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SOME STRATEGIC ISSUES IN BREEDING FOR HIGH AND STABLE YIELD IN GROUNDNUT IN INDIA

S.N.NIGAM*

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh.

INTRODUCTION

Groundnut is the major oilseed crop in India. In spite of its declining contribution over the years to the oilseed basket of the country (from 42% in 1992-93 to 36% in 1996-97), it continues to occupy the leading position among oilseed crops. However, it may not maintain this position if remedial measures are not taken to increase its productivity and competitiveness vis-a-vis other oilseed crops such as rapeseed and mustard, sunflower, and soybean, which threaten its dominant position.

About 80% of the total groundnut area in the country is under rainfed conditions. Because of this, the annual groundnut production, and average groundnut productivity, in the country are closely linked to amount and distribution of rainfall during the crop season in the major groundnut growing States (Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, and Maharashtra). In addition to droughts, groundnut suffers from several diseases and pests that can cause serious damage and limit productivity. These stresses cause wide fluctuations in annual production and productivity, particularly in the rainy season groundnut crop, and need to be arrested if groundnut is to retain its leading position among oilseed crops. Notwithstanding almost a century of groundnut research in the country, an effective and economic solution to many of these ailments continues to elude scientists.

REVIEW OF THE PAST GROWTH AND POTENTIAL FOR FURTHER GROWTH

During the period of 1949-50 to 1964-65, the major increase in groundnut production in the country (from 3.43 m t to 6.00 m t) was brought about through the increase in the area under the crop (from 3.97 m ha to 7.37 m ha) rather than through improved productivity (Anonymous, 1996). The compound annual growth rate of the area during this period was 4.01% and that of pod yield was 0.31%. Together, they resulted in the compound annual growth rate of 4.34% in production. However, this trend was reversed during the period of 1967-68 to 1994-95. The scope for further area expansion was drastically reduced; it grew only at compound annual growth rate of 0.56%. The compound growth rate of pod yield, 1.14% per annum, became the major source of increase in groundnut production during this period, which grew at an annual compound growth rate of 1.71%. The part that research has played in increasing groundnut production is indicated by the compound annual growth rate of pod yield. This contribution became more pronounced in the latter period. The increase in pod yield was brought about by both genetic and non-genetic factors, but it is not possible to accurately apportion their individual contributions. An analysis of multilocation on-farm demonstrations dealing with improved groundnut production technologies, organized jointly by ICRISAT and State Departments of Agriculture during 1987 to

* Principal Scientist (Groundnut Breeding), Genetic Resources and Enhancement Program
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1990 in India, showed that improved cultivars resulted in 30% increase in pod yield and improved package of cultural practices 25% over local cultivars and cultural practices. When both were used together, they interacted synergistically and gave an increase of 60% over local varieties and cultural practices (Legumes Program, ICRISAT, 1992). The pod yield in improved technology demonstrations ranged from 1.39 t ha^{-1} to 3.10 t ha^{-1} in the rainy season and from 2.40 t ha^{-1} to 3.82 t ha^{-1} in the postrainy season. The range of yield under local varieties and cultural practices was from 0.86 t ha^{-1} to 1.84 t ha^{-1} in the rainy season and from 1.47 t ha^{-1} to 2.25 t ha^{-1} in the postrainy season. The national average of groundnut yield (1990-91 to 1994-95) in the rainy season is 0.83 t ha^{-1} and in the postrainy season is 1.5 t ha^{-1} (Directorate of Economics and Statistics, 1995). In spite of technological developments, groundnut at the farm level, barring a few isolated examples, continues to be a 'low input' and 'low output' crop. Pod yield as high as 9.4 t ha^{-1} has been obtained under high management in a fairly large sized plot in farmer's field (Table 1). This clearly demonstrates the high yield potential of currently available varieties under improved management technologies. Even the older cultivars like JL 24 can produce 5.1 t ha^{-1} under good crop management. For achieving high yield in a sustainable manner, the role of cultural management is critical. Further increase in groundnut production in the country will come only through yield stabiliztion and a greater realization of the yield potential of improved cultivars through better farm management practices. Scope for further increase in area under the crop is very limited barring a few niches outside the traditional crop area, which remain fallow either before or after their main crop and introducing it as an intercrop with other crops.

Table 1. On-farm pod yields of improved groundnut cultivars obtained by farmers in different states of the country.

Variety	Area	Pod Yield (t ha^{-1})
Tamil Nadu (1986/87, Postrainy season)		
ICGS 44	1.5 cent[1]	8.8 (113)[2]
ICGS 11	1.5 cent	6.6 (113)
JL 24	1.5 cent	5.1 (101)
Maharashtra (1996/97, Summer season)[3]		
TG 26	0.2 ha	9.4 (115)
ICGS 11	0.4 ha	7.0 (115)
TAG 24	0.2 ha	5.3 (115)
Andhra Pradesh (1996/97, Postrainy season)		
ICGS 35	3 cent	9.5
ICGS 44	13 cent	7.2
ICGS 44	4 acre	5.0

1: 100 Cent = 1 acre; 2 : Days to harvest ; 3 : Under broad bed and polythene mulch system

(Source : ICRISAT - Unpublished data)

REASONS FOR INSTABILITY IN GROUNDNUT PRODUCTION AND YIELD

A perusal of coefficient of variation (CV) in pod yield and area of groundnut during the period 1970-71 to 1993-94, estimated by Singh and Singh (1997), presents an interesting picture (Table 2). Gujarat and Andhra Pradesh are the two leading groundnut-producing States in the country. In Gujarat, the CV for yield was 45.8% and for area 13.4%. The reverse was true for Andhra Pradesh, the CV for yield being 14.2% and for area 25.9%. The reasons for these contrasting scenarios need to be fully understood to evolve appropriate strategies to increase and stabilize groundnut productivity and production. The fluctuations in yield and area could result from differing intensities of biotic and abiotic stresses in space

Table 2. Coefficient of variation (%) for groundnut pod yield and area in major groundnut growing States in India (1970-71 - 1993-94).

	Coefficient of variation (%)	
State	Pod yield	Area
Gujarat	45.8	13.4
Andhra Pradesh	14.2	25.9
Tamil Nadu	20.5	9.8
Karnataka	24.9	19.4
Maharashtra	26.7	11.7
Rajasthan	28.1	18.3
Orissa	12.6	54.7
Madhya Pradesh	23.6	23.7
Uttar Pradesh	23.2	42.2
Punjab	13.0	71.9
All India	13.39	8.00

(Source: Singh and Singh, 1997)

and time, due to non-availability of seed of improved cultivars, delayed onset of rains, and policy influences affecting economics of groundnut production. There could be other factors as well.

AGRO-ECOLOGIES

There are three major groundnut agro-ecologies in the country:rainfed, irrigated, and residual moisture.

RAINFED AGRO-ECOLOGY: This ecology covers about 80% of the area sown to groundnut in the country. Most of the groundnut farmers are small landholders and are resource-poor. The rainy season groundnut production bears the brunt of most of the constraints that are associated with production. These include low soil fertility, low inputs, low initial plant population (due to poor texture of soil, seed and seedling diseases, insect pests, and poor seed quality), weeds, moisture stress at different stages of growth, diseases (rust, late leaf spot, collar rot, stem rot, pod rots, aflatoxin contamination, bud necrosis among others), insect pests (thrips, jassids, Spodoptera, Helicoverpa, leaf miner, red hairy caterpillar, termites, white grubs, pod borers among others), nematodes, field sprouting in Spanish groundnuts, and pod loss at harvest.

IRRIGATED AGRO-ECOLOGY: About 20% of the groundnut area in the country is under irrigation. Most of the irrigated production occurs in the postrainy season. Notwithstanding its endowment with better resources, the irrigated agro-ecology also suffers from constraints. In addition to diseases and insect pests, abiotic factors such as low temperature at germination, higher temperature at podding, and iron chlorosis are important. Furthermore, poor water management during crop growth and moisture stress late in the season (in case of well or canal irrigation) also affect groundnut yield and aflatoxin contamination.

RESIDUAL MOISTURE AGRO-ECOLOGY: Rice fallows and riverbed ecosystems are predominant in this agro-ecology. Most of the constraints of the irrigated agro-ecology also apply to this agro-ecology. However, this ecology is characterized by short growing season due to receding soil moisture and also poor plant stand due to difficulty in proper and timely land preparation after harvest of the previous crop.

The severity and extent of these constraints vary in space and time. There is general recognition of important production constraints in different agro-ecologies and cognizance of greater severity and complexities of constraints in the rainfed agro-ecology. However, better quantification and resolution is required to reset the priorities for each agro-ecology. In some cases local or regional constraints may override the priorities set at the national level.

APPROACHES AND OPPORTUNITIES TO STABILIZE YIELD

Both, improved cultivars and improved cultural practices not only contribute significantly towards increase and stability of yield but also have a synergistic effect. Research on soil, water, and nutrient management in groundnut has not received adequate attention in India. Most of the recommendations are very general in nature and do not address location specific issues associated with cultural management. At the higher levels of productivity, larger amounts of nutrients are required (Table 3). There is an urgent need to develop improved location specific cultural practices to increase and sustain groundnut productivity and production in the country.

Management of constraints to groundnut yield is essential to stabilize and increase the latter at the farm level. Many of these are common across the agro-ecologies. Some of the constraints listed earlier are amenable to genetic solutions and some others to non-genetic solutions; some others require both approaches. The choice of approach will depend on cost and time, probability of success, and rates of return associated with each approach. Generally, the non-genetic solution to diseases and insect pests management is uneconomic in the rainfed agro-ecology due to low levels of groundnut yield obtained and resource limitation of the farmers. The genetic solution holds out a better promise in such a situation. In the irrigated agro-ecology, where groundnut yields are higher, both genetic and non-genetic solutions are feasible. However, the non-genetic solutions may not always be eco-friendly. On the other hand, when genetic resistance is incorporated into cultivars against prevailing biotic and abiotic stresses, there is always a price to be paid in terms of yield potential (Parsons, 1979; Subrahmanyam

Table 3. Estimated nutrients required to produce targeted pod yield of groundnut.

Pod yield t ha^{-1}	Kg ha^{-1}									
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B
1	58	5	18	11	9	4	2	0.09	0.08	0.05
2	117	10	36	23	18	9	4	0.19	0.16	0.11
3	174	15	54	34	27	13	6	0.29	0.24	0.16
4	232	20	73	45	36	18	8	0.38	0.32	0.22
5	290	25	91	56	45	22	10	0.48	0.41	0.27
6	348	30	109	68	54	26	12	0.58	0.49	0.33
7	406	35	126	77	63	30	14	0.68	0.56	0.38
8	464	40	144	88	72	34	16	0.78	0.64	0.44
9	522	45	162	99	81	38	18	0.88	0.72	0.49
10	580	50	180	110	90	42	20	0.98	0.80	0.54

(Source: Calculated by Singh and Oswalt (1991), based on Sahrawat et al., (1988)) *et al.*, 1984; Pixley *et al.*, 1990; Wynne *et al.*, 1991; Knauft and Wynne, 1995). Most resistance sources among cultivated genotypes originate from native landraces and generally have low yields and undesirable pod and seed characteristics. The higher the level of resistance incorporated into cultivars, the greater the reduction in yield potential (Table 4). However, this price in reduced yield potential may not have any economic significance, if a wide gap exists between the currently realized yield and the potential yield of cultivars. The key lies in striking a proper balance between genetic resistance and non-genetic resistance and non-genetic management to realize the best socio-economic benefit and to ensure eco-friendly systems. This can be achieved better when we know the level at which the genetic resistance becomes uneconomical. Many more physiological studies are required to gain better insight into the underlying mechanisms determining the economics of genetic resistance.

Resistance breeding

Some of the constraints, which are amenable to genetic solution, are listed in Table 5. Many of these constraints occur in combination.

When several pathogens are competing for the same feeding site (such as leaves, pods, and roots) in a plant system, an obvious requirement is multiple stress resistance. If resistance is incorporated against a single stress factor, the plant may show more susceptibility to others due to reduced competition among the remaining pathogens for the same feeding site. Breeding for moderate levels of resistance to the pathogens involved is the best strategy in such a situation to avoid a heavy sacrifice in yield potential. However, when the whole plant system is under stress, the strategy would depend on the nature of damage to the plant system. In the case of a 'kill-situation', such as occurs with many virus diseases, a high degree of resistance or even immunity, would be required. However, with this approach there is always a danger in the long run of forcing the pathogen to evolve to overcome the genetic resistance. In cases where the plant system is weakened by the pathogen, such as drought and iron chlorosis, "tolerance" may be more desirable. Stress resistance breeding, when indicated by proper socio-economic analysis, should be accorded the highest priority in the national research program.

Table 4. Combined effect of genetic resistance and chemical control of foliar fungal diseases on pod yield in groundnut.

Cultivar	Control Pod yield (kg ha $^{-1}$)	Gain in pod yield (kg ha $^{-1}$) Number of sprays 2	4	6
Resistant (ICGV 86699)	2370	185 (8.2)	470 (19.80)	620 (26.2)
Moderately Resistant (ICGV 86590, ICG (FDRS) 10, ICGS 76)	1760	688 (39.1)	1028 (58.4)	1224 (69.5)
Susceptible (TMV 2)	1120	200 (17.9)	460 (41.1)	644 (57.5)

Figures in parenthesis denote gain in pod yield in percent
(Source: Pande *et al.*, ICRISAT, Unpublished data)

Table 5. Groundnut production constraints amenable to genetic intervention

Rainfed	
1.	Ability to perform well under low inputs
2.	High water use effiency (drought tolerance)
3.	Diseae resistance
4.	Insect pest resistance
5.	Nematode resistance
6.	Resistance to aflatoxin contamination
7.	Seed dormancy
8.	High yielding cultivars with different maturity duration
Irrigated	
	2,3,4,5,8, tolerance to low temperature during germination and to high temperature during pod filling, and tolerance to Iron chlorisis
Residual Moisture	
	2,3,4,5,6,8 (Short-duration)

Genetic diversification

A cursory analysis of about 100 improved groundnut cultivars released in the country since 1905 showed that 48% resulted from selection either in local landraces or in introduced materials, 45% from hybridization followed by selection, and the remaining 7% from mutation breeding. Of these cultivars, only Girnar 1, ICG (FDRS) 10, and ICGV 86590 are resistant to foliar diseases, which cause most significant loss in yield and quality. However, these cultivars suffer from inferior agronomic traits such as low shelling outturn, long duration, and poor pod shape. Because of this and in spite of their higher pod yield under disease epidemic conditions, these cultivars have not been popular with the farmers.

Over 14,880 accessions of cultivated groundnut and 450 accessions of wild *Arachis* species, available to national programs through ICRISAT, are a vast reservoir of genetic variability for most of the biotic and abiotic stresses affecting groundnut production (Lynch, 1990'; Stalker, 1992; Singh *et al.*, 1997). However, much of this variability remains poorly understood and least used in improvement programs. Only three disease resistant parents (J 11, NC Ac 17090, and PI 259747) appear in the parentage of cultivars released in India.

There is an urgent need to evaluate and characterize the genetic variability available for various economic traits in genus *Arachis*. Currently, this information is very fragmented. With better information on genetic resources, the efficiency of genetic enhancement efforts should increase, and more diversified breeding material for short-(utilizing cultivated germplasm) and long- (utilizing wild *Arachis* species) term gains can be developed. Further improvement in yield would come through hybridization (Norden, 1973) and diversification of breeding material. More long term, concerted efforts are needed to exploit wild *Arachis* species which are not only excellent sources of resistance to several biotic and abiotic stresses, but may also provide 'new' genes for yield and yield related attributes (Guok *et al.*, 1986; Halward *et al.*, 1991).

Yield potential

There are two situations where further increase in existing yield potential is justified. These are 1. Where groundnut is grown in stress-free environments, 2. Where a ceiling is reached in realized yield. Application of physiological models makes it possible to interpret genotypic and environmental effects on yield, thus help in assessing the scope for genetic improvement for a given trait.

For improving yield potential, an

understanding of physiology of yield is essential. The reproductive yield (Y) is a function of crop growth rate (C), duration of reproductive growth (D), and the fraction of crop growth rate partitioned towards reproductive growth (p) (Duncan *et al.*, 1978). C is defined as dry matter produced per unit land area per unit time (g m^{-2} day^{-1}). It is the integration of intercepted radiaion use efficiency. D and p are the integration of period of reproductive growth and ability of partitioning of photosynthates to pods. 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. D can be increased to some extent by reducing the duration of the vegetative phase i.e., by selecting for early emergence and early flowering. However, a plant has to acquire a certain minimum vegetative growth before it can start producing productive flowers. In groundnut, after initiation of flowering, both vegetative and reproductive growth run simultaneously for quite some time. Thus, in a fixed crop duration, C and p are the major determinants of the final yield.

Variations in C are dominated by environment and genotype x environment interactions. Variation in radiation use efficiency, a determinant of C, is small under non-limiting conditions in a species (Duncan *et al.*, 1978; ICRISAT, 1983; Bennett *et al.*, 1993). The scope for variation in intercepted radiation, another determinant of C, is large and can be manipulated by ensuring early ground cover. At a leaf area index (LAI) of 3.0 to 3.5, 95% radiation is intercepted. Further manipulation of LAI does not contribute significantly towards increase in intercepted radiation. At full energy interception, C depends on availability of water and D.

Variation in p is dominated by genotype; environment has a lesser role to play except in the case of photoperiod sensitive genotypes. At full radiation interception, p is the major source of variation in yield under non-stressed conditions. In the USA, the progressive increase in yield in successive varietal releases was associated with improvements of p, and an earlier transition to reproductive growth (Duncan *et al.*, 1978; Wells *et al.*, 1991).

In water stressed situation, amount of water transpired (T) and water-use efficiency (WUE) also become important determinants of pod yield (Passioura, 1986). Greater water-capture due to extensive root systems provides drought tolerance/resistance but has a penalty to pod yield potential in non-stressed conditions. Exploitation of genetic differences for WUE is also problematic. It has a close negative association with partitioning (Wright *et al.*, 1994, Whether this association can be broken is not clear and needs further studies. However, it is not easy to measure water-capture traits and WUE directly in a large breeding program. Surrogate traits such as specific leaf area (SLA) for WUE can be used in a breeding program but their utility and efficiency need to be established.

Local adaptation and test environments

Adaptation of plants to the local environment with all its abiotic and biotic stresses is the substance of evolution. The main role of plant breeding is to hasten this process of evolution and give to it a socio-economic face for the benefit of humanity and its surroundings.

Most of the groundnut in India is grown under low input and rainfed conditions, very often in marginal soils. An appropriate response to this situation by plant breeders should be to select under these conditions rather than merely doing trials to identify potential cultivars after selecting in favourable environments (Simmonds, 1991).

However, creating uniform, reliable, and repeatable test/selection environments under such conditions will require ingenuity on the part of scientists. The temptation to go for favourable environments as an easy way out will have to be resisted. Sometimes, yields in poor environments can be related to one or a few factors limiting production. For example, leafspot resistance was found to be the major determinant of groundnut productivity in various management systems (including lower yielding environments) in the USA (Kvien *et al.*, 1993). When this occurs, the traits with moderate or high heritability can be bred into lines to greatly increase the probability of developing cultivars that are tolerant to such conditions (Knauft and Wynne, 1995).

For varietal evaluation and decision making, the All India Coordinated Research Project on Groundnut has divided the total groundnut growing area in the country (about 6.9 m ha in the rainy season and about 1.3 m ha in the postrainy season) into five zones in the rainy season and four zones in the postrainy (rabi/summer and spring) season (Table 6). This macro classification is based primarily on weather and some major edaphic factors. It fails to capture the full spectrum of variability caused by various abiotic and biotic stress factors, different cropping systems, and management levels. In the state of Andhra Pradesh alone, groundnut is cultivated in six different state zones, each having a different varietal requirement (ICRISAT, 1993). The selection/test environments should represent the farming situations of the zone/region. For operational and economic reasons, a compromise may be needed while selecting these environments. However, the compromise should not lead to a sacrifice in breeding gains.

Table 6. Agroecological zones for coordinated evaluation of new groundnut varieties in the All India Co-ordinated Research Project on Groundnut.

A. Rainy season Groundnut Zones	
Zone 1:	Rajasthan (except western parts), Haryana. Punjab, Uttar Pradesh
Zone 2:	Gujarat and western Rajasthan except Sri Ganganagar and Bikaner (Irrigated canal areas).
Zone 3:	Northern Maharashtra and Madhya Pradesh
Zone 4:	Bihar, West Bengal, Orissa and North-coastal districts of Andhra Pradesh, Tripura, and other North-eastern areas.
Zone 5:	Southern Maharashtra, Andhra Pradesh (except North-coastal districts), Tamil Nadu, Karnataka. Kerala
B. Postrainy season groundnut zones	
Zone 1	(Spring Groundnut):Uttar Pradesh, Punjab, Haryana, North Rajasthan
Zone 2	(Summer Groundnut):Gujarat, North Maharashtra. Madhya Pradesh
Zone 3	(Rabi/Summer Groundnut): Western and southern Maharashtra, Andhra Pradesh, Orissa, Tamil Nadu, Karnataka, Kerala.
Zone 4	(Rabi/Summer Groundnut in non-traditional area):Bihar, West Bengal, Tripura,, Assam, Andaman

(Source: All India Co-ordinated Research Project on Oilseeds, 1988)

SUMMARY

The average groundnut productivity in India hovers around 1 t ha^{-1}. If rains are good and well distributed, the yields exceed this level, but if rains fail they go down. Several abiotic and biotic stresses also severely affect groundnut productivity in the country. Many farmers who can afford better management are able to achieve much higher yields than the national average, even with the cultivars currently in vogue. The gap between realized yield at the farm level and the potential yield of groundnut cultivars is very wide. Under

these circumstances, the stress resistance breeding should receive the highest priority in the national program, even if it implies some sacrifice in yield potential. Breeding for increased yield potential should receive a low priority until the gap between realized yield and potential yield is narrowed down. Research on evaluation and characterization of genetic resources and on exploitation of wild *Arachis* species needs strengthening. Strategies in breeding and evaluation should favour adaptation to specific environment/cropping system. Groundnut production in the country is concentrated in the western and the peninsular regions. Research priorities and resources should focus on issues, which affect groundnut productivity in these two regions. Immediate remedial measures are requied to overcome the shortage of good quality seed of improved cultivars in the country. Improved cultivars alone will not bring about a significant jump in groundnut production. They need to be supported by appropriate cultural practices. Location specific research on cultural practices should be strengthened to discern the mechanisms underlying the complex process of yield determination and yield x stress resistance interactions in groundnut.

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