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Plant Breeding Abstracts

Groundnut breeding: constraints, achievements and future possibilities

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I. ABSTRACT

Considerable progress has been made at ICR [SAT and elsewhere in identifying germplasm lines with multiple resistance to biotic and a biotic stresses. Several high yielding cultivars possessing resistance to insect pests and diseases have been released for cultivation in many countries. However, their impact has yet to be felt. Approaches to overcome problems encountered in resistance breeding are discussed, with particular reference to foliar fungal diseases, aflatoxins, viruses, bacterial wilt, insects, drought, shade and acid soils. Progress in breeding for confectionery requirements and adaptation is also considered. Further gains in yield may be achieved by techniques yet to be applied to this crop, such as interspecific hybridization and genetic engineering to transfer useful genes from wild *Arachis* species and other sources into *A. hypogaea* lines.

II. INTRODUCTION

Groundnut *(Arachis hypogaea),* an annual legume, is a native of South America which is now grown throughout the tropical and warm temperate regions of the world. It is grown on 18 million ha with a total production of 19 million metric tons. The approximate limits of the present commercial production are between Latitudes 40°N and 40°S. More than 100 countries in the world grow groundnut on a significant scale. India (33.4%), China (27.8%), USA (9.3%), Senegal (4.2%), Indonesia (4.2%), Nigeria (3.3%), Myanmar (3.0%), Sudan (2.7%) and Argentina (2%) are the leading producers of the crop. Groundnut is an important cash crop both internally and for export, although the proportion of world output which is internationally traded is relatively small.

Groundnut seeds are rich in oil and protein, and about two-thirds of world groundnut production is crushed for cooking oil. The remaining one-third is used in the form of edible products. Groundnut cake obtained after oil extraction is used as animal feed or for making other food products. Groundnut haulms are widely used as good quality animal fodder. Groundnut shells can be used as food for livestock, burnt as fuel, made into particle boards or put to many other uses.

The USA remains the world leader in groundnut production. Yields in the USA have been increasing over the last 3 decades except for the drought year of 1980. The average yield, which was 1097 *kg* in 1961, has now reached 2760 kg/ha. Yields of 4000-5000 kg/ha are not uncommon. In contrast, the average yield of groundnut in developing countries remains around 1000 kg/ha. Yield increases in the USA have resulted from a combination of factors including improved cultivars, new agronomic practices, and new pesticides and herbicides. A package approach with strong extension

support resulted in the adoption of improved technology by farmers. Development of machinery to mechanize cultivation of groundnuts also motivated farmers to achieve higher productivity.

The main reasons for low productivity in Asia and Africa are diseases and insect pests, unpredictable and unreliable rainfall. lack of improved agronomic practices and production technology, and also few technology responsive cultivars adapted to local conditions, low financial inputs and lack of suitable small-scale farm implements and of the infrastructure to supply quality seed of the currently available improved cultivars. Changing weather conditions over recent years have also resulted in shortening of the growing season in northern parts of many West African countries, making once adapted long season cultivars unsuitable for cultivation.

III. VARIABILITY IN GROUNDNUT

The cultivated groundnut is an allotetraploid (2n = 40) with a basic chromosome number (x)of 10. Six centres of primary genetic diversity for the cultivated groundnut are recognized in South America. Africa is an important centre of secondary genetic variation. Variability of the cultivated groundnut has led to classification into 2 subspecies: A. *hypogaea* subsp. *hypogaea* and *A. hypogaea* subsp. *fa.stigiata.* These 2 subspecies have each been divided into 2 botanical varieties. Of these, var. *hypogaea* (the Virginia type) in the former subspecies and vars. *fartigiala* (the Valencia type) and *vulgaris* (the Spanish type) in the latter are commercially cultivated. In addition to the cultivated groundnut, there are more than 70 wild species of the genus *Arachis* which provide additional sources of variation for many traits. All species of *Arachis* are native to South America. Those belonging to section *Arachis* are cross compatible with *A. hypogaea.* However, most of these are only diploid.

ICRISAT's Genetic Resources Unit maintains a world collection of over 12 000 accessions of cultivated groundnut and wild *Arachis* species.

IV. GROUNDNUT BREEDING RESEARCH

In 1976 groundnut was added to ICRISAT's mandate with the objective of improving the low yields obtained by small-scale farmers in the semi-arid tropics (SAT) by producing high-yielding breeding lines with resistance to the main yield reducing factors, both biotic and abiotic, which limited production. In the following pages, progress made at ICRIS AT and published in various ICRISAT Annual Reports since 1976 is reviewed together with progress made elsewhere in research areas where ICRISAT has an interest. New approaches that may be required to overcome some of these constraints are also discussed.

1. Biotic stresses

(a) Foliar Fungal diseases

Late leaf spot. *(LLS) (Phaeoisariopsis personate [Mycosphaerella berkeleyi]),* early leaf spot (ELS) *(Cercospora arachidicola [Mycosphaerella arachidis])* and rust *(Puccinia arachidis)* are the 3 most widely distributed and economically important foliar diseases of groundnut. They are commonly present wherever groundnut is grown but their incidence and severity vary between localities and seasons. Each disease alone is capable of causing substantial yield loss but when they occur together yield tosses arc further increased. For example, rust and LLS together can cause up to 70% yield loss in India. These diseases also have an adverse influence on seed quality and grade characteristics, as well as reducing the quality of the haulms.

Sources of resistance

Effective field and laboratory resistance screening methods have been developed at ICRISAT and elsewhere for all 3 diseases. Over 12 000 *A. hypogaea* lines have been screened for resistance to LLS and rust at ICRISAT. A total of 54 lines with resistance to LLS and 124 with resistance to rust have been identified. Twenty-nine of these are resistant to both LLS and rust. In the case of ELS. only I united screening has been possible at ICRISAT due to irregular and erratic occurrence of this disease. Screening at other sites in India has shown a moderate level of resistance to ELS in several lines. Eight lines with multiple resistance to these 3 diseases are NC Ac] 7127, NC Ac 17500, 198/66 Coll. 182, 58-295, PI4761.43, PI476176, P[476033, and PI476176 (Waliyar *et al.,* 1988). Such lines constitute the most useful sources of resistance because foliar diseases usually occur in combination.

In contrast to the *A. hypogaea* lines, several wild *Arachis* species show *immunity* or a high level of resistance to the diseases. Those with multiple disease resistance include *A cardenasa* (P[2621.4 I), A. *chacoense(P[276235)* and *A. stenosperma* (P1338280), which are cross compatible with the cultivated types.

The resistance of many *A. hypogaea* lines to rust operates through rate reducing components. They have increased incubation period, decreased infection frequency, and reduced pustule size, spore production and spore germinability. In the case of interspecific derivatives, uredosori are small and slightly depressed and do not rupture to release the comparatively few uredospores produced. Resistance to LLS operates in a similar fashion.

Stability of resistance

The rust and LLS resistances of these genotypes are generally stable over a wide range of geographic locations. Only for NC Ac 17090 and PI298115 has variation in rust scores been observed across locations.

Preliminary studies at ICRISAT suggest that extended photoperiods can influence disease reaction of genotypes through their major influence on partitioning. Variations observed in the disease reaction of NC Ac17090 and P129811.5 may be associated with this physiological implication arising from changes in the latitudes of the locations.

Variation in response to ELS has been much more pronounced. Germplasm lines NC3033, PI270806, PI259747, PI350680, PI l 09839 and GP-NC343, which are resistant to ELS in the USA, were susceptible in India and Malawi. Similarly, 2 *Arachis* wild species, *A. chacoense* and *A. stenosperma,* rated highly resistant to ELS in the USA, did not show this disease reaction in Malawi. A joint ICRISAT-IRHO (Institut de Recherches pour les Huiles et Oleagineux) project is currently under way at Montpellier in France to elucidate the race situation and variation in these pathogens.

Genetics of resistance

Limited studies on the genetics of resistance to rust in *A. hypogaea* reveal that resistance is recessive in nature and generally controlled by duplicate recessive genes. However, some sources of resistance cannot be explained by a 2-gene system. Additive genetic effects and additive types of epistasis have also been found for crosses between resistant and susceptible genotypes. On the contrary, resistance in some of the diploid wild *Arachis* species is partially dominant.

Studies on the inheritance of resistance components of LLS and ELS conducted in North Carolina, USA, indicated substantial additive genetic effects among early generation progenies. In later generations, however, both additive and additive X additive epistasis are significant. Dominant genetic variance for LLS in early generations is significant for several components of resistance.

Issues involved in resistance breeding

Most of the resistance sources in *A. hypogaea* have thick shelled, highly reticulated, constricted, prominently ridged and conspicuously beaked pods which are commercially unacceptable. Similarly, pods of wild *Arachis* species are small and catenate. This undesirable association between resistance and pod and seed characteristics slows down progress in breeding.

Whenever resistance to foliar diseases is incorporated into adapted cultivars, their duration is increased. This is much more so in interspecific derivatives. This increased duration often becomes a serious limitation affecting these lines in many areas of the SAT where the growing season is short or the crop is grown in multiple cropping systems, as in Asia.

High yield potential and high disease resistance do not generally go together. Williams *el al.* (1984) found appreciably lower partitioning in rust and LLS resistant genotypes. Phytoalexins having sucrose as a precursor have been associated with resistance to diseases in other legumes. It was postulated that if similar compounds are involved in resistance of groundnut to foliar diseases, the high partitioning necessary for high yield may limit the expression of resistance.

Resistance breeding

A strategy of selecting in segregating populations of crosses between multiple disease resistant sources and locally adapted but susceptible cultivars for pod yield and agronomic acceptability under high disease pressure at ICRISAT has resulted in the development of breeding lines which are able to produce high yields under heavy disease pressure. These lines carry only a moderate level of resistance against foliar diseases. Several stable tetraploid interspecific derivatives with good yield and a high degree of resistance have also been developed but they are late in maturity. Two *A. hypogaea* lines, ICGV87160 (fCG(FDRS)10) and ICGV86590 have recently been released in India. The fodder quality and quantity in foliar disease resistant cultivars is also better than in susceptible cultivars. In the USA, Southern Runner, a high yielding LLS resistant cultivar was released in 1984. Breeding for resistance for ELS has not led to the release of a cultivar to date in the USA; however, adequate levels of resistance have been found among progenies of a cross between GP-NC343 and NC5. Lines derived from this cross and other sources of resistance are being used in the breeding programmes. In the ICRISAT Malawi programme, many breeding lines with high yield under heavy ELS pressure have been identified. These lines retain a higher proportion of foliage for a longer period compared to the susceptible cultivars.

A combination of leaf spot resistance, lower partitioning to pods (allowing leaf growth), and a slightly longer podfill period has allowed satisfactory yields in Southern Runner without leaf spot control (Pixley *et al* , 1990). However, Coffelt *er al.* (1989) suggested that future increases in yield might best be accomplished by developing cultivars with a combination of high reproductive efficiency, high harvest index and high total flower count. This raises an important issue concerning disease-resistance breeding. What is the optimum balance between genetic resistance and yield potential? At what level does genetic resistance become uneconomic? Can we replace genetic resistance with chemical disease control after an optimum level of the former is incorporated without sacrificing yield potential' More critical physiological studies are required to answers these questions. A better understanding of these issues will help us develop an efficient disease management strategy without compromising yield potential.

(b) Aflatoxin

Aflatoxin contamination of groundnut is a serious quality problem. Environment and cultural practices can make groundnut seed prone to invasion by the *Aspergillus* group of fungi and to subsequent contamination with aflatoxin before harvest, during post-harvest curing and drying, or during storage. Several recommendations have been made on cultural practices, curing and drying procedures, and storage conditions to minimize seed invasion by *A. fiavus.* However. these remain mostly unadopted in developing countries where groundnut production is also subject to the vagaries of climate.

After the discovery of seed-coat resistance to invasion and colonization by *A. flavus* in 2 germplasm lines in 1973 in the USA, research on varietal resistance was stimulated in several countries.

Resistance to *A. fiavus* in groundnut operates at 3 sites in the plant, namely pod, seed coal and cotyledons. Differences in pod shell structure, presence of antagonistic microflora in the shell and the presence of thice-walled parenchyma cells have been cited as responsible for varietal differences in pod resistance. Seed-coat resistance has been attributed to the presence of chemicals such as dimethoxyisoflavone and tannin, and to contents of soluble amino compounds and arabinose. Seed-coat resistance is only operative in seeds with an intact testa. Varietal differences have been in seed ability to support aflatoxin production. However, very little is known about its mechanism.

Recent studies by Utomo *a al* (1990) on heritability of all 3 types of resistance indicate that there is no correlation among mechanisms and that the 3 mechanisms are controlled by different genes.

Sources of resistance

Various laboratory methods have been developed to screen germplasm for preharvest seed infection, *in vitro* seed invasion and colonization (IVSCAF) and aflatoxin production. Field screening techniques involving imposing late season drought or creating a water-deficit gradient or adding artificial inoculum have been perfected to screen material for *A. fiavus* infection and aflatoxin contamination (M ehan, 1989) Many sources of resistance have been reported. These include PI337409, PI337394F, UP1513,111, Ah7223, U-4-47-7, 55-437 and 73-30 for preharvest field infection and IVSCAF, and U-4-7-5 and VRR245 for aflatoxin production. Two wild *Arachis* species, *A cardenasil* and *A. duranensis,* are also resistant to IVSCAF and aflatoxin production. Some of these have been evaluated in more than one country.

Resistance breeding

Many breeding lines which combine seed-coat resistance equal to that of resistant parents with high yield have been developed. Resistance in these breeding lines has remained stable over years and locations in India (Vasudeva Rao *a of* , 1989) Similar progress in breeding *A.* jffivus-resistant cultivars has been reported in the USA. However, the conditional nature of IVSCAF limits the utility of these lines.

With the discovery of varietal differences in preharvest field infection and ability to support aflatoxin production, opportunities have increased to minimize the problem of aflatoxin contamination by combining different kinds of resistance. Many IVSCAF-resistant lines also show significantly low preharvest infection in the field. However, some IVSCAF-resistant genotypes (PI337394F, PI337409, .111, UF71513) support high levels of aflatoxin B, production. Those genotypes which do not support high levels of aflatoxin B, production (U4-7-5 and VRR245) are susceptible to IVSCAF. It is hoped that high-yielding lines with resistance to IVSCAF and preharvest infection and low levels of aflatoxin production will be developed in the future. Such breeding lines will offer a much greater genetic barrier to the fungus and subsequent production of aflatoxin. However, genetic resistance alone may not be enough in this case unless it is accompanied by better cultural and agronomic practices, proper drying and curing facilities and better storage conditions. With increasingly rigid toxin tolerance limits being fixed by groundnut importing countries, recourse to genetic engineering may be required to satisfy their requirements

(c) Virus diseases

Groundnut is a host to several virus diseases but only a few are economically important. These include groundnut rosette virus (GRVD) in Africa, bud necrosis disease (BND) in India and the USA, peanut mottle potyvirus (PMV) world-wide, peanut stripe potyvirus (PStV) in South and Southeast Asia, and Indian peanut clump furovirus (PCV) in West Africa and India. Effective laboratory and field techniques have been developed to screen for resistance to these virus diseases. Except for GRVD, the nature of inheritance of resistance is not known. Resistance to GRV in cultivated types is controlled by 2 independent recessive genes (Nigam and Bock, 1990).

Groundnut rosette virus (GRVD)

GRVD is transmitted by *Aphis craccivora* and gives either a chlorotic or green rosette. The chlorotic rosette is prevalent throughout Africa whereas the green rosette is reported from West Africa and Uganda.

Three agents are involved in the expression of GRVD symptoms: groundnut rosette virus (GRV), groundnut rosette assistor luteovirus (GRAN) and a satellite RNA. GRV is dependent upon GRAY and the satellite RNA for transmission by the aphid vector. The satellite RNA, largely responsible for GRVD symptoms, is dependent upon GRV for replication (Murant *et al.*, 1988). Expression of different forms of rosette disease is dependent on the presence of different forms of the satellite RNA (Murant and Kumar, 1990)

Resistance to GRVD was discovered in the late 1950s in local landraces in Burkina Faso. Utilizing these resistant sources, which were semi-erect and late maturing, cultivars such as KH149A, KH241D, 69-101, RMP12, RMP91 and RG I were developed and released in Africa. These cultivars and other breeding lines are now used as sources of resistance in many breeding programmes. However, they are not immune and individual plants can become infected with the disease under heavy inoculum pressure. This resistance apparently operates against both chlorotic and green rosette and is directed against GRV and its satellite RNA. These sources are susceptible to GRAY which on its own induces no obvious symptoms.

Most of the rosette resistant cultivars released so far are late maturing. There is an immediate need to transfer this resistance into early maturing cultivars which are adapted to local conditions.

Bud necrosis disease (END)

This is caused by tomato spotted wilt virus (TSWV) and transmitted by thrips. TSWV has many serologically distinct isolates and produces a wide range of symptoms (Reddy, 1991).

Many germplasm and breeding lines with consistently low disease incidence in the field have been identified at ICRISAT. Some of these lines are CI02, CI21, CI36, NC Ac343, NC Ad 741, NC Ac2232, NC Ac2242, NC Acl 7888, ICGV86029 and 1CGV86031. Of these, only 1CGV86029 and ICGV86031 show tolerance of the virus. Recently, 2 high yielding cultivars with field resistance to BND, ICGSI I (ICGV87123) and ICGV87128 (ICGS44), have been released in India.

With the discovery of resistance to the virus, breeding is now in progress at ICRISAT to combine vector resistance with virus resistance to further reduce disease incidence and yield losses in the field.

Peanut mottle potyvirus (PMV)

PMV disease is widespread and present in all the major groundnut growing areas of the world. The most important vectors are A. *craccivora, A gossypii* and *Myzus persicae.* It is also seedborne and has a rate of 0.5-1% seed transmission.

No line showed resistance to the virus in field screening of over 3000 *A. hypogaea* lines. However, some lines consistently sustained much lower yield losses than controls. These included NC Ac2240 and NC Ac2243. Two wild *Arachis* species, *A. chacoense* (GKPI 0602) and *A. pusilla* (GKPI 2911), remained free from infection even after repeated graft inoculations. Some of the rust resistant germplasm lines, NC Ac17090, EC76446 (292) and NC Ac17133 (RF), although suffering yield loss do not transmit the virus through the seed.

The breeding approach at ICRISAT consists of combining vector resistance and tolerance of PMV with absence of seed transmission.

Peanut stripe potyvirus (PStV)

PStV, transmitted by aphids, is seedborne in nature. It occurs as distinct strains which can be distinguished on the basis of host range tests. In field screening tests at 2 sites in Indonesia, no resistance was found in 9000 *A. hypogaea* lines. Among 54 wild *Arachis* species, only *A. cardenasii* was immune. A few others showed a resistant reaction. Currently their interspecific derivatives are being screened in Indonesia.

Peanut clump furovirus (PCV

PCV is soil borne and transmitted by *Polymyxa gramini.s.* It has serologically distinct variants which produce symptoms of differing severity on groundnut cultivars. It is also seedborne. No useful source of resistance was found in 7000 *A. hypogaea* germplasm lines tested in the held. Due to the occurrence of serologically distinct variants of the virus and lack of resistance in germplasm, no resistance breeding is in progress for this disease.

(d) Bacterial wilt

Bacterial wilt (BW) of groundnut, caused by *Pseudomonas solanacearum,* occurs in many Asian and African countries. It causes significant yield losses (up to 30%) in China and Indonesia. Resistance to BW is partially dominant and is controlled by 3 pairs of major genes and some cytoplasmic effects (Liao *et al.,* [986). Despite a lack of clear understanding of the basis of resistance to BW and its underlying mechanisms, considerable progress has been made in the development of resistant cultivars.

Schwarz 21, resistant to BW, was the first disease resistant cultivar, developed in 1925 in Indonesia. Since then, several resistant cultivars such as Luhua 3, Ehua 5, Zhoonghua 2, Guiio 2 and Yueio 2 in China, and Gadjah, Macan, Tupai, Pelanduk, Kidang and Anoa in Indonesia have been released for cultivation.

(c) Insect pests

More than 360 soil and foliage inhabiting arthropod pests of groundnut have been reported in the literature. However, only a few are economically important to the crop either because they cause significant direct yield loss or because they are vectors of virus diseases. These include: aphids, thrips. jassids, leaf miner, *Spodoptera,* and white grub in Asia, and aphids, jassids, *Spodoptera, Hilda,* millipedes, termites and white grub in Africa.

Several sources of resistance to insect pests, particularly thrips, jassids and termites, have been identified in groundnut germplasm (Wightman *et al.,* 1990; Lynch, 1990). Tolerance of *Spodoptera* has been found in 2 breeding Imes, ICGV86031 and 1CGV86029. These lines are also moderately resistant to thrips and jassids. Some resistance to aphids was observed in EC36892, NC Ac343 and GBPRS 15 (ICGV 86030). Attempts to identify sources with a high level of resistance to leaf miner have not been successful. Many germplasm lines with resistance to more than one insect pest have been identified. These include NC6, NC Ac343, NC Ac I 705, NC Ac2142, NC Ac2214, NC Ac2230, NC Ac2232, NC Ac2240, NC Ac2242, NC Ac2243 and NC Ac2460 In addition to the cultivated types, resistance to many insect pests has also been found in several wild *Arachis* species including *A. correntina, A chacoense, A. stenosperma* and *A. villosulicarpa.*

Mechanism and generics of resistance

The presence of long dense trichomes on leaves of genotypes NC Ac2214, NC Ac2230 and NC Ac2240 and the thick leaf cuticle in NC Ac2242 and NC Ac2243 are associated with resistance to jassids. Dwivedi *et al.* (1986) reported predominantly non-additive genetic variance for all trichome characters. For trichome length and jassid damage additive genetic variance was also important. In North Carolina, USA. for a complex of pests (thrips, jassids and *Helicoverpa),* additive genetic variance was predominant (Holley *et al.,* 1985).

Preliminary studies have indicated that aphid resistance operates by reducing growth and fecundity (Padgham *et al., 1990).* Further studies to identify the physical and chemical factors responsible for reduced growth and fecundity are in progress.

Breeding strategy

Excellent progress has been made in transferring resistance to jassids and thrips into genotypes with superior agronomic backgrounds. Wherever insect pests are involved as vectors of virus diseases, the breeding strategy has been discussed under the appropriate virus disease. The current emphasis in pest resistance breeding at ICRISAT is focused on leaf miner, *Spodopiera* and aphids.

2. Abiotic stresses

(a) Drought

At ICR LSAT, a line-source technique is used to simulate the 3 most commonly occurring drought patterns in the SAT (end-of-season, mid-season and long-term droughts) with a view to identifying resistant or tolerant germplasm and breeding lines. Genotypic differences for response to these patterns of drought have been found in many germplasm lines. Further, genotypic variation for root characteristics (root length, root number and root volume), recovery response, particularly after the

release of mid-season drought, and water use efficiency were observed in several germplasm and breeding lines. Studies to elucidate the mechanisms determining recovery from mid-season drought, and water use efficiency are in progress.

A modest breeding programme at ICRISAT is currently aiming to combine different mechanisms of drought resistance in superior genetic backgrounds.

Some of the recently released ICRISAT cultivars such as (CGS' (ICGV87119), ICGSS (ICGV87121), ICGS37 (ICGV87187) and ICGS76 (ICGV87141), though not bred for drought resistance, are tolerant of mid-season drought.

(b) Shade

Groundnut is often intercropped with field and plantation crops which partially shade it. This partial shading results in etiolation of the plants and a reduction in yield. Screening of groundnut genotypes for shade tolerance under an artificial shade structure using black nylon cloth, which provides 36-58% shading throughout the crop season, is in progress in the Philippines (Miranda•Abilay *et al.,* 1988). Four ICRISAT early maturing lines, ICGS(E)22, ICGS(E)61, ICGS(3)120 and ICGS(E)123, tolerate partial shade. These are now being used in the Philippines national breeding programme to develop high-yielding shade tolerant cultivars.

(c) Acid soils

Many countries in Asia and Africa have acid soils, deficient in calcium, where groundnut yields are low and pod filling is poor (occurrence of pops or empty pods). Excellent screening work done in the past in the copperbelt of Zambia resulted in release of the pop-tolerant line TMVI as Copper Belt Runner. Recently, 8 genotypes, IPB Pn24-2. 1PB Pn24-3, IPB Pn24-6, BPI P9, UPL Pn-2, UPL Pn-4, RLRS I and Accession 25, tolerant of acid soils, have been identified in the Philippines (Samonte and Ocampo, 1989). These lines, however, failed to show tolerance when tested in acid soils in Indonesia.

Breeding for tolerance of acid soils is complex since soil acidity may be associated with deficiency or toxicity of various nutrients depending on location.

3. Breeding for confectionery requirements

Various physical, sensory and biochemical factors determine the quality of groundnut seed. Physical factors include intact testa, size and shape of the seed, ease of blanching and resistance to seed splitting. Sensory factors include seed colour, texture and flavour. Biochemical factors are mainly concerned with oil and protein content, and with fatty acid composition which also influences flavour.

Over 8000 germplasm lines have been screened at ICRISAT for oil and protein contents: oil content ranged from 31 to 55% and protein from 16 to 34%. Selected germplasm and breeding lines were also screened for oil composition. The oleic : linoleic acid ratio (O:L) which is an indicator of oil stability and shelf life of groundnut products varied between 1 and 3. However, in 2 Florida breeding lines in the USA, an O:L ratio of 40 was reported (Norden *et al.,* 1987). Moore and Knauft (1989) followed up this work further and reported that the high O:L ratio in these lines was governed by 2 recessive genes.

Most of the pod and seed traits are largely controlled by additive genetic effects. Maternal and maternal interaction effects are also significant in many cases (Dwivedi *et at,* 1989). Excellent progress has been made in developing large-seeded cultivars (>80 g/100 seed) with attractive seed and pod shape and colour. These cultivars require a high level of crop management to achieve their full yield and quality potentials.

Work is also in progress to identify cultivars with better in-shell boiling characteristics, a mode of utilization preferred in many Southeast Asian countries.

4. Breeding for adaptation

Many factors contribute to the adaptability and stability of performance. Some of these are duration of the cultivar, its response to temperature and photoperiod, and reactions to various biotic and a biotic stresses.

Crop duration at any particular site is determined chiefly by the availability of soil moisture and by temperature. However, the time required for a cultivar to attain maturity is dependent on environmental factors such as temperature, photoperiod, solar radiation and the cultivar itself. The concept of cumulative thermal time has been successfully integrated into-the breeding programme at ICRISAT to develop early cultivars with a stable maturity period across locations (Nigam *et al.,* 1988). Some of these cultivars have performed well in West Africa and Southeast Asia. These include ICGS(E)52 (ICGV86014) in the Gambia and ICGS(E)56 (ICGV86015) in the Republic of Guinea. Associated with earliness is a requirement for limited seed dormancy. Breeding efforts at ICRISAT have been successful in incorporating a 2-3 week dormancy period into early maturing Spanish

cultivars, which inhibits field sprouting and deterioration in pod quality if rain falls at the time of maturity.

Our success in the development and release of medium maturing eultivars in Asia and Africa has been most rewarding. Six ICRISAT cultivars have been released in India. Of these, ICGS1 I (1CGV87123) and ICGV83128 (ICGS44) for the irrigated post rainy season and ICGV87141 (ICGS76) for rainy season cultivation have become extremely popular with farmers. Other releases include BARD699 (a multiline of ICGV87123 and ICGV87128) in Pakistan, ICGS35 as Jinpungtangkong in Korea, ICGS114 as Sinkarzei in Ghana and [CGMS42 in Malawi and Zambia.

(a) Photoperiod effects

Photoperiod has very little influence on phenological development of groundnut but has a major influence on reproductive processes. The large differences in floral efficiency (fruit flower ratio) and yield depend on exposure to short or long days. As groundnut is grown between 40° N and 40°S latitudes the photoperiodic response of a cultivar plays a significant role in its adaptation.

At ICRISAT, 2 crops are grown in a year. The rainy season crop (June-October) has a mean photoperiod duration of 13.5 h and the post rainy season crop (November-April) one of 11.5 h. As selection in breeding material is practiced in both seasons, most of the selected lines are relatively insensitive to pholoperiodic effects. Further, the advanced breeding lines are also screened in the field for photoperiodic response by extending the light duration artificially (ICRISAT, 1990). This screening procedure has resulted in the identification of several cultivars which have wide adaptation. These photaperiod insensitive cultivars include ICGS11, ICGS44 and ICGS37. Studies to understand the mechanism and inheritance of photoperiod insensitivity are in progress.

(b) Zonalization of groundnut growing environments

Work on this topic is in progress at ICRISAT. Based on growing season length, availability of soil moisture, soil type, temperature, photoperiod, and biotic and abiotic stresses, similar groundnut growing environments are being identified. A priority combination of stress factors for each zone is also identified. This will help to regionalize the breeding programme and to target the breeding requirements of each region more precisely.

5. Genetic gain

Mozingo et a1., (1967) attributed yearly yield increases of 14.7 kg/ha to genetic improvement in the large-seeded Virginia types in the USA. The highest yielding cultivars developed during the 1950s, 1960s and 19705 showed an average yield increase of 3.4, 10.2 and 18.5%, respectively, over the standard cultivar NC4, released in 1944. However, during the 1970s, breeding emphasis was placed on pest resistance and quality acceptance. Consequently, yields of Virginia type cultivars released in the 1980s have not surpassed the cultivar with the highest yield developed during the 1970s (NC7 in the early maturity group, NC6 and GK3 in the medium to late maturity group).

A similar exercise conducted with recently released ICRISAT cultivars in India indicated a genetic gain of 1.3-3.2% per year under rainfed cultivation.

V. FUTURE CHALLENGES

Most groundnut cultivation is confired to rainfed areas under low input conditions. Significant gains in yield have been achieved but they are not as spectacular as in the case of wheat, rice or maize. The following research areas could lead to further progress in yield improvement in the near future.

1. Interspecific hybridization

Wild Arachis species provide a reservoir of greater genetic variability for resistance to many insect pests and diseases than the cultivated groundnut (Stalker and Moss, 1988). They also contain factors for high yield, since a recurrent selection programme in an interspecific population has led to significant improvement in pod yield (Guok el at, 1986).

For compatible diploid wild species of section Arachis, several techniques have been developed to facilitate their use in a breeding programme. However, in the case of incompatible species belonging to 6 other sections, difficulties have been encountered in producing interspecific hybrid plants successfully. Very few laboratories in the world are working on the utilization of wild Arachis species. A more concerted effort is needed to exploit these species successfully.

2. Biotechnology

Since mid 1989, the University of Georgia Research Foundation and Gold Kist Incorporated, USA, have been involved in a joint research programme to develop technology that will facilitate the production of high-yielding disease and insect pest resistant groundnut cultivars. Scientists have been successful in (1) producing a groundnut plant through embryogenic callus, (2) developing a laboratory assay to determine resistance to white mould *(Sclerotium), (3)* expanding peanut chromosome mapping activities to wild *Arachis* species and (4) identifying certain species of *Agrobacterium* to serve as a vector in gene transfer.

Current research at the USDA Southern Regional Research Centre in New Orleans, USA, is focused on understanding the aflatoxin biosynthesis pathway. Scientists have identified 0-methylsterigmatocystin as the last known precursor, and the enzyme oxidoreductase, that catalyses the conversion of this precursor to aflatoxin B_1. When the gene responsible for the enzyme is located, it could be removed or altered to stop production of aflatoxin. Other areas where recourse to bioengineering may help are resistance to *Spodoptera* and leaf miner. Work on these new approaches has only recently started in a few laboratories.

VI. REFERENCES

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