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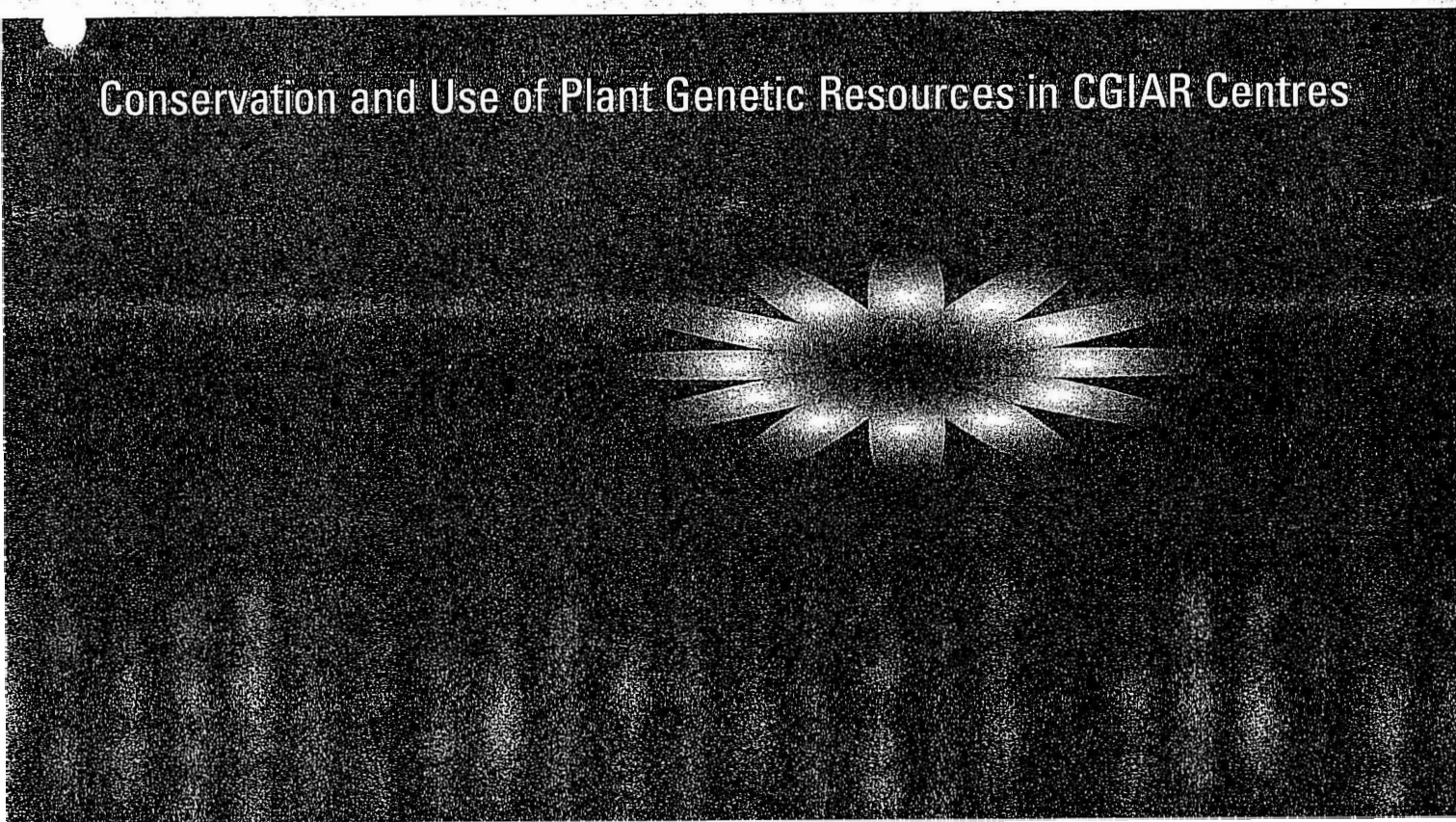
Biodiversity in Trust



Conservation and Use of Plant Genetic Resources in CGIAR Centres

Chapter 9

Groundnut[1]

A.K. Singh and S.N. Nigam

Groundnut, *Arachis hypogaea* L. (also called peanut in English, *mani* in Spanish, *amondoim* in Portuguese, *pistache* in French, *mungphali* in Hindi and *ying zui dou* in Chinese), ranks 13th among food crops and annual oilseed crops (FAO 1995). Its high oil and protein contents serve important needs for food, energy and industrial uses. Although a native of South America, the crop is now cultivated in tropical, subtropical and warm temperate regions of the world extending from 40°N to 40°S.

BOTANY AND DISTRIBUTION

Arachis hypogaea L. is a member of family Leguminoseae-Papilionoideae, tribe Aeschynomeneae and subtribe Stylosanthinae. It is a tetraploid with $2n$=40. Krapovickas and Gregory (1994) divided the genus *Arachis* into nine sections. Section *Arachis* contains cultivated groundnut, *A. hypogaea*, another tetraploid species *A. monticola* Krapov. & Rigoni and a number of wild diploid species. Gregory *et al.* (1973) earlier divided *A. hypogaea* into two subspecies, *fastigiata* Waldron and *hypogaea* Krap. et Rig., and each subspecies into two botanical varieties. According to the new classification, subsp. *fastigiata* is subdivided into four botanical varieties, *fastigiata*, *peruviana* Krapov. & W.C. Gregory, *aequatoriana* Krapov. & W.C. Gregory and *vulgaris* C. Harz. The two botanical varieties in subsp. *hypogaea* are *hypogaea* and *hirsuta* Kohler. The key for identification of different botanical varieties is given in Box 9.1.

Origin, Domestication and Diffusion

The genus *Arachis* is naturally restricted to Argentina, Bolivia, Brazil, Paraguay and Uruguay in South America. Both Krapovickas (1969, 1973) and Gregory *et al.* (1980) postulated a planalto profile from Corumba to Joazeiro, Brazil as the centre from which distribution of *Arachis* occurred. Cultivated groundnut most probably originated in the region of southern Bolivia and northwestern Argentina (Krapovickas 1969), which is an important centre of diversity of subsp. *hypogaea*. A few forms of subsp. *fastigiata*, certain wild diploid annuals such as *A. duranensis* Krapov. & W.C. Gregory and *A. batizocoi* Krapov. & W.C. Gregory and *A. monticola*, considered to be the probable ancestors of *A. hypogaea* (Singh 1988), also occur naturally in this area. It has been suggested that *A. duranensis* (with A genome) and *A. batizocoi* (with B genome) initially evolved into the wild tetraploid *A. monticola* through amphidiplodization, which on domestication gave rise to the cultivated *A. hypogaea* (Smartt *et al.* 1978; Singh 1986, 1988), although RFLP results do not show *A. batizocoi* to be close to *A. hypogaea*. Subsequent spread of the crop to different agroclimatic zones brought further diversification and variability in growth habit and seed and pod characteristics (Singh 1995).

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Box 9.1. Key to distinguish the taxa of *Arachis hypogaea*

A.	Central axis without flowers and lateral branches, the vegetative and reproductive branches alternate regularly (alternate ramification).	**subsp. *hypogaea***
	B. Leaflets with a glabrous dorsal surface or with some hair along the midrib.	**var. *hypogaea***
	B'. Leaflets with hairy (1-2 mm) dorsal surface, entire surface is hairy.	**var. *hirsuta***
A'.	Central axis with flowers and lateral branches, the reproductive and vegetative branches show no order (sequential ramification).	**subsp. *fastigiata***
C.	Fruits with more than two seeds. Open/widespread fruiting.	
D.	Leaflets with a glabrous dorsal surface and hair only on the midrib.	
	E. Fruits with smooth or lightly marked reticulation, without highlighting of the longitudinal ribs. Reproductive branches mostly short and thin.	**var. *fastigiata***
	E'. Fruits with very marked reticulation, and with prominent longitudinal ribs. Long, strong, reproductive branches (5-10 cm), with strong central axis and lateral branches.	**var. *peruviana***
	D'. Leaflets with a hairy (1-2 mm) dorsal surface, entire surface hairy. Long reproductive branches, mainly the lateral branches. Central axis mostly with short inflorescence and reproductive branches.	**var. *aequatoriana***
	C'. Fruits mostly 2-seeded. Bunched fruits, pointing to the base of the plant. Frequently with compact ears.	**var. *vulgaris***

Source: Krapovickas and Gregory 1994 (translated from Spanish).

Domestication probably first took place in the valleys of the Parana and Paraguay river systems in the Gran Chaco area of South America. Early European explorers found native Indians cultivating this crop in many islands in the Antilles, on the northeastern and eastern coasts of Brazil in all warm regions of the Rio de la Plata basin; extensively in Peru and sparsely in Mexico (Hammons 1994).

In South America, where the greatest diversity is found, Krapovickas (1969) and Gregory and Gregory (1976) recognized the Chaco region between southern Bolivia and northwestern Argentina as the primary centre of diversity and another six regions as secondary centres of diversity for cultivated groundnut (Fig. 9.1).

On the basis of presence of distinct landraces found during further exploration in Ecuador, Singh and Simpson (1994) recently have added Ecuador as another secondary centre of diversity. Most authorities believe that in the late 15th century the Portuguese carried two-seeded groundnut varieties from the east coast of South America (Brazil) to Africa, to the Malabar coast of southeastern India and possibly to the far east. The Spaniards in the early 16th century took three-seeded Peruvian types (including

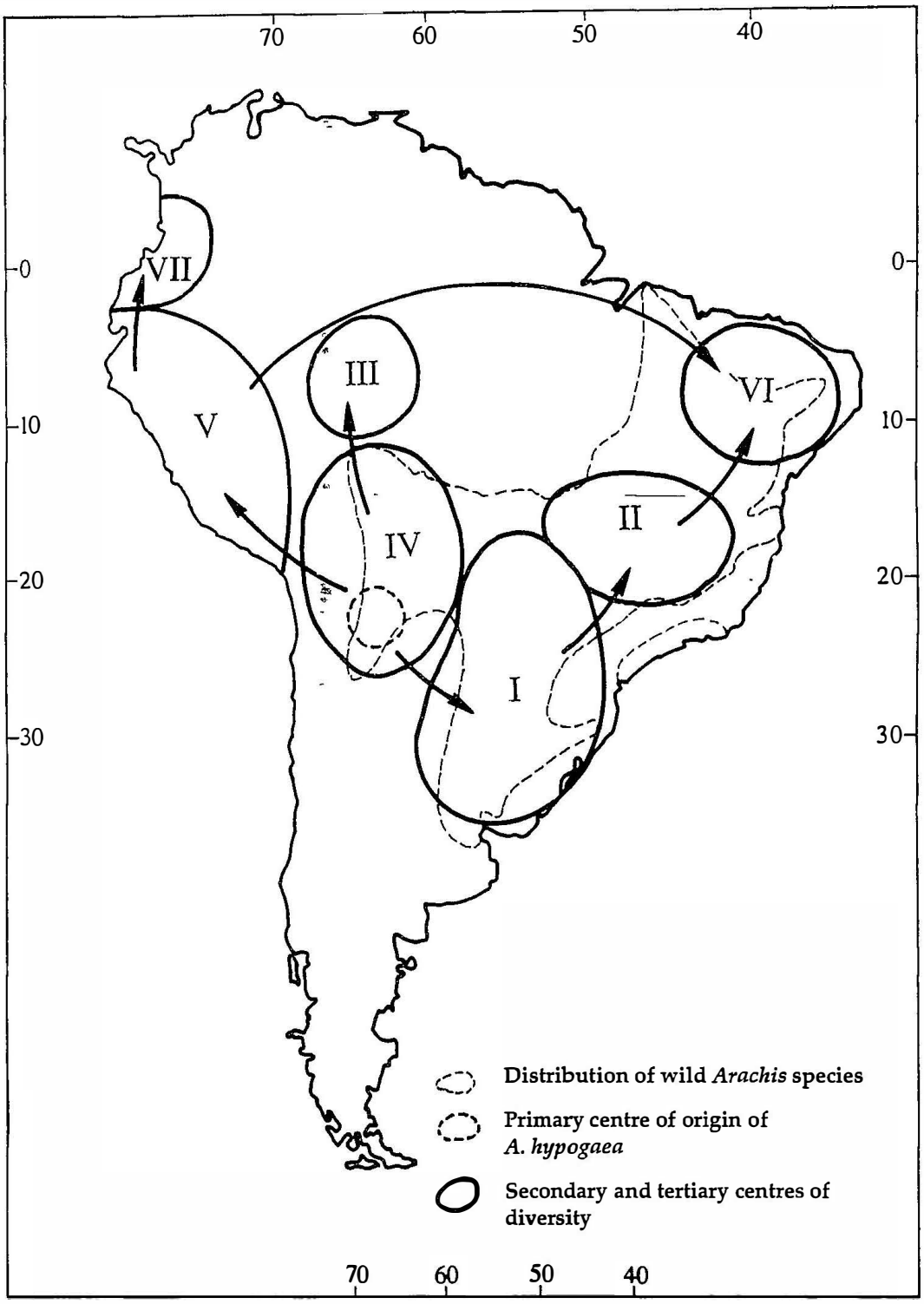

Fig. 9.1. Centres of origin and diversity of *Arachis hypogaea* in South America. I subsp. *fastigiata* var. *fastigiata* and var. *vulgaris*; II subsp. *fastigiata* var. *fastigiata*; III subsp. *hypogaea* var. *hypogaea*; IV subsp. *hypogaea* var. *hypogaea*, subsp. *fastigiata* var. *fastigiata*; V subsp. *hypogaea* var. *hypogaea* and var. *hirsuta*, subsp. *fastigiata* var. *fastigiata* and var. *peruviana*; VI subsp. *fastigiata* var. *fastigiata* and var. *vulgaris*; VII subsp. *fastigiata* var. *aequatoriana*.

hirsuta) to Indonesia and China up to Madagascar from the west coast of South America via the western Pacific. By the middle of the 16th century, groundnut made its way to North America from Africa as well as from the Caribbean islands, Central America and Mexico and was distributed worldwide. By the 19th century, groundnut became an important crop in West Africa, India, China and the USA. Among these new areas of

introduction, Africa is considered a tertiary centre of diversity. Although various types of groundnut introduced into Africa came from a single centre in South America, near Bolivia, there exists a significant variability in the continent. Similarly, India and China, with long histories of groundnut cultivation and landraces, are considered other important centres of diversity.

In addition to *A. hypogaea*, the wild *Arachis* species, some of which are used for edible seeds (e.g. *A. villosulicarpa* Hoehne) or forage (e.g. *A. glabrata* Benth., *A. pintoi* Krapov. & W.C. Gregory and *A. repens* Handro) constitute another genetic reservoir of useful characteristics for the improvement of cultivated groundnut. They are notable as sources of host-plant resistance to diseases and insect pests and perhaps also of agronomic traits (Gouk *et al.* 1986).

Genetic diversity in genus *Arachis* has been classified into four genepools by Singh and Simpson (1994).

1. Primary genepool consisting of landraces of *A. hypogaea* and its wild form *A. monticola* (although some consider *A. monticola* as a separate genepool).
2. Secondary genepool consisting of diploid species from section *Arachis* that are cross-compatible with *A. hypogaea.*
3. Tertiary genepool consisting of species of section *Procumbentes* that are weakly cross-compatible with *A. hypogaea.*
4. The fourth genepool consisting of the remaining wild *Arachis* species classified into seven other sections.

Reproductive Biology

Groundnut is an annual or weakly perennial herb that may flower as early as 17-18 days from the date of emergence. Most flowers are self-pollinated before or as they open (cleistogamy) and cross-pollination is rare, but some wild species, such as *A. lignosa,* may also require insects for pollination (Banks 1990). Sporogenesis or gametogenesis occurs 2 days prior to anthesis, when bud length is around 5 mm. Unlike other legumes, groundnut antipodals degenerate several hours before fertilization. The pollen tube takes around 10-18 hours after pollination to reach the ovary and effect fertilization. After fertilization the flowers wither rapidly and the intercalary meristematic cells that comprise the basal tissue of the ovary produce a geotropic stalk-like structure called a peg (carpophore). Initially associated with embryo development, the peg grows at first slowly and then rapidly. The tip of the peg usually contains two (sometimes 3-5, depending on variety) fertilized ovules. At the time of peg growth, the embryo is at the 8-12 cell stage and becomes quiescent. Peg growth continues until penetration into the soil (after 8-14 days of fertilization), and when it receives mechanical stimulus the peg transforms into a pod. Ovules and embryos then start growing, mature to form seeds within the pod, which later becomes dry and brittle to form the shell.

GERMPLASM CONSERVATION AND USE

We have made significant progress in the collection of groundnut germplasm from various centres of diversity in the last two decades (Table 9.1). Gaps in genetic diversity and geographical representation still exist. *Arachis hypogaea* subsp. *hypogaea* var. *hirsuta,* one among the six botanical varieties of *A. hypogaea,* remains unrepresented in the ICRISAT collection of 14 000 accessions of groundnut. Similarly, traditional groundnut areas in subsistence agriculture, areas of early introduction in countries like Laos and China in Asia, Angola, Malagasay Republic, Namibia and South Africa in Africa, and the areas of secondary centres of diversity in South America, Peru, Ecuador, Uruguay and Paraguay have not been fully explored. Information on each accession is available for most of the important features indicated in Groundnut Descriptors (IBPGR and ICRISAT 1992), but data on several descriptors in passport data, and for some characteristics of regional or local importance in evaluation data, are still far from complete.

Most of the traditional landraces, which constitute around 33% of the total world collection conserved at ICRISAT, originate from different countries of South America, Africa and Asia (Tables 9.1 and 9.2). Variability analysis of the world collection has shown comparatively greater amounts of variation in landraces than other germplasm (Singh *et al.* 1992). Most variability, particularly for resistance to diseases and insect pests and also for some agronomic characters like seed mass, is mainly available in the landraces originating from the primary and secondary centres of diversity in South America (Table 9.3).

Genus *Arachis* presents a considerable amount of botanical diversity. The basic plant structure in wild *Arachis* species and *A. hypogaea* is similar. In growth habit, genotypes can be procumbent runner type with short or long main axis and laterals growing horizontally to various lengths. Other genotypes may be decumbent, where laterals have an ascending tendency or are erect with shortened internodes. The angle between the main axis and secondary branches may vary and consequently the growth habit, classified into decumbent types (IBPGR and ICRISAT 1992). Table 9.3 summarizes the range of variability recorded at ICRISAT for various plant, pod and seed characters.

Three foliar diseases – late leaf spot [*Phaeosariopsis personata* (Berk. & Curt.) V. Arx.], early leaf spot (*Cercospora arachidicola* Hori) and rust (*Puccinia arachidis* Speg.) – are the most widely distributed and economically important diseases of groundnut. At ICRISAT 143 rust-resistant lines have been identified (Mehan *et al.* 1994b; Subrahmanyam *et al.* 1995). Extensive screening for leaf spot resistance has resulted in identification of several resistance sources (Foster *et al.* 1980, 1981; Melouk *et al.* 1984; Subrahmanyam *et al.* 1982). Fifty-four lines resistant to late leaf spot have been identified, 29 of which are also resistant to rust (Subrahmanyam *et al.* 1995). Screening of more than 2000 accessions in Malawi for early leaf spot over seasons has resulted in identification of five promising lines (Subrahmanyam, pers. comm.). Many wild *Arachis* species have been evaluated against these three foliar diseases and high levels of resistance have been identified in a large number of species/accessions for early leaf spot (Gibbons and Bailey 1967; Abdou *et al.* 1974; Foster *et al.* 1981), late leaf spot and rust (Abdou *et al.* 1974; Subrahmanyam *et al.* 1985).

Six important groundnut virus diseases are groundnut rosette (GRV) in Africa, peanut bud necrosis virus (PBNV) in India, tomato spotted wilt virus (TSWV) in the USA, peanut mottle (PMV) worldwide, peanut stripe (PStV) in East and Southeast Asia and peanut clump (PCV) in West Africa and India. Resistance to GRV disease was found in landraces from Burkina Faso (de Berchoux 1960) and also in wild *Arachis* species, *A. glabrata* and *A. repens* (Gibbons 1969). Recently, wild *Arachis* species, *A. appressibila* (30003), *A. chacoensis* (now *A. diagoi* Hoehne) (K.R. Bock, pers. comm.) and an interspecific derivative involving *A. diagoi* have shown high levels of resistance to GRV disease (Moss *et al.* 1993). Numerous lines with consistently less than 20% PBNV disease incidence in the field – such as ICGs 848, 851, 852, 862, 869, 885, 2271, 2306, 3806, 5030, 6135, 7676, 7892 – have been identified at ICRISAT (Dwivedi *et al.* 1995). Among wild *Arachis* species, *A. diagoi* showed no infection after mechanical or vector-effected inoculation (Subrahmanyam *et al.* 1985).

Screening of around 9000 accessions for PStV in Indonesia did not result in identification of any resistant line in *A. hypogaea*. However, screening of wild *Arachis* species has resulted in identification of several accessions with negative reaction to PStV (Culver *et al.* 1987; Prasada Rao *et al.* 1991). For PMV some germplasm lines, such as NC Ac 2240 and NC Ac 2243, have shown consistently low yield losses due to this disease (ICRISAT 1983). For PCV, screening of 7000 accessions did not result in identification of any resistant line. For both PMV and PCV, a number of wild *Arachis* species have shown promise (ICRISAT 1985; Subrahmanyam *et al.* 1985). Considerable variability for apparent resistance to TSWV has been reported in breeding lines in the USA (Culbreath *et al.* 1994).

Variation in reaction to several soilborne diseases has been reported in the germplasm. Resistance to bacterial wilt caused by *Pseudomonas solanacearum* (Smith)

Table 9.1. Number of accessions of cultivated groundnut and wild *Arachis* species from different centres of diversity available at ICRISAT (December 1994).

	Centres of diversity					
Collections	**Primary**	**Secondary**	**Tertiary**	**India/China**	**Others**	**Total**
Accessions	601	945	1194	88	1974	4802
Landraces	408	786	1943	1422	587	5146
Breeding lines	135	81	987	1558	1801	4562
Named cultivars	10	1	28	135	146	320
Interspecific derivatives	–	–	–	167	8	175
Wild *Arachis* spp.	132	146	–	–	31	309

Table 9.2. Status of groundnut germplasm accessions by botanical variety (December 1994).

	Number of accessions				
Botanical group	**Landraces**	**Breeding lines**	**Released cultivars**	**Others**[†]	**Total**
vulgaris	1738	1494	158	1384	4774
fastigiata	978	529	24	575	2106
peruviana	325	5	0	10	390
acquatoriana	3	4	0	7	14
hypogaea (bunch)	1128	1574	75	856	3633
hypogaea (runner)	1064	956	63	656	2739
hirsuta	0	0	0	0	0

[†] Others includes 165 interspecific derivatives and other accessions with status not known, doubtful, or not clear.

Smith was identified as early as 1920. Around 5000 germplasm accessions and breeding lines have been screened in wilt-sick plots in China and Indonesia, resulting in identification of about 54 lines (Mehan *et al.* 1994a). Most of these belong to the Chinese dragon type (subsp. *hypogaea* var. *hirsuta* ?). Resistance to black rot disease caused by *Cylindrocladium crotalariae* (C.A. Loos) D.K. Bell & Sobers has been identified in several Virginia and Spanish genotypes (Green *et al.* 1983) and *A. monticola* (Fitzner *et al.* 1985). NC 3033, a line resistant to black rot, was found resistant to *Sclerotium rolfsii* Sacc. Genotypes resistant to *Pythium* pod rot, *Sclerotinia minor*, have been identified (Smith *et al.* 1989).

Aflatoxin contamination in groundnut is a serious concern. Many sources have been found with resistance to pre-harvest seed infection, *in vitro* seed colonization and aflatoxin production. These include PI 337409, PI 337394F, UF 71513 (resistant to seed invasion and colonization), Doran and Shulamit (resistant to pod infection), U-4-477, 55-437, 73-30 and J 11 (resistant to seed infection in the field), and U 4-7-5 and VRR 245 (low production of aflatoxin B_1) (Mehan 1989).

Sources of resistance to most insect pests have been identified in both *A. hypogaea* and wild *Arachis* species (Lynch *et al.* 1981; Stalker and Campbell 1983; Stalker *et al.* 1984; Wightman *et al.* 1989; Lynch 1990; Wightman and Ranga Rao 1994). Some wild *Arachis* are cross-compatible with *A. hypogaea*. Resistance in wild *Arachis* spp. has been identified for the plant-parasitic nematodes *Meliodogyne arenaria* and *M. hapla* (Baltensperger *et al.* 1986; Nelson *et al.* 1988; Holbrook and Noe 1990). Eleven *A. hypogaea* have been reported resistant to these two nematode species (Anonymous 1985). A number of genotypes – such as ICGs 1697, 4110, 6322, 7889, 7897 – have been identified as resistant to a severe nematode disease popularly called Kalahasti Malady caused by *Tylenchorhynchus brevilineatus* in Andhra Pradesh, India (Mehan *et al.* 1993). Recently groundnut germplasm has been evaluated for crop growth rate, water use efficiency and partitioning (Nageswara Rao *et al.* 1994). The number of accessions identified with resistance to various biotic and abiotic stresses, variation in reaction, and the total number of accessions screened are summarized in Tables 9.4 and 9.5.

Table 9.3. Range of variation in cultivated groundnut observed at ICRISAT Asia Center.

Character	Minimum	Maximum	Intermediate(s)
Life form	Annual	–	–
Growth habit	Erect	Procumbent	Decumbent
Branching pattern	Sequential	Alternate	Irregular
Stem pigmentation	Absent	Present	–
Stem hairiness	Glabrous	Woolly	Hairy, very hairy
Reproductive branch length	> 1 cm	10 cm	Continuous
No. of flowers/ inflorescence	1	5	2,3,4
Peg colour	Absent	Present	–
Standard petal colour	Yellow	Garnet	Lemon yellow, light orange, orange, dark orange
Standard petal markings	Yellow	Garnet	Lemon yellow, light orange, orange, dark orange
Leaf colour	Yellowish green	Dark green	Light green, green, bottle green
Leaflet length (L)	17 mm	94 mm	Continuous
Leaflet width (W)	7 mm	52 mm	Continuous
Leaflet L/W ratio	1	6	Continuous
Leaflet shape	Suborbicular	Linear lanceolate	Elliptic, ovate, obovate, oblong
Hairiness of leaflet	Subglabrous	Profuse and long	Scarce and short, scarce and long, profuse and short
No. of seeds/pod	1	5	2,3,4
Pod beak	Absent	V. prominent	Slight, moderate, prominent
Pod constriction	Absent	Very deep	Slight, moderate, deep
Pod reticulation	Smooth	Prominent	Slight, moderate
Pod length	14 mm	65 mm	Continuous
Pod width	7 mm	20 mm	Continuous
Seed colour pattern	One	Variegated	–
Seed colour	White	Dark purple	Yellow, shades of tan, rose shades of red, grey-orange, shades of purple
Seed length	4 mm	23 mm	Continuous
Seed width	5 mm	13 mm	Continuous
100-seed weight	14 g	140 g	Continuous
Days to emergence	4	18	Continuous
Days to 50% flowering	15	54	Continuous
Days to maturity	75	> 155	Continuous
Fresh seed dormancy	0 days	> 66 days	Continuous
Oil content	31.8%	55.0%	Continuous
Protein content	15.8	34.2	Continuous

Groundut germplasm is conserved as pods or seeds, except for some wild *Arachis* species, mostly in section *Rhizomatosae*, which are conserved as live plants in concrete rings under contained conditions. The following facilities are used for processing and *ex situ* conservation of seed.

1. **Short-term storage.** This facility at ICRISAT is maintained at 18°C and 30% RH. Pods/seeds in these chambers remain viable for a few years without much loss in viability.

Table 9.4. Number of accessions identified with resistance to different biotic and abiotic stresses and high biological nitrogen fixation capacity (BNF)[†] at ICRISAT.

	Status[‡]					Botanical type[§]					
Stress/Factor	**LR**	**BL**	**RC**	**Wild**	**Others**	**Vul**	**Fst**	**Hyb**	**Hyr**	**Pru**	**Aeq**
Biotic stresses											
Late leaf spot	49	6	–	27	4	2	17	2	–	37	1
Rust	135	15	–	57	4	3	19	19	6	105	2
Seed invasion and colonization by *A. flavus* in the laboratory	18	11	1	–	9	35	2		–	2	–
Seed infection by *A. flavus* in the field	2	2	1	–	2	6	1	–	–	–	–
Peanut bud necrosis	1	19	–	–	3	–	–	13	10	–	–
Aphids	–	2	–	–	2	–	–	2	2	–	–
Leaf miner	6	7	–	–	1	–	3	9	2	–	–
Jassids	70	48	7	–	11	13	14	38	42	29	–
Thrips	–	14	1	3	–	–	–	9	6	–	–
Abiotic stresses											
Drought	20	12	7	–	7	28	11	7	–	–	–
High BNF	3	4	1	–	–	3	3	1	1	–	–

[†] Source: ICRISAT published and unpublished data.

[‡] LR=Landrace, BL=Breeding line, RC=Released cultivar, Wild=*Arachis* spp.

[§] Vul=*vulgaris*, Fst=*fastigiata*, Hyb= *hypogaea* bunch, Hyr=*hypogaea* runner, Pru=peruviana, Aeq=aequatoriana.

Table 9.5. Variation in reaction of groundnut accessions to various stresses and for nutritional factors at ICRISAT.

Stress/Factor	Level of reaction[1] HR/H	R/M	MR/L	Susceptible/ Average	Access. screened
Fungal disease					
Early leaf spot	–	–	5	2084	2089
Late leaf spot	–	59	39	10103	10201
Rust	79	75	23	10024	10201
Aflatoxin production	–	4	–	578	582
Aspergillis flavus seed invasion	21	8	10	539	580
Pod rot	–	6	–	3216	3222
Viral disease					
PBNV	–	–	23	7377	7400
PMV	–	–	2	6942	6944
Pest					
Thrips	–	15	–	5330	5345
Jassids	105	28	3	6709	6845
Termites	–	9	–	511	520
Aphids	2	2	–	596	600
Leaf miner	14	–	–	10187	10201
Abiotic stress					
Drought	–	38	8	774	820
Nutritional quality					
High oil	20	5247	632	8849	8868
High protein	117	3119	97	8751	8868

1. HR=Highly Resistant, R=Resistant, MR=Moderately Resistant; H=50-58%, M=40-50%, L=31.8-40% for oil and H=>31%, M=21-30%, L=< 20% for protein and Average=average oil and protein contents.

2. **Medium-term chambers.** These modules are maintained at a temperature around 4°C and 20% RH. The pods can remain for 25-35 years without much loss in seed viability.

3. **Long-term chambers.** These modules are maintained at –18°C without any control over RH and host 1000-1500 seeds of base or duplicate collections. The seeds are dried to a moisture level of 4-5% in the dryers maintained at a temperature of 15°C and 15% RH and are hermetically sealed in aluminium pouches before being transferred to long-term chambers. Long-term chambers can hold the seeds for periods in excess of 35-50 years without much loss in viability.

Seed/pod samples have been supplied worldwide for research and use in breeding programmes to improve the genetic potential of existing groundnut cultigens (Table 9.6). Several wild *Arachis* species have been used for transfer of foliar disease resistance into cultivated groundnut.

Properties and Uses

Groundnut is rich in oil and protein, most of which is found in the cotyledons. Chemically a groundnut seed contains around 30% protein, 48% fat, 15.0% carbohydrate, 3.0% crude fibre, 5.0% moisture and 2.0% ash (Natrajan 1980). Groundnut protein is deficient in lysine, methionine and threonine (Pancholy *et al.* 1978). Non-protein or free amino acids are thought to react with glucose and fructose, produced by hydrolysis of sucrose during the browning process, to produce the typical roasted groundnut flavour, colour and aroma (Young *et al.* 1974; Woodroof 1983). The ratio of these amino acids varies with seed size (Young *et al.* 1974). A methionine-rich protein (MRP) also has been identified in groundnut seed. Studies have shown considerable variation in MRP composition, thereby suggesting the possibility of improving the nutritional value of groundnut (Basha 1991).

Table 9.6. Number of groundnut germplasm accessions distributed to different regions of the world from ICRISAT Center (1976 to December 1995).

Region	Individual	University	Internat. Programme	National Programme	Others†	Total
Asia	59	492	727	14201	10	15489
Europe	8	98	133	771	6	1016
India	11	15732	62311	21956	53	100063
Oceania	0	32	0	598	0	630
N & E Africa	0	25	12	1207	0	1244
S Africa	5	61	11028	983	8	12085
W & C Africa	20	65	5434	924	0	6443
C America	30	57	80	67	0	234
N America	14	207	68	291	12	592
S America	0	43	25	312	98	478

† Others includes supplies to commercial companies, non-governmental organizations and regional institutes.

Groundnut shells are used in many ways: as fuel, conditioner for heavy soil, filler in cattle feed, a raw source of activated carbon, combustible gases, organic chemicals, reducing sugars, alcohol and extender resins, a cork substitute and a component of building block and hardboard. The use of shells as mulch or manure is beneficial in areas of scarce rainfall. Residue left after furfurol extraction makes good compost after treatment with H_2SO_4 and neutralization with tricalcium phosphate. Groundnut hay (haulm) is used for livestock feed. Nutritionally it is not superior to alfalfa but is comparable to or better than grasses. Recently there has been some interest in exploitation of wild *Arachis* species for forage. *Arachis glabrata* and *A. pintoi* have been released as forage species in Australia, Brazil and the USA. These species are good sources of protein for livestock in grazing lands.

Breeding

Breeding procedures in use for cultivar development in groundnut are those generally used for self-pollinated crops. A real boost to groundnut breeding came with the perfection of a field hybridization procedure (Nigam *et al.* 1990). A modified pedigree (single-seed descent) procedure has been followed in some countries with good success (Hildebrand 1985). Only limited use has been made of the recurrent selection procedures (Wynne and Gregory 1981), owing to space and hybridization requirements. However, intercrossing of derived breeding lines is commonly resorted to, and it represents a delayed recurrent selection programme. Backcross breeding has been used to a limited extent to transfer simply inherited traits such as resistance to groundnut rosette virus disease into adapted cultivars (Gibbons 1969). Resistance to most of the diseases and insect pests is not simply inherited. Bulk and bulk pedigree methods are extensively used in regional and international programmes to retain variability in breeding populations for exploitation by the breeders in collaborating countries.

Prospects

Most of the cultivars of groundnut stand on a very narrow genetic base, either because of non-availability of varied sources from different centres of diversity or lack of proper characterization of available groundnut genetic resources. Utilization of available genetic resources can be improved with the use of some advanced molecular marker techniques in genetic characterization and identification of uniqueness of genotypes.

Poor partitioning, particularly in runner-type landraces of subsp. *hypogaea,* has resulted in the erosion of these types from traditional production systems all over the world. Besides causing ecological imbalance, this loss also has resulted in soil degradation because of lack of soil-binding capacity in the introduced erect types.

Correction is required, either through simple *in situ* conservation of runner types or an on-farm *in situ* conservation with a mixture of local and introduced high-yielding runner types in these areas.

With the development of new mixed production systems and agroforestry, the lack of tolerance to shade, heat and cold could become a limitation in the further spread of groundnut. South America has extensive areas where groundnut can be cultivated but is not, because of acid soils and deficiency of micronutrients. Evaluation of genetic diversity for resistance to these constraints could help overcome them and spread groundnut to new production systems and areas.

Biotic and abiotic stresses reduce yield, and some of these are amenable to chemical and cultural controls but such approaches are not always possible in low-input rain-fed agriculture. Abiotic stresses such as drought, nutrient toxicity, nutrient deficiency and low pH have received very little attention in breeding. Genetic amelioration to stresses, through exploitation of host-plant resistance by conventional methods, has been successful in many cases, such as rust, late leaf spot and groundnut rosette virus diseases, but much more remains to be done. The wild *Arachis* species are resistant to many stresses such as early leaf spot, peanut stripe virus, peanut bud necrosis virus, *Spodoptera* and leafminer where the genetic variation in *A. hypogaea* is limited. Advancement in molecular techniques related to the groundnut crop is expected to overcome some of the barriers to gene transfer between wild and domesticated species.

Lack of adapted cultivars is often cited as one of the major constraints in increasing groundnut production and further spread of groundnut cultivation to new areas. Development of location-specific, improved germplasm with stable performance will require more attention by breeders. In sub-Saharan Africa, which is characterized by increased frequency of a shorter and less reliable wet season, extra-early genotypes are required if groundnut is to maintain its position there.

Limitations

Compared with the leading agricultural crops of the world the groundnut crop remains poorly researched and as such suffers from many limitations. In spite of significant developments in crop improvement research, benefits have been very slow to reach small farmers because of low seed multiplication rates and the bulky nature of the seed of this crop. These limitations have made the crop unattractive to the commercial seed sector. Public sector seed-producing agencies have not been able to meet the demand for improved seed.

Since most of the Ca requirement of the developing pod and seed is met by direct absorption, the availability of moisture in the first 8-10 cm of topsoil at the pod-developing stage is crucial for high yield. The crop is not able to make use of soil moisture in deeper layers in a productive manner in spite of its availability at the pod-developing stage. In certain soil types and under conditions of end-of-season drought, the harvesting of pods becomes very difficult. Because the crop is indeterminate the crop lacks uniformity in maturity of pods at the time of harvest. Consequently, the economic yield is reduced owing to discarding of immature pods.

The current world trade of groundnut is mainly in edible types. With increasing health consciousness, the high oil content of groundnut becomes a limitation in food trade. Susceptibility of groundnut to aflatoxin contamination is a serious health hazard. With better crop husbandry, tolerant genotypes and appropriate post-harvest technology, this problem can be overcome to a large extent. However, groundnut remains predominantly a rain-fed crop making it vulnerable to aflatoxin contamination in the field due to drought stress at the pod-developing stage. Groundnut as an oilseed crop is losing its competitiveness with other oilseed crops in many countries. If groundnut is to maintain its position as a leading oilseed crop, its productivity under low-input rain-fed agriculture will have to increase to meet the requirements and expectations of small-scale farmers in developing countries, where it continues to be a labour-intensive crop.

To exploit its full potential on the world food market, the crop will have to move away from the subsistence level. As a food crop, complete freedom from aflatoxin and chemical residues in the produce will be an essential requirement. To meet this requirement, crop husbandry including curing and drying will require more attention. Crop husbandry will have to be more environmentally friendly with less dependence on agrochemicals. Quality considerations also will become more important: seed shape, size and colour, low oil content, better taste and flavour and increased shelf-life.

Diversification in crop uses and development of new groundnut products will help increase groundnut demand in the world market. Despite relatively low nutritional value, groundnut protein has unique functional properties, such as low solution viscosity and relatively high concentration (5-10%), good compatibility with bread dough systems, white colour and bland flavour. In view of this, opportunities exist for the food industry to manufacture defatted groundnut flours, groundnut protein isolates and concentrates as well as a wide range of food products, which might include vitamin-fortified infant food, precooked dehydrated foods, groundnut bread, groundnut cheese and groundnut milk. Texturized groundnut protein can provide an excellent substitute for expensive animal protein to meet the food requirements of developing countries in Africa and Asia. Many less-industrialized countries do not produce enough vegetable oil to meet domestic demand. It is usually in rural areas where deficit occurs because of the cost of transportation and distribution. The development and introduction of technologies for processing of groundnut oil on a small scale for use in rural areas will help alleviate the short supply of edible oil and generate employment, adding value to agricultural production and developing local engineering skills for rural agro-industrial development.

Groundnut shells can be processed for economically useful purposes such as in the manufacture of activated charcoal, biogas, alcohol, extender resins, cork substitute and hardboards. The manufacture of adhesive glues, fire-extinguishing liquid and water-resistant powder from groundnut press cake has not yet been exploited commercially. Groundnut has good potential to move into new and non-traditional areas of cultivation. However, suitable cultivars will have to be tailored for such areas. In the rice- and wheat-based cropping systems, groundnut can play a significant role together with other legumes in restoring the balance in soil fertility and arresting the decline in productivity of the system. The use of wild *Arachis* species, which have great diversity for growth forms and adaptation, in forage production is another potential area for future research and conservation in forage germplasm banks. To date only three species have been recognized and commercialized for forage production. These species have demonstrated high yields and high quality of forage, high palatability, excellent haymaking quality, persistence under intensive grazing, tolerance to low fertility and high aluminium and manganese, good drought tolerance and minimal loss due to pest and diseases, which are essential for good forage and successful animal production.

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