or where such pressure can be artificially induced. At the ICRISAT Center, field screening with infector rows is used to challenge host plants in a worst-case situation (Subrahmanyam *et al.*, 1982a). Genotypes and breeding populations to be screened are planted in a nursery together with rows of highly susceptible cultivars arranged systematically throughout the nursery. The ratio of test and infector rows varies from season to season and location to location. A mixture of short- and long-season susceptible cultivars is used to ensure

inoculum supply for a longer period. Plants in infector rows are inoculated with spore suspensions to enhance disease development. This procedure is most successful if infector rows are inoculated in the evening immediately following overhead irrigation. Potted 'spreader' plants heavily infected with rust are also placed systematically throughout the field to provide another source of inoculum. The nursery may be irrigated by overhead sprinklers until harvest as required by climatic conditions.

Disease reaction on test plants is scored using a nine-point scale (Subrahmanyam *et al.*, 1982a, b). Disease scores are recorded about 10 days before harvest in preliminary screening and at several growth stages in advanced screening and other studies. These techniques are useful for grouping lines into resistant and susceptible classes but not for identifying moderate levels of resistance. Germplasm and advanced breeding lines can also be screened in the glasshouse using potted plants or in the laboratory using detached leaves to measure components of disease resistance such as latent period, lesion number, lesion size and sporulation rate.

Screening methods similar to those used for rust are also used for late leaf spot using plots of test genotypes interspersed at regular intervals with susceptible infector rows inoculated with late leaf spot spores. Additional inoculum is provided by scattering on the infector rows leaf debris collected from infected plants in the previous season.

In the USA, field methods for identifying moderate resistance to leaf spots generally require isolation of test genotypes from one another to minimize the effect of adjacent plots. In North Carolina, isolation has been accomplished with border rows of non-host crop species such as maize (*Zea mays* L.), soybean (*Glycine max* [L.] Merr.) or cotton (*Gossypium hirsutum* L.) with eight border rows at 90 cm spacing between adjacent plots and 6–7 m of border between plots occupying the same rows in the field. Each plot is inoculated with spore suspension to ensure the presence of the pathogen, and disease progress is monitored after inoculation. Defoliation of the mainstem is the primary criterion of resistance and is expressed as a proportion or percentage of nodes defoliated. Isolation of the plots reduces the influence of neighbouring susceptible plants on accessions with partial resistance.

Sources of resistance to rust were reported by Bromfield and Cevario (1970). Hammons (1977) summarized the screening of groundnuts for rust resistance and concluded that resistant sources originated from three sources: Tarapoto (PIs 259747, 341879, 350680, 381622, and 405132), Israeli line 136 (PIs 298115 and 315608), and DHT 200 (PI 314817). Tarapoto and DHT 200 both originated in Peru. ICRISAT has screened more than 12 000 accessions of groundnut for rust resistance in the field, using infector rows to develop disease pressure (Subrahmanyam and McDonald, 1983),and 124 lines have been found with rust resistance (Nigam *et al.*, 1991). These include 14 rust-resistant lines released jointly by USDA and ICRISAT (Subrahmanyam and McDonald, 1983). In addi-

tion, several wild *Arachis* species and their interspecific derivatives with cultivated groundnuts have been screened for resistance to rust under both field and laboratory environments (Subrahmanyam *et al.*, 1983c). The rust resistance identified in the cultigen is of a 'slow-rusting' type. Resistant lines exhibit increased incubation period, decreased infection frequency and reduced pustule size, spore production and spore germinability (Subrahmanyam *et al.*, 1983a, b). Many wild *Arachis* species, and lines derived from their hybridization with the cultigen, have been screened for resistance to rust under field and laboratory conditions. Accessions of several species were found to be immune to rust: *A. batizocoi* (PI 298639, PI 338312), *A. duranensis* (PI 219823), *A. cardenasii* (PI 262141), *A. chacoensis* (PI 276235), *A. pusilla* (PI 338449), *A. villosa* (PI 210554) and *A. correntina* (PI 331194) among others (Subrahmanyam *et al.*, 1983c). Most of the interspecific derivatives showed a high degree of resistance to rust. They had small and slightly depressed uredinia that did not rupture to release the comparatively few uredospores produced.

Screening for resistance to the leaf spots caused by *C. arachidicola* and *P. personata* has been extensive in recent years. Several sources of resistance to both early and late leaf spots have been reported (Foster *et al.*, 1980, 1981; Gorbet *et al.*, 1982; Hassan and Beute, 1977; Melouk *et al.*, 1984; Subrahmanyam *et al.*, 1985). Screening for late leaf spot resistance has been most extensive at ICRISAT where the 12 000 or more genotypes screened for rust have also been screened for late leaf spot. Fifty-three accessions of *A. hypogaea* have now been identified with documented resistance to late leaf spot (Nigam *et al.*, 1991) and 29 of these 53 lines are also resistant to rust (Table 14.3). Resistance to late leaf spot operates through much the same mechanisms as resistance to rust (Subrahmanyam *et al.*, 1982b).

Among the many accessions of wild *Arachis* species tested at ICRISAT Center, *A. chacoense* (PI 276325), *A. cardenasii* (PI 262141) and *A. stenosperma* (PI 338280) of section *Arachis* combined cross-compatibility with the cultigen and immunity or high resistance to the pathogen. Highly resistant wild species from other sections included *A. repens*, *A. appressipila*, *A. paraguariensis*, *A. villosulicarpa*, *A. hagenbeckii* and *A. glabrata* (Subrahmanyam *et al.*, 1985).

Several lines, including NC 3033, NC 5, PI 270806, GP-NC 343, PI 109839, PI 259747 and PI 350680, have been shown to possess epidemiological components of rate-reducing resistance to early leaf spot in the USA (Foster *et al.*, 1981; Green and Wynne, 1987; Hassan and Beute, 1977; Sowell *et al.*, 1976). Some of these lines (NC 3033, PI 270806, PI 259747 and PI 350680) did not show resistance in India or Malawi when infector-row inoculation techniques were used (Nigam, 1987; ICRISAT, 1984). Because early leaf spot does not usually occur readily in the field at Patancheru, screening has been less extensive at ICRISAT than for either rust or late leaf spot, but incidences of heavy disease at ICRISAT Center in

1983 and 1987 were utilized to screen germplasm already planted in the field. Also in 1987, screening for early leaf spot resistance on a limited scale was initiated by ICRISAT in Pantnagar, India, where *C. arachidicola* occurs more regularly. Of 3000 genotypes screened for early leaf spot, several showed moderate levels of field resistance at both locations (Waliyar *et al.*, 1989):

ICG 2711 (NC 5)
ICG 6709 (NC Ac 16163)
ICG 7291 (PI 262128)
ICG 7406 (PI 262121)
ICG 7630
ICG 7892 (PI 393527-B)
ICG 9990.

In Malawi, screening for early leaf spot resistance has not identified significant sources of resistance. More than 1000 selected germplasm lines of the cultigen have been screened individually but none showed any appreciable level of resistance to the disease. In 1986–87, 'bulk' testing was utilized to evaluate a large number of lines: 110 bulk populations were constructed by compositing five seeds from each of 100 lines. All lines in a given bulk population shared a common botanical variety. This method allowed representation of 11 000 lines in the screening although the identities of individual lines were lost. Only two bulks had a few plants which merited further testing. In the 1987–88 season, component lines of the two bulks were planted separately and scored for the disease. Only three germplasm lines – ICG 50, ICG 84 and ICG 11282 – were retained for further testing. Other lines that retained a higher than usual proportion of foliage despite heavy disease pressure (ICRISAT, 1986) were:

ICGM 189 (ICG 5216, PI 262087)
ICGM 197 (ICG 6012, NC Ac 16142, PI 262093)
ICGM 281 (ICG 8515)
ICGM 284 (ICG 8521)
ICGM 285 (ICG 8522)
ICGM 286 (ICG 8523)
ICGM 292 (ICG 8529)
ICGM 300 (ICG 8569, NC Ac 868, PI 119072)
ICGM 473 (ICG 3431)
ICGM 500 (ICG 3150)
ICGM 525 (ICG 6151).

Thirty-five lines reported to have resistance to early leaf spot at ICRISAT Center were not resistant in Malawi (ICRISAT, 1989).

Several wild species of *Arachis*, including *A. cardenasii*, have been reported to be resistant to early leaf spot; however, only *Arachis* species 30003 has shown consistent resistance when tested in Malawi using

TABLE 14.3 *Sources of resistance to both rust (*Puccinia arachidis*) and late leaf spot (*Phaeoisariopsis personatum*) available at ICRISAT Centre in 1989*

ICG No.	Identity	Botanical variety	Seed colour	Origin	Disease score[2]	
					Rust	Late leaf spot
1703	NC Ac 17127	*fastigiata*	Variegated	Peru	4.7	5.0
1707	NC Ac 17132	*fastigiata*	Purple	Peru	4.0	4.0
1710	NC Ac 17135	*fastigiata*	Dark purple	Peru	4.0	4.0
2716	EC 76446 (292)	*fastigiata*	Dark purple	Uganda	3.3	4.7
3527	USA 63	*fastigiata*	Purple	USA	4.7	4.7
4747	PI 259747	*fastigiata*	Purple	Peru	3.7	4.0
4995	NC Ac 17506	*fastigiata*	Purple	Peru	4.3	4.3
6022	NC Ac 927	*fastigiata*	Purple	Sudan	4.0	4.0
6330	PI 270806	*hypogaea*	Tan	Zimbabwe	2.1	3.3
6340	PI 350680	*fastigiata*	Dark purple	Honduras	3.0	4.0
7013	NC Ac 17133(RF)	*fastigiata*	Dark purple	India	3.3	4.0
7881	PI 215696	*fastigiata*	Dark purple	Peru	4.3	3.7
7884	PI 341879	*fastigiata*	Purple	Israel	3.0	3.7
7885	PI 381622	*fastigiata*	Purple	Honduras	3.0	4.3
7886	PI 390593	*fastigiata*	Tan	Peru	4.7	3.3
7894	PI 393641	*fastigiata*	Variegated	Peru	4.0	4.7
7897	PI 405132	*fastigiata*	Purple	Peru	2.7	4.0

TABLE 14.3 *Cont.*

ICG No.[1]	Identity	Botanical variety	Seed colour	Origin	Disease score[2]	
					Rust	Late leaf spot
10010	PI 476143	*fastigiata*	Variegated	Peru	4.0	5.0
10023	PI 476152	*fastigiata*	Tan	Peru	4.3	4.7
10028	PI 476163	*fastigiata*	Purple	Peru	4.7	5.0
10029	PI 476164	*fastigiata*	Tan	Peru	4.3	5.0
10035	PI 476172	*fastigiata*	Purple	Peru	4.0	3.7
10889	PI 476016	*fastigiata*	Red	Peru	3.3	4.3
10915	PI 476148	*fastigiata*	Variegated	Peru	2.3	5.0
10936	PI 476168	*fastigiata*	Dark purple	Peru	4.3	4.0
10940	PI 476173	*fastigiata*	Variegated	Peru	2.3	5.0
10941	PI 476174	*fastigiata*	Light purple	Peru	4.7	4.7
11182	PI 476174	*fastigiata*	Tan	Peru	2.7	5.0
11485	--	*fastigiata*	Light purple	Peru	5.0	3.7
Susceptible check cultivars:						
221	TMV 2	*vulgaris*	Tan	India	8.3	8.0
799	Robut 33–1	*hypogaea*	Tan	India	7.7	7.3

[1] ICRISAT groundnut accession number.
[2] Scored on a modified 9-point disease scale where 1 = 0%, 2 = 1 to 5%, 3 = 6 to 10%, 4 = 11 to 20%, 5 = 21 to 30%, 6 = 31 to 40%, 7 = 41 to 60%, 8 = 61 to 80% and 9 = 81 to 100% damage to foliage (ICRISAT Center, rainy season 1989).

TABLE 14.4 *Reaction of some groundnut germplasm lines with resistance to early (Cercospora arachidicola) and late leaf spot (*Phaeoisariopsis personatum*) and rust (*Puccinia arachidis*), ICRISAT Center, rainy season 1987*

Entry	Original name	Disease reaction[1]		
		Early leaf spot	Late leaf spot	Rust
ICG 1703	NC Ac 17127	4.7	5.0	4.7
ICG 6284	NC Ac 17500	5.0	7.0	3.3
ICG 7340	198/66 Coll 182	5.7	5.1	2.7
ICG 9294	58–295	5.1	6.0	2.7
ICG 10010	PI 476143	5.7	5.1	4.1
ICG 10040	PI 476176 (SPZ 451)	5.0	4.7	3.7
ICG 10900	PI 476033	5.3	4.7	4.1
ICG 10946	PI 476176	5.0	6.0	4.1
Susceptible controls				
ICG 799	Kadiri 3 (Robut 33–1)	8.0	7.0	7.0
ICG 221	TMV 2	8.0	8.0	8.0
Mean (n=500)		6.9	6.5	4.9
Standard error[2]		±0.48	±0.7	±1.1
CV (%)		7.0	11	22

[1] Mean of 3 plots, each 2 4-m rows, rated on a 1–9 scale where 1=no disease and 9=50–100% foliar destruction.
[2] Standard error and CV calculated on the basis of all 500 genotypes tested.

infector-row inoculation techniques (ICRISAT, 1989). Among other species, *A. chacoensis* and *A.* sp. 30085 showed high promise in the first year of screening but were susceptible in subsequent tests. *A. stenosperma* was found to be highly susceptible in Malawi (ICRISAT, 1988), contrary to reports from the USA. Several interspecific derivatives were found to retain more foliage than the susceptible control cultivar.

Table 14.4 shows that eight lines of groundnuts with moderate to high levels of resistance to all three foliar diseases – rust, early leaf spot and late leaf spot – have been identified (ICRISAT, 1988; Waliyar *et al.*, 1989). The rust and late leaf spot reactions of most accessions are stable over a wide range of geographic locations. Only for NC Ac 17090 and PI 298115 has variation in rust reaction been observed across locations. Reaction to early leaf spot has exhibited greater variation across locations. The eight lines in Table 14.4 are potentially the most useful parental lines available, since the foliar diseases generally occur in combination.

The genetics of resistance to these three diseases is not well understood. Bromfield and Bailey (1972) first reported that resistance to rust in the cultigen was controlled by two recessive genes. However, Nigam *et al.* (1980) found continuous variation in the progeny of crosses among rust-resistant FESR lines (Bailey *et al.*, 1973) and suspected that rust resistance, though recessive in nature, might be governed by more than two genes. In generation means analysis of resistant-by-susceptible crosses, Reddy *et al.* (1987) found additive, additive-by-additive and additive-by-dominance effects for rust resistance. In some diploid wild *Arachis* species, resistance appeared to be partially dominant (Singh *et al.*, 1984).

Nevill (1982) studied five F_2 progenies from crosses between two resistant and three susceptible cultivars for components of resistance to late leaf spot in detached leaf tests. To account for the observed distribution of phenotypic values in the F_2, he postulated a five-locus polygenic system assuming resistance to be completely recessive. Non-additive gene action was concluded to be extremely important but its nature could not be elucidated due to the omission of the F_1 generation from the study.

14.2.2 Viral pathogens

Variation for resistance to several virus diseases has been reported in groundnut (Nigam *et al.*, 1991). The crop is host to several viruses but only a few are considered economically important. These include groundnut rosette (GRV) in Africa, bud necrosis (BNV) in India, tomato spotted wilt (TSWV) in the USA, peanut mottle (PMV) worldwide, peanut stripe (PStV) in east and south-east Asia, and peanut clump (PCV) in West Africa and India. Laboratory and field screening techniques have been developed for all these virus diseases. Resistance to rosette virus was discovered in local land races in Burkina Faso in the 1950s (de Berchoux, 1958, 1960). Of seven wild species of *Arachis* screened in an SADCC–ICRISAT regional groundnut project, two species (*A.* sp. 30003 and *A.* sp. 30017) remained symptom-free throughout the season. The apparent immunity of *A.* sp. 30003 to rosette and its high resistance to early leaf spot suggest that efforts to use this species should be emphasized (Bock, 1989).

Several groundnut accessions with consistently low symptoms of bud necrosis have been identified at ICRISAT, including:

C102
C121
C136
GP-NC 343
NC Ac 2232
NC Ac 2242
NC Ac 17888
ICGV 86029
ICGV 86031.

Only ICGV 86029 and 86031 showed tolerance to the virus (Nigam *et al.*, 1991). Southern Runner, a cultivar with resistance to late leaf spot, has

shown fewer symptoms of tomato spotted wilt virus than other cultivars in the USA.

Peanut stripe, both aphid-transmitted and seed-borne, is composed of strains which can be distinguished on the basis of differential host reaction. Over 9000 lines of *A. hypogaea* were screened at two sites in Indonesia without any resistance being found (Nigam *et al.*, 1991). A few wild species have shown resistance with one species, *A. cardenasii*, being immune (Stalker and Moss, 1987).

Peanut mottle virus (PMV) disease of groundnut is widespread and generally present in varying intensity in all major groundnut-growing areas of the world. It can cause up to 30% loss in yield (Kuhn and Demski, 1975). Because PMV's foliar symptoms are inconspicuous, it has not received much attention in crop improvement programmes. Infected plants show mild mottling and vein clearing in newly formed leaves. Older leaves show upward curling and interveinal depression with occasional dark green islands. Infected plants are not severely stunted and older plants seldom show typical symptoms. The virus is sap-transmitted and its vectors are *Aphis craccivora*, *A. gossypii* and *Myzus persicae* among others. It is also seed-transmitted in a range from 0.1% to 3.5%, depending on the groundnut genotype (Ghanekar, 1980).

From a 5-year study on PMV epidemiology in Georgia, USA, Kuhn and Demski (1975) concluded that the initial inoculum of the disease in the field came from seedlings originating from infected seeds. Taking a lead from this observation, the groundnut group at ICRISAT adopted the approach of combining resistance/tolerance to PMV with absence of seed transmission in the disease resistance breeding. Limited breeding efforts are under way to achieve this objective.

A rapid method of field inoculation has been developed (Ghanekar, 1980), by means of which about 1000 plants can be inoculated in 1 hour with 80% infection frequency. The method involves the spraying of extracts from infected leaves, prepared in phosphate buffer containing celite and mercaptoethanol, onto test plants through a fine nozzle under pressure of 50 psi. More than 2500 germplasm lines of *A. hypogaea* have been screened in the field. No line has shown resistance to the virus; however, many germplasm lines suffered much lower yield loss than controls. Two germplasm lines, NC Ac 2240 and NC Ac 2243, have shown significantly low yield loss due to disease over years (ICRISAT, 1983). A few breeding lines have also shown tolerance to the disease.

Fifty wild *Arachis* species accessions have been screened for PMV resistance under glasshouse conditions using mechanical leaf rub and air brush inoculations. Of these, only two species, *A. chacoensis* (10602) and *A. pusilla* (12911), remained free from infection even after repeated graft inoculations (Subrahmanyam *et al.*, 1985).

Seeds of PMV-infected plants of several germplasm lines were screened in the laboratory for virus presence, using ELISA (Reddy, 1980). With this technique, 1000 seeds can be screened in 2 days. A small portion of cotyledon is adequate for the test. Two rust-resistant germplasm lines, EC 76446(292) and NC Ac 17133(RF), have failed to show any seed transmission in repeated tests over years on seeds totalling more than 13 000 (ICRISAT, 1988). A recently released Indian cultivar and many breeding lines with these rust-resistant parents in their ancestry also have shown no seed transmission. Lines with low yield loss and no seed transmission characteristics have been crossed and advanced generation lines are in field tests for measuring yield loss due to the disease. Promising lines from these tests will be studied for non-seed transmission in the laboratory.

Peanut clump virus (PCV) disease has been reported from West Africa (Trochain, 1931; Bouhot, 1967) and India (Sundararaman, 1926; Reddy *et al.*, 1979). The virus is soil-borne and seed-transmitted (ICRISAT, 1986). Infected plants are severely stunted with small, dark green leaves. The young tetrafoliolate leaves show mosaic mottling and chlorotic rings. Roots become dark in colour and the outer layers peel off easily. Most of the early-infected plants fail to produce pods. Even in case of late infection, losses of up to 60% are recorded. The virus has many serologically distinct isolates which produce varying severity of disease on groundnut varieties and different reactions on diagnostic hosts. A few soil fungi and nematode species have been suspected as possible vectors of the virus. Studies in India have shown that *Polymixa graminis*, a soil fungus, can transmit the virus (ICRISAT, 1988).

The disease occurs in both warm summer and rainy season crops. The extent of area infected with the disease is not well documented. Individual fields can become severely infected with the virus, forcing farmers to abandon groundnut cultivation in those fields. Chemicals such as Nemagone®, Temik®, and Carbofuran® can greatly reduce disease and increase yields. However, these chemicals are expensive for most farmers of the semi-arid tropics. Solarization treatment of the infected areas of the field greatly reduces the disease incidence (ICRISAT, 1987).

More than 7000 germplasm lines of the cultivated groundnut species *Arachis hypogaea* have been screened in farmers' diseased fields in the Indian states of Punjab and Andhra Pradesh. None of these lines showed resistance to the virus. A few lines showed tolerance to the disease as they did not suffer severely in growth and yield. Of 38 wild *Arachis* species and their 200 interspecific derivatives tested, only *Arachis* species 30036 did not become infected in the field (ICRISAT, 1985). Due to the genetic complexity of virus populations and lack of high-level tolerance in germplasm, no resistance breeding activity has been started for this disease.

14.2.3 Soil-borne pathogens

Screening of groundnut germplasm for resistance to soil-borne diseases has been less extensive than screening for resistance to foliar fungal pathogens

because of the local prevalence of most soil-borne diseases. Nevertheless, variation for reaction to several soil-borne diseases has been found in groundnut. Resistance to bacterial wilt caused by *Pseudomonas solanacearum* was reported in the 1920s by Dutch scientists working in East Java (Indonesia) (Buddenhagen and Kelman, 1964). The disease occurs in several Asian and African countries but significant losses are reported only for Indonesia and China. Numerous resistant genotypes have been identified in those two countries (Nigam *et al.*, 1991).

From screening in North Carolina, USA, a few virginia and several spanish genotypes were reported to be resistant to *Cylindrocladium crotalariae*, which causes cylindrocladium black rot disease (CBR) (Green *et al.*, 1983). NC 3033, a line resistant to CBR, was also found to be resistant to *Sclerotium rolfsii*, the causal organism of southern stem rot (Beute *et al.*, 1976).

Toalson, PI 341885 and TxAG-3 (a selection from PI 365553) were found to be resistant to southern stem rot and pythium pod rot caused by *Pythium myriotylum* in Texas (Smith *et al.*, 1989). Resistance has also been found to *Sclerotinia minor* in screening studies in Oklahoma and Virginia (Coffelt and Porter, 1982). Sources of resistance include Chico, germplasm from Texas (TX 498731, TX 798736, TX 804475), germplasm from Virginia (TRC 02056-1), and seven accessions from China (PIs 467829, 476831, 476834, 476835, 476842, 467843, and 467844) (Wynne *et al.*, 1991).

14.2.4 Aflatoxin

Environment and cultural practices can make groundnut plants and seeds prone to invasion by toxigenic species of *Aspergillus* (*A. flavus* and *A. parasiticus*) – discussed also in Chapters 10 and 13. Seeds may be contaminated with aflatoxin before harvest, during post-harvest curing and drying, or during storage. In some regions the problem develops predominantly post-harvest while in others it is largely a preharvest phenomenon. Several recommendations have been made regarding cultural practices, curing and drying procedures, and storage conditions to minimize seed invasion by *A. flavus*. However, these recommendations have not been widely adopted in developing nations where groundnut production is subject to the vagaries of the weather.

Aflatoxin contamination was considered a post-harvest problem and received little attention in breeding programmes until it was reported by Mixon and Rogers (1973) that two germplasm lines, PI 337409 and PI 337394F, were resistant to seed invasion and colonization by *A. flavus*. Their screening method used rehydrated, sound, mature seeds inoculated artificially with *A. flavus* conidia in an environment favourable to fungal growth. They suggested that this resistance to invasion and colonization to *A. flavus*, associated with the seed coat, could be an effective means of preventing aflatoxin contamination. Varietal resistance to aflatoxin production in groundnut seed also was reported by others (Rao and Tulpule, 1967; Kulkarni *et al.*, 1967). These findings stimulated further research on varietal resistance in several countries.

Resistance to *A. flavus* in groundnut may operate at three sites in the plant: the pod, the seed coat and the cotyledons. Genetic variation in pod resistance to *A. flavus* has been attributed to differences in pod-shell structure (Zambetakkis *et al.*, 1981), presence of antagonistic microflora in the shell (Kushalappa *et al.*, 1979; Mixon, 1980), and the presence of thick-walled parenchyma cells (Pettit *et al.*, 1977). Field screening for pod resistance has been limited somewhat due to the problem of consistently reproducing the environmental conditions required to promote infection. Infection of seeds from the field may be assessed by surface sterilizing seeds from mature intact pods and then incubating them under conditions conducive to fungal growth. Disease reaction is typically expressed as the percentage of seeds exhibiting colonization.

Seed-coat resistance has also been associated with different characteristics such as the compact arrangement of testa cells and small hilum with little exposure of parenchyma cells (Taber *et al.*, 1973), waxes deposited on the testa (LaPrade *et al.*, 1973), 5,7-dimethoxyisoflavone (Turner *et al.*, 1975), tannin (Sanders and Mixon, 1978; Lansden, 1982; Karchesy and Hemingway, 1986), and total soluble amino compounds and arabinose content (Amaya *et al.*, 1980). However, Jambunathan *et al.* (1989) did not find significant correlation between seed colonization and polyphenol content in seed coat. Procedures for assay of *in vitro* seed colonization by *A. flavus* (IVSCAF) utilize artificial inoculation to ensure uniform exposure of seeds to the pathogen. Sound mature seeds from intact, dried pods are surface sterilized, imbibed, and inoculated with a conidial suspension of a toxigenic strain of *A. flavus* or *A. parasiticus*, then incubated to promote mycelial growth (Mixon and Rogers, 1973; Mehan *et al.*, 1981).

Many sources of resistance have now been reported for preharvest seed infection, *in vitro* seed colonization and aflatoxin production (Table 14.5). These include PI 337409, PI 337394F, UF 71513, J 11, Ah 7223, U-4-47-7, 55-437, and 73-30 for preharvest field infection and colonization and aflatoxin production. J 11 is grown commercially in India, as are 55-437 and 73-70 in Senegal and other West African nations. Three lines with resistance to IVSCAF (PI 337394F, PI 337409 and J 11) have been evaluated in more than one country. J 11 exhibited resistance to seed infection in India and the USA. PI 337409 was resistant in tests in Senegal and India, but was susceptible in the USA (Kisyombe *et al.*, 1985). Mixon (1976) recorded percentage colonization of seeds in the F_1 and F_2 generations of crosses between PI 337409 and PI 331326, a susceptible line. Broad-sense heritability was estimated at 78.5%. Based on diallel and factorial matings conducted at ICRISAT Center, Vasudeva Rao *et al.* (1989) reported that UF 71513, Ah 7223, PI 337394F and PI 337409 had good combining abilities for seed-coat resistance. Resistance to IVSCAF in breeding lines

TABLE 14.5 *Sources of resistance to* Aspergillus flavus *or* A. parasiticus

Source of resistance	Type of resistance	Country where used	Reference
1–4	IVSCAF	India	Ghewande *et al.*, 1989
1–7	IVSCAF	India	Ghewande *et al.*, 1989
55–437	Field infection	Senegal	Waliyar and Bockelee-Morvan, 1989
			Zambetakkis *et al.*, 1981
	IVSCAF	Senegal	Zambetakkis *et al.*, 1981
73–30	Field infection	Senegal	Waliyar and Bockelee-Morvan, 1989
			Zambetakkis *et al.*, 1981
	IVSCAF	Senegal	Zambetakkis *et al.*, 1981
73–33	Field infection	Senegal	Waliyar and Bockelee-Morvan, 1989
			Zambetakkis *et al.*, 1981
	IVSCAF	Senegal	Zambetakkis *et al.*, 1981
A. cardenasii	Aflatoxin production	India	Ghewande *et al.*, 1989
	IVSCAF	India	Ghewande *et al.*, 1989
A. duranensis	Aflatoxin production	India	Ghewande *et al.*, 1989
	IVSCAF	India	Ghewande *et al.*, 1989
Acc 63	IVSCAF	Philippines	Pua and Medalla, 1986
Ah 6487	IVSCAF	China	Tsai and Yeh, 1985
Ah 7223	Field infection	India	Mehan *et al.*, 1986b, 1987
	IVSCAF	India	Mehan and McDonald, 1980
			Ghewande *et al.*, 1989
AR-1	IVSCAF	USA	Mixon, 1983b
AR-2	IVSCAF	USA	Mixon, 1983b
AR-4	IVSCAF	USA	Mixon, 1983b
Basse	IVSCAF	China	Tsai and Yeh, 1985
C 116(R)	IVSCAF	China	Tsai and Yeh, 1985
C 184	IVSCAF	China	Tsai and Yeh, 1985
Celebes	IVSCAF	Philippines	Pua and Medalla, 1986
CES 48–30	IVSCAF	Philippines	Pua and Medalla, 1986
CGC 7	IVSCAF	India	Ghewande *et al.*, 1989
CGC-2	IVSCAF	India	Ghewande *et al.*, 1989
Darou IV	Pod infection	Senegal	Zambetakkis, 1975
F-7	IVSCAF	China	Tsai and Yeh, 1985
Faizpur	IVSCAF	India	Mehan and McDonald, 1980
GE 652	IVSCAF	China	Tsai and Yeh, 1985
GFA-1	IVSCAF	USA	Mixon, 1983a
GFA-2	IVSCAF	USA	Mixon, 1983a
J 11	Field infection	India	Mehan *et al.*, 1986b, 1987
	IVSCAF	India	Mehan and McDonald, 1980
			Ghewande *et al.*, 1989
		USA	Kisyombe *et al.*, 1985

TABLE 14.5 *Cont.*

Source of resistance	Type of resistance	Country where used	Reference
M395	IVSCAF	China	Tsai and Yeh, 1985
Maria-B	IVSCAF	China	Tsai and Yeh, 1985
Monir 240–30	IVSCAF	India	Mehan and McDonald, 1980
NC 449	IVSCAF	China	Tsai and Yeh, 1985
NC 482	IVSCAF	China	Tsai and Yeh, 1985
PI 196621	IVSCAF	China	Tsai and Yeh, 1985
PI 196626	IVSCAF	China	Tsai and Yeh, 1985
PI 337394F	Field infection	India	Mehan *et al.*, 1986b, 1987
		Senegal	Waliyar and Bockelee-Morvan, 1989
			Zambetakkis *et al.*, 1981
	IVSCAF	India	Mehan and McDonald, 1980
		Senegal	Zambetakkis *et al.*, 1981
		USA	Mixon and Rogers, 1973
PI 337409	Field infection	Senegal	Zambetakkis, *et al.*, 1981
	IVSCAF	India	Mehan and McDonald, 1980
		Senegal	Zambetakkis *et al.*, 1981
		USA	Kisyombe *et al.*, 1985
			Mixon and Rogers, 1973
PI 339407	Field infection	India	Mehan *et al.*, 1986b, 1987
		Senegal	Waliyar and Bockelee-Morvan, 1989
RMP 12	IVSCAF	China	Tsai and Yeh, 1985
Roxo (Sal)	IVSCAF	China	Tsai and Yeh, 1985
S 230	IVSCAF	India	Ghewande *et al.*, 1989
Shulamith	Pod infection	Senegal	Zambetakkis, 1975
Sp. 218	IVSCAF	China	Tsai and Yeh. 1985
Sp. 424	IVSCAF	China	Tsai and Yeh, 1985
U4–47–7	Field infection	India	Mehan *et al.*, 1986b, 1987
	IVSCAF	India	Mehan and McDonald, 1980
U4–7–5	Aflatoxin production	India	Mehan *et al.*, 1986a
UF 71513	Field infection	India	Mehan *et al.*, 1986b, 1987
	IVSCAF	India	Mehan and McDonald, 1980
	IVSCAF	USA	Bart *et al.*, 1978
UPL Pn4	IVSCAF	Philippines	Pua and Medalla, 1986
Var 27	IVSCAF	India	Mehan and McDonald, 1980
VRR 245	Aflatoxin production	India	Mehan *et al.*, 1986a

developed in India has remained stable over years and locations (Vasudeva Rao *et al.*, 1989).

In the United States, there is controversy as to the value of IVSCAF in practical control of *Aspergillus* contamination. Wilson *et al.* (1977) found production of aflatoxin in PI 339396F and PI 339407 to be similar to IVSCAF-susceptible genotypes PI 334360 and Florunner when seed lots were stored under high humidity. All lots exhibited 2–3% infection of seeds by *Aspergillus* spp. prior to storage. None of the lots was inoculated. Davidson *et al.* (1983) compared aflatoxin contamination in farm-grown samples of Florunner with Sunbelt Runner, a cultivar selected for resistance to IVSCAF. Seeds of Sunbelt Runner sampled prior to storage exhibited levels of natural infection and aflatoxin production comparable to Florunner. Seed-coat resistance is operative only in seeds with intact testae. The conditional nature of this resistance limits its utility under field conditions. Its effectiveness is reduced by mechanical operations causing pod and seed damage or by faulty curing, drying and storage conditions.

Genetic variation has been observed for the ability of groundnut cotyledons to support production of aflatoxins (Rao and Tulpule, 1967; Kulkarni *et al.*, 1967; Doupnik, 1969; Aujla *et al.*, 1978; Doupnik and Bell, 1969; Nagrajan and Bhat, 1973; Tulpule *et al.*, 1977). Very little is known about the mechanism of resistance to aflatoxin production. Several studies have reported effects of fungal nutrition on toxigenesis by *Aspergillus* spp. grown on defined media. Payne and Hagler (1983) observed differences in the growth of *Aspergillus* spp. on media containing different amino acids. Casein, proline, asparagine and ammonium sulphate supported fungal growth and toxin production better than did tryptophan or methionine. Venkitasubramanian (1977) found toxin production to be enhanced on defined media containing casamino acids rather than urea or ammonium nitrate as the nitrogen source. Maggon *et al.* (1973) studied the effects of micronutrients on aflatoxin biosynthesis, finding that toxin production was stimulated by copper but inhibited by cadmium, barium and vanadium. Screening methods for aflatoxin production are similar to those used for seed colonization. Some researchers have removed the testa of the seed prior to inoculation in order to remove any barrier to infection contained therein. Inoculated seeds are incubated and aflatoxin measured using thin layer chromatography (Mehan and McDonald, 1980). Mehan *et al.* (1986) identified U4-7-5 and VRR 245 as resistant to production of aflatoxin. U-4-7-5 and VRR 245 do not support high levels of aflatoxin production but are susceptible to colonization and seed invasion. A previous report of two wild species, *A. cardenasii* and *A. duranensis*, supporting production of only trace levels of aflatoxin (Ghewande *et al.*, 1989) was not confirmed in subsequent screening performed at ICRISAT (Mehan *et al.*, 1992).

A. flavus is a weak pathogen. Its ability to invade intact pods and seeds is strongly influenced by environmental conditions during pod and seed development. Developing pods must be predisposed to infection by the occurrence of water stress in the soil surrounding them and by high soil temperatures (38–40 °C) in the podding zone (Cole *et al.*, 1989). These conditions weaken the host plant and suppress the growth of soil microbes antagonistic to or competitive with *A. flavus*. At ICRISAT Center, field screening for resistance to preharvest infection is conducted in the post-rainy season; severe drought stress is imposed by withholding irrigation late in the growth cycle.

14.2.5 Insect pests

Groundnut is subject to reduction of yield and quality due to feeding by insects and arachnids on leaves, pegs, pods and seeds. In addition to causing damage directly, some insects serve as vectors of viral diseases. Insects of global importance include aphids, thrips, jassids and *Spodoptera*. Leaf miner, *Hilda*, *Helicoverpa* and other lepidopterous species present problems in specific regions. In Asia and Africa, white grub is the most economically important pod-feeding pest, but termites, millipedes and ants may also damage pods in specific regions. In the USA, lesser cornstalk borer (*Elasmopalpus lignosellus*), white-fringed beetle (*Graphognathus* spp.) and southern corn rootworm (SCR, *Diabrotica undecimpunctata howardii*) are the primary agents of damage to pegs and pods. Damage from pod feeders not only reduces yield but also permits entry into the pod of soil-borne pathogens such as *A. flavus*.

Sources of resistance to most insect pests have been identified (Lynch, 1990; Wightman *et al.*, 1990; Nigam *et al.*, 1991) although levels of resistance do not approach immunity. Some sources exhibit resistance to more than one pest:

NC 6
GP-NC 343
NC Ac 01705
NC Ac 02142
NC Ac 02214
NC Ac 02230
NC Ac 02232
NC Ac 02240
NC Ac 02242
NC Ac 02243
NC Ac 02460.

These sources of resistance trace ancestry to PI 121067 or to X-irradiated leaf mutants of NC 4 selected by W.C. Gregory and D.A. Emery at North Carolina State University in the 1950s. Several have dense, elongated or erect trichomes on leaflet surfaces.

Dwivedi *et al.* (1986) reported predominantly non-additive genetic variance for trichome characters. Additive genetic effects were important for

trichome length and jassid damage. Holley *et al.* (1985) found additive genetic effects to predominate for resistance to a complex of insect pests (thrips, jassids and *Helicoverpa*) in North Carolina. Several breeding lines and cultivars resistant to foliar diseases (ICG [FDRS] 4, ICG [FDRS] 10, ICGV 86590, GP-NC 343 and NC 6) also exhibit tolerance to one or more insect species such as *Spodoptera*, leaf miner or jassids.

14.3 BREEDING METHODS

Early breeders of groundnut used mass selection to exploit natural variation in local cultivars. This method was commonly used in the USA during the 1950s but was gradually replaced by use of mutagenesis or hybridization as means of creating new genetic variation. It is interesting to note that mass selection is still used to some extent today, especially in conjunction with genetic stocks introduced from outside the USA. It is common for groundnut cultivars to exhibit some phenotypic variation in the field. This could be the result of segregation within the progeny of the last single plant selected in the course of cultivar development, of segregation and assortment following natural hybridization between pure-line components of a genetically heterogeneous but phenotypically homogeneous cultivar, or of duplication or deletion of chromosomal segments following the occasional formation of quadrivalents in the first meiotic division of the tetraploid groundnut. The most recently released American cultivar developed by mass selection was Avoca 11, a virginia cultivar selected from Florigiant and released in 1976.

The method most commonly used by groundnut breeders is the pedigree method. This allows the breeder to practise selection for highly heritable characters such as pod and seed size and shape, plant type and testa colour in early segregating generations. Because these traits determine market type and conformation to local standards, they are generally the focus of intensive early-generation selection. This practice serves to reduce quickly the size of individual segregating populations. Only when the desirable plant, pod and seed type have been recovered is emphasis placed on quantitative characters such as yield and seed composition.

Modified pedigree (single-seed descent) procedures and recurrent selection have been used in groundnut (Wynne, 1975; Hildebrand, 1985) but are not the methods of choice. Despite the recommendation of Brim (1966) that single-seed descent be used to allow segregating populations to resolve into collections of pure lines before selecting even for qualitative traits, groundnut breeders have continued to favour the pedigree method. The basis for this preference may lie in the space-intensive nature of plot work in groundnut. In modified pedigree procedures, the breeder must for several generations carry forward large populations of plants, selecting a single pod from each at random. This necessitates planting at population

densities sufficiently low to allow identification of individual plants. Particularly in populations segregating for spreading growth habit, individual groundnut plants may occupy large areas relative to small grains or grain legumes bearing aerial fruit.

Backcross breeding has not been used extensively in groundnut due to the paucity of simply inherited disease and insect resistances. This methodology may find greater favour in the future as recently identified resistances to rust and late leaf spot or characters such as the Florida high O/L ratio are transferred into existing cultivars that meet exacting standards of processors and consumers. Backcrossing augmented by use of molecular techniques for identifying heterozygotes may be used for transfer of genes introduced into *A. hypogaea* through transformation procedures, although it is to be hoped that transformation protocols insensitive to the recipient genotype will be developed, allowing independent transformation of any existing cultivar.

Development of genetic maps utilizing allozymes, RFLPs or random amplified polymorphic DNAs (RAPDs) as markers has promised to resolve the poly- or oligogenically inherited, quantitative traits such as yield to essentially qualitative traits by allowing the breeder to identify chromosomal segments bearing genes with measurable effects on the quantitative traits. Such methodology requires the genomic map to be saturated with markers, i.e. that there be markers exhibiting polymorphism in the segregating population of interest at average intervals of 5–20 centimorgans. Unfortunately, cultivated groundnut exhibits very little polymorphism for allozymes or RFLPs, making this approach to groundnut improvement impractical at present. On the other hand, the diploid wild species of *Arachis* exhibit large amounts of polymorphism for allozymes and RFLPs. It may be possible to utilize these markers for construction of a genomic map in the diploid species and to monitor the incorporation of wild species' germplasm in populations of cultivated groundnut. The foremost potential obstacle to use of molecular markers in wild species is the possibility of abnormal recombination between homologous chromosomes of related species, especially if the specific genomes are differentiated by structural rearrangements such as inversions or translocations.

14.4 REGIONAL PROGRESS

14.4.1 Africa

An important cash and food crop in Africa, groundnuts have declined there in terms of area, yield and productivity over the past 20 years. Two epiphytotics of groundnut rosette virus in West Africa in 1975 and 1987 almost wiped out the crop in many countries, leaving not even enough seed for farmers to plant their next crop. The changing rainfall pattern in West Africa and other parts of the continent has resulted in reduction of the

length of the rainy season and forced groundnut out of cultivation in desiccated areas where it once was a major crop.

Groundnut research in Africa began during the colonial period. Colonial governments made serious efforts to establish and increase groundnut production in their colonies to meet the increasing demands of home industries and population. This effort was strengthened during and after World War II, when shortages in Europe became acute. During that period, much research was conducted in Burkina Faso, Senegal, Nigeria, Uganda, Tanzania, Zambia, Zimbabwe, Malawi, Sudan and Zaire. After the decolonization of Africa the same impetus in research could not be maintained by newly independent nations. Civil strife, lack of physical resources, deteriorating infrastructure and lack of trained scientists and technicians resulted in the near-death of many national research programmes. Work was discontinued, valuable germplasm lost, records destroyed and cultivars mixed.

Over the past two decades many national programmes have been revitalized with the support of international organizations and donor agencies such as FAO, UNDP, ICRISAT, ODA, USAID, IDRC, IRHO, IRAT, GTZ and others. However, the revival process has been slow and many national programmes collapse as soon as financial support by donor agencies is withdrawn. Many countries have better trained and qualified scientists, but the lack of the resources necessary to conduct needed research continues to plague many national programmes. Lately the World Bank has taken interest in restructuring the national agricultural apparatus in Africa. IRHO, IRAT, and ICRISAT through its regional programmes in Malawi and Niger have made long-term commitments to the region and are making efforts to strengthen national programmes. USAID's Peanut Collaborative Research Support Program (CRSP) has been involved in development of West African peanut research for the past 10 years (Peanut CRSP, 1990).

Most results of research conducted in Africa are confined to annual reports of individual projects. Very little is published in international journals. Due to poorly developed seed production, distribution and extension programmes, most new cultivars and new cultural practices have not been adopted by producers at large. Uncertain tenure of land, lack of price support and unavailability of credit have discouraged farmers from increasing their groundnut production. Importing nations, particularly the European Community, have established extremely low tolerances for aflatoxin in imported groundnuts – levels difficult to meet for developing nations with generally poor storage and handling facilities. Export markets for African countries have declined due to poor quality and irregular supply of groundnuts.

From reports of 30 African nations published in proceedings of workshops conducted by ICRISAT and in reports of other organizations, the most important constraints on increased groundnut production in Africa

(excluding socioeconomic factors) include important biotic stresses such as foliar fungal diseases (early leaf spot, late leaf spot, rust), viral diseases (groundnut rosette virus, peanut clump virus and peanut mottle virus), arthropod pests (aphids, thrips, leaf miner, *Spodoptera*, jassids, white grubs, *Hilda patruelis*, termites and millipedes) and other animal pests (nematodes, rats, squirrels and monkeys).

Abiotic stresses of primary importance are drought and poor soil fertility. Other stresses are restricted in distribution to one or two countries. They include bacterial wilt in Uganda; *Alectra* species; phanerogamic root parasitic weeds in Nigeria and Malawi; acid soils in Zaire, Zambia and Malawi; and *Phoma arachidicola* in Zimbabwe.

Breeding objectives of the national programmes in Africa can be summarized as development of high-yielding oil type and/or confectionery cultivars with adaptation to specific agroecological conditions and resistance to the stresses constraining yield. Resistance to leaf spots, rust, *A. flavus*, groundnut rosette virus, tolerance to drought and early maturity rate high in most breeding programmes. Very little effort has been expended on breeding for resistance to animal pests.

Breeding methods employed in Africa are similar to those used elsewhere in the world. Programmes with limited resources or technical expertise for hybridization and selection rely primarily on introduction and pure-line selection within local landraces. International institutes such as ICRISAT and bilateral programmes such as IRHO and USAID's Peanut CRSP continue to be major sources of new genetic material in African national programmes.

Hybridization has been used in only a few national programmes and only intermittently in those. Countries with stronger programmes distribute their cultivars to neighbouring nations and to nations sharing common linguistic or economic ties with a former colonial power. For example, Burkina Faso and Senegal have shared their cultivars with other countries in francophone West Africa while Zambia has provided cultivars to nations of southern Africa with ties to the UK. In programmes using hybridization, pedigree selection has been the most commonly used method of generation advance. The backcross method has been used in breeding for disease resistance. Zimbabwe's national programme used a modified pedigree method (single-seed descent) to develop two cultivars (Hildebrand, 1985). The Zambian national programme has also used single-seed descent.

Interspecific hybrids obtained from the University of Reading, North Carolina State University and ICRISAT have been evaluated for resistance to foliar diseases in Malawi and Zimbabwe and for resistance to foliar diseases and insect pests in Nigeria. A programme of mutation breeding was initiated in Uganda to create variability for selection because the breeder there found the time required for emasculation and pollination to be excessive (Busolo-Bulafu, 1990).

Increased desertification in sub-Saharan Africa has made breeding for

drought resistance a primary objective in that region. The Senegalese programme at the Bambey centre of the Institut Sénégalais de Récherches Agricoles (ISRA) has developed many cultivars with improved resistance to drought, including 47-16, 50-127, 73-33 and 55-437 (Bockelee-Morvan *et al.*, 1974). Adaptation to dry climate was achieved by shortening the growing cycle of the breeding lines using 'Chico' as a source of early maturity and screening lines for tolerance to drought (Gautreau and De Pins, 1980). Recently, a joint programme between ISRA and the Sebele Research Station of the Botswana Department of Agriculture at Gaborone was initiated to improve drought tolerance in groundnut. Two crops are grown each year, one in Senegal and one in Botswana. Eight cultivars (virginia types 47-16, 57-422, 59-127 and 73-33 and spanish types 49-20, 55-437, 68-111 and TS 32-1) were used as parents in a convergent (pyramidal) crossing scheme (Mayeux, 1987). Drought-tolerant germplasm developed at ICRISAT Center near Hyderabad, India, has been introduced into southern and West Africa.

Breeding for resistance to rust and late leaf spot is ongoing in many national programmes including Burkina Faso, Malawi, Nigeria, Senegal, Zambia and Zimbabwe. These continue to emphasize the introduction of improved resistant germplasm from ICRISAT and the USA. 'RMP 91', a GRV-resistant cultivar developed in Burkina Faso, was found to be tolerant to leaf spots. A few programmes have crossed introduced sources of resistance with local cultivars. No cultivar with resistance to foliar fungal pathogens has been released in Africa to date.

African cultivars have been screened to identify resistance to early leaf spot, but no resistant cultivars have been found. At the SADCC-ICRISAT Regional Groundnut Program in Malawi, several germplasm lines and advanced breeding lines have been found to retain foliage longer than checks under intense disease pressure (Bock, 1987). These sources of resistance to defoliation are being intermated to improve the level of resistance. Of the *Arachis* species screened in Malawi, *A.* sp. 30003 exhibited a high level of resistance to early leaf spot. Unfortunately, this diploid species cannot be crossed directly with *A. hypogaea*.

Breeding for resistance to groundnut rosette virus has been remarkably successful in Africa. Resistance to GRV was identified in local landrace cultivars in Burkina Faso by de Berchoux (1958),who later (1960) showed that the resistance was governed by two independent recessive genes. The resistance operates equally against both chlorotic (de Berchoux, 1960) and green (Harkness, 1977) rosette. Nigam and Bock (1990) confirmed de Berchoux's observations and described an effective field screening technique for rosette. Utilizing resistance from landraces, IRHO breeding programmes in Burkina Faso and Senegal have developed several GRV-resistant cultivars including RMP 12, RMP 91, 69-101, KH-149A and KH-241D. The last two cultivars are spanish type; the others are virginia type. In southern Africa, the Malawi national programme developed a

GRV-resistant cultivar, RG1. For many regions in Africa, current emphasis in breeding for resistance to rosette is on transferring resistance into early-maturing cultivars. The SADCC–ICRISAT Regional Groundnut Program and the Nigerian national programme are actively involved in GRV-resistance breeding.

Other than local landraces, the genetic source that has contributed most to varietal development in Africa is Mani Pintar. The history of this line illustrates the powerful role of introduction in crop improvement. Mani Pintar was collected from a market place in La Paz, Bolivia, by Stephens and Hartley in 1947 (Hartley, 1949). The name is undoubtedly a corruption of 'maní pintado' or 'painted groundnut'. The characteristic features of the line are red-and-white variegated testa and spreading bunch growth habit (cultivar group Nambyquarae). The original seed sample was shared by the Queensland Department of Agriculture and Stock in Australia and the USDA. In the USA, the accession was assigned plant introduction number PI 162404. In 1955 the accession was introduced to the Mount Makulu Research Station in Zambia, where pure line selection was practised in subsequent years. A single-plant selection with solid red testae led to the release of 'Makulu Red' in 1961 (Smartt, 1978). Mani Pintar and Makulu Red were introduced into Zimbabwe in 1960. Sigaro Pink, a variant with pink testae, arose from Makulu Red, presumably as a result of natural hybridization, and was released in Zimbabwe in 1968–69. Further selection within Sigaro Pink gave rise to Apollo in 1972–73 and Egret in 1975. Mani Pintar is also one of the parents of GRV-resistant cultivars RMP 12 and RMP 91, which are very popular in West Africa.

There are more than 65 released cultivars reported in the literature from Africa. However, only a few are grown on a large scale and are pan-African in nature (Table 14.6). Most of the common cultivars of West Africa were developed by ISRA's Centre Nationale pour les Récherches Agricoles (CNRA) at Bambey, Senegal, and by IRHO in Burkina Faso.

14.4.2 East Asia

China, Japan and South Korea are the major groundnut-growing countries in east Asia. China is the leading groundnut producer in the world. In 1989, the groundnut area in the country was 2 946 000 ha and the total production was 5 362 000 t with an average yield of 1815 kg/ha. Compared with the 1970s, the groundnut area in China in the 1980s increased by 50%, the production by 124% and the yield by 48%. In this period, old cultivars were replaced by new improved cultivars in 95% of the groundnut area of the country. Groundnut cultivation in China is concentrated in the northern region, which accounts for 60% of the total groundnut area. Shandong Province in the northern region is the leading groundnut-producing province in China with an average pod yield of 2.7 t/ha. Other important areas are the southern (21%) and central (12%) region.

TABLE 14.6 *Cultivars released in Africa*

Cultivar	Type	Origin or pedigree	Year	Description
Burkina Faso (IRHO, Niangoloko Station)				
Te.3	Spanish	Selection from a local population from Upper Volta	1958	90-day cycle, erect growth habit, medium leaflet size, semi-compact fruiting habit, small (70–80 g/100) 2-seeded pods with crest and slight constriction, no beak, small (38–40 g/100) flattened seeds, salmon pink testa, 67–70% meat content, 47–48% oil content, no seed dormancy, 41–43% oleic acid content, 33–35% linoleic acid content, resistant to drought. Used in Benin, Burkina Faso.
RMP 12	Virginia	F_9 selection following hybridization, 1036 / Mani Pintar	1963	135–150-day cycle, semi-spreading growth habit, medium leaflet size, compact fruiting habit, medium (80–90 g/100) 2-seeded pods with no crest or constriction, marked reticulation, moderate beak, medium (50–55 g/100) oblong flattened seeds, pink variegated testa, 72% meat content, 49% oil content, 98% seed dormancy, 55–58% oleic acid content, 24–26% linoleic acid content, sensitive to drought, excellent resistance to GRV, susceptible to rust. Used in Benin, Burkina Faso, Mozambique, Nigeria.
RMP 91	Virginia	F_9 selection following hybridization, 48–37 / Mani Pintar	1963	135–150-day cycle, semi-spreading growth habit, medium leaflet size, compact fruiting habit, small (75–85 g/100) 2-seeded pods with no crest or constriction, marked reticulation, moderate beak, small (48–50 g/100) oblong seeds, pink testa, 68% meat content, 48% oil content, 98% seed dormancy, 55–58% oleic acid content, 24–26% linoleic acid content, sensitive to drought, excellent resistance to GRV, tolerant to early and late leaf spots. Used in Benin, Burkina Faso, Cameroon, Nigeria.
KH-149 A	Spanish	F_7 selection following hybridization, GH 119–7.1II–III / 91 Saria	1964	90-day cycle, semi-spreading growth habit, medium leaflet size, semi-compact fruiting habit, small (65–75 g/100) 2-seeded pods with deep constriction, no crest, slight beak, small (30–35 g/100) oblong seeds, red testa, 67–70% meat content, 48–50% oil content, no seed dormancy, 37–39% oleic acid content, 34–36% linoleic acid content, low resistance to drought, resistant to GRV. Used in Benin, Burkina Faso, Niger.
KH-214 D	Spanish	F_7 selection following hybridization, GH 1185.2 II/ 91 Saria	1964	90-day cycle, semi-spreading growth habit, medium leaflet size, semi-compact fruiting habit, medium (80–90 g/100) 2-seeded pods with very slight constriction, no crest, moderate beak, small (35–40 g/100) flattened seeds, red testa, 70% meat content, 49–50% oil content, no seed dormancy, 38–40% oleic acid content, 35–37% linoleic acid content, resistant to drought, resistant to GRV. Used in Benin, Burkina Faso.

TABLE 14.6 *Cont.*

Cultivar	Type	Origin or pedigree	Year	Description
TS 32–1	Spanish	Selection following hybridization, Spanlex Te. 3	1966	90-day cycle, erect growth habit, medium leaflet size, semi-compact fruiting habit, small (70–80 g/100) 2-seeded pods with moderate constriction, no crest, slight beak, small (35–38 g/100) slightly flattened seeds, pink testa, 68–70% meat content, 50–51% oil content, no seed dormancy, 44–46% oleic acid content, 31–33% linoleic acid content, resistant to drought. Used in Benin, Burkina Faso, Chad, Niger.
Congo (IRHO, Loudima)				
A-124 B	Valencia	Selection from a local population, Loudima Red	1956	Long Manyema group, 90-day cycle, erect growth habit, large leaflet size, large (165 g/100) 3- or 4-seeded pods with deep dorsal constriction, no crest, marked reticulation, prominent beak, small (42 g/100) oblong seeds, red to purplish-blue testa, 69% meat content, 48–50% oil content, no seed dormancy, 45–47% oleic acid content, 31–33% linoleic acid content, low resistance to drought.
Malawi				
RG 1	Virginia (bunch)	Selection following hybridization, Makulu Red / 48–34	1976	Resistant to GRV.
Chitembana	Virginia (runner)	Selection following hybridization, Chalimbana / RJ5	1980	Confectionery type.
Mawanga	Virginia (bunch)	Introduced from Bolivia	1980	Oil type.
ICGM 42	Virginia (bunch)	Selection following hybridization, USA 20 / TMV 10	1990	Red testa.
Senegal (IRHQ)				
756A	Virginia	Selection from a local population from the Casamance region of Senegal	1951	125-day cycle, erect growth habit, medium leaflet size, semi-compact fruiting habit, large (160–200 g/100) 2-seeded pods with no constriction or crest, no beak, medium (65–75 g/100) round distinctly flattened seeds, pink testa, 70% meat content, 48% oil content, complete seed dormancy, 55–58% oleic acid content, 18–20% linoleic acid content, sensitive to drought.

TABLE 14.6 *Cont.*

Cultivar	Type	Origin or pedigree	Year	Description
Senegal (ISRA, Bambey CNRA)				
28–206	Virginia	Selection from a population from Bamako, Mali	1928	Samaru group, 120-day cycle, erect growth habit, medium leaflet size, compact fruiting habit, medium (100–125 g/100) 2-seeded pods with very slight constriction, no crest, fine reticulation, no beak, small (45–49 g/100) round distinctly flattened seeds, pink testa, 73% meat content, 50% oil content, complete seed dormancy, 65–68% oleic acid content, 15–18% linoleic acid content, sensitive to drought. Used in Cameroon, Gambia, Mali, Niger, Senegal.
47–10	Spanish	Selection from a population received from Madagascar, Ambata B / Morovoay	1947	Manyema group, 90-day cycle, erect growth habit, large leaflet size, medium (105 g/100) 2-seeded pods with moderate dorsal constriction, prominent crest, prominent reticulation, very prominent beak, small (45 g/100) slightly flattened seeds, salmon pink testa, 71% meat content, 48% oil content, no seed dormancy, 43–45% oleic acid content, 32–33% linoleic acid content, moderate resistance to drought, low resistance to *Pythium myriotylum*. Used in Mali.
55–437	Spanish	Selection from a population of probable South American received from Hungary	1955	Natal Barberton group, 90-day cycle, erect growth habit, large leaflet size, compact fruiting habit, small (85–95 g/100) 2-seeded pods with slight constriction, prominent reticulation, almost no beak, small (35–38 g/100) slightly flattened seeds, pale pink testa, 75% meat content, 49% oil content, 30% seed dormancy, 46–49% oleic acid content, 27–30% linoleic acid content, resistant to drought. Used in Botswana, Cameroon, Chad, Gambia, Mali, Niger, Nigeria, Senegal, Uganda.
57–422	Virginia	Selection from a hybrid population imported from Tifton, Georgia, USA, F334–3–404	1957	105–110-day cycle, erect growth habit, large leaflet size, large (165–175 g/100) 2-seeded pods with very deep constriction, no crest, very slight reticulation prominent beak, medium (65–69 g/100) slightly flattened oblong bumpy seeds, yellowish pink testa, 78% meal content, 50% oil content, 95–100% seed dormancy, 50–53% oleic acid content, 27–30% linoleic acid content, moderate resistance to drought, susceptible to late leaf spot and *A. niger*, tolerant to PCV. Used in Mozambique, Niger, Senegal.
57–313	Virginia	Selection from a population from Ouagadougou, Burkina Faso	1957	Samaru group, 125-day cycle, erect growth habit, medium leaflet size, diffuse fruiting habit, medium (125–130 g/100) 2-seeded pods with slight constriction, no crest, fine reticulation, no beak, small (48–52 g/100) round distinctly flattened seeds, pink testa, 75% meat content, 50% oil content, complete seed dormancy, 64–67% oleic acid content, 14–17% linoleic acid content, sensitive to drought.

TABLE 14.6 *Cont.*

Cultivar	Type	Origin or pedigree	Year	Description
GH 119–20	Virginia	Introduced from Tifton, Georgia, USA, in 1960, F_4 selection from Southeastern Runner / Dixie Giant, 210–4 // Virginia Runner	1960	Jumbo group, 110-day cycle, erect growth habit, large leaflet size, fair fruiting habit, large (230–240 g/100) 2-seeded pods with moderate constriction, no crest, marked reticulation, large (85–90 g/100) oblong seeds, pink testa, 70% meat content, 43–46% oil content, medium seed dormancy, 63–66% oleic acid content, 14–17% linoleic acid content, sensitive to drought. Used in Ethiopia, Senegal.
69–101	Virginia	BC_3F_5 selection following hybridization, 55–455 / 4*28–206	1969	Saloum group, 125-day cycle, erect growth habit, medium leaflet size, compact fruiting habit, medium (130 g/100) 2-seeded pods with very slight constriction, no crest, fine reticulation, no beak, small (46–50 g/100) round distinctly flattened seeds, pink testa, 73% meat content, 50% oil content, complete seed dormancy, 65–68% oleic acid content, 14–17% linoleic acid content, sensitive to drought, resistant to GRV. Used in Benin, Burkina Faso, Senegal.
73–27	Virginia	F_8 selection following hybridization, 756A / GH 119–20, Line 252	1972	Jumbo group, 120–125-day cycle, erect growth habit, large leaflet size, fair fruiting habit, large (200, 210 g/100) 2-seeded pods with moderate constriction, no crest, slight reticulation, no beak, large (85–90 g/100) oblong seeds, salmon pink testa, 71% meat content, good seed dormancy, 58–61% oleic acid content, 20–22% linoleic acid content, sensitive to drought, used for confectionery purposes.
73–28	Virginia	F_8 selection following hybridization, 756A / GH 119–20, Line 255	1972	Jumbo group, 120–125-day cycle, erect growth habit, large leaflet size, fair fruiting habit, large (190 –200 g/100) 2-seeded pods with moderate constriction, no crest, slight reticulation, no beak, large (85–90 g/100) oblong seeds, salmon pink testa, 72% meat content, good seed dormancy, 55–58% oleic acid content, 21–23% linoleic acid content, sensitive to drought, used for confectionery purposes.
73–30	Spanish	F_8 selection following hybridization, 61–24 (spanish) / 59–127 (virginia type Saloum)	1973	95-day cycle, erect growth habit, medium to large leaflet size, compact fruiting habit, medium (100 g/100) 2-seeded pods with slight constriction, no crest, slight reticulation, no beak, small (40 g/100) oblong seeds, salmon pink testa, 73% meat content, 48% oil content, complete seed dormancy, 60–63% oleic acid content 18–21% linoleic acid content, resistant to drought.
73–33	Virginia	F_{12} selection following hybridization, 58–650 / 59–46	1973	Fung group, 105–110-day cycle, very erect growth habit, medium leaflet size, compact fruiting habit, medium (120–125 g/100) 2-seeded pods with deep constriction, no crest, marked reticulation, medium beak, small (50–52 g/100) oblong seeds, pink, 73% meat content, 50% oil content, 95% seed dormancy, 58–61% oleic acid content, 20–22% linoleic acid content, resistant to drought. Used in Gambia, Senegal.

TABLE 14.6 *Cont.*

Cultivar	Type	Origin or pedigree	Year	Description
South Africa				
Natal Common	Spanish			Erect growth habit, large leaflet size, 2 seeds per pod, no constriction or beak, pale tan testa. Used in Mozambique, South Africa, Tanzania, Zambia Zaire.
Tanzania				
Nyota	Spanish	Introduced from USA in 1978 (Spancross)	1983	
Johari	Spanish	Introduced from India in 1980 (Robut 33–1)	1985	
Zaire				
A 65	Valencia	Introduced from Brazil	1958	90-clay cycle, erect growth habit, rose-tan testa. Used in Burundi, Zaire.
G 17	Valencia	Selection from a local landrace following apparent natural hybridization	1975	105-day cycle, erect growth habit, rose-tan testa.
Zambia (Mount Makulu Research Station)				
Mani Pintar	Virginia	Collection from a market in La Paz, Bolivia, introduced to Mt. Makulu Station in 1955	1955	130–140-day cycle, spreading bunch growth habit, dark green leaves, large 2-seeded pods with no constriction, pronounced beak, medium large flattened seeds, red and white variegated testa. Used in Malawi, Uganda, Zambia.
Makulu Red	Virginia	Selection from Mani Pintar	1961	130–140-day cycle, spreading bunch growth habit, dark green leaves, large leaflet size, large 2-seeded pods with no constriction, pronounced beak, medium large flattened seeds, red testa, 67% meat content, 45% oil content, field resistance to early leaf spot. Used in Tanzania, Uganda, Zambia, Zimbabwe.

TABLE 14.6 *Cont.*

Cultivar	Type	Origin or pedigree	Year	Description
Chitembana	Virginia	Selection from a local population from eastern Zambia	1964	140–150-day cycle, runner growth habit, large leaflet size, thick stems, large coarse 2-seeded pods with slight constriction, no beak, flattened seeds, dark tan testa, used for confectionery purposes. Used in Malawi, Zambia.
Comet	Spanish	Introduced from USA (Comet)	1984	
MGS 2	Virginia (runner)	Introduced from India (M13)	1988	
Zimbabwe				
Egret	Virginia	Selection from naturally occurring pink variants in Makulu Red	1974	130–140-day cycle, spreading bunch growth habit, large leaflet size, large 2-seeded pods with no constriction, pronounced beak, medium large flattened seeds, pink testa, 67% meat content, 45% oil content, field resistance to early leaf spot.
Flamingo	Virginia (bunch)	PI 261911 / Natal Common	1982	
Plover	Spanish	Introduced from Brazil (PI 336954)	1982	
Swallo	Virginia (bunch)	PI 261911 / Makulu Pink selection	1982	

In the northern region, the main constraints to groundnut production are early and late leaf spots, viruses (peanut stripe, peanut stunt, cucumber mosaic, TSWV), aphids, *Helicoverpa*, *Spodoptera*, thrips, nematodes and drought. Surveys conducted in the 1970s indicated that more than 300 000 ha were infested with nematodes in nine provinces of China. *Meloidogyne hapla* is widespread in the north, whereas it is *M. arenaria* in the south of the country. These nematodes cause on average 20–30% yield loss in the country. Breeding began at the Peanut Research Institute at Laixi in Shandong Province in 1959. Since then 15 cultivars have been released for cultivation in the province and other parts of the country (Table 14.7). Following hybridization, the single-seed descent method has been used to advance breeding generations. Twelve of the 15 cultivars released by the institute are the result of hybridization and the remaining three are pure line selections among local landraces. Hua 37 and Luhua 4 are very popular among farmers and have good export quality. Hua 37 covers more than 100 000 ha in the country. With new production technology, which includes polyethylene mulching, these cultivars can produce 7.5 t pods/ha. The main emphasis in groundnut breeding in Shandong Province has been to increase pod yield and improve quality. Quality parameters that have received attention in breeding are large elongated seed, high oil (55%), O/L ratio (>1.4 for large-seeded virginia types, >1.2 for spanish types), high protein (>30%), high blanchability, pink testa colour, and flavour (by organoleptic test).

In the central region, early and late leaf spots, rust, bacterial wilt, viruses (peanut stripe, peanut stunt, cucumber mosaic, TSWV), aphids, *Helicoverpa*, *Spodoptera*, thrips, leafhoppers, white grub, drought, waterlogging and high temperature are serious constraints to production. The Oil Crops Research Institute at Wuhan is responsible for groundnut research in Hubei Province in this region. The Institute maintains a collection of 4350 accessions of groundnut, including 130 wild *Arachis* species. All accessions have been characterized for agronomic characters. In collaboration with the Peanut Research Institute in Shandong Province, 4029 lines have been screened for resistance to nematodes (*M. hapla*), to which two lines – Tian Fu No. 4 and Da Hua Cheng – have shown a high level of resistance. Three other lines with moderate resistance and five lines with tolerance also have been identified. Four thousand lines have been screened for bacterial wilt, rust, late leaf spot and early leaf spot. Seventy lines with resistance to bacterial wilt and many lines with resistance to rust and late leaf spot have been identified, but a satisfactory level of resistance to early leaf spot has not yet been located. Many of the lines resistant to foliar disease were obtained from ICRISAT. The germplasm has also been screened for biochemical factors. The protein content in the collection ranges from 14.0% to 36.8% and oil content from 36.0% to 60.21%. There are many lines with O/L ratios greater than 3.0.

Breeding objectives at the institute include high yield, early maturity, improved quality, and resistance to diseases and insect pests. Following hybridization, the pedigree method is followed to advance breeding generations. From 1986 to 90, the significant achievements of the breeding group at the institute included identification of sources of resistance to bacterial wilt and rust.

About 200 000 ha are infected with bacterial wilt in the central region of China. Yield loss to this disease averages 10–15% and may go up to 60%. Since 1970, more than 4000 germplasm accessions have been screened in the field and screenhouse; 70 resistant lines have been identified. The resistance in these lines is generally stable under field conditions but it can break down under heavy artificial inoculation and with a highly virulent strain. Inheritance studies involving spanish types indicated that resistance to bacterial wilt is partially dominant and is governed by three major genes with additive effects (Boshou *et al.*, 1990).

Peanut stripe virus (PStV), although widely distributed in the country, is mainly important in central and northern China. A 50% disease incidence is often found in these areas, reaching up to 100% in many fields. In southern China, the disease incidence is <1%. In laboratory and field studies, 20% yield loss was observed with early infection of the virus. More than 1300 germplasm lines have been screened without identifying any resistant accessions.

In the central region mostly spanish and peruvian types are grown. Four new groundnut cultivars have been released by the institute in the last five years (Table 14.7). Current breeding activities (1991–95) include development of cultivars with multiple resistance to diseases and pests, utilization of wild *Arachis* species to develop cultivars resistant to leaf spot, screening for resistance to virus diseases, screening for tolerance to acid soils and breeding for increased nitrogen fixation.

In China's southern region, the primary constraints to production are rust, bacterial wilt, waterlogging and soil acidity. Guangdong Province, where mainly spanish types are grown, leads the region in groundnut production and its Industrial Crops Research Institute, Guangzhou, carries out groundnut research in the region. The main objective of its present groundnut research programme is to develop high-yielding cultivars with resistance to bacterial wilt and rust and adaptation to different growing conditions in the province. The six sources of bacterial wilt resistance used in the breeding programme are Teishan Sanliyue (a valencia cultivar from China), Teishan Zhenzhu (a spanish cultivar from China), Xie Kong Chung (a spanish cultivar from China), Schwartz (a spanish cultivar from Indonesia), Yindu Huapi (a virginia cultivar from India) and Tianjin Don (a runner cultivar from China). Sources of rust resistance have been obtained from ICRISAT.

In Japan, groundnut is a minor crop. The main centre of production is the Kanto region in the central part of the country. The consumption of groundnut in Japan amounted to 85 000 t in 1989, of which 44% was

TABLE 14.7 *Groundnut cultivars released in East Asia*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
China (Northern Region)[1]				
Fuhuasheng	Spanish		1960	
Hua 27	Virginia		1967	
Hua 11	Spanish		1969	
Hua 19	Virginia		1975	
Hua 28	Intermed. between spanish and virginia (M)		1979	
Hua 31 (Hai Hua 1)	M		1984	
Hua 37	M		1985	Good quality
Hua 39 (Luhua 4)	Virginia		1986	Good quality
Hua 17	Virginia		1974	O/L ratio 1.45
Hua 98	Virginia		1974	Tolerant to drought
Luhua 3	Spanish		1982	High oil, resistant to bacterial wilt
Luhua 6	M		1986	
Luhua 8	M		1988	
Luhua 9	Virginia		1988	Good quality
China (Central Region)				
El Hua 4		Hongmei Zhao / El Hua 2		High yield, early maturity, high quality, tolerant to drought
Zhong Hua 1		El Hua 3 / Taishan Zenghou		High yield, tolerant to leaf spot
Zhong Hua 2		El Hua 4 / Taishan Sanlirou		High oil and protein, resistant to bacterial wilt
Zhong Hua 117				Resistant to rust, moderately resistant to bacterial wilt, high protein, high yield

TABLE 14.7 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
China Southern Region)				
Yue You 39		Yue You 116 / Yindu Huapi		Resistant to bacterial wilt and rust
Yue You 223		Shan You 26 / EC 76446 (292)		Tolerant to rust
Yue You 92		Yue You 116 / Xie Kang		Resistant to bacterial wilt, high in oil content (54%)
Yue You 256		Yue You 116 / Xie Kang		Resistant to bacterial wilt, high yield
Japan				
Wase-dairyu	Spanish			Early maturing, large seed
Tachi-masari	Spanish			Early maturing, large seed
Chiba-handachi				Medium maturing cultivar with large seed
Nakate-yutaka				Medium maturing, high yielding cultivar with good eating and external quality
Azuma-yutaka				Medium maturing, high yielding cultivar with good eating and external quality
Sayaka				Medium maturing (later than Nakate-Yutaka), high yielding, better suited for roasting due to its thicker shell than Nakate-yutaka
Yude-rakka				Early maturing, good eating quality, white pod colour with superior external appearance, suitable for unshelled whole pod or frozen boiled groundnut trade

TABLE 14.7 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Korea				
Younghotangkong	Virginia		1980	Late maturing, large elongated seed, pods with deep constriction
Saedltangkong	Inter. between spanish and valencia		1983	Early maturing, erect plant type, an intermediate type between spanish and valencia
Jinpungtangkong (ICGS 35)			1986	Early maturing, small seeded, high yielding spanish type
Daekwangtangkong	Intermed. between spanish and valencia	Florigiant / Chiba-handachi // Chiba-handachi /3/ F393–6–3–2–3–1–2	1985	Early maturing, high yielding, high oil content, erect plant type with few branches and large seed.
Namdaettangkong	Virginia (bunch)	Virginia bunch Improved / Suwoen 30	1988	Large seeded, high yielding, high in oil content, tolerant to *Phoma arachidicola*

[1] Cultivars released by the Peanut Research Institute, Laixi, Shandong Province, China.

produced locally and the rest was imported. Since the end of World War II, groundnut breeding in Japan has pursued two main objectives: breeding early-maturing cultivars for warm and cool areas, and breeding medium and late-maturing cultivars. Because groundnut is a delicacy in Japan, both eating quality and external quality are important attributes (Gocho, 1991) and improvement in quality has received the most attention in groundnut breeding. Sucrose content and hardness of seed are closely related with eating quality and they decrease if harvesting is delayed. The seed hardness is measured when the moisture content in seed is in the range of 5–9%. (All cultivars under test should have the same moisture level within this moisture range.)

Groundnut is also a minor crop in Korea, where yields are affected by leaf spots, rust, and low temperature at the ripening stage. The main breeding objective at the Crop Experiment Station, Rural Development Administration, Suwan, is to develop cultivars with large seed and erect plant type (Lee *et al.*, 1986, 1989).

14.4.3 Southern Asia

Groundnut research and production in southern Asia are dominated by India. Other groundnut-growing countries in the region are Bangladesh, Bhutan, Myanmar, Nepal, Pakistan and Sri Lanka. Except for Myanmar, groundnut production in these countries is small. The crop in India and Myanmar is grown mainly for edible oil production and in other countries in the region for direct consumption or for use in confectionery. The region accounts for 43.4% of the area and 35.7% of the production of groundnut in the world. However, the average productivity in the region (0.94 t/ha) remains below the world average (FAO, 1990). The main biotic constraints to increased groundnut production in the region include diseases – late leaf spot, rust, early leaf spot, collar rot (*Aspergillus niger*), stem rot (*Sclerotium rolfsii*), *A. flavus*, bud necrosis disease (BNV) – and insects (thrips, jassids, aphids, leaf miner, *Spodoptera*, *Helicoverpa*, red hairy caterpillar, whitegrub and termites). Abiotic constraints include drought, lack of high-yielding cultivars adapted to local growing conditions, lack of availability of good quality seeds and lack of small-scale farm machinery for groundnut cultivation.

Introduction and reselection in introduced populations continue to be the main methods of crop improvement in the region – with the exception of India where, over the past decade, the majority of new cultivars have resulted from hybridization between parents selected for their desirable characteristics. However, in countries where the research programmes are small and the scientists are responsible for more than one crop, dependence on the introduction of improved germplasm from various sources is heavy. ICRISAT has played an important role in such introductions.

Prior to 1980, breeding efforts were directed mainly towards improving

TABLE 14.8 *Groundnut cultivars released in South Asia*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
India (old popular cultivars)				
Gangapuri	Valencia	–	–	Early maturing, 3–4-seeded, small–medium pods, preferred as table variety, good source for earliness, popular in central India
Spanish Improved	Spanish	Selection from spanish peanut	1905	Small-seeded, suitable for light soils (proposed for denotification)
Kopergaon I	Virginia (bunch)	Selection from local variety	1933	Medium sized pods (proposed for denotification)
TMV 2	Spanish	Selection from 'Gudhiatham Bunch', a local variety	1940	Widely adapted, well suited for rainy and summer season cultivation in southern India, a leading spanish variety in the past, still continues to be popular with farmers
AK 12–24	Spanish	Selection from local variety	1940	Widely adapted, suited for medium to heavy soils (proposed for denotification)
Punjab Groundnut I	Virginia (runner)	Selection from 'Samrala Local'	1953	Wide adaptability (proposed for denotification)
Karad 4–11	Virginia (runner)	Selection from local variety	1957	Late maturing, 1–3-seeded medium to long pods
RSB 87	Virginia (bunch)	Selection from a Brazilian collection	1961	3-seeded pods with dark red seeds
J 11 (SB XI)	Spanish	Ah 4218 / Ah 4354	1964	Widely adapted, resistant to collar rot and *A. flavus* seed colonization
S 206	Spanish	Selection from 'Manvi Local'	1969	Reticulated pods with slight beak and constriction
S 230	Virginia (runner)	Selection from 'Tandur Local'	1969	–
M 13	Virginia (runner)	Selection from NC 13	1972	Large-seeded variety with tolerance to leaf spots
JL 24	Spanish	Selection from EC 94943	1978	Large dark green leaves, smooth 2–3-seeded pods, early in maturity

TABLE 14.8 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
India (cultivars released since 1980)				
Kisan	Spanish	Spanish Improved B 31	1980	Small pod with prominent reticulation, released for Orissa State
M 37	Virginia (runner)	A1 / C 6–4–7–2	1980	Two-seeded pods with small beak, light brown seed coat, released for Punjab State
KRG 1	Spanish	Selection from 'Argentine' variety	1981	Two-seeded medium sized pods, released for Karnataka State
TG 17	Spanish	'Dark Green' Mutant / TG 1	1982	Large-seeded, pinkish seed coat, high harvest index, fresh seed dormancy, released for Maharashtra State
M 197	Virginia (bunch)	C 501 / U 4–7–2	1982	Dark green leaves, large-seeded pods with smooth reticulation, released for Punjab State
GG 2	Spanish	J11 / EC 16659	1983	Two-seeded reticulated pods, early flowering with dark green leaves, released for Gujarat State
Jawan	Spanish	J11 / Asiriya Mwitunde	1983	Medium elongated pods with moderate beak, rose seed coat, released for Orissa State
CO 2	Spanish	EMS Mutant from Pollachi 1	1983	Two-seeded medium plumpy pods with rose colour testa, released for Tamil Nadu State
Dh 8	Spanish	Selection from RS 144	1984	Dark green leaves, compact plant, tolerant to late leaf spot, small pods with smooth rose seeds round at one end and sharply pointed at the other, released for Karnataka State
Chitra	Virginia (runner)	Spanish 5B–1 / EC 1688	1984	Dark green leaves, variegated testa with rose background, released for Uttar Pradesh State
Kaushal	Virginia (bunch)	Selection from T 28	1984	2–3–1-seeded pods, compact plant with dark green leaves early in maturity, released for whole of India
UF 70–103	Virginia (bunch)	Introduction from USA	1984	Suitable for summer cultivation in Maharashtra State
GG 11	Virginia (runner)	M 13 / Gaug 10	1984	Leaflets and pod bigger than Gaug 10, released for Gujarat State

TABLE 14.8 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
TG 3	Spanish	A mutant of Spanish Improved	1985	Spanish, medium–large pods, suitable for both rainy and summer seasons, tolerant to pod borer
MA 16	Virginia (bunch)	Selection from EC 16664	1986	Large seeded suitable for HPS trade
SG 84	Spanish	Selection from ICGS 1	1986	Mainly 2-seeded, medium sized pods, suitable for summer/spring cultivation in north India
M 335	Virginia (runner)	M 13 / F7	1986	2–1–3-seeded large pods with prominent reticulation and moderate constriction, seeds large with light brown testa, large dark green leaves with compact plant, released for Punjab State
ICGS 11 (ICGV 87123)	Spanish	Selection from natural hybrid population of Robut 33–1	1986	2-seeded smooth medium sized pods with no beak and slight to moderate constriction, seeds tan colour, 100-seed mass 60 g, oil 49%, protein 22%, above average tolerance of end-of-season drought, photoperiod insensitive. Field tolerance of bud necrosis disease, adapted to post-rainy season cultivation in India, performs well in West Africa also
VRI 1	Spanish	TMV 7/ FSB 7–2	1986	Large pods with deep constriction and prominent beaks
ALR 1	Spanish	Pollachi 2/ PPG 4	1987	Small dark green leaves, red testa, resistant to rust and late leaf spot
Girnar 1	Valencia	X14–4–B–19B / NC Ac 17090	1988	Early maturing, resistant to late leaf spot, rust, collar rot, and seed colonization by *A. flavus*, 2–3-seeded with reticulated, constricted and beaked pods
ICGV 87128 (ICGS 44)	Spanish	Selection from natural hybrid population of Robut 33–1	1988	2-seeded smooth small to medium sized pods with no or little beak, seeds tan in colour, 100-seed mass 60 g, oil 49%, protein 25%, field tolerance to bud necrosis disease, good recovery from midseason drought, relatively photoperiod insensitive, adapted to post-rainy season cultivation in India, performs well in Pakistan also
RG 141	Spanish	Robut 33–1 /NC Ac 2821	1989	Spanish with dark green foliage suitable for black soils
VRI 2	Spanish	JL 24 / CO 2	1989	Mostly 2-seeded large pods with moderate beak, constriction and reticulation. Seeds light rose in colour, 100-seed mass 50 g, oil 48%

TABLE 14.8 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
ICGV 87141 (ICGS 76)	Virginia (bunch)	TMV 10 / Chico	1989	Mainly 2-seeded medium sized pods with moderate to prominent reticulation, slight to moderate constriction and beak, seeds tan in colour, 100-seed mass 44 g, oil 43%, protein 20%, good recovery for pod yield from midseason drought, field tolerance to bud necrosis, adapted to rainy season cultivation in India, performs well in Sudan also
ICGV 87121 (ICGS 5)	Virginia (bunch)	Robut 33–1 / NC Ac 316	1989	2-seeded medium sized pods with none to slight beak and reticulation, slight to moderate constriction, seeds tan in colour, seed mass 38 g/100, oil 58%, protein 22%, shows good recovery for pod yield from midseason drought, adapted to rainy season cultivation in India
ICGS 1 (ICGV 87119)	Spanish	Selection from natural hybrid population of Robut 33–1	1990	Mainly 2-seeded medium sized pods with slight to moderate constriction, none to slight beak, and smooth to slight reticulation, seeds tan in colour, oil 51.1%, protein 21%, 100-seed mass 35 g, shows good recovery for pod yield from midseason drought, field tolerance to bud necrosis
Birsa Groundnut-3	Virginia (bunch)	Early Runner / Asiriya Mwitunde	–	Early maturing
ICGV 87187 (ICGS 37)	Spanish	Selection from natural hybrid population of Robut 33–1	1990	Mainly 2-seeded medium sized pods with slight reticulation, slight to moderate constriction and none to slight beak, seeds tan in colour, 100-seed 53 g, oil 48%, protein 23%, tolerance to end-of-season drought, field tolerance of bud necrosis disease, photoperiod insensitive, tolerant to rust and late leaf spot, adapted to summer season cultivation in India, also performs well in Pakistan
ICGV 87160 [ICG(FDRS)10]	Spanish	Ah 63 / NC Ac 17090	1990	2-seeded stubby pods with moderate to prominent ridges, slight reticulation, beaks and constriction either absent or less conspicuous, seeds tan in colour, 100-seed mass 36 g, oil 48%, protein 27%, resistant to rust, tolerant to late leaf spot, field tolerance to bud necrosis disease, less susceptible to stem and pod rots caused by *S. rolfsii*, moderately resistant to leaf miner
VRI 3	Spanish	J 11 / Robut 33–1	1990	Small-seeded pods with moderate constriction and little or no beak
RSHY 1	Spanish	GDM / TMV 2	1990	Suitable for residual moisture situation
ICGV 86590	Spanish	X14–4–B–19–B / PI 259747	1991	3-seeded pods, resistant to rust, tolerant to late leaf spot, bud necrosis disease, stem and pod rots, and *Spodoptera*

TABLE 14.8 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Pakistan				
Banki	Virginia (bunch)	Introduction in 1973	–	160–180 days to maturity
No. 334	Virginia (runner)	–	–	180–200 days to maturity
BARD 669	Spanish	A composite of ICGS 44 and ICGS 37	1989	150–160 days to maturity, high yielding, high in shelling turnover
Bangladesh				
Dhaka-1 (Maizchar Badam)	Spanish	–	1976	Oil 48–50%, shelling 75%, matures in 135–140 days, highly susceptible to leaf spots
DG 2 (Basanti Badam)	Virginia (bunch)	–	1979	Mainly 2-seeded large pods, 170–175 days in maturity, seed dormancy for 40–50 days, tolerant to leaf spots
DM 1	Valencia	Introduced from India	1987	Very dwarf, early in maturity, tolerant to leaf spots and rust
Acc 12	Valencia	–	1988	Tolerant to drought, leaf spots and rust
Sri Lanka				
Red Spanish	Valencia	–	1961	Semi-erect, large 3-seeded pods, dark pink seed colour, 100-seed mass 45 g, shelling 68%, 110–120 days maturity
MI 1	Spanish	–	–	2-seeded medium pods with pink colour seed, 100-seed mass 40 g, shelling 72%, 110–120 days maturity
No. 45	Spanish	Introduction from ICRISAT, India	1982	2-seeded medium pods with pink seed colour, 100-seed mass 45 g, shelling 75%, 110–120 days maturity
X14–4–1–6–19–6	Spanish	Introduction from India	1982	2-seeded medium pods with pink seed colour, 100-seed mass 48 g, 115–120 days maturity

TABLE 14.8 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Nepal				
B 4	Virginia (bunch)	Introduction from Pakistan	1976	135–140 days to maturity, 3–2 seeded medium sized pods, tan colour seed with high oil content, oil purpose cultivar
Janak	Virginia (runner)	NC Ac 343	1987	140–145 days to maturity, 2-seeded large pods, tan colour seed with high oil content, moderately resistant to disease and insects, a dual purpose cultivar
Myanmar				
Sinpadetha 2	Spanish	JL 24	1984/85	–
Sinpadetha 3	Virginia (bunch)	Robut 33–1	1984/85	–
SP 121	Spanish	–	–	2-seeded small pods, early maturing
Magwe 10	Spanish	SP 121/070 / S 550–05		2-seeded small pods, high shelling (76%), high oil (54%), early maturing
Magwe 11	Spanish	Selection from Shawat 21/6	–	2-seeded small-medium pods with high oil content (55%)
Magwe 12	Spanish	–	–	2–1–3-seeded medium sized pods with high oil content (55%)
Magwe 15	Spanish	UPL Pn-2 / Kyaung Gone	–	2–1–3-seeded medium pods, high shelling (77%), high oil content (54%), seed dormancy for 2 weeks
Kyaung Gone	Virginia (bunch)	–	–	2–1-seeded, seed dormancy up to 2 months
MS 2	Virginia (runner)	–	–	2–3–1-seeded pods, seed dormancy up to 3 months
Bhutan				
				In Bhutan some undefined cultivars are grown in small pockets in the valleys for local consumption

yield potential. With the identification of sources resistant to major diseases and insect pests at ICRISAT and in the national programme in India, resistance breeding received a strong stimulus resulting in release of cultivars with multiple resistances in India. A genetic gain of 1.3–3.2% per annum was achieved during the 1980s under rainfed conditions in India (Nigam *et al.*, 1991). A large number of cultivars have been released in India, particularly since 1980 (Table 14.8). Notwithstanding the release of several improved cultivars, some very old ones are still grown extensively due to lack of availability of seed: only 20% of the seed requirement in improved cultivars is met at present in India. The situation is not very different in other countries of the region. Pakistan, Sri Lanka, Nepal, and Bangladesh have very small groundnut research programmes and rely mainly on introduction for improved germplasm. Although Myanmar has a sizeable area under groundnut, its research programme is hampered by lack of trained scientific manpower.

Approximately 80% of India's groundnuts are grown in the rainy season (July–October). The remaining 20% is grown with irrigation in the post-rainy season (October/November–March/April) and the summer (January/February–April/May). The groundnut area in the post-rainy/summer season has increased recently as pod yields are high at this time. Varietal requirements of rainy and post-rainy/summer seasons differ because of differing disease and insect pest complexes occurring in them. High pod yield, high shelling percentage and high oil content are requirements common to both growing seasons. Additional requirements of improved cultivars in the rainy season are: drought tolerance; adaptation to agroecological zones differing in rainfall pattern and length of growing season; fresh seed dormancy in spanish/valencia types; tolerance to insect pests such as aphids, jassids, thrips, leaf miner, *Spodoptera* and white grub; and tolerance to diseases such as early and late leaf spots, rust, collar rot, stem rot, *A. flavus* and bud necrosis. In the post-rainy/summer season, disease pressure is generally very low but tolerance/resistance to insect pests such as leaf miner and *Spodoptera*, tolerance of low temperature in the early stages of crop growth, early maturity, and responsiveness to fertilizers and irrigation are needed in new cultivars.

Much of the emphasis in the past in groundnut breeding in India was placed on the improvement of pod yield. The quality characteristics which received attention included shelling percentage and oil content. Oil quality itself received virtually no attention. During the VIII Plan (1990–95), India's most recent programme for the improvement of agricultural production, the following breeding activities have been accorded high priority:

- For dryland conditions, emphasis is on development of drought-tolerant, high-yielding, early-maturing spreading groundnut cultivars.
- For use in paddy fallows, early-maturing bunch cultivars able to extract residual soil moisture are being developed.

- For post-rainy/summer season irrigated conditions, the objective is to produce high-yielding spanish cultivars tolerant of iron chlorosis.
- For rainfed crops, resistance to foliar diseases is a high priority.

There is also demand for cold-tolerant, early-maturing cultivars possessed of fresh seed dormancy. High oil content is a primary objective for cultivars developed for use as oilseeds, while large seeds and less susceptibility to *Aspergillus* species are the objectives in cultivars for confectionery.

For each breeding activity, targets have been fixed and responsibilities have been assigned to main groundnut research centres under the aegis of the All-India Coordinated Research Project on Oilseeds (AICORPO) at the Indian Council of Agricultural Research (ICAR), New Delhi. Hybridization between adapted cultivars and donor parents of desirable characteristics, followed by selection for such traits combined with high yield in segregating populations, has been adopted to achieve the target of the breeding activities listed above. Wherever required, interspecific hybridization is also being pursued. Some of the sources of desirable characteristics in use in hybridization are:

For earliness:

Chico	JB(E)559
TG(E)1	ICGS 6
TG(E)2	ICGS 51
VG(E)55	ICGV 86309
91176	ICGV 86315
ICGS(E)21	ICG 11199
ICGS(E)22	CSMG 881
ICGS(E)52	CSMG 902
ICGS(E)217	CSMG 905
TG 7	CSMG 917
J(E)5	CSMG 918
J(E)6	CSMG 9102
JB(E)194	Kadiri 3.
JB(E)262	

For drought tolerance:

ICGV 86607	ICGV 87264
ICGV 86707	Gujarat Narrow Leaf Mutant, A 13
ICGV 87259	

For cold tolerance:

A. monticola	NRCG 9608
NGCG 1339	CGC 498

For seed dormancy:

Dh 8	TG 7
CGC 7	TG 9
ICGS 30	TG 17

ALG 56
Kadiri 3
TMV 10
C 390
CGC 3
RSHY 6

For high shelling percentage:
J 13
Spancross
CSMG 916
Kadiri 3

For bold seed:
ALG 62
JSP(HPS)19
Somnath
CSMG 33
CSMG 35
CSMG 81-1
CSMG 83-1
CSMG 9101
M 13

For high oil content:
NC Ac 17500
C 174
TMV 3
TMV 10
TG 7

For iron chlorosis tolerance:
NGS 7
JL 24
GG 2

For resistance to rust and late and early leaf spots:
PI 259747
PI 270934
PI 393516
PI 393517
PI 393643
PI 393527
PI 414331
NC Ac 17090
NC Ac 17129
ICG(FDRS)43
ICG(FDRS)68
ICG(FDRS)69
ICGV 86350
ICGV 86598
ICGV 86707
ICGV 87160
ICGV 87261
ICGV 87264
ICG 1697
ICG 7894
CSMG 84-1

For tolerance to bud necrosis disease:
ICGV 86031

For insect tolerance:
Leaf miner:
ICG 5240
GBFDS 273
GBFDS 592
ICG 11786
ICGV 86137

Spodoptera:
ICGV 86350
ICGV 87264
ALG 50

Jassids:
NC Ac 2663

Multiple insect resistance:
ICG 2271
JL 83
JL 116

For *A. flavus* tolerance:
Monir 240-30
UF 71513
Ah 7223
J 11
PI 337409
PI 337394F

Indian scientists have attempted to access genetic variability in the wild relatives of groundnut. Interspecific hybridization between the tetraploid *A. hypogaea* and diploid wild species *A. cardenasii*, *A. stenosperma* and *A. chacoense* has been carried out in Tamil Nadu state in India. Derivatives of the interspecific hybridizations are currently under evaluation. Irradiation and chemical mutagens have been used frequently in India to create additional variability for use in breeding programmes. Cultivars such as MH 2, TG 1 (Trombay Groundnut 1), TG 3, BG 1 (Birsa Groundnut 1) and BG 2 were developed by mutation breeding using irradiation, and CO 2 (Coimbatore 2) from chemical mutagenesis.

14.4.4 South-east Asia

Groundnut is an important food legume and oil crop in south-east Asia. Indonesia, Vietnam, Thailand and the Philippines are the major producers in the region; other countries – Malaysia, Laos and Cambodia – have only small areas under groundnut. Thailand, Vietnam and Indonesia are able to meet their domestic demand but in the other countries there is a big gap between domestic production and demand. Consumption of groundnut pods and seeds in the boiled form is very popular in this region. Peanut butter is a popular groundnut product in Malaysia and the Philippines.

The region grows groundnut on about 0.92 million ha with a total production of 950 000 t. Average pod yields are low compared with China and the USA. Major production in the region comes from upland areas, where groundnut is generally grown as a monocrop. In plantation areas it is intercropped with young rubber, oil palm and coconut trees. A sizeable area of groundnut is grown in rice fallows under residual moisture conditions.

Several biotic and abiotic factors are responsible for low productivity in the region. The major constraints to increased groundnut production are late leaf spot, rust, sclerotium wilt, bacterial wilt, peanut stripe virus, leaf miner, leafhopper, *Spodoptera*, *Helicoverpa*, aphids, thrips, drought, acid soils, low soil fertility, shade under plantation crops, low price of groundnut and lack of seed availability of improved cultivars.

Groundnut research in Thailand, Vietnam, Indonesia and the Philippines is very active. Malaysia has a small groundnut research programme.

TABLE 14.9 *Improved groundnut cultivars released in South-east Asia*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Indonesia				
Gajah	Spanish	Schwartz 21 / Spanish	1950	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 1.51 t/ha, resistant to bacterial wilt
Kidang	Spanish	Schwartz 21 / Small Japan	1950	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt
Macan	Spanish	Schwartz 21 / Spanish	1950	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt
Banteng	Spanish	Schwartz 21 / Spanish	1950	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt
Pelanduk	Spanish	Kidang / VB 1	1983	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt and *A. flavus*
Tapir	Spanish	Kidang / VB 1	1983	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 2.0 t/ha, resistant to bacterial wilt and *A. flavus*
Tupai	Spanish	US 26 / Kidang	1983	Adapted to upland cultivation, 95–100 days to maturity, seed size 45–50 g/100, pod yield 2.0 t/ha, resistant to bacterial wilt and *A. flavus*
Rusa	Spanish	Gajah / AH 223	1983	Adapted to upland cultivation, 100–110 days to maturity, seed size 35–40 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt and rust
Anoa	Spanish	Gajah / AH 223	1983	Adapted to upland cultivation, 100–110 days to maturity, seed size 35–40 g/100, pod yield 1.5 t/ha, resistant to bacterial wilt and rust
Kelinci	Valencia	Acc 12	1987	Adapted to upland and lowland cultivation, 100–110 days to maturity, seed size 40–45 g/100, pod yield 2.0 t/ha, tolerant to bacterial wilt and resistant to leaf spot
Jepara	Spanish	–	1989	Adapted to lowland cultivation, 90–100 days to maturity, seed size 35–40 g/100, pod yield 1.2 t/ha, tolerant to bacterial wilt
Landak	Spanish	Schwartz 21 / Spanish	1989	Adapted to upland and lowland cultivation, 90–95 days to maturity, seed size 45–50 g/100, pod yield 1.8 t/ha, tolerant to bacterial wilt

TABLE 14.9 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Mahesa	Spanish	PI 350680 / Kidang	1991	Adapted to upland and lowland cultivation, 95–100 days to maturity, seed size 46 g/100, pod yield 2.0 t/ha, resistant to bacterial wilt, tolerant to rust
Badak	Valencia	FESR 12 /Local Depok	1991	Adapted to upland and lowland cultivation, 95–100 days to maturity, small seed size, pod yield 2.0 t/ha, tolerant to bacterial wilt and leaf spot
Biawak	Spanish	–	1991	Adapted to upland cultivation, 90–95 days to maturity, medium seed size, pod yield 2.0 t/ha, resistant to bacterial wilt
Komodo	Spanish	–	1991	Adapted to upland cultivation, 95–100 days to maturity, medium seed size, pod yield 2.0 t/ha, resistant to bacterial wilt and rust
Vietnam				
Do Bac Giang	Spanish	Local cultivar	–	
Sen Nghe An	Spanish	Local cultivar	–	
Moket	Spanish	Local cultivar	–	
Ly	Spanish	Local cultivar	–	
Giay	Spanish	Local cultivar	–	
Cuc Nghe An	Spanish	Local cultivar	–	
Sutuyen	Spanish	Selection from China	1970	
Tram Xuyen	Spanish	Selection from China	1970	
V 79	Spanish	X-ray mutant of Bachsa 77	1980	
B 5000	Spanish	X-ray mutant of Bachsa 77	1983	
Sen Lai (75–23)	Spanish	Sen Nghe An / Tram Xuyen	1985	

TABLE 14.9 *Cont.*

Cultivar	Botanical type	Pedigree	Year of release	Characteristics
Philippines				
UPL Pn 6	–	CES 103 / PI 298115	1986	
UPL Pn 8	–	CES 101 / PI 298115	1989	
BPI Pn 2	–	–	–	
UPL Pn 2	Spanish	Moket	1976	
UPL Pn 4	Valencia	Acc 12 (PI 314817)	1978	
BPI P9	Spanish	E.G. Red / Fante 17	1973	
CES 101	Spanish	Pureline selection from unknown cultivar	1973	
Thailand				
Khon Kaen 60-1	Spanish	Moket	–	
Khon Kaen 60-2	Valencia	TMV 3	1988	
Khon Kaen 60-3	Virginia	Selection from NC 7	1988	
Lampang	Valencia	–		
SK 38	Valencia	Selection in local cultivar		
Tainan 9	Virginia (bunch)	Introduction		
Malaysia				
MKT 1			1990	

Not much is known about Laos and Cambodia. The Peanut CRSP of USAID in Thailand and the Philippines, ACIAR of Australia in Indonesia, and IDRC of Canada in Thailand have supported or continue to support groundnut research in the region. ICRISAT has played an important role in introducing improved germplasm in the region. In Thailand and the Philippines, the national groundnut programmes have strong multidisciplinary teams of scientists. In addition to introducing improved germplasm, hybridization has been commonly adopted to develop new cultivars in Indonesia, Thailand and the Philippines. Several cultivars have been released in the region (Table 14.9). In Indonesia, almost all improved cultivars are either resistant or tolerant to bacterial wilt; Schwartz 21, the first disease-resistant groundnut cultivar developed through hybridization, was released here as early as 1927.

Groundnut research activity in Malaysia is very limited. Improved germplasm introduced from ICRISAT and other sources is evaluated for local adaptation, including resistance to prevailing diseases and insect pests.

The research programme in Vietnam is in its infancy and suffers from lack of trained manpower, poor infrastructure and paucity of resources. However, in collaboration with ICRISAT, breeding activities covering resistance to foliar diseases (late leaf spot and rust) and bacterial wilt, earliness, high yield and improved seed quality have been initiated recently. ICRISAT is developing single-seed descent breeding populations derived from crosses between Vietnamese cultivars and other desirable donor parents at its centre in India: at the F_5 stage, these populations will be grown in Vietnam for *in situ* selection.

In Indonesia, the main objective of the groundnut improvement programme is to improve yield potential and adaptation to varying agroecology and cropping systems. The specific issues that receive attention are early maturity, tolerance to excess soil moisture, tolerance to drought, tolerance to soil acidity, tolerance to mineral toxicities, adaptation to inter- and mixed-cropping, tolerance/resistance to insect pests and diseases, and tolerance to heat. A massive field screening exercise was undertaken in Indonesia to evaluate *Arachis* germplasm for resistance to peanut stripe virus. No resistance was found among 9000 lines of *A. hypogaea*; among 54 accessions of wild *Arachis* species, only *A. cardenasii* was immune. A few others showed a resistant reaction.

The primary objective of groundnut breeding in the Philippines is to develop groundnut cultivars with desirable agronomic traits such as high yield, early maturity, acceptable quality and resistance to rust, late leaf spot, *A. flavus*, leafhopper and spider mites. In addition, the improved cultivars should have tolerance/adaptation to drought, partial shade and acidic soil conditions, and improved nitrogen-fixing ability. From the screening activities, several promising sources of desirable characters have been identified for use in the breeding programme (PCARRD, 1985).

They are:

Rust:
- PI 259653
- PI 109839
- ICGS 55

Sclerotium wilt:
- IPB Pn 82-71-27
- IPB Pn 82-68-16

Multiple insect pests:
- NC Ac 343
- NC Ac 2214
- ICG(FDRS)11
- Bhairwa

Local factors:

Drought:
- Acc 847
- EG Pn 12

Shade:
- UPL Pn 2
- IPB Pn 12-14
- ICGS(E)123
- ICGS(E)120

Acid soils:
- IPB Pn 24-2
- IPB Pn 24-3
- IPB Pn 26-4
- BPI P9
- UPL Pn 4

High nitrogenase activity:
- RLRS 5
- RLRS 7
- IPB Pn 49-12
- 57-422

The most active groundnut breeding programme in the region is that of Thailand, the objectives of which include: high yield and earliness; adaptation to after-rice, unirrigated condition and before-rice growing conditions; resistance to foliar diseases (rust and late leaf spot); resistance to *A. flavus*, *A. niger* and *Sclerotium rolfsii*; and large-seeded confectionery and boiling-type cultivars. Significant progress is being made in achieving these objectives;. Two cultivars were released recently, and several breeding lines with good promise have been identified and are under evaluation.

14.4.5 Australasia

The Australasian region is not very important from the perspective of global groundnut production. Production in the region is dominated by Australia, which provides high quality groundnuts for world trade during the off-season for producing nations in the northern hemisphere. Major constraints to increased production in Australia include the foliar pathogens (early and late leaf spots and rust); soil-borne diseases (Cylindrocladium black rot, Sclerotinia blight, and *A. flavus*); and drought. Other countries in the region include Papua New Guinea, Solomon Islands, Vanuatu, Tonga, New Zealand and Fiji, all of which produce only limited amounts of groundnut for local consumption.

Australia has the most active research programme in the region. Prior to the programme of varietal improvement started in 1977–78, the primary source of cultivars in Australia was introduction. A high degree of mechanization permits widespread use of cultivars with spreading or runner growth habits. Large-seeded virginia-type cultivars such as Shulamith and NC 7 are preferred here. The spanish cultivar 'McCubbin' was released by the Australian national programme, the goals of which are yield improvement, quality maintenance (particularly shelf life), and resistance to foliar diseases.

Other countries in the region do not have breeding programmes but still rely exclusively on introduction for new cultivars. Recently, Papua New Guinea and Fiji obtained advanced breeding lines from ICRISAT for evaluation and *in situ* selection. Red-seeded spanish is the preferred type grown in the Solomon Islands and Papua New Guinea.

14.4.6 North America

The United States is the largest producer of groundnuts in North America and conducts the bulk of the groundnut research in the region. Collection, maintenance and evaluation of groundnut germplasm have been high priorities in the USA. Placement of a full-time groundnut curator for the national germplasm collection at Griffin, Georgia, has helped to organize efforts in this area. During the last decade, breeders have identified considerable germplasm that can be used to improve the groundnut (Wynne and Halward, 1989b). At the same time, collection expeditions have continued to add to the diversity available for improvement of the groundnut (Simpson, 1983, 1990).

Utilization of the wild species of *Arachis* to improve the cultigen has been investigated in the USA by research programmes in North Carolina, Oklahoma and Texas. Much of the research has been concerned with the crossing relationships among the various species and with cultivated groundnuts. Pathways for the transfer of genetic material from the species to cultivated groundnuts have been established (Simpson, 1991; Stalker and Moss, 1987). The progress of research in this area has been reviewed recently (Wynne and Halward, 1989b; Stalker and Moss, 1987).

Cultivar development programmes at state experiment stations in Florida, Georgia, Oklahoma, North Carolina, Texas and Virginia and at a private company (formerly Gold Kist; now Agratech) released numerous cultivars (Table 14.10). Over the past 10 years, these have broadened the genetic base of the groundnut crop in the USA and provided sources of pest resistance (Knauft and Gorbet, 1989). Knauft and Gorbet assessed the genetic diversity among cultivars released by 1988 and concluded that the genetic base had been broadened considerably since 1976. This broadening has continued through additional cultivar releases since this report (Isleib and Wynne, 1992).

Cultivars released for their pest resistance include NC 6 (southern corn rootworm), NC 8C and NC 10C (cylindrocladium black rot), Va 81B

TABLE 14.10 *Groundnut cultivars released in the United States*

Cultivar	Market type	Pedigree	Year of release
Florigraze*	Rhizoma	Selection from PI 118457 (*Arachis glabrata* Benth. cv. 'Arb', collected by W.A. Archer near Campo Grande, Brazil, in 1936)	1978
Arbrook	Rhizoma	PI 262817 (*Arachis glabrata* Benth. collected by W.C. Gregory (Col. No. 9569) near Trinidad, Itapua Department, Paraguay, in 1959)	1985
Dixie Runner	Runner	Small White Spanish 3x-1 / Dixie Giant	1943
Virginia Bunch 67*	Runner	Selection from 'Virginia Bunch' obtained in 1941 from East Georgia Peanut Co., Bulloch Co., GA	1945
Southeastern Runner 56–15*	Runner	Selection from 'Southeastern Runner'	1947
Early Runner	Runner	Small White Spanish 3x-2 / Dixie Giant	1952
Florispan Runner	Runner	Basse / Spanish 18–38, GA 207–3 // Early Runner	1953
Georgia 119–20	Runner	Southeastern Runner / Dixie Giant, 210–4 // Virginia Runner	1954
Florunner	Runner	F334A–3–14 (Florispan sib) / F230–118–B–8–1 (Early Runner sib)	1969
Altika	Runner	F393–7–1 (NC-FLA 14 sib) /3/ GA 119–20, Southeastern Runner / Dixie Giant, 210–14 // Virginia Runner	1972
GK19	Runner	F334–3–5–5–1 (Florispan derivative) / Jenkins Jumbo, F393–6 // F334–9 (Florispan sib)	1973
Tifrun	Runner	Florida Small Spanish / Dixie Giant, F231–51 /4/ F385–1–7–2, Pearl (F228) // F68–74 S_3–1–2, McSpan (F13, Small White Spanish) / Virginia Jumbo Runner (F14), F249–42–3–1 /3/ Jenkins Jumbo, T1645 (selection from F416) / T1861, selection made in 1966 from local virginia stock in Georgia, thought to have arisen from a virginia × spanish hybrid)	1977
GK7	Runner	F334–3–5–5–1 (Florispan derivative) / Jenkins Jumbo, F393–2 // GK 19	1982
Sunbelt Runner	Runner	F392–12–B–28 (Florigiant sib) / VA Bunch 67, A4–4 // Florunner	1982
Sunrunner	Runner	F439–16–10–1–1 (Florunner component) // UF393–7–1 (NC-FLA 14 sib), UF334A–3–5–5–1 (Florispan derivative) / Jenkins Jumbo	1982
Southern Runner	Runner	PI 203396 (resistant to *Cercospora arachidicola* and *Phaeoisariopsis personata*) / Florunner	1984
Langley	Runner	Florunner/PI 109839	1986

TABLE 14.10 *Cont.*

Cultivar	Market type	Pedigree	Year of release
Okrun	Runner	Florunner / Spanhoma	1986
Tamrun 88	Runner	Goldin I (Wilson County Peanut Co., Pleasanton, TX) / Florunner	1988
Georgia Runner	Runner	Krinkle-leaf (var. *vulgaris*) / PI 331334 ('Criollo', var. *hypogaea* from Bolivia)	1990
MARC I	Runner	Early Runner / Florispan, F439–17–2–1–1 (Florunner sib) // F459B–3–2–4–6–2–2–1 (Early Bunch component)	1990
Improved Spanish 2B*	Spanish	Selection from local Spanish made *c.* 1918 at Florence, SC	
Spanish 18–38*	Spanish	Selection from farmers' spanish stocks	
Spanish No. 146	Spanish	Spanish introduction (Coll. No. 146) obtained from India by Tom Huston Peanut Co.	
GFA Spanish*	Spanish	Selection from 'Small Spanish' obtained from a grower in 1930	1941
Spantex*	Spanish	Selection from farmers' spanish stocks	1948
Dixie Spanish*	Spanish	Selection from Spanish introduction (Coll. No. 146) obtained from India by Tom Huston Peanut Co.	1950
Argentine*	Spanish	Selection from PI 121070 (var. *vulgaris*)	1951
Spanette*	Spanish	Selection from Spanish 18–38	1959
Starr	Spanish	Spantex / PI 161317 (var. *vulgaris* obtained in 1947 from Salto, Uruguay)	1961
Spanhoma*	Spanish	Selection from 'Argentine'	1969
Comet*	Spanish	Selection from 'Starr'	1970
Spancross	Spanish	Argentine (PI 121070–1) / PI 405933 (*Arachis monticola*)	1970
Tifspan	Spanish	Argentine (PI 121070–1) / Spanette	1970
Tamnut 74	Spanish	Starr // TPL 647–2–5, Spantex / *Arachis monticola*	1974
Goldin I	Spanish	Obtained from E. Goldin, Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot, Israel by the Wilson Co. Peanut Co., Pleasanton, TX	1976
Toalson	Spanish	PI 221057 (var. *vulgaris*) / Selection 26 (Spantex sib), TPL 673–A // Starr	1979
Pronto	Spanish	Chico / Comet	1980

TABLE 14.10 *Cont.*

Cultivar	Market type	Pedigree	Year of release
Spanco	Spanish	Chico / Comet	1981
Tennessee Red*	Valencia	Selection from farmers' valencia stocks	1971
New Mexico Valencia A*	Valencia	Selection from 'New Mexico Valencia'	1973
McRan*	Valencia	Selection from African plant introduction	1979
New Mexico Valencia C*	Valencia	Selection from PI 355987, irradiated 'Colorado Manfredi' obtained from the research station at Manfredi, Argentina	1986
Georgia Red	Valencia	UF439–16–10–3 (Florunner component) / New Mexico Valencia A	1944
NC 4*	Virginia	Selection from 100 plant isolations made in 1929 from NC farmers' cultivars by P.H. Kime, NCSU agronomist, Selection #4 deemed typical virginia bunch	1945
Holland Jumbo*	Virginia	Selection from farmers' virginia stocks	1945
Holland Virginia Runner*	Virginia	Selection from farmers' virginia stocks	1952
Virginia Bunch 46–2*	Virginia	Selection from 'Virginia Bunch Large'	1952
Virginia Bunch G2*	Virginia	Selection from 'Virginia Bunch' obtained in 1941 from East Georgia Peanut Co., Bulloch Co., GA	1952
Virginia Bunch G26*	Virginia	Selection from 'Virginia Bunch' obtained in 1941 from W.A. Groover, Bulloch Co., GA	1952
NC 1	Virginia	NC4 / Improved Spanish 2B	1952
NC 2	Virginia	Basse / Spanish 18–38, GA 207–2 // White's Runner	1952
Virginia 56R*	Virginia	Selection from 'Atkins Runner'	1956
NC 4X	Virginia	Selection from irradiated 'NC 4'	1959
Florigiant	Virginia	Basse / Spanish 18–38, GA 207–3 // F230–118–2–2 (same as F230), F334A–5–5–1 /3/ F359–1–3–14, Jenkins Jumbo // F230–118–5–1, Dixie Giant / Small White Spanish 3x-2	1961
Virginia 61R*	Virginia	Selection from 'Atkins Runner'	1962
NC 5	Virginia	NC 1 // C12, PI 121067 / NC Bunch	1964
Shulamith	Virginia	Florigiant / F334A–B–17–1 (Florispan derivative)	1968

TABLE 14.10 *Cont.*

Cultivar	Market type	Pedigree	Year of release
NC17	Virginia	F334A–3–5–5–1 (Florispan derivative) / Jenkins Jumbo	1969
Virginia 72R	Virginia	VA 61R / VA A89–15 (selection from farmers' stocks, perhaps Atkins Runner)	1971
NC-FLA 14	Virginia	Jenkins Jumbo / F334A–3–5–5–1 (Florispan derivative)	1973
Keel 29*	Virginia	Selection from 'Florigiant'	1974
Avoca 11*	Virginia	Selection from 'NC 2'	1976
GK 3	Virginia	Florida Small Spanish / Dixie Giant, F231–51 /4/ F385–1–7–2, Pearl (F228) // F68–74 S_3–1–2, McSpan (F13, Small White Spanish) / Virginia Jumbo Runner (F14), F249–42–3–1 /3/ Jenkins Jumbo, F416–2 /5/ F392 (Florigiant sib)	1976
NC 6	Virginia	NC Bunch / PI 121067, C12 // C37 (same as C12), GP–NC 343 (selection from NC Ac 4508) // VA 61R: Resistant to SCR	1976
Early Bunch	Virginia	Virginia Station Jumbo /4/ F385–1–7–4, Pearl (F228) // F68–74 S_3–1–2, McSpan (F13, Small White Spanish) / Virginia Jumbo Runner (F14), F249–42–3–1 /3/ Jenkins Jumbo, F406A /5/ F420, F231–51 (Dixie Runner sib) / F392–12–1–7 (Florigiant sib)	1977
NC 7	Virginia	NC 5 // F393, F334–3–5–5–1 (Florispan derivative) / Jenkins Jumbo	1978
VA 81B	Virginia	F392–8 (Florigiant sib) /3/ GA 119–20, Southeastern Runner / Dixie Giant, 210–14 // Virginia Runner	1981
NC 8C	Virginia	NC 2 // A48, NC 4 / Spanish 2B, NC Ac 3139 /3/ Florigiant	1982
NC 9	Virginia	NC 2 / Florigiant	1985
NC10C	Virginia	NC 8C / Florigiant	1988
NC-V 11	Virginia	Florigiant / NC 5 // Florigiant / PI 337396 (var. *fastigiata*)	1989
VA-C 92R	Virginia	Florigiant // F393, F334–3–5–5–1 (Florispan derivative) / Jenkins Jumbo, NC Ac 17213 /3/ NC 7	1992
VC-1	Virginia	F334–3–5–5–1 (Florispan derivative) / Jenkins Jumbo, F393 // F334 (Florispan derivative) / F393 /3/ F392 (Florigiant sib) / GA 186–28 // F439 (Florunner component)	1991

* Developed by selection within a plant introduction or existing cultivar.

(sclerotinia blight) and Southern Runner (late leaf spot). The cultivars that have been released primarily for their pest resistance have generally compromised one or more agronomic traits, making them less competitive in absence of the pest.

Considerable effort to develop pest-resistant groundnut cultivars began during the 1980s in the USA. Wynne *et al.* (1991) summarized progress in breeding for disease resistance. They concluded that although several USA breeding programmes had been initiated for resistance to diseases – *Aspergillus* spp. (aflatoxin), tomato-spotted wilt virus, nematodes, early and late leaf spots, sclerotinia blight, and cylindrocladium black rot – few cultivars had yet been released, due to the short duration of the efforts. However, many sources of disease resistance were identified by screening programmes during the 1980s and breeding for disease resistance is now a priority in most USA programmes. Much progress can be expected.

Considerable effort in the USA has also been devoted to the use of wild species of *Arachis* for sources of resistance to pests. Programmes to transfer the high levels of resistance or immunity to early and late leaf spots, rust, nematodes and viruses were active during the 1980s (Stalker and Moss, 1987; Wynne and Halward, 1989a). To date, no cultivar incorporating germplasm from diploid wild species has been released.

Recently the groundnut industry identified quality and aflatoxin resistance as two major issues that needed additional research and were considered of highest priority because of the effect they have on the export of groundnuts. Substantial funding from the National Peanut Foundation and USDA has increased conventional breeding and molecular genetic research to address these problems.

Several researchers in the USA are now investigating and developing methodologies to use molecular techniques for groundnut improvement. The use of RFLPs as molecular markers is being investigated by a University of Georgia researcher (Kochert and Branch, 1990) in co-operation with several others. Little variation has been reported among cultivars but abundant polymorphism has been found among the diploid species of *Arachis*. Similar results were found for isozymes (Grieshammer and Wynne, 1990; Stalker *et al.*, 1990).

Several USA researchers are investigating somatic embryogenesis and plant regeneration in groundnuts. At least two laboratories have developed a repetitive somatic embryogenesis system and have established plants in soil (Durham *et al.*, 1991; A. Weissinger, North Carolina State University, personal communication, 1991). These successes should expedite the use of gene transfer systems in the crop. The use of microprojectile bombardment as part of a gene transfer system in groundnut is being evaluated in at least two laboratories. The success of these systems will allow the movement of agronomically important genes into the groundnut.

Several laboratories are identifying and sequencing genes from viruses and from other plants that may be useful in improving the groundnut. This

research is receiving funding support from the Peanut CRSP, private companies, the USDA and state experiment stations.

14.4.7 South America

The area under commercial groundnut production in South America is about 350 000 ha. Argentina ranks first in groundnut area in the region (180 000 ha), followed by Brazil (100 000 ha) and Paraguay (30 000 ha). The area in other countries, such as Bolivia, Chile, Ecuador, Peru, Uruguay and Venezuela, does not exceed 5000 ha. Although the region's area under groundnuts has been declining, the total production has not suffered significantly, due to increase in productivity: average yields in the 1980s were nearly 50% higher than those of the 1970s. New crop production technology and improved cultivars have contributed to increased yields.

Average seed yield in Argentina has increased from 0.79 t/ha in the 1970s to 1.20 t/ha in the 1980s. During the 1970s two valencia cultivars, Colorado Irradiado INTA and Blanco Rio Segundo, contributed 80% to the total groundnut production; the remaining 20% was contributed by Blanco Manfredi 68, a derivative of a cross between virginia and spanish types (Godoy and Giandana, 1992). Since then, the varietal picture in the country has changed completely as virginia runner types proved better adapted to the main groundnut-growing region of the country. By 1989, Florman INTA and Florunner accounted for 80% of the total groundnut area and production. This development is somewhat disturbing in view of the international community's expressed desire to maintain genetic diversity in food crops, particularly in the centres of diversity for those species. However, it is necessary to balance against this desire the needs of the individuals and nations in those regions. The good adaptation of runner types to the climate and soil in the country led Argentina to become the third largest exporter of edible groundnut in the world, after the USA and the People's Republic of China.

Average pod yields in Brazil in rainy seasons are 2.0–2.1 t/ha and in the dry season about 1.5 t/ha. The reduction in area and production has been dramatic: the cultivated area in 1972 was 759 000 ha and it declined to 100 000 ha in 1988, while production fell from 956 000 to 167 000 t in the same period. The main reason for such a sharp decline was establishment of soybean as the leading oilseed crop in the country. However, the average yield of groundnut has increased from 1.5 t/ha in the 1970s to 1.8 t/ha in the 1980s in São Paulo province (the main groundnut-growing area in the country). In the Ribeirao Preto region, the pod yield averages 2.5 t/ha but yields up to 4.0 t/ha can be obtained with the red valencia cultivar Tatu, which has a short growing cycle of 90–100 days and now occupies 80% of the groundnut-growing area in São Paulo. Another cultivar, Tatu Branco, which is similar to Tatu except for its seed colour,

occupies 10% of the groundnut area; it has undefined tolerance to drought and is adapted to low fertility. Recently three new cultivars with 15–20% higher yield than Tatu have been released – Tupa, Oira and Poitara. All three are derived from valencia-by-spanish crosses; they mature in 110–120 days and have two-seeded medium sized pods.

Groundnut cultivation in Bolivia is manual and local cultivars are grown. The three main local cultivars are Coloradito Palmer, an erect type with 125 days maturity; Cuero Padilla, a semi-erect type with 135 days maturity; and Bayo Gigante (also called Colorado Grande), a runner type with 145 days maturity.

In Paraguay, groundnuts are grown in three regions which differ in soil type, climatic conditions and level of technology input. In the Chaco region, cultivation is mechanized and spanish cultivars are grown. In the central region, valencia and spanish types are grown by small farmers in less fertile soils with low levels of technology input. In the southern region, long-season virginia types are cultivated on fertile soils. The present yields in Paraguay (1.3 t/ha) are 50% higher than those of 20 years ago.

Pod yields in Uruguay range from 0.7–1.8 t/ha. Groundnuts are generally cultivated by small farmers on acidic sandy soils which are low in Ca content, with family labour and little technology. Predominantly valencia types are grown; spanish and virginia types are also cultivated to a limited extent.

In 1990, the southern nations of South America (Argentina, Brazil, Bolivia, Paraguay and Uruguay) initiated a co-operative research effort called PROMANI (pro = program; maní = groundnut). Its objective is to promote groundnut research and extension activities in the participating countries. Research in Argentina and Brazil has been intensified since the early 1980s. Both countries have their own active breeding programme, whereas other PROMANI countries rely mostly on introduction of improved cultivars and selection in local cultivars/landraces.

In Argentina, groundnut research is focused on studies of the taxonomy of the genus *Arachis* and on the development of new cultivars of medium duration (125–130 days) with tolerance to drought and leaf spots, resistance to *A. flavus* infection, high O/L ratio, low iodine value, improved content and quality of seed proteins, and improved flavour and aroma. In Brazil, research objectives include germplasm collection and taxonomic studies on genus *Arachis*; breeding for resistance to late leaf spots; selection of early-maturing, high-yielding, red-seeded valencia/spanish types with improved pod/seed appearance and shelling out-turn; development of high-yielding virginia runner cultivars with resistance to leaf spot and other diseases; resistance to *Aspergillus* infection; and resistance to thrips.

Development of high-yielding, leaf spot-resistant cultivars with acceptable agronomic and quality attributes will benefit the South American region most. Other diseases which could be potentially important in the region are rust, scab and *Sclerotium*. Except for some areas in Argentina, groundnuts in the region are generally grown under rainfed conditions. Drought is the most common abiotic stress in the region.

14.5 ACCOMPLISHMENTS AND FUTURE EFFORTS

On a worldwide basis, the most important results of groundnut breeding in the past 10–20 years have been the identification of sources of resistance to the three globally important foliar fungal pathogens and the transfer of resistance into breeding populations with the locally appropriate agronomic attributes. It remains to be seen whether release of cultivars resistant to rust and leaf spot will significantly affect patterns of groundnut production.

Closely following the foliar diseases in importance is the aflatoxin problem. Despite the identification of seed-coat resistance and the release of IVSCAF-resistant cultivars, aflatoxin contamination remains the largest single problem affecting international trade in groundnut. The recent adoption by the European Community of extremely low tolerances for aflatoxin may eliminate some nations from the array of groundnut exporters. Although this problem is certainly not confined to the realm of plant breeding, the international community looks primarily to a genetic solution.

Breeding for resistance to insect pests has not been emphasized to the same degree as breeding for resistance to foliar diseases. Common foliar diseases occur with great regularity in most parts of the world while many insect species require particular environmental conditions in order to reach the population densities necessary to cause economic damage. Under management systems with minimal or no application of insecticides and fungicides, insect pest populations may be curbed by the presence of predatory insects and animal or fungal parasites. Host, pests, predators and parasites exist in a balance sensitive to subtle changes in the ecological dynamic. In such production systems, pest resistance of low or intermediate level may be sufficient to shift the balance in favour of the host plant. In many developing nations, the microeconomics of the production system and the infrastructure for distribution and acquisition of pesticides prohibit widespread use of pesticides for control of insects. Host-plant resistance to insects will be the most effective means of reducing losses in yield and quality associated with insect depredation.

Under intensive management systems, insect pests are controlled by applications of pesticides that may also destroy beneficial species whose absence allows unchecked growth of pest species that develop later in the growing season, thereby necessitating further applications of pesticides. Recently, socioeconomic forces in developed nations have created the concept of LISA – low-input sustainable agriculture – as a paradigm for

mechanized agricultural production systems. These forces include demand by consumers for agricultural products free from pesticide residues, public concern over the effects of pesticides on the environment, reduction of production costs, and the increasing difficulty encountered by manufacturers of pesticides in obtaining government approval for their registration and sale. Key concepts of LISA include minimal application of pesticides that have potentially harmful effects on consumers or environment; emphasis on soil conservation, including reduced tillage and use of green manure animal waste as sources of organic matter and incorporation of leguminous species into rotations to reduce use of mineral fertilizers that can contaminate groundwater supplies. In short, LISA comprises a set of production practices which by choice avoid extensive reliance on the products of the chemical revolution that has so dramatically changed the face of agriculture in developed nations in the last 50–60 years. While use of herbicides and fungicides are affected by these practices, insecticides are probably affected most because of their generally greater acute toxicity to mammals. This trend may provide impetus for increased efforts in breeding for insect resistance in developed nations. It remains to be seen whether the consuming public in developed nations is sufficiently desirous of pesticide-free produce to accept groundnuts bearing evidence of insect feeding. Assuming that it is not, countries supplying edible groundnuts will need to deploy cultivars with high levels of resistance to insects, a practice that will certainly place strong selective pressure on pest populations.

Until recently, the gene pool for cultivated groundnut comprised the global collection of the cultigen (some 12 000 accessions) and the smaller collection of *Arachis* species of which genes only from species of section *Arachis* were accessible through sexual transfer. In the summer of 1992, researchers from several public and private institutions reported success in transforming groundnut with exogenous DNA and regeneration of fertile plants from transformed tissues. Transformation has been effected through microprojectile bombardment of embryonic axes (Brar *et al.*, 1992), embryogenic immature cotyledonary tissue (Weissinger *et al.*, 1992) and callus derived from embryonic leaflets (Weissinger *et al.*, 1992), and through electroporation of protoplasts (Demski *et al.*, 1992). It would appear that the array of transformation techniques effective in soybean can be adapted to groundnut through modification of protocols. This effectively converts the gene pool from a portion of the genetic information in genus *Arachis* to virtually all genes in the planetary biosphere. The key problem in groundnut breeding is changing from location of sources of useful genes within the cultigen to identification of the genes *per se*, i.e. the DNA base sequences, of potential economic value in groundnut regardless of the source of those genes. Issues of the proprietary nature of such genes and the payment of royalties, particularly by groundnut producers in developing nations, will doubtless interest the groundnut breeding community for decades to come.

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