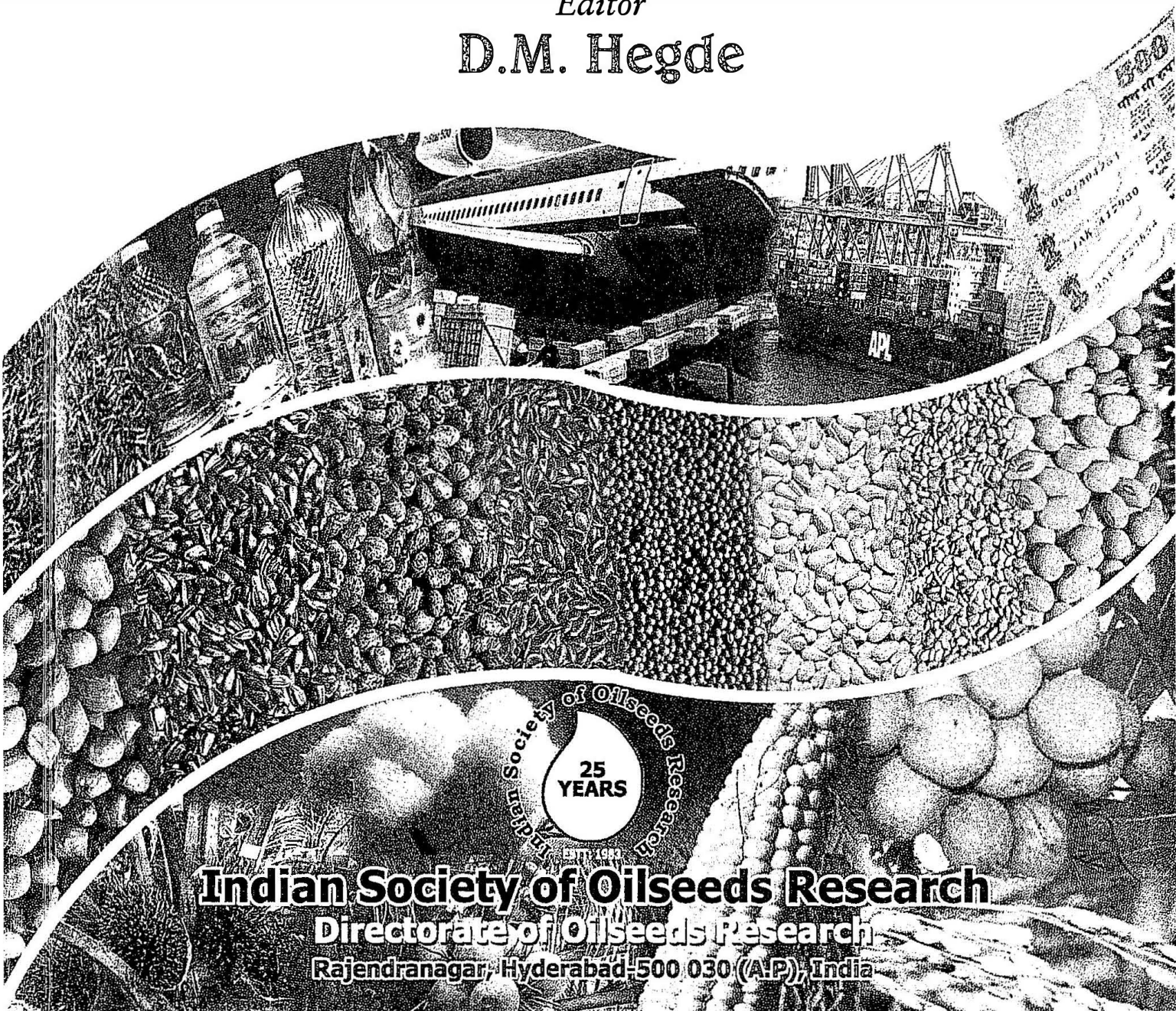


Vegetable Oils Scenario : Approaches to Meet the Growing Demands

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Crop Improvement Strategies in Groundnut

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Abstract

Groundnut is photosynthetically a highly efficient crop and its potential has been demonstrated in India itself by record pod yields in excess of 9.0 t/ha obtained in small areas with good management. There remains a large gap in potential yield and realized yield at farm level, particularly in rainfed agriculture, where 80% of the crop is grown. For sustainable and consistent gains in yield, a well defined and focused research agenda on priority constraints and appropriate policy support addressing socio-economic and infrastructure related issues are needed. Breeding strategies addressing major abiotic (drought) and biotic (foliar diseases and aflatoxin contamination) stresses, eco-regional adaptation and enhanced yield potential and emerging tools of biotechnology (genetic transformation and marker-assisted selection) are discussed in the paper. In India, we have not paid enough attention to the exploitation of environment and stabilization/management of genotype x environment interaction in groundnut. Both improved cultivars and improved cultural practices not only contribute significantly towards increase and stability of yield but they also have a synergistic effect on productivity. The management practices should be not only location-specific but also variety-specific and farmer-specific taking into account his/her socio-economic condition. Farmer-participatory varietal selection approach offers a new avenue to enhance the impact of improved varieties. Further, informal seed sector must be strengthened to meet the huge demand for quality seed of groundnut which arises from its high seed rate and low multiplication ratio. Collaborative research among Indian institutions must be promoted to realize the power and synergy of partnership.

Keywords: Physiological models, stress resistance breeding, yield barriers, yield potential

Introduction

Groundnut is grown in 22.2 m. ha in more than 100 countries in the world with a total production of 34.5 m.t. and an average productivity of 1.55 t/ha (FAO, 2006). Asia accounts for 55.2% of the global area and 66.7% of the global production of the crop compared to 40.3% of the area and 25.6% of the production in Africa. The average yield of groundnut among the groundnut growing countries in the world varies between 300 kg and 5400 kg/ha.

During 1980-2006 period, the global groundnut area grew by 1.0%, yield by 2.4% and production by 3.4% annually (Table 1). During the same period, the growth rates for Asia were 0.6%, 3.2% and 3.8%, respectively and for Africa, they were 2.2%, 1.5% and 3.7%, respectively. In Asia, it was the yield which contributed to increased production but in Africa, the increased production came largely through area expansion.

Productivity and production of groundnut in Asia picked up substantially 1991 onwards with very little increase in area (Fig. 1). In Asia, China and Vietnam led

Table 1. Annual growth rates of groundnut area, yield and production in world, Asia and Africa, 1980-2006

Parameter	Annual growth rate during 1980-2006 period (%)		
	Area	Yield	Production
World	1.0	2.4	3.4
Asia	0.6	3.2	3.8
Africa	2.2	1.5	3.7

the way. The advancement in groundnut production and productivity came along in a step by step manner with scientific achievements, governments' encouragement and the hard work of the farming communities in these countries. In contrast, India, inspite of having the largest area under the crop in the world, has lagged behind in groundnut growth (Table 2 and Fig. 2). Area and production show declining trend due to competition from other crops (Bt cotton, soybean, sunflower and maize, etc.). Small gains in productivity have not been enough to compensate the decline in area to maintain total production in India.

The approach followed for irrigated agriculture during green revolution has not delivered the similar results in rainfed agriculture. There is a need to revisit agricultural research and extension approach in India and bring in required changes in them to accelerate growth in rainfed agriculture in the country. Rainfed agriculture lacks homogeneity, is subject to vagaries of weather and requires different approach in research and development than that followed for irrigated agriculture.

Record yields in groundnut: Groundnut is photosynthetically a highly efficient crop. Some of the examples of record pod yields are as follows:

- 10.5 t/ha over a small area under intensive cultivation in Shandong Province, China (Yanhao *et al.*, 1996)
- 9.6 t/ha in large plots in Zimbabwe (Hildebrand, 1996)
- 9.4 t/ha in a 0.2 ha plot in a summer groundnut crop in Maharashtra and 9.5 t in a 3 cent plot in Andhra Pradesh, India (Nigam, 2000)

These figures represent the yield potential of groundnut for the respective agroecological zones. Theoretical potential pod yield that can be reached in the crop in Shandong Province in China is 17.3 t/ha (Yanhao *et al.*, 1996).

What ails groundnut in India?

Most of the groundnut in India is grown under four major agroecologies: i. Rainfed (*kharif* season), ii. Irrigated (*rabi* season), iii. Residual moisture (*rabi* season) and iv. Irrigated (summer/spring

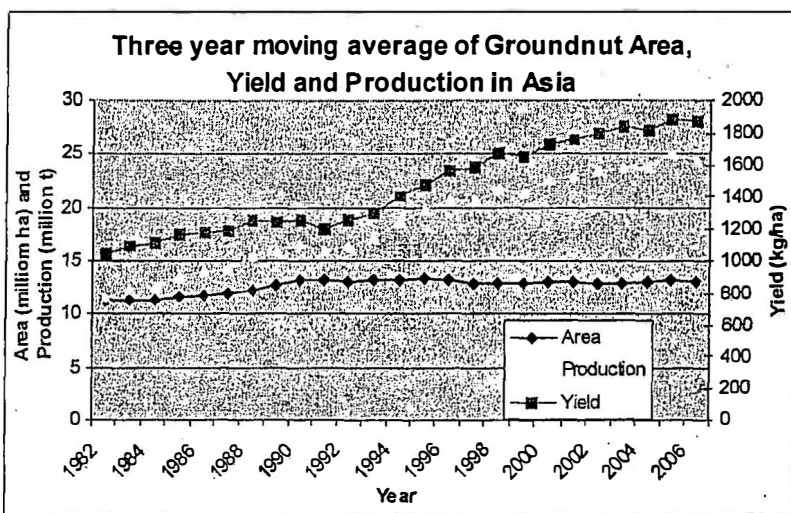


Fig. 1. Three-year moving averages of groundnut area, yield and production in Asia (1980-2006)

Table 2. Annual growth rates of groundnut area, yield and production in India, 1980-2006

Parameter	Annual growth rate (%)			
	1980-89	1990-1999	2000-2006	1980-2006
Area	1.6	- 2.3	- 0.30	- 0.71
Yield	2.0	1.0	0.06	0.94
Production	3.6	- 1.2	- 0.30	0.23

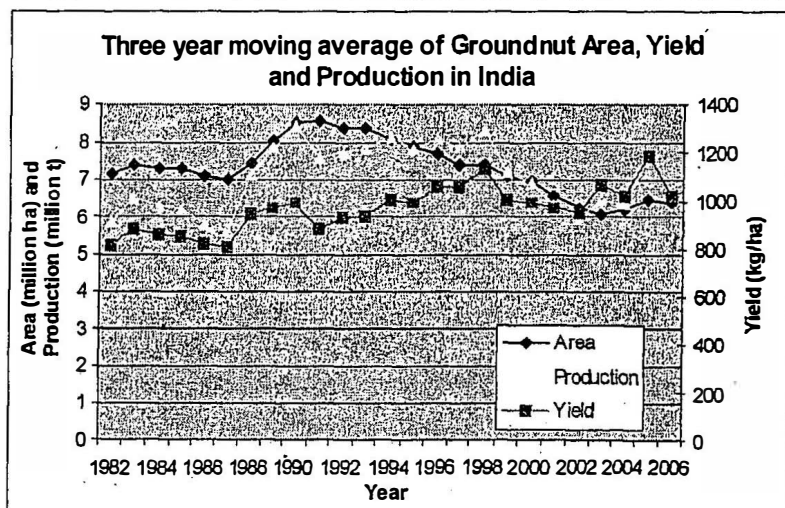


Fig. 2. Three year moving averages of groundnut area, yield and production in India (1980-2006)

season). In all the four major agroecologies, various constraints operate that limit groundnut productivity. Some of the constraints are common across all the four agroecologies.

Prioritization of the constraints: In spite of the moderate gains in productivity made in India, there remains

For a well-defined and focused research agenda that will ensure sustainable yield gains in a consistent manner, the following is required.

- Identify production constraints including socio-economic factors operating in various agroecologies
- Rank them in order of their adverse impact on productivity
- Identify best management (genetic/non-genetic) options for major constraints based on benefit-cost ratio for return on research investment for each identified constraint
- Identify research lags
- Indicate probability of success and research investment costs

SAUs and their regional research stations should focus on the priority constraints of their region. In many cases, a non-genetic option may be an easier and profitable solution of constraint alleviation. Socio-economic, policy and infrastructure related issues affecting groundnut productivity and production will have to be dealt with at Government level removing impediments in reaping the benefits of research outputs by farmers.

Back to drawing board

There is a need to revisit the famous equation of genetics/plant breeding to understand where we missed or what needs to be done to make groundnut a healthy crop.

Phenotypic model of the yield: $YT \text{ or } YR = G + E + G \times E + \delta$

YT = Total yield or YR = Reproductive yield is the sum of the effects of the following components:

G = Genetic; E = Environmental; G x E = Genotype by environment interactions; δ = Error

Thus, yield is not the function of genotype alone but also of environment and genotype x environment interactions. In India, we have not paid enough attention to exploitation of E and stabilization/management of G x E interactions in groundnut. We remained focused largely on G.

Need for better management of environment (E): Both improved cultivars and improved cultural practices not only contribute significantly towards increase and stability of yield but they also have a synergistic effect on productivity. Research on water and nutrient management has not received adequate attention in India. Most agronomic recommendations are very general in nature and do not address location-specific issues associated with cultural management. The management practices should be not only location-specific but also variety specific and farmer-specific taking into account his/her socio-economic conditions.

Yield potential: Maximum yield obtainable by the best genotype available in a specified agroclimatic environment, when the known biotic and abiotic constraints are overcome is the yield potential of a variety and its associated agroecology (Johansen and Nageswara Rao, 1996).

Environmental and soil factors place a limit to yield potential at a given location. Ambient radiation, temperature and carbon dioxide regimes characterize the agroclimatic environment. Soil physical characteristics are also important in groundnut because of subterranean nature of podding in the crop.

Yield gap: The difference between yield realized by the farmers and potential yield is large, greater than 5 t/ha for major producing countries or regions (Fig. 3).

Abiotic factors (such as soil moisture and nutrient availability) can be alleviated and biotic factors (diseases and insect pests) can be managed through appropriate control measures. As such they do not limit the yield potential of a genotype, but they do affect yield gap. This implies considerable scope for increasing realized yield at farm level by identifying and addressing the biotic and abiotic constraints responsible for this gap at a given location.

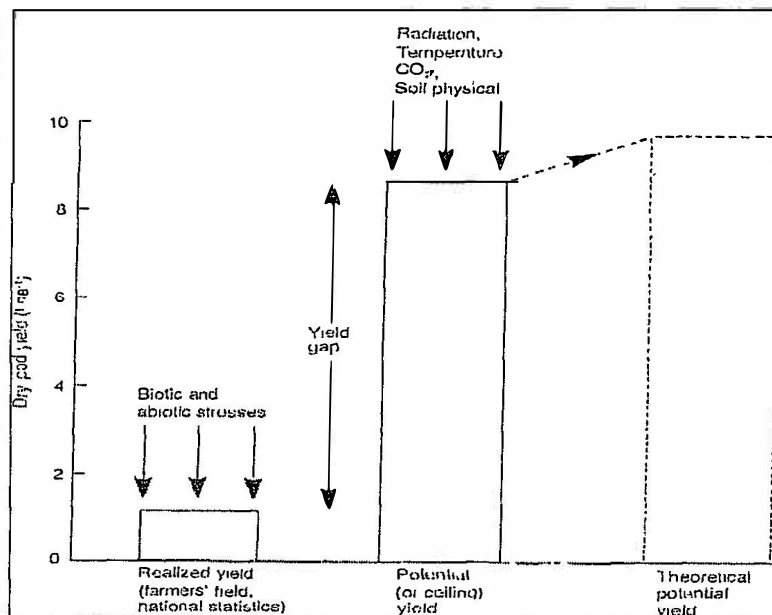


Fig. 3. Factors responsible for yield gap between realized yield and potential yield

Bridging the yield gap

Stress resistance breeding entails some sacrifice in yield potential. However, it should not matter much at this stage as the gap between the realized and potential yield is large. It is essential to strike a balance between level of resistance and the sacrifice in yield potential so that the genetic option of management remains economically viable.

Biotic stresses: When several pathogens/pests are competing for the same site (such as leaves, pods and roots) in a plant system, an obvious requirement is multiple stress resistance. Breeding for moderate levels of resistance to the pathogens/pests will be the best strategy to avoid a heavy penalty in yield potential while improving the levels of realized yields.

However, in a 'kill' situation, which occurs with many virus diseases, a high degree of resistance or even immunity would be required. With this approach there is always a danger in the long run of forcing the pathogen/pest to evolve to overcome the genetic resistance.

Abiotic stress (water-limited conditions): Yield (Y) under water-limited conditions can be attributed to the following three functional components (Passioura, 1977).

$$Y = T \times TE \times HI$$

Where, T = Amount of water transpired;
TE = Drymatter produced per unit of T
HI = Harvest index

High yields can be achieved by manipulating T, TE and HI in a positive direction. However, under water-limited conditions, exploitation of T may not be possible as the available water is limited. Under such circumstances, exploitation of TE and HI become more important. Selection for TE through surrogates (specific leaf area (SLA) and SPAD chlorophyll meter reading (SCMR)) (Bindu Madhava *et al.*, 2002; Sheshshayee *et al.*, 2006; Nigam and Aruna, 2008) and HI can be done under normal growing conditions without creating moisture stress.

Raising the yield potential

Further increase in yield potential is justified in two situations: i. where groundnut is grown in stress free environment and ii. where a ceiling is reached in realized yield. In marginal environments, none of these situations applies. Therefore, in rainfed environments, the priority should be on bridging the yield gap.

Application of physiological models makes it possible to interpret genotype and environmental effects on yield and helps in assessing the scope for genetic improvement for a given trait. The yield potential of a genotype can be expressed through the following physiological model (Duncan *et al.*, 1978):

$YR = C * DR * P$ Where: C = Mean crop growth rate; DR = Duration of reproductive growth
P = Mean fraction of C partitioned towards the reproductive organs

- C is defined as dry matter produced per unit land area per unit time ($g/m^2/day$) - an integration of intercepted radiation and radiation-use efficiency.
- DR and P are the integration of period of reproductive growth and ability of partitioning of photosynthates to pods.

In this model, C provides a measure of 'source' and P and DR are the terms that describe the 'sink'. The crop duration is generally fixed for a given location or cropping system. It is determined by soil moisture availability and prevailing temperatures during the cropping season. DR can be increased to some extent by reducing the duration of the vegetative phase by selecting for early emergence and profuse early flowering (Nigam and Aruna, 2007). In a fixed crop duration, C and P are the major determinants of the final yield. Variations in C are dominated by E and G x E interactions. Variation in radiation-use efficiency, a determinant of C, is small under non-limiting conditions in a species. The scope for variation in intercepted radiation, another determinant of C, is large and can be manipulated by ensuring early ground cover. At full energy interception, C depends on availability of water and DR. In groundnut, both genotypic and photoperiod differences are important sources of variation in P (Nigam *et al.*, 1994; Nigam *et al.*, 1998). At full radiation interception, P is the major source of variation in yield under non-stressed conditions.

Various environmental factors have different influences on C, DR and P. For example, drought will influence C and P, Ca deficiency will influence P and foliar diseases will mainly influence C. DR and P are likely to have high heritability, C is largely the factor responsible for low heritability of yield.

Functional groundnut ideotype

Based on physiological model, a target environment specific ideotype can be conceptualized. For example, for rainfed, relatively short-season, long-day environment prone to intermittent drought stress, a functional ideotype should have: (i) Rapid emergence, (ii) Early growth vigour (shoots and roots), (iii) Early flowering, (iv) Insensitivity to photoperiod, (v) High radiation-use efficiency (narrow leaves) (vi) High TE (thick leaves), (vii) High HI and minimum thermal time to physiological maturity

Functional ideotype would be different for different environments. But parameters such as TE and HI would be common across all the environments. Surrogates of TE (SLA and SCMR) could easily be integrated in the selection scheme of a breeding programme.

Genetic improvement of groundnut

In subsistence farming (rainfed), the emphasis in crop improvement should be on arresting yield and quality losses from abiotic and biotic stresses (bridging the yield gap through breeding for pro-poor traits). The priority constraints of global importance include drought, foliar diseases (rust and early- and late- leaf spots) and aflatoxin contamination by *Aspergillus flavus*. In south Asia, bud necrosis disease caused by peanut bud necrosis virus is also important in some regions. Location-specific constraints in India include pod and stem rot caused by *Sclerotium rolfsii* in Gujarat, peanut stem necrosis caused by tobacco streak virus in Anantapur in Andhra Pradesh and 'Kalahasti malady' caused by *Tylenchorhynchus brevilineatus* nematodes in Kalahasti area in Andhra Pradesh, among others.

Biotechnological approach: Groundnut events transformed with drought responsive elements (rd29A:DREB1A) have shown very encouraging results in dry-down experiments under contained glasshouse conditions. Many transformed events had not only high TE but also positive root response under water limited conditions (Bhatnagar Mathur *et al.*, 2007). This opens up a new possibility to transfer drought responsive elements in high yielding genetic backgrounds.

New developments are also occurring in the area of applied genomics in groundnut. Varshney *et al.* (2008) reported 2-5 QTLs each for T, TE, SLA and SCMR but these accounted for only 3.5-14.1% phenotypic variation in these traits. They constructed the first genetic map of cultivated groundnut and demonstrated its utility for molecular mapping of QTLs controlling drought-related traits in groundnut. Further work is in progress. In due course marker-assisted selection (MAS) for physiological traits associated with drought will become operational.

Breeding for resistance to foliar diseases: Rust (caused by *Puccinia arachidis*), late leaf spot (LLS) (caused by *Phaeoisariopsis personata*) and early leaf spot (ELS) (caused by *Cercospora arachidicola*) are the major foliar fungal diseases of groundnut world wide. Each one of them can cause losses in pod yield up to 50-55%. However, rust and LLS often occur together and the combined yield losses in yield can reach up to 60-70%. These diseases reduce not only pod and haulm yields but also affect seed and haulm quality adversely.

Sources of resistance: Efficient field (infector-row technique) and laboratory techniques are available for screening against foliar diseases (Subrahmanyam *et al.*, 1982; Subrahmanyam *et al.*, 1995). To date, over 13,000 groundnut accessions originating from 89 countries have been screened for resistance to rust at ICRISAT Center. Of these, 169 accessions with disease scores of 5 or less on a 1-9 scale (where 1= no disease, and 9=81-100% damage to the foliage) are reported as resistant. Although many of these sources (ICG # 7896, 7897, 7899, 10014, 10030, 10052, 10053, 10067, 10933, 10939, 10940 and 10943) have low disease score, they have poor agronomic characters. Some other resistance sources in cultivated types identified later (ICG # 10056, 10567, 10925, 10932, 11108, 12059, 12112 and 12113) and interspecific hybrids produced from introgression of genes from wild *Arachis* species, particularly those involving *A. batizocoi* and *A. duranensis* (ICG # 11301, 11315 and 11321) have high levels of resistance in good agronomic backgrounds (Singh *et al.*, 1997). However, the latter are of longer duration than normally required under Indian conditions. Like rust, most of the accessions of 69 sources of resistance to LLS from cultivated types have poor agronomic characters. However, some resistance sources in cultivated types (ICG # 10920, 11182 and 12720) and interspecific hybrids produced from introgression of genes from wild *Arachis* species, particularly those involving *A. cardenasii* (ICG # 11317, 11325, 11337, 13917 and 13919) have high levels of resistance in good agronomic backgrounds. ICG # 1707, 6330, 7013, 7884, 7897, 11317, 11321, 11325, 11337, 13916, 13919, 13920 and 13922, among others, carry high levels of resistance to both rust and LLS. ELS pathogen is suspected to have variability as very few resistance sources are found stable across locations (ICG # 6284, 6802, 7878, 10000, 10948 and 13917) or temperature regimes (ICG # 6902, 11476 and 8298).

Unresolved issues in foliar diseases resistance breeding: The first generation foliar diseases resistant varieties (high levels of resistance to rust and moderate levels of resistance to LLS) released in India, ICG (FDRS) 10 and Girnar 1, in spite of their higher yields, did not find acceptability among the farmers due to their poor pod shape, low shelling turnover and prolonged duration. There was linkage drag associated with resistance genes. Although, they had higher levels of resistance, the linkage drag was similar in the case of interspecific derivatives (Nigam *et al.*, 1991). However, when these resistant varieties/breeding lines were recycled in the crossing programme, in resultant selections/varieties (ICGV 86590, ICGV 86699 and ALR 2), there was significant improvement in pod and seed characters. But they still had relatively longer duration, which made them to suffer under end-of-season drought conditions. Also, there was some dilution in levels of resistance to these

diseases in these varieties. ICGV 86699, a selection from interspecific population, (*A. batizocoi* x *A. duranensis*) x *A. hypogaea* cv. NC 2, did not find acceptance among farmers in spite of its outstanding performance as its kernels left bitter after taste in mouth upon consumption. It is essential to evaluate varieties for nutritional quality and other associated factors when they contain gene(s) from related wild species or alien sources. Some new cultivars such as GPBD 4, originating from KRG 1 (*A. hypogaea*) x ICGV 86855 (*A. hypogaea* x *A. cardenasii*) cross, are reported to be resistant to late leaf spot and rust with desirable pod and seed characters including duration (Gowda *et al.*, 2002). There is a need to search for higher levels of resistance particularly to LLS and ELS in cultivated types.

Biotechnological approaches: At ICRISAT, screening of transgenic events with antifungal genes is in progress (Sharma *et al.*, 2006). Preliminary results are encouraging. As the level of resistance in wild *Arachis* species is very high, it would be useful to identify markers to tag resistance gene(s) for use in regular breeding programmes.

Khedikar *et al.* (2008) reported 12 QTLs for late leaf spot accounting for 1.2 -5.6% phenotypic variation and 13 QTLs for rust accounting for up to 54.4% phenotypic variation in three different environments. A major QTL associated with rust accounted for 18.4-54.4% phenotypic variation. Mapping work is in progress at other locations also. It will be possible to practise MAS, in due course, for foliar diseases resistance in groundnut.

Breeding for resistance to aflatoxin contamination: The *A. flavus* infection and the consequent aflatoxin contamination of groundnut present a serious quality problem worldwide. In the semi-arid tropics, *A. flavus* infection mainly occurs before the crop is harvested, particularly under late-season drought conditions. In wet and humid areas, infection predominantly occurs postharvest during drying and curing and in storage. Aflatoxin has serious implications on human and livestock health and export of produce. Groundnut importing countries have in place now very stringent standards for maximum permissible limit of aflatoxin in groundnut and its products, which are difficult to meet by developing countries where groundnut is grown under rainfed conditions.

Status of resistance breeding: Pre-harvest seed infection, *in-vitro* seed colonization and aflatoxin production are three independent events and are inherited independently. The levels of resistance for these three events in cultivated groundnut are not very high. Wild *Arachis* species are reported to have much higher levels of resistance to these events (Xue *et al.*, 2004). However, they need to be studied more thoroughly for these traits before using them in resistance breeding programme. It is likely that they may carry different genes for resistance to aflatoxin production. Conventional breeding efforts produced limited success only. It could transfer only available resistance to high yielding backgrounds. Unless screening techniques and sampling procedures are further improved to give reliable and repeatable results, much progress through conventional breeding efforts is hard to come by (Nigam *et al.*, 2009). Some of the breeding lines so developed, among others, are ICGV # 91278, 91283, 91284, 94379, 93305 and 94434. The last one showed low aflatoxin contamination when evaluated in India, China and the USA.

Current management options: As genotypes with high levels of resistance are not available, the current management options involve a holistic approach combining genetic option (tolerant varieties) and appropriate cultural practices and biological control (deep ploughing, soil inversion), use of biological (atoxicogenic *A. flavus* strains, *Trichoderma*, *Pseudomonades* and *Actinomycetes*) and chemical pesticides as deterrent to fungus, use of lime, farmyard manure and crop residues as soil amendments, protective irrigation, timely harvest, improved drying methods (row and batch drying, timely and safe threshing, drying pods to <10% moisture, segregating infected and immature pods before storage) together into an integrated crop management package (Waliyar *et al.*, 2004).

Looking ahead: Various biotechnological approaches are being pursued in the USA, China, India and elsewhere to overcome the problem of aflatoxin contamination in groundnut. Recent

developments such as availability of whole genome data of *A. flavus*, development of ESTs and microarrays for groundnut and findings from host-fungus interaction studies may contribute to comprehensive understanding of resistance mechanisms in groundnut and may lead to the development of new tools that can aid the precise selection of genotypes with resistance to aflatoxin contamination. At ICRISAT, genetic transformation with 13S-lipoxygenase (13S-Lox) gene is being followed (Sharma *et al.*, 2006). 13S-Lox gene down-regulates aflatoxin production.

Breeding for eco-regional adaptation: In addition to resistance/tolerance to prevailing biotic and abiotic stress factors, a variety for being successful should be in harmony with the edaphic and climatic factors of the ecosystem. The duration of a variety, irrespective of its growth habit, should match with the period of soil moisture availability, particularly under rainfed conditions. Farmer- and market-preferred traits should guide a breeding programme to have wider acceptability of their products. In many situations, dual purpose varieties (pod yield and fodder) are needed by the farmers. Similarly, varieties for both oil and food use are required. However, for food use, the produce should be of a very high standard free from aflatoxin contamination and chemical residues.

Short-duration (<100 days): Short-duration varieties are needed for areas where end-of-season droughts are more frequent, rice fallows under residual moisture, inter and multiple cropping and spring/summer season cultivation, which is gaining popularity in north India, particularly in Uttar Pradesh and Punjab. However, one must be prepared to accept some sacrifice in yield potential in short-duration varieties.

Medium-duration (100-120 days): Where rainy season is longer and the rainfall is well distributed, medium-duration varieties suitable for oil and food use as a sole crop are the choice.

Breeding for high yield potential and edible uses: There are two situations where further increase in existing yield potential is justified: (i) where the ceiling in realized yield has reached, and (ii) where the crop is grown under stress-free environment with high levels of inputs and management. End-product specific traits and consumer preferences of the targeted region need to be kept in mind while selecting new genotypes for edible use. Some of the traits which are important for edible uses are attractive pod shape, large seed size for table purpose, uniformity testa integrity, low oil content, high oleic and linoleic fatty acid ratio (O/L ratio), sensory factors like taste and flavour and freedom from aflatoxin and chemical residues. The programmes aiming at developing varieties suitable for export should gather information on traits preferred by importing countries. These would vary depending up on the end-use. Marker-assisted selection (MAS) is being practised in the USA to combine high O/L ratio with nematode resistance (Holbrook *et al.*, 2008). The MAS is resulting in considerable saving in time and effort as genotype of each individual plant can be determined immediately and the plant can be used for another round of backcrossing.

Approaches to enhance impact of improved varieties

In spite of more than 162 improved varieties released by the national programmes in India, very old varieties such as TMV 2, AK 12-24, J 11/SB 11, JL 24 etc. continue to dominate varietal scenario in groundnut cultivation particularly in states such as Andhra Pradesh, Karnataka, Maharashtra and Orissa. Predominance of old varieties in cultivation due to various reasons keeps the productivity of groundnut in India at a lower level. Front line demonstrations carried out with newly released varieties have not been fully successful in popularizing them.

Farmer-participatory varietal selection (FPVS): Farmer-participatory varietal selection innovative approach where farmers evaluate a basket of advanced breeding lines/varieties with farmer- and market- preferred traits on their fields in a participatory mode. Varieties selected by the farmers themselves have wider acceptability and farmers develop a sense of ownership over such varieties. They also assist in propagating such varieties widely by sharing their seeds with friends and relatives.

Strengthening informal and formal seed sectors: The seed rate being very high in groundnut (100 kg/ha or more), the quantity of quality seed requirement each year in the crop is very high. Further, the seed multiplication ratio in groundnut is low (normally taken as 8-10). No single agency can meet the requirement of quality seed of groundnut. In addition to strengthening formal seed sector through enhanced breeder seed production, there is need to monitor and to account for production of subsequent classes of seed. The old varieties must be removed from the formal national seed production chain, even if their demand is raised by State Departments of Agriculture. The resources, thus saved, can be better utilized in multiplying newly released varieties, which have consistently demonstrated their superiority over old varieties.

The informal seed sector, operated largely by traders/millers, plays a major role in meeting seed demand of groundnut in India. The role of informal seed sector needs recognition and strengthening and must be brought under quality control. The aim should be to create seed self-sufficiency at the village level by empowering individual farmers in seed production and promoting seed enterprises at local level. India is fortunate to have multiple cropping seasons. The advantage should be taken to establish *kharif-rabi/summer-kharif* seed production chain for groundnut in the country. Strengthening of informal seed sector may require some policy changes. In addition to notified varieties and certified seeds, farmer-preferred varieties and quality assured seed should also find place and recognition in government schemes of seed production and distribution. The private seed sector should be encouraged to take up seed multiplication and distribution of self pollinated oilseeds and pulses as part of their corporate social responsibility.

Improving efficiency and returns on investment in research

It is very important to realize the power of partnership in research and development in agriculture. It brings not only synergy in research efforts but also hastens the research process and enhances rate of returns on investment. All India Coordinated Research Projects are not necessarily collaborative efforts as most of the partners of the project work in isolation. It is only the final products from different partners that are brought together on a common platform (trials) in these coordinated projects. What is required is the collaborative research with common planning and implementation and exchange of materials that are going to lead to synergy and hastening the research process and its outputs and outcomes.

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