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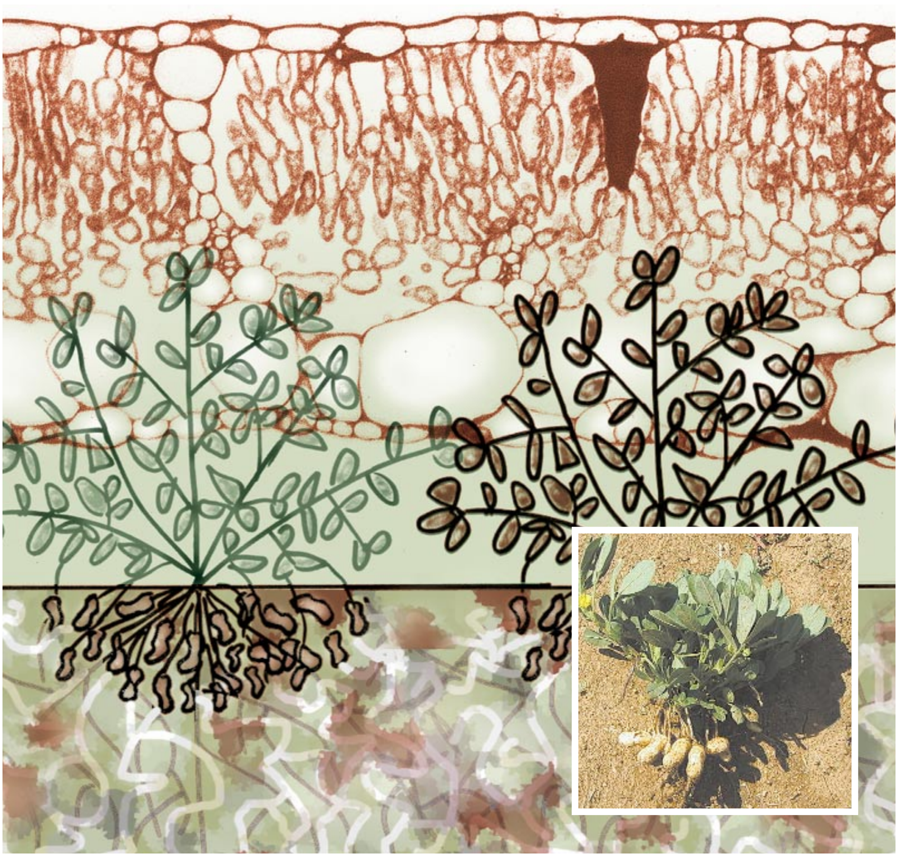
BREEDING OF DROUGHT-RESISTANT PEANUTS



ACIAR PROCEEDINGS

No. 112

Breeding of Drought-resistant Peanuts

Proceedings of a Collaborative Review Meeting
held on 25–27 February, 2002
at Hyderabad, Andhra Pradesh India

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Queensland Department of Primary Industries (QDPI)
Indian Council for Agricultural Research (ICAR)

Editors: **A.W. Cruickshank, N.C. Rachaputi, G.C. Wright** and **S.N. Nigam**

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Cover: Schematic diagram showing a leaf cross-section from a high water-use efficient peanut plant (top). Inset photo shows a drought-resistant peanut plant generated during the project.

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Above: Project review and planning meeting at Udaipur, Rajasthan, India.

Below: Collaborating scientists inspecting breeding trials at the Regional Agricultural Station, S.V. Agricultural College Campus, Tirupati, Andhra Pradesh, India.

Above: Inspecting the mini-lysimeter facility established by the ACIAR project at Regional Agricultural Station, S.V. Agricultural College Campus, Tirupati, Andhra Pradesh, India.

Below: Drs M.S. Basu and Colin Piggin inspecting aflatoxin genotype resistance screening plots at ICRISAT Centre, Andhra Pradesh, India.

Acknowledgments

We thank ACIAR, ICRISAT, QDPI and ICAR and for their funding support throughout project CS 97/114 ‘More Efficient Breeding of Drought-resistant Peanuts in India and Australia’. The following people were involved in the collaborative research project from 1997 to 2002. Their involvement and contributions are gratefully acknowledged.

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Contents

Introduction

YIELD OF PEANUT in India and Australia is usually limited by water deficits during crop growth. This deficit arises from unpredictable rainfall, high evaporative demands, and production on low water-holding capacity soils.

The breeding of more drought-resistant genotypes can increase long-term productivity in drought-prone environments. New breeding approaches utilising physiological traits have been proposed to improve the understanding and efficiency of selection for superior drought-tolerant genotypes. However most of these efforts to date have been unsuccessful because the specified traits have been considered in isolation, often unrelated to superior performance under drought stress.

Plant breeders and crop physiologists now believe more rapid progress can be aided by a priori knowledge of the physiological basis of crop performance under drought conditions. This strategy involves the breeding of better adapted and higher-yielding cultivars by identifying reliable traits of drought-tolerance to complement conventional breeding programs.

New opportunities to develop higher yielding drought-tolerant peanut genotypes emerged in the precursor to the current project, Selection for WUE in Food Legumes (PN9216)(1993–98), which developed a detailed understanding of the physiological factors determining yield in water-limited environments. A simple crop analytical model has been used to analyse pod-yield variation under water-limited conditions into three functional components following the framework proposed by Passioura (1977)*, the formula for which is:

Pod Yield = T x TE x HI

where:

T = the amount of water transpired by the crop
TE = dry matter produced per unit of T
HI = the ratio of pod weight to total dry matter.

There were two main outcomes of the PN9216 project. The first was the identification of significant variation in peanut germplasm for T, TE and HI traits. The second main outcome was the development of cheap, rapid and easily-measured surrogate measures for each of these traits, thus allowing their potential quantification in large numbers of breeding populations.

The new project, More Efficient Breeding of Drought Resistant Peanuts in India and Australia (CS97/114), aimed to implement and apply this physiological knowledge. The purpose was to test whether indirect selection using the trait approach can improve the efficiency of selection in large-scale peanut breeding programs. Breeders, physiologists and modellers worked together in a truly collaborative research program.

Specific objectives of the project were to:

- develop more efficient screens and selection methods for yield component traits through better physiological understanding, focusing on the SPAD chlorophyll meter;
- make crosses involving parents identified for high T, TE and HI, as well as combining them in the background of locally-adapted varieties
- evaluate and validate the use of physiological selection traits to achieve superior yield performance in appropriate target environments in both Australia and India
- make a quantitative assessment of the cost-benefit of using indirect selection methods compared to conventional yield-selection approaches for the identification of drought-resistant peanut cultivars.

These proceedings report papers presented at the final external review of project CS 97/114. They provide a useful summary of the conduct, analysis and significant outcomes from this unique project, which has had a long history of funding support from ACIAR.

The development of drought-resistant peanut germplasm in this project has been built on the fundamental research of Professor Graham Farquhar, at the Australian National University in Canberra. In the early 1980s he discovered that exploitable variation for transpiration efficiency existed in a number of crop

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plants, including peanuts. ACIAR supported this 'blue sky' research in two ACIAR projects (Legume Water Use Efficiency (PN8407), and Peanut Improvement in Indonesia (PN 8419 & 8834)), which continued with PN9216, until breeding populations and a selection program targeting Passioura's drought-component traits was completed in the current project.

All project collaborators and our respective institutions sincerely thank ACIAR for its continued support for the blue-sky research to be realised in the development and testing of superior-yielding peanut varieties in farmers' fields.

G.C. Wright

Agency for Food and Fibre Sciences, QDPI,
PO Box 23 Kingaroy, Queensland 4610, Australia

* Passioura, J.B. 1977. Grain yield, harvest index and water use of wheat. Journal of the Australian Institute of Agricultural Science 43: 117–120.

Selection Tools and Breeding Methodologies

•

Use of SPAD Chlorophyll Meter to Assess Transpiration Efficiency of Peanut

•

The Physiological Basis for Selection of Peanut Genotypes as Parents in Breeding for Improved Drought-resistance

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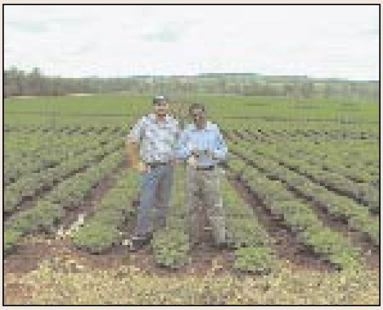
Derivation and Improvement of the Selection Index and Estimation of Potential for Further Improvement

Aflatoxin genotype resistance screening plots at ICRISAT Centre, Andhra Pradesh, India.



Drs G. Wright and S.N. Nigam in a peanut field near Kingaroy, Qld, Australia.

Taking canopy infra red temperatures on F4 progeny rows at QDPI, Kingaroy, Qld, Australia.

Use of SPAD Chlorophyll Meter to Assess Transpiration Efficiency of Peanut

H. Bindu Madhava, M.S. Sheshshayee, A.G. Shankar, T.G. Prasad and M. Udayakumar[1]

Introduction

PEANUT IS GROWN as an oil-seed, food and cash crop under rain-fed as well as irrigated conditions between 40°N and 40°S latitudes. Over two thirds of the global peanut production occurs in seasonally rain-fed regions where drought is a potential constraint for crop production (Smartt 1994). Erratic or insufficient rainfall is a major constraint for production in rainfed environments, and water is increasingly becoming a scarce commodity even in irrigated agriculture. Genetic enhancement to maximize crop production per unit input of water has been a major research thrust of crop improvement programs throughout the world.

In peanut (*Arachis hypogaea* L.) conventional breeding methods to improve drought adaptation have been based on selection for pod yield in a given drought environment. While direct selection for yield can be effective (White *et al*. 1994), the limitations of this approach are high resource investment and poor repeatability of the results due to the large G x E (genotype x environment) interaction for yield (Branch and Hildebrand, 1989; Cooper and Hammer 1996). Simple analytical crop models can provide a framework for the understanding of genotypic variation in yield and the effects of environment on the physiological processes contributing to yield. Passioura (1977) hypothesized that Yield (Y) is a function of transpiration (T), transpiration efficiency (TE) defined as the biomass produced per unit of water transpired, and harvest index (HI), which is a proportion of economic yield in the total biomass.

In peanut a significant genotypic variation for the T, TE and HI, has been demonstrated in pot conditions (Hubick *et al*. 1986; Wright *et al*. 1988) as well as field conditions (Nageswara Rao *et al*. 1993; Wright *et al*. 1994). However, application of this physiological model in breeding programs has not been possible because of practical difficulties associated with measurement of T and TE under field conditions. Close

[1] Department of Crop Physiology, University of Agricultural Sciences, GKVK Campus, Bangalore 560 065, India

relationships between carbon isotope discrimination ($\Delta^{13}C$) and TE in leaves (Farquhar and Richards, 1984; Farquhar *et al*. 1989) have increased the scope for using $\Delta^{13}C$ as an indirect selection tool to assess the genetic variability in TE in peanut (Hubick *et al*. 1986; Wright *et al*. 1988, 1994; Roy 1995; Udayakumar, Sheshshayee *et al*. 1998).

Studies by Wright *et al*. (1994) and Nageswara Rao and Wright (1994) reported a positive correlation (r = 0.90 to 0.93**) between specific leaf area (SLA, ratio of leaf area to leaf dry weight) and $\Delta^{13}C$, and a negative relationship with TE, suggesting that SLA could be used as a surrogate measure of TE in peanut.

Although a close correlation of SLA with TE has been established in controlled experiments, the strength of correlation varied (r = 0.71–0.94) between SLA and $\Delta^{13}C$ (Wright *et al*. 1994) when tested over a range of peanut genotypes and environments (Wright *et al*. 1996). Recent studies have shown that SLA is influenced by factors such as time of sampling, leaf age (Wright and Hammer, 1994; Nageswara Rao *et al*. 1995; Nageswara Rao *et al*., 2001) and accuracy of the measurement.

A recent study by Nageswara Rao *et al*. (2001) highlighted the importance of a standardised sampling method to select for SLA in large-scale peanut breeding programs. This study has also shown significant correlations between the SPAD Chlorophyll Meter Readings (SCMR), SLA and specific leaf nitrogen (SLN) in peanut and suggested that SCMR could be used as a rapid, low-cost, non-destructive technique to screen large breeding populations for SLA or SLN.

Since TE in peanut is controlled mainly by mesophyll rather than stomatal factors (Roy 1995; Wright *et al*. 1994; Nageswara Rao *et al*. 1995; Udayakumar, Sheshshayee *et al*. 1998), parameters such as SCMR, which is strongly linked with mesophyll efficiencies, should also be linked with TE. However, there have been no studies to examine the direct relationship between SCMR and TE in peanut. The major objective of the current study was to examine that relationship in six selected and three non-nodulating peanut genotypes grown under adequately irrigated conditions. The relationship of SCMR with a number of physiological parameters, such as net assimilation rate (NAR), SLA and SLN was also determined.

Materials and Methods

Two pot experiments were conducted to assess the relationship between transpiration efficiency and SPAD Chlorophyll meter readings. The first experiment involved six selected peanut genotypes (ICGS 44, ICGV 86031, TAG 24, TMV 2, ICGS 76, ICG 476); the second involved three non-nodulating lines (ICGL-2, ICGL-4, ICGL-5). The seed material was procured from the ICRISAT Asia Centre.

Experiment I

The seeds were treated with a fungicide to prevent any seedling diseases prior to sowing in carbonised rubber containers 45 x 15 x 20 cm filled with 20 kg of red sandy loam and farmyard manure in a ratio of 3:1. Each genotype was sown in 12 containers with five to six seeds, but later thinned to two uniform and healthy seedlings per container. The containers were arranged randomly under a mobile rainout shelter (ROS) (Chauhan *et al*. 1997), to prevent interference from rain during the experimental period. The soil surface in each container was mulched with plastic pieces to minimize soil evaporation.

All containers received adequate irrigation until 35 days after sowing (DAS), after which various physiological measurements were made as described elsewhere.

Experiment II

A factorial design was used with the three non-nodulating genotypes and three Nitrogen rates: Zero-N; Recommended-N (1.3 g urea per pot with 30 kg of red loamy soil); and Twice-recommended-N (2.6 g urea per pot with 30 kg of red loamy soil). P and K were added at the rate of 11.25 g/pot of Super Phosphate and 1.52 g/pot of Muriate of Potash.

Prophylactic measures were taken to protect the plants from pests and diseases. On the 35th day after sowing (DAS), plants were sampled and leaf area and dry weight were measured as described below. The experiment was extended up to the pod-filling stage (85 DAS), after which another growth sampling was done.

Measurement of Transpiration (T)

Transpiration was monitored during 35–85 DAS from individual containers using the gravimetric method (Udayakumar, Devendra *et al*. 1998). During this period plants were supplied with known amounts of water on a daily basis to replace water lost through transpiration, and to maintain the plants at 100 per cent field capacity.

Plant growth analysis

A set of 24 pots (6 genotypes x 4 replications) were sampled, each at 35, 55 and 85 DAS. At each sampling time, plants were removed from pots and washed with water. Leaves were separated from plants and leaf area of a sub-sample of leaflets was determined using an automatic leaf area meter (model-ΔT, UK). Other plant parts (leaves + stems + roots) were oven-dried at 80°C for 48 hours before determining the dry weight.

Computation of physiological parameters

Plant growth parameters such as change in the dry matter during the treatment period (DM, grams), leaf area duration (LAD, dm^2.day), net assimilation rate (NAR, mg/dm^2.day), mean transpiration rate (MTR, ml/dm^2.day) and TE were computed as:

$LAD = \{(LA_1+LA_2)/2\} \times d$

$NAR = DM/LAD$

$TE = DM/CWT$

where:

LA_1 = leaf areas of plants at 35 DAS

LA_2 = leaf areas of plants at 55 DAS

d = duration of the experimental period (days)

CWT = cumulative water transpired in the period (mm).

Specific Leaf Area (SLA), SPAD, Chlorophyll content and Specific Leaf Nitrogen (SLN)

Observations on SPAD, SLA, chlorophyll content and SLN were recorded on the third fully-expanded leaf from the apex.

SPAD chlorophyll meter readings and leaf chlorophyll content

The SPAD chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ) measurement was made on each of the four leaflets of the third fully-expanded leaf from the apex, with four readings per leaflet. After recording the SCMR, leaf areas of individual leaflets were measured and the leaflets were processed for the measurement of specific leaf area (SLA), as well as chlorophyll content. The two leaflets on the left side of the petiole were oven-dried at 80°C for at least 48 hours before determining the leaf dry-weight. SLA was calculated as the ratio of leaf area to leaf dry weight.

Chlorophyll content was measured on the two leaflets on the right side of the petiole. The leaflets were cut into small pieces and immersed in tubes containing 15 mL of Acetone (80%) and DMSO (1:1). The absorbance at 652 nm was recorded (Spectonic-21) after the leaf pieces were completely bleached.

Total nitrogen content

In Experiment I, the total leaf N content in leaves was determined in the leaflets used for SLA measurement. The N content was determined based on TCD (Thermal Conductivity Detector) using an Elemental Analyser (CE instruments, UK, model: NA 1110) and expressed as g N m^{-2} leaf area (SLN).

In Experiment II, the $\Delta^{13}C$ and N content for non-nodulating lines of peanut were determined simultaneously in the same leaf sample using the Finnigan Mat IRMS linked with on-line Flash-EA, at the National Facility Centre on Stable Isotope Studies in Biological Sciences, Department of Crop Physiology, University of Agricultural Sciences, Bangalore, India.

Results and Discussion

A significant positive relationship ($r = 0.66$, $P<0.05$, $n = 18$) between SCMR measured at 55 and 85 DAS, implied maintenance of genotypic ranking for SCMR and hence a low G x E interaction for this trait.

Genotypes tested in the current study used similar amounts of water (9–10 kg) except for TMV 2, which used 14.2 kg of water during the 20-day (35–55 DAS) treatment period. There was significant variation among genotypes for dry matter produced during the treatment period (27–42 g), which resulted in a significant variation in the TE. The TE ranged from 2.76 $g.kg^{-1}$ in ICG 476 (Chico) to 3.58 $g.kg^{-1}$ in ICGV 86031, representing a significant variability among the genotypes. TE showed a significant negative relationship with SLA ($r = -0.80$, $P<0.01$) and a positive relationship with SLN ($r = 0.91$, $P<0.01$, $n = 6$) confirming the earlier studies (Wright *et al*. 1994; Nageswara Rao and Wright 1994). Measurement of SLA involves a destructive sampling procedure, and is prone to variation depending on the prevailing environmental conditions. This led to a search for other non-destructive surrogate approaches. Further, there is a need to evaluate the causal relationship between SLA and TE.

In peanut TE variation is primarily driven by photosynthetic capacity, and hence carboxylation efficiency determines the variation in TE (Nageswara Rao *et al*. 1995). Since RuBisCO content is regulated by leaf N status, specific leaf nitrogen (SLN) can be considered as one of the alternate surrogate traits for TE.

In the present study, positive relationships between SLN and chlorophyll content ($r = 0.76$; $P<0.05$, $n = 6$) and also between SCMR and leaf chlorophyll content ($r = 0.86$, $P<0.01$, $n = 6$), were observed. Leaf nitrogen status is often reflected through leaf chlorophyll content and such associations have been shown in several crops (Takabe *et al*. 1990, Chapman and Baretto, 1997). Significant relationships between SPAD chlorophyll meter readings and chlorophyll content and N content in leaves have been found in crops such as rice (*Oryza sativa* L.) (Balasubramanian *et al*. 2000; Takabe *et al*. 1990), corn (Dwyer *et al*. 1995; Chapman and Baretto 1997) and wheat (Reeves *et al*. 1993). Accordingly in the present set of peanut genotypes, a significant positive relationship between TE and SCMR was observed (Figure 1a).

A strong inverse relationship between SLA and SLN on both sampling dates ($r = -0.92$, $P<0.01$ at 55 DAS; $r = -0.82$, $P<0.05$ at 85 DAS) meant that SLN might be the cause of linkage between SCMR and SLA in peanut. This was evident from the strong positive relationship between SCMR and SLN (Figure 1b), which is in accordance with an earlier study (Nageswara Rao *et al*. 2001). To validate these aspects further, a study was conducted to examine the influence of nitrogen levels on the relationship of SCMR on SLN and TE. Since peanut is a legume, it has the ability to fix the atmospheric nitrogen and this hampers the influence of input N. To overcome this problem, non-nodulating genotypes of peanut were used.

In peanut, variation in TE is primarily controlled by differences in chloroplast efficiency associated with chlorophyll and RuBisCO contents that constitute the major pool of N in the plant. Since SCMR is a measure of leaf N status, it can be considered as an estimate of TE as well.

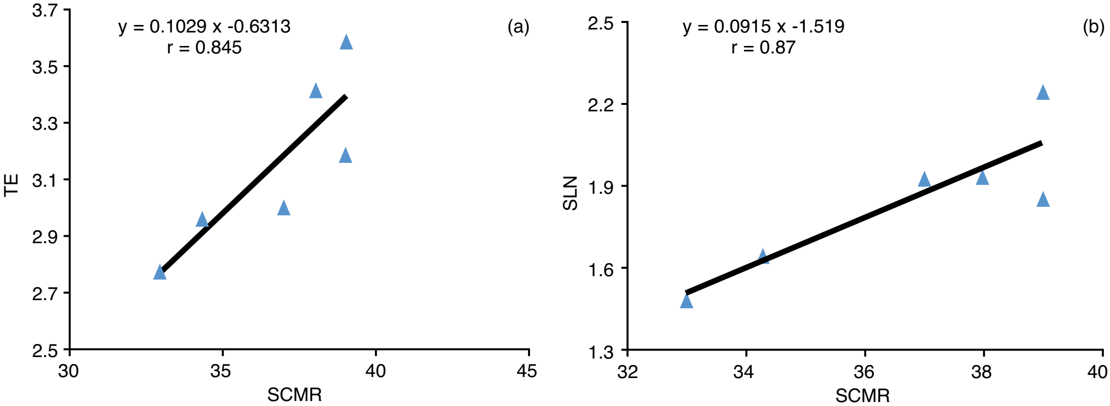


Figure 1. For six genotypes of peanut, relationship between SCMR and: (a) TE); (b) SLN.

Table 1. Genetic variability in various physiological parameters among three non-nodulating genotypes of peanut grown under different nitrogen inputs.

Genotype	Treat	TDM/pot	CWT/pot	WUE	$\Delta^{13}C$	SCMR	SLA	%N	SLN
ICGL-2	Zero N	50.14	14.38	2.00	19.31	40.34	146.20	2.61	1.79
	1.3 g N	60.38	11.54	2.60	19.02	45.89	146.80	3.48	2.37
	2.6 g N	72.82	13.33	2.73	18.95	46.85	139.40	3.50	2.51
ICGL-4	Zero N	51.90	10.75	2.07	19.76	35.27	150.40	2.21	1.47
	1.3 g N	58.59	11.85	2.02	19.90	36.19	163.90	2.77	1.69
	2.6 g N	61.50	14.64	2.10	19.40	41.62	157.30	2.92	1.80
ICGL-5	Zero N	59.20	10.38	2.05	19.44	35.43	155.90	1.93	1.52
	1.3 g N	69.28	15.64	2.63	19.17	41.12	141.80	2.39	1.94
	2.6 g N	82.24	14.39	2.86	19.29	42.88	141.30	2.71	2.20
F test									
Treatment		***	***	***	NS	***	*	***	***
Genotype		***	NS	***	*	***	NS	***	***
Interaction		***	***	***	NS	*	NS	NS	NS
LSD (5%)									
Treatment		6.210	1.130	0.192	-	1.890	2.230	0.315	0.220
Genotype		6.210	-	0.192	0.381	1.890	-	0.315	0.220
Interaction		10.750	1.958	0.333	-	3.282	-	-	-

Notes: *** differences were significant with a probability <0.01; * significant at <0.05; NS = Not significant; CWT = Cumulative Water Transpired

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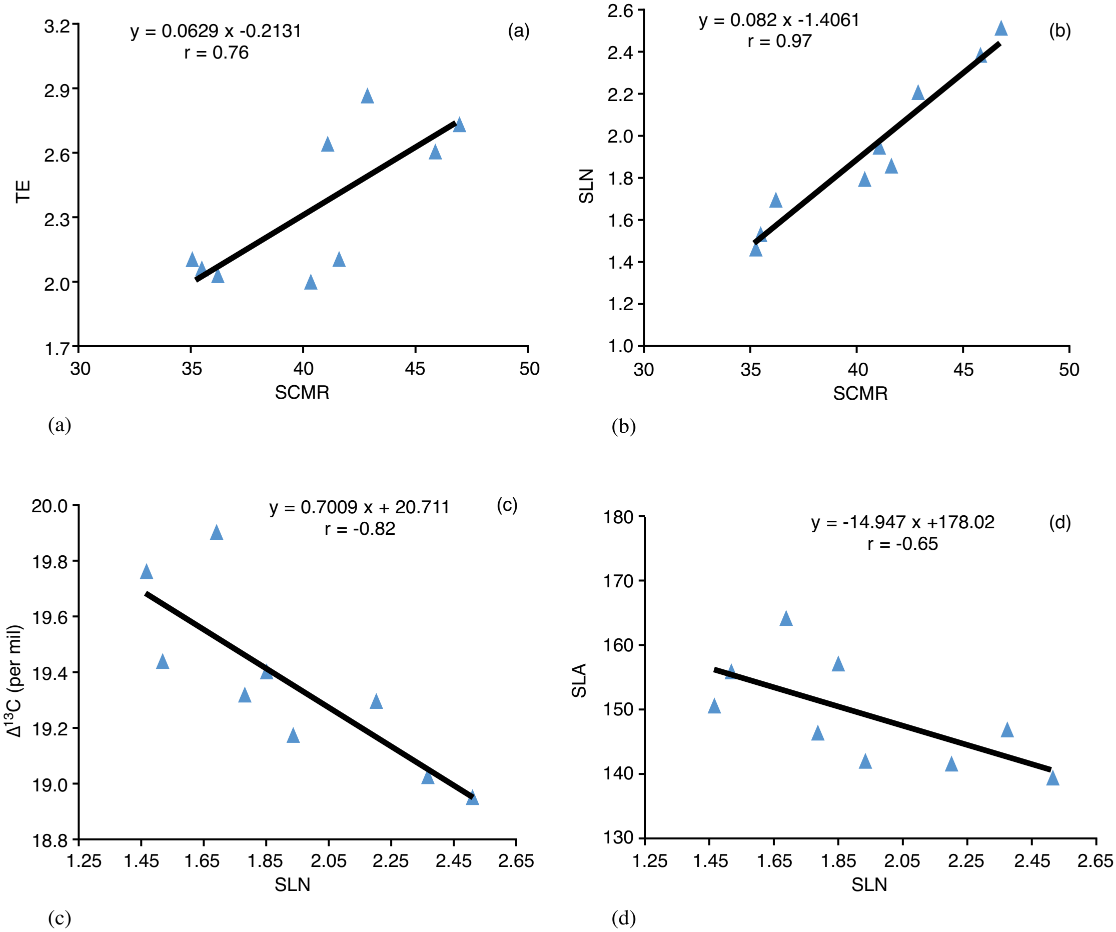

Figure 2. For non-nodulating genotypes of peanut grown under different nitrogen dosage, relationship between SCMR and: (a) TE; (b) SLN; and relationship between SLN and: (c) $\Delta^{13}C$; (d) SLA.

Significant variations in SCMR, SLA and SLN were observed among the three-non nodulating lines across the nitrogen levels. This difference was apparent at each nitrogen level in a given genotype suggesting an expected response for added N-dosage. There was a clear indication of variability in leaf nitrogen (%) and SLN in low (Zero-N), medium (Recommended N) and high (Twice recommended N) levels of N (Table 1).

It is evident that a strong positive relationship between SCMR and SLN (r= 0.97, P<0.01, n = 9) and an inverse relationship between SCMR and SLA (r= -0.52, P<0.05, n = 9) supports our earlier results obtained from the six nodulating lines of peanut.

Relationship of SCMR and SLN with TE and $\Delta^{13}C$

We found considerable genotypic variations in TE and $\Delta^{13}C$ ranging from 1.75 to 2.97 g/kg and from 18.11 to 19.31 per ml, respectively. A progressive increment in TE was noticed in all the three non-nodulating lines as N-level increased. This is well substantiated by increased TDM and total transpiration (Table 1). A strong positive relationship between SCMR and TE (Figure 2a) and SCMR with SLN (Figure 2b) were observed, which in accordance with the results obtained earlier with the six nodulating lines of peanut.

Discussion

A strong positive correlation between SLN and TE in both the experiments and an inverse relationship between SLN with $\Delta^{13}C$ in the non-nod experiment (Figure 2c) further substantiated the conclusion that SCMR is a potential physiological trait to employ as a surrogate for TE in peanut.

A strong positive relationship between SLN and chlorophyll content and SCMR with chlorophyll content further suggests SCMR could be a representative measure of SLN (which is again an integrated measure, at least in peanut).

The significant positive correlation between SCMR and SLN in both of the experiments reiterates our concept of employing SCMR as a rapid, yet reliable alternate technique for SLN. Especially in the case of non-nodulating lines of peanut, increases in SCMR and SLN in response to added-nitrogen level were such that the correlation coefficient value was $R = 0.96$, demonstrating the closeness of the relationship between these two traits.

Several of the earlier studies have clearly demonstrated that TE in peanut is related to SLA. In this investigation we provide evidence that such a relationship is predominantly due to a strong association between SLA and SLN (Figure 2d). The observed relationship between SLN and TE in peanut can be largely attributed to the dependence of TE on intrinsic mesophyll efficiency in this species.

Since the RuBisCO level has a direct association with leaf N status, it is likely that SLN and photosynthetic efficiency are strongly related. Results of this study also reveal that Net Assimilation Rate (NAR), a reflection of integrated photosynthetic efficiency at a whole plant level, showed a positive relationship with SLN ($r = 0.91$, $P<0.01$). The relationship between NAR and TE has well been established in peanut (Roy 1995; Udayakumar, Sheshshayee *et al*. 1998). We reconfirmed such a relationship in the two current experiments (data not presented).

Therefore, a quick determination of SLN through SCMR could reflect the intrinsic mesophyll efficiency and hence effectively estimate TE in peanut.

Conclusions

The important outcome of this investigation is that we have established a relationship of SCMR with SLN and SLA. From these interrelationships, it can hence be inferred that measurement of leaf transmittance is a potential approach to estimate variations in TE among peanut genotypes.

The present study confirmed the hypothesis that in plants where TE is determined by differences in leaf N status, SCMR would reflect the variations in TE; and also provide an explanation for the relationship between TE and SCMR. This suggests that the SPAD chlorophyll meter can be used as a rapid preliminary screening tool to select peanut genotypes with high TE.

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The authors acknowledge the ICRISAT centre, Patencheru, Andhra Pradesh, India, for providing the seed material of peanut genotypes. The leaf nitrogen content was determined using the Elemental Analyser facility at the Research School of Biological Sciences, Australian National University, Canberra, Australia; we thank Prof. Graham Farquhar, Head, Environmental Biology, for use of the facility and Ms. Susan Wood for technical assistance. Financial assistance for this work was received from ACIAR Project CS 97-114.

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Drs M.P. Deshmukh and M.S. Basu inspecting breeding plots at Jalgaon Oilseeds Research Station, Maharashtra, India.

Inverted peanuts awaiting harvest.

The Physiological Basis for Selection of Peanut Genotypes as Parents in Breeding for Improved Drought Resistance

N.C. Rachaputi and G.C. Wright[1]

Introduction

FIELD EXPERIMENTS were conducted during the 1993–95 rainy seasons at six locations in India, under the ACIAR-funded collaborative project (PN 9216) involving QDPI, ICAR and ICRISAT on Selection for Water Use Efficiency in Food Legumes.

The aims of the project and experimental details were described by Wright *et al*. (1994) and presented in ICRISAT annual reports (ICRISAT 1993, 1994, 1995). The project resulted in the development of a range of indirect selection procedures to assist in the identification of peanut germplasm with physiological traits contributing to drought tolerance. The material and methods used in the multi-location experiments and results have been reported in the project report on G x E Analysis of Yield and Physiological Traits in Groundnut (Nageswara Rao 1997).

This paper summarises the main elements of the above report, outlining the physiological basis for selections of genotypes that were used as parents in the crossing program conducted within the current project.

Materials and Methods

Environments

Field experiments were conducted at five or six locations throughout India during three rainy seasons (June to October) of 1993-95 — Durgapura (DRG), ICRISAT (IAC), Jalgaon (JAL), Junagadh (JUN), Tirupati (TPT) and Vridhachalam (VRC).

Treatments

Irrigation regimes

At each location, the crop was subjected to two watering regimes: adequate irrigation (IRR); and rainfed (RF).

Genotypes

Test entries were selected as a result of an exhaustive survey conducted at IAC, based on specific leaf area (SLA), partitioning of dry matter to pods (HI) and yield performance under water deficit conditions. The numbers of test entries were increased from 50 in 1993 to 68 in 1994 and 1995 in order to increase variability for the SLA and HI traits.

[1] Agency for Food and Fibre Sciences, QDPI, Kingaroy, PO Box 23, Qld 4610, Australia

Measurements

The data on time to emergence and flowering (in days) of half the plants in each plot was recorded. Specific Leaf Area (SLA) was recorded at 40 and 80 days after sowing (DAS) and at final harvest. At maturity vegetative and pod dry weight dry weight was recorded.

Computation of transpiration (T), transpiration efficiency (TE) and harvest index (HI)

Pod yield was analysed in terms of a simple physiological model described by Passioura (1977):

Pod Yield (PY) = T x TE x HI

where:

T = transpiration (kg)

TE = transpiration efficiency (g of dry matter produced per kg of transpiration)

HI = harvest index.

The model parameters were estimated from simple measurements of specific leaf area, vegetative and pod dry matter at harvest, following the methods described by Wright *et al*. (1996).

Statistical Analysis

Principal Component Analysis (PCA) was used to examine and identify genotypes with broad and specific adaptation by visually grouping them based on biplots derived from performance of pod yield and yield traits (T, TE and HI). The *Spluswin* statistical package was used for the PCA and for producing biplots.

Results

Climate

Daily weather data was recorded from meteorological stations situated near to the experimental sites. In general, Northern Indian centres (DRG, JUN and JAL) experienced warmer and drier conditions than the southern Indian centres (IAC, TPT and VRC). Thus, the timing and intensity of water deficits varied among locations and seasons.

Results from PCA and Biplot Analysis

PCA analysis was used to examine performance of genotypes across locations and to cluster genotypes with similar responses. Chapman *et al*. (1996) described this use of PCA analysis in detail. This analysis resulted in identification of genotypes with broader adaptation (Figure 1). It also showed that >90% of variation in yield could be accounted for by clustering genotypes into five groups. Some groups showed consistently superior performance across most of the environments (for example, Group 53), while some groups showed superior performance only in some environments (for example, Groups 34 and 51). This effect no doubt was responsible for the observed large G x E interaction.

The membership of the best-performing group (Group 53) consisted of 11 entries. The yield performance of individual genotypes in this group was further examined using the Finlay and Wilkinson (1963) approach, by plotting the genotypic yield against the mean response in each environment. The regression coefficients from this analysis for the genotypes belonging to Group 53 are presented in Table 1.

Greater intercepts indicated superior performance of the genotype above the mean in poor environments, while the slope indicated sensitivity of the genotype to changing environments. For example, the performances of CSMG 84-1 and ICGV 87354 genotypes across environments are presented in Figure 2 show that the higher intercept of CSMG 84-1 (0.99) meant a better performance in poorer environments. The lower slope value (0.84) indicated that its performance tended to approach the mean as environments became more favourable. ICGV 87354 compared with CSMG 84-1 had a smaller but positive intercept; however its higher slope indicated its superior performance in more favourable environments. This approach allowed selection of the best-adapted genotypes based on yield performance as well as sensitivity of genotypes to environments.

Analysis of physiological traits contributing to yield

Performance of the broadly adapted genotypes in Group 53 in terms of T, TE and HI is presented, in comparison with the mean performance, in Table 2. The data indicate superiority of the Group 53 membership over the mean performance, being up to 30 per cent higher for T and HI, and up to six per cent for TE.

It was apparent that high levels of at least two out of the three physiological traits were necessary for superior yield performance of a genotype. Interestingly, genotypes involving parents selected from drought screening work conducted at ICRISAT (e.g. ICGSs 44 and 76, ICGVs 86754 and 87354) had superior yield performance because of higher TE and HI or all the three traits, while for the other genotypes, the dominant contribution to yield was from T and/or HI. This analysis indicated scope for developing new genotypes by pyramiding the traits, or identifying the deficient traits, in the popular genotypes; in this way, the parental selection and genetic enhancement can be focussed to improve levels of the deficient trait in acceptable agronomic backgrounds.

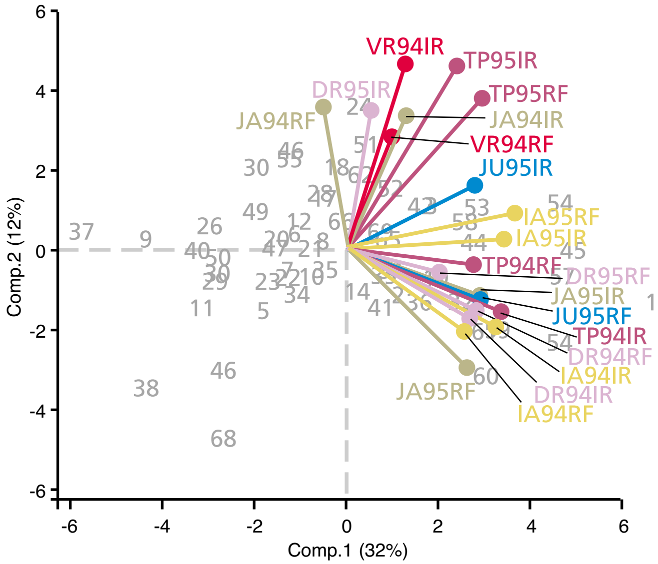

Figure 1. PCA bi-plot for pod yield from 1994-95 seasons. Genotypes are indicated with numbers; environmental vectors are indicated as solid lines.

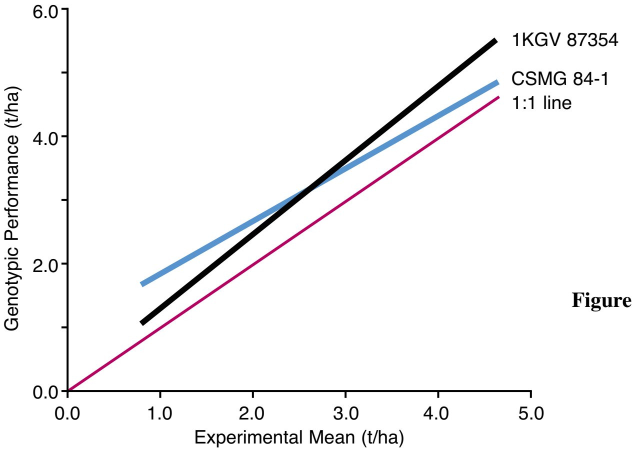

Figure 2. Pod yield performance of ICGV 87354 and CSMG 84-1 compared to the mean performance under irrigated and rainfed conditions in the 1994-95 rainy seasons at the multi-location experimental sites.

Table 1. Coefficients derived from regression of pod yield of 11 selected genotypes belonging to Group 53, against environmental mean yield.

Genotype	Intercept (t/ha)	Slope	r^2
CSMG 84-1	0.99	0.84	0.59
DRG 101	0.08	1.06	0.82
DRG 102	0.64	0.83	0.69
ICGS 44	0.25	1.01	0.83
ICGS 76	0.50	1.05	0.75
ICGV 86754	0.35	0.99	0.77
ICGV 87354	0.13	1.16	0.75
Kadiri 3	0.87	0.80	0.78
NCAC 343	0.76	0.79	0.62
Somnath	0.56	0.87	0.62
TAG 24	0.67	0.86	0.47

Table 2. Performance of genotypes in Group 53 for T, TE and HI relative to experimental mean (as %) in 1994-95 seasons.

	% change from the mean			
Genotype	**Pod Yield**	**T**	**TE**	**HI**
CSMG 84-1	28.8	29.3	0.3	-0.4
DRG 101	10.5	1.2	1.0	10.8
DRG 102	12.7	8.8	1.0	6.1
ICGS 44	13.0	-16.5	2.2	31.7
1CGS 76	27.0	7.7	5.5	11.8
ICGV 86754	15.5	6.5	2.5	4.9
ICGV 87354	22.5	5.0	1.8	10.5
KADIRI 3	19.6	12.8	-0.8	10.2
NCAC 343	13.9	8.5	0.3	5.4
SOMNATH	12.9	0.5	0.5	10.8
TAG 24	16.6	-10.1	1.7	30.1
Exp. Mean	**2.23 (t/ha)**	**290.5 (mm)**	**2.7 (g/kg)**	**0.31**

Further analysis on trait performance across and within groups was possible by comparing group mean and genotypic mean with the experimental mean for various traits using the Finlay and Wilkinson (1963) approach.

It was apparent that the clustering analysis was effective in grouping the genotypes based on adaptation for the pod yield and other physiological traits. Group 53, which had membership of genotypes with broad adaptation for pod yield also showed superior performance with regard to T (Figure 3b) and HI (Figure 3d), but had TE performance similar to that of mean. Group 42, which represented genotypes with poor adaptation, showed superior performance for TE compared to the mean.

Following similar procedures described for the pod yield analysis, PCA analysis, including visual inspection of biplots, was applied to better understand G x E interactions for the traits and to identify genotypes with high levels of T, TE and HI.

Using the Finlay and Wilkinson (1993) approach, performance of each genotype was also examined by comparing it with the mean performance, and regression coefficients from this analysis (Tables 3, 4 and 5).

This analysis indicates that a few genotypes with broad adaptation for pod yield (see Table 2) also showed superior performance in terms of physiological traits. They were: T, (CSMG 84-1); TE (ICGS 76); and HI (ICGS 44 & TAG 24).

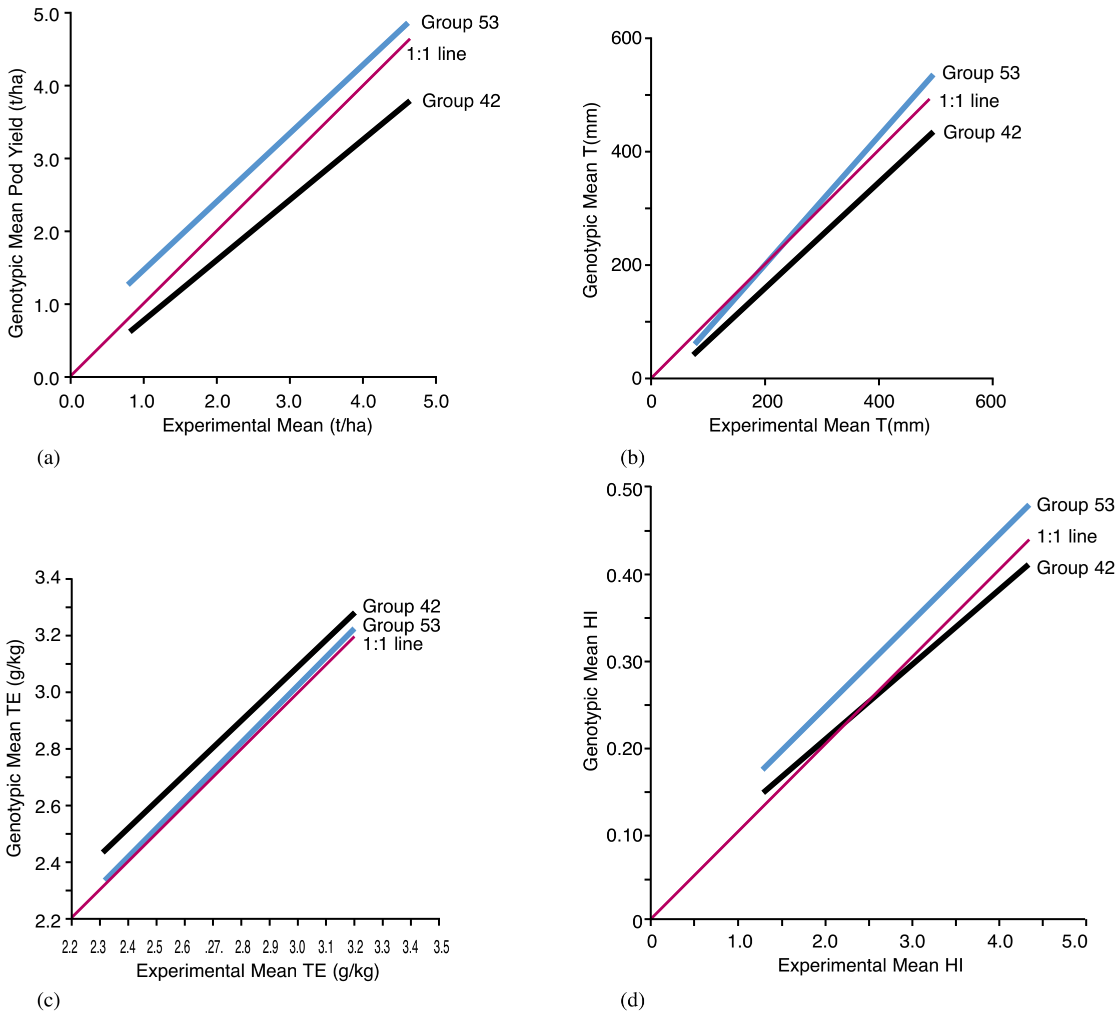

Figure 3. Group mean performance of genotypes from Group 53 (with broad adaptation) and Group 42 (with poor adaptation) relative to the mean performance for pod yield (a) and physiological attributes, ie T(b), TE(c) and HI(d).

It is clear that these genotypes would get first priority for selection as parents since they have high levels of at least two drought-tolerance traits. However, groups with broad adaptation for these traits also contained other genotypes which, while not being high pod yielders, had high levels of desirable drought-tolerance traits.

Table 3. Regression coefficients indicating performance of selected genotypes with broad adaptation for transpiration (T) plotted against mean T for each environment.

Genotype	Intercept (mm relative to mean)	Slope	R^2
CSMG84-1	-0.90	1.29	0.79
DH43	-15.50	1.32	0.80
ICG3056	26.10	1.08	0.73
ICG3793	52.10	1.01	0.68
ICG4446	25.50	1.13	0.70
ICG5263	6.50	1.25	0.75

Table 4. Regression coefficients indicating performance of selected genotypes with broad adaptation for transpiration efficiency (TE) plotted against mean TE for each environment.

Genotype	Intercept (mm relative to mean)	Slope	R^2
DRG103	-0.22	1.15	0.63
ICGS76	0.40	0.89	0.65
ICGV86031	-0.65	1.35	0.71
TMV2NLM	0.38	0.94	0.51

Table 5. Regression coefficients indicating performance of selected genotypes with broad adaptation for harvest index (HI) plotted against mean HI for each environment.

Genotype	Intercept (mm relative to mean)	Slope	R^2
ICG 476	0.10	0.89	0.56
ICGS 44	0.08	1.06	0.67
TAG 24	0.10	1.00	0.58
TG 17	0.03	1.17	0.73
TG 22	-0.06	1.39	0.81
TG 26	0.06	1.15	0.70

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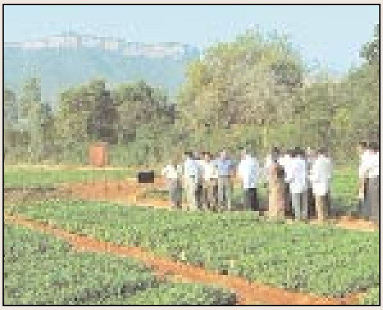
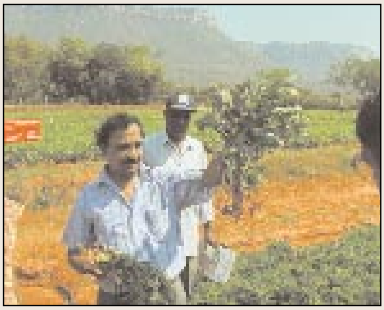


Inspecting aflatoxin screening plots at the Regional Agricultural Station, S.V. Agricultural College Campus, Tirupati, Andhra Pradesh, India.



Promising drought-resistant genotypes.

Hybridisation and Description of the Trait-based and Empirical Selection Programs

S.N. Nigam[1], M.S. Basu[2] and A.W. Cruickshank[3]

Introduction

PARENTS SELECTED on the basis of the three main physiological traits (TE, W and HI) were used in a crossing program that was implemented at four locations in India and one location in Australia. Details of the crossing program are given below.

Crosses

There were four crosses at each centre. There were originally intended to be three common crosses and one cross involving the best locally-adapted line by a parent possessing the drought trait most deficient in the adapted line. For example, in the QDPI program, Streeton with good HI and T was crossed with a high TE parent, ICGV 86031.

At a workshop at ICRISAT in June 1997, Indian and Australian collaborators jointly decided the best crosses to be made. They considered factors such as maturity and level of expression of specific traits, as described by Rachaputi and Wright (2003). The aim was to ensure that parents which were deficient in one trait were crossed with another having high expression in that trait. Germplasm availability in both India and Australia was also taken into account. The crosses ultimately decided are shown in Table 1.

During the PN 9216 extension project (July 1997 to June 1998), potential parents were introduced into

Table 1. Crosses made at the five different breeding locations.

Location	Female Parent	Male Parent
All centres	ICGV 86031	TAG 24
All Indian centres	ICGS 76	CSMG 84-1
All Indian centres	ICGS 44	CSMG 84-1
ICRISAT	ICGS 44	ICGS 76
Jalgaon	JL 220	TAG 24
Tirupati	K 134	TAG 24
NRCG	GG 2	ICGV 86031
Kingaroy	Streeton	ICGV 86031
Kingaroy	Streeton	CSMG 84-1
Kingaroy	TAG 24	CSMG 84-1

[1] ICRISAT, Patancheru, Andhra Pradesh, India
[2] National Research Centre for Groundnut, Junagadh, India
[3] Agency for Food and Fibre Sciences, QDPI, PO Box 23, Kingaroy, Queensland, Australia

Australia via the Australian Quarantine and Inspection Service (AQIS). Unfortunately ICGS 44 and ICGS 76 were not available for crossing in time. Comparable crosses were made with the best available material.

Minimising the impact of maturity

The June 1997 workshop discussed at length the issue of crop maturity and its potential confounding effect on the drought breeding selection experiments. Crop phenology can have a strong impact on pod yield performance under drought, via drought escape factors. Therefore during the evaluation phase selected lines must maintain a comparable maturity duration so that genotypic comparisons are not confounded by maturity differences, such as drought escape or pod loss.

It was ultimately decided that parents of relatively similar maturity (c. 110–120 days in India) be used in the hybridisation phase. This approach resulted in segregating populations of relatively uniform maturity on which selection was subsequently practiced. This ensured that any measured genetic gain in pod yield performance was achieved through selection for our drought 'resistance' traits.

To facilitate this process, a specific crop duration (in terms of a thermal time target such as 1500 Growing Degree Days (GDD)) was used as a selection criterion. This specific target varied slightly between locations, and was based on long-term climate analysis to determine optimum maturity for a region or location, using the analysis reported by Wright (1997).

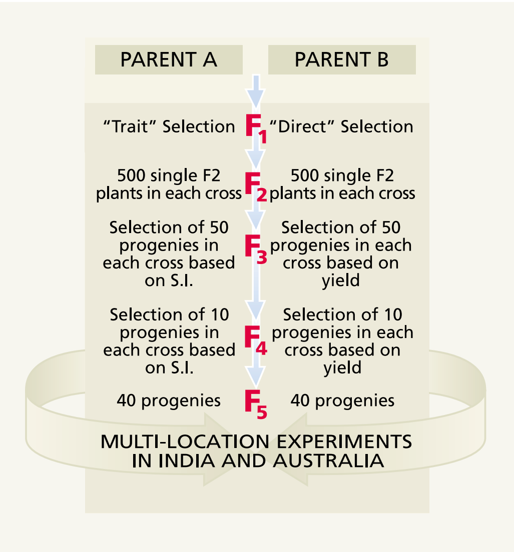


Figure 1. The protocol followed for hybridisation, selection and multi-location evaluation processes for 4 crosses at each breeding location in India and Australia.

It was anticipated that in the evaluation phase of the project, selected lines would be of similar maturity, but that some lines may have significantly different maturity. The latter could therefore be harvested at their 'optimal' maturity, and subsequently classified into separate maturity classes to enable a non-confounded analysis. In practice, the greatest maturity differences occurred among crosses. As crosses were kept separate through the selection phase, harvests of crosses could be staggered. This allowed harvest at near-optimal maturity.

Selection Protocols

Trait (indirect) program

This program combined high TE, HI and T traits using a Selection Index approach.

The trait-based approach necessarily involved intensive measurements on large numbers of progeny bulks from the F_3 onwards. These numbers were less than in a normal breeding program, but still comprised large numbers for intensive physiological measurement. Considering the existence of the apparent negative association between HI and TE, it is considered that these numbers of plants are justified in order to increase the chances of breaking the apparent genetic correlation.

The trait-based selections were made using a selection index (SI) approach described by Nigam and Chandra (2003). The form of SI was consistent over all crosses and locations. In the first round of selection there was one environment per location. In the second round there was both a 'stressed' and a 'non-stressed' environment at each location. In some cases the stressed environment was simply rainfed, in other cases it was a 'managed stress' created by selectively withholding irrigation.

The timetable of activities is represented in a flowchart (Figure 1) and outlined below.

- The F_1 plants from the initial crosses (c50 plants/cross) were grown out under non-stressed conditions as spaced plants to maximise seed multiplication.
- The F_2 seed from these crosses was grown out as spaced plants to maximise seed multiplication for the F_3 populations (assumed to be c1000 seeds/cross, based on c25 seeds/plant).This population was then divided equally between 'trait' and 'empirical' selection approaches (c500 F_2 plants/cross).
- $F_{2:3}$ progeny bulks (derived from the spaced F_2 plants, c50 seeds/row @ 20 cm spacing) were planted out and grown under water-non-limiting conditions.

- All $F_{2:3}$ progeny bulks were assessed for pod yield, TDM, TE (via SLA and SPAD), HI and T (using the reverse engineering approach of Wright *et al.* (1996), by sampling 0.5 m^2 quadrats at maturity. SPAD (and in some cases SLA) were measured 2–3 times during the crop growth cycle. As soon as possible after this data had been collated and analysed, a selection index (SI) value was calculated for each progeny, and the top 10% of progeny bulks (or the top 50 if n<500) carried forward to the $F_{2:4}$ generation. Some 400 progenies (including both trait-based and empirical selections), incorporating representative members from each cross, were carried forward at each centre.
- The carried forward $F_{2:4}$ progeny bulks were then planted out under both stressed and non-stressed conditions, and the same measurements made as for the F_3 generation. The ability to select progenies under both stressed and non-stressed conditions enabled an assessment of the relative merit of selection environment during the final evaluation studies. This further cycle of selection was implemented in the F_4 generation, and the top 10% (top 20% at Kingaroy) of the progenies were advanced.
- The selected $F_{2:4}$ families were used to generate five $F_{2:5}$ families at each breeding site for each selection method. In India, these $F_{2:5}$ families from both selection methods were advanced to $F_{2:6}$ and their seed increased. The replicated field trials, conducted in 2000-01, consisted of 192 $F_{2:6}$ families, three each from no-moisture-stress and managed-moisture-stress for trait selection method, and six from the empirical selection method for each cross/breeding site combination. In Australia, the $F_{2:5}$ seed was adequate to plant the multi-site evaluation.

Empirical (direct) program

In order to maintain consistency between empirical and trait-based selection protocols, the empirical selection procedure practised pod-yield selection at the same time as the trait-based measurements/selections (i.e. in $F_{2:3}$ and $F_{2:4}$ generations). In essence, the procedure was similar to the plan for trait-based selections, except that selections were made in an appropriate target environment as chosen by the relevant breeding program (for example, under rain-fed or irrigated conditions at the main experimental site, like normal practice for the local breeding program). By the end of the selection cycles, the empirical selection approach carried out at the four centres in India, and Kingaroy centre in Australia, supplied a subset of $F_{2:5}$ progenies for inclusion in the multi-location testing. As for the tait-based approach, selection for yield was strictly within maturity classes to avoid confounding the effects of crop phenology, drought escape and yield-determining traits.

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Collaborating scientists at the National Research Centre for Groundnut at Junagadh, Gujarat, India.

Inspecting multi-location trials at ICRISAT Centre, Andhra Pradesh, India.

Derivation and Improvement of the Selection Index and Estimation of Potential for Further Improvement

S.N. Nigam and S. Chandra[1]

Introduction

A SELECTION INDEX is a useful concept for improving several traits simultaneously. It is also useful for enhancing the effectiveness of selection for one trait by suitably incorporating information on one or more secondary traits.

Selection index

Both the traits to be included in the current project, and the form of the selection index (SI), were decided by a consensus of the breeding and physiology staff involved in the project. The model components for the large segregating populations were derived from the simple measurements of TE using SPAD chlorophyll meter readings (Nageswara Rao *et al*. 2001, Sheshayee *et al*. 2002), total dry matter, and pod and kernel yield at final harvest following Wright *et al*. (1996). Various options for the form of the index were considered.

In traditional indices the coefficients would involve estimates of either phenotypic, or phenotypic and genetic, variances and covariances. It is essential that these estimates be derived from the material to be selected; in our case, this meant the $F_{2:3}$ and $F_{2:4}$ families. These variances and covariances would differ between crosses or sites; and, among the unreplicated F_3 progenies, the phenotypic variances would be inseparable from the genotypic estimates. We considered a simple index using the sum of standardised values of HI, TE and T, but this assumes a normal distribution of each trait. There are no such assumptions if standardising with median and range, but the range was vulnerable to the extreme values measured.

The final choice of index used the quartile range (3rd quartile to 1st quartile), which satisfies the need for both simplicity and robustness.

The three traits (T, HI and TE) were combined into the selection index:

$$S=\sum_j (x_j\text{-med}_j)/SIQR_j$$

where:

$SIQR_j$ = semi-inter-quartile range = $\{Q_{3(j)}\text{-}Q_{1(j)}\}/2$

Q_3 = third quartile

Q_1 = first quartile

[1] ICRISAT, Patancheru, Andhra Pradesh, India

In our case, there are j = 3 traits (T, HI and TE) included in the index. The index, S, was based on the median (med) and the (SIQR) to ensure selection was not being influenced by extreme values and to give equal weight to each trait. The index, S, was used to select the top 10% of $F_{2:3}$ families to get 50 $F_{2:4}$ families in each cross, and the top 10% (or 20% in Australia) in the $F_{2:4}$ experiments.

Measurement of outcome of selection

Analysis of Variance (REML) was used to predict means and estimate the variance components and their corresponding standard errors (se) due to: Environment, σ_E^2; Genotype, σ_G^2; Genotype x Environment, σ_{GE}^2; and Error, σe^2. Using the progeny means, selection methods were compared using the criterion frequency of trait-based (T) and empirical (E) genotypes in the top 5% and 10% of high-yielding genotypes.

Measurement of Potential Further Improvement

Genetic variances were computed for the progenies selected by each selection method. The predicted selection efficiency under selection method T, relative to selection method E, was estimated using the concept of response to selection, computed as:

$RE_T = R_T/R_E$

where:

$R_T = i_T\ h_T\ s_{GT}$ = Response to selection under T

$R_E = i_E\ h_E\ s_{GE}$ = Response to selection under E.

This gives the efficiency of T relative to E as:

$RE_T = \{i_T/i_E\}\ \{h_T/h_E\}\ \{s_{GT}/s_{GE}\}$

$RE_T = \{h_T/h_E\}\ \{s_{GT}/s_{GE}\}$ for $i_T = i_E$

where:

i = selection intensity

h = square root of heritability

s_G = genetic standard deviation.

For selection method T to be superior to E, RE_T should exceed unity. This can happen when any one of these conditions hold:

1. $h_T > h_E$ for $s_{GT} = s_{GE}$
2. $s_{GT} > s_{GE}$ for $h_T = h_E$
3. $\{h_T/s_{GT}\} > \{h_E/s_{GE}\}$.

The above formulation of relative efficiency assumes the genotype effects within the selection method are random. This is true because the selected progenies are really a subset of a much larger set of possible selections.

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Evaluation of Selections in Individual Environments

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National Research Centre for Groundnut, Junagadh, Gujarat, India

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Jalgaon, Maharashtra, India

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Udaipur, Rajasthan, India

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Agricultural Research Station, Anantapur, Andhra Pradesh, India

•

Vriddhachalam, Tamil Nadu, India

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Tirupati, Andhra Pradesh, India

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ICRISAT Centre, Patancheru, Andhra Pradesh, India

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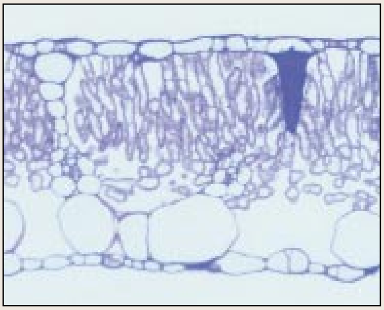
Kingaroy, Queensland, Australia.



Histological section of high WUE genotype.

Plants from a breeding block at ICRISAT Centre, Andhra Pradesh, India.

WUE collaborators during a planning workshop at at QDPI, Kingaroy, Australia in June 1999.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at the National Research Centre for Groundnut, Junagadh, Gujarat, India

M.S. Basu, R.K. Mathur and P. Manivel[1]

Introduction

ONE OF THE IMPORTANT oilseed crops of the world is peanut (*Arachis hypogaea* L.). Compared with several other crops, peanut is regarded as drought-resistant. Because of this, this crop is mainly grown under rain-fed conditions. As such, it is quite popular among farmers of the marginal semi-arid tropics, where due to low and erratic precipitation the crop is subjected to mild to severe water deficit stress.

In India, peanut is primarily grown on about 7 M ha where drought results in very large fluctuations in total production. In Gujarat, for example, it is grown on 1.92 M ha, 90 per cent of which is rain-fed.

Several morphological and physiological adaptations are known to impart drought resistance in crop plants. Genotypic variation for physiological traits such as water transpired (T), water-use efficiency (TE) and harvest index (HI) has been identified. These traits can be highly correlated with pod yield. Based on these attributes, potential genotypes were identified in the first phase of the ACIAR-ICAR Water Use Efficiency Project (PN9216) in order to combine these traits through appropriate breeding approaches.

Various breeding populations have been developed at selected locations in India and Australia derived through hybridisation of selected genotypes. The current project was designed to practice ‘indirect’ or trait-based selection on these populations, and therefore enable a definitive assessment of the new breeding approach for the identification of drought-resistant peanut lines. The development of high-yielding drought-resistant cultivars which can still produce high yield under drought, is therefore a priority issue for peanut improvement programs in India.

Based on the above considerations, the current project entitled ‘More Efficient Breeding of Drought Resistant Peanut in India and Australia’ was launched, with the objectives described elsewhere in these Proceedings.

[1] NRCG, Junagadh, Gujarat, India

This paper reports the performance of selections evaluated at the National Research Center for Groundnut (NRCG), Junagadh, Gujarat, India.

Materials and Methods

During the 2000 rainy and 2001 post-rainy seasons, multi-location trials consisting of 192 entries comprising 12 entries from each cross (6 progenies from trait selection and 6 from empirical selection methods) x 4 crosses x 4 breeding locations, was conducted at NRCG, Junagadh.

The eight parents used in the crossing program were also included in the trial. The trial was laid out as an Alpha design with three replications. The plot size was four rows each of 4 m length, spaced at 45 cm. Sowing was carried out on 5th July in the 2000 rainy season and 12th February in the 2001 post-rainy season. Based on the maturity of the test entries, harvesting of the 2000 rainy season trial was completed from 16th October to 4th November 2000. The 2001 post-rainy season trial was harvested from 15th May to 1st June, 2001. Both the sowing and harvesting operations were carried out manually. All the packages and practices recommended for the peanut crop management in the Saurashtra region of Gujarat state were followed.

Observations were recorded on initial plant stand, final plant stand, days to maturity, number of mature pods/plant, dry pod yield, kernel yield, haulm weight, 100-kernel weight, and shelling percent. Specific leaf area and SPAD were recorded at 60 DAS. Kernel HI, TE and T were also computed using methods described in this proceedings.

Weather data during the experiment

Junagadh centre lies on the 70.36ºE longitude and 21.31ºN latitude at an altitude of 60 m amsl. The soils are medium-black and shallow, 0.15–0.45 m deep. Annual rainfall of this semi-arid region is 350–800 mm. The rainfall is highly erratic and more than 90 per cent of the rainfall is received between June and September, with intermittent long dry spells.

During the crop period, the maximum and minimum temperatures were 28.3–40.2ºC and 18.2–27.6ºC, respectively. Total precipitation received during this period was 458 mm. The crop experienced end-of-season drought.

In the case of the post-rainy season trial, the maximum and minimum temperatures were 29.7–42.6ºC and 13.1–28.0ºC, respectively. Only 24.2 mm of precipitation (29–31 May 2001) was received during this season.

Results and Discussions

The data of the top 20 performing genotypes based on kernel yield are summarised in Table 1 and Table 2 for the 2000 rainy and 2001 post-rainy season trials, respectively. The salient results obtained from these evaluation trials conducted at Junagadh are discussed for each season below.

2000 rainy season

For the top 20 entries, about half were derived from the empirical approach and half from trait-based selection. This indicates that the breeders' approach (empirical) for selecting superior types was as good as the trait-selection method followed to isolate superior types.

In the top 20 performing entries, eight were developed at ICRISAT, four at Junagadh, five at Jalgaon (including one parental line), and three at Tirupati.

Out of the 20 top entries, 14 were derived only from three crosses: ICGS 44 x ICGS 76 (5); ICGS 76 x CSMG 84-1(5); and ICGS 44 x CSMG 84-1 (4). Only three parents were involved in these crosses: ICGS 44; ICGS 76; and CSMG 84-1. This indicates the considerable contribution of these three parental lines in tailoring superior genotypes.

The kernel yield of the top 20 entries ranged from 2131 kg/ha for JAL 36 (ICGS 44 x CSMG 84-1) to 2424 kg/ha for ICR 20 (TAG 24 x ICGV86031). None of the selections in the top 20 were significantly less than the top-ranking selection ICR 20. However the top seven entries had significantly higher kernel yields (30–40%) than the local check variety GG 2. The parental line, JL 220, which ranked seventh for kernel yield, was as good as any other top performing selection derived through hybridisation. This variety had high HI (0.32) and the lowest TE (2.37 g/kg) and moderate T (318 mm) among the top 20 genotypes.

Unlike kernel yield, significant differences were observed for HI, TE and T among the selections. Nine selections registered significantly higher HI over the lowest HI observed in the top 20 entries (based on kernel yield). Seventeen selections had significantly greater TE than JL 220, which recorded the lowest TE among the top 20 entries. For T only one selection, ICR 27, which had the lowest HI, had significantly higher T than the lowest one in the top 20 entries.

2001 post-rainy season

In the 2001 post-rainy season, 50% of the top 20 performing entries were developed by the empirical approach (as observed in the rainy season trial).

Seven entries from Junagadh, five from ICRISAT, four from Tirupati, three from Jalgaon and one check

Table 1. Kernel Yield, HI, TE and T of the 20 highest-yielding genotypes during the 2000 rainy season at Junagadh.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
ICR 20	IRR	2425	0.34	2.54	304
ICR 10	DRO	2384	0.30	2.55	319
JUG 15	IRR	2346	0.32	2.64	288
JAL 03	DRO	2235	0.31	2.61	313
JUG 28	EMP	2321	0.29	2.63	321
ICR 27	EMP	2307	0.26	2.55	375
JL 220	P	2250	0.32	2.37	318
ICR 40	EMP	2211	0.31	2.52	300
ICR 11	DRO	2201	0.29	2.61	302
JUG 27	EMP	2198	0.31	2.45	304
ICR 12	DRO	2192	0.31	2.53	303
JUG 33	EMP	2178	0.33	2.49	283
JAL 05	DRO	2175	0.30	2.52	298
TIR 47	EMP	2172	0.32	2.5	284
TIR 16	IRR	2164	0.32	2.49	283
ICR 43	EMP	2161	0.30	2.55	298
JAL 17	IRR	2154	0.32	2.48	288
ICR 24	IRR	2150	0.31	2.56	279
TIR 42	EMP	2137	0.33	2.57	272
JAL 36	EMP	2131	0.32	2.45	288
GG 2	P	1723	0.26	2.53	265
SED		259.2	0.034	0.053	31
LSD ($P \leq 0.05$)		508	0.066	0.104	60.7

Table 2. Kernel Yield, HI, TE and T of the 20 highest-yielding genotypes during the 2001 post-rainy season at Junagadh.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
TAG 24	P	2285	0.33	1.36	540
ICR 20	IRR	2249	0.23	1.37	692
JUG 21	IRR	2229	0.26	1.39	624
JUG 24	IRR	2194	0.22	1.37	727
TIR 39	EMP	2125	0.22	1.33	748
JUG 37	EMP	2089	0.24	1.36	678
JUG 27	EMP	2056	0.19	1.38	755
ICR 07	DRO	2030	0.19	1.39	755
TIR 23	IRR	2008	0.20	1.30	791
ICR 45	EMP	2001	0.22	1.38	666
JUG 22	IRR	1993	0.21	1.39	699
JAL 34	EMP	1990	0.19	1.32	816
TIR 48	EMP	1989	0.23	1.34	657
ICR 09	DRO	1984	0.24	1.42	603
ICR 40	EMP	1939	0.23	1.39	636
JAL 23	IRR	1878	0.20	1.35	695
TIR 46	EMP	1859	0.17	1.36	774
JAL 12	DRO	1848	0.18	1.30	796
JUG 38	EMP	1844	0.24	1.41	545
JUG 48	EMP	1832	0.21	1.29	682
GG 2	P	1685	0.19	1.40	641
SED		235.4	0.022	0.034	62.5
LSD ($P \leq 0.05$)		461.4	0.043	0.067	122.6

variety, TAG 24, constituted the 20 top performing entries.

Kernel yield ranged from 1832 kg/ha for JUG 48 (GG2 x ICGV86031) to 2285 kg/ha in TAG 24 (P) among the top 20 entries.

No statistical differences were found among the top 20 entries for kernel yield. However, when compared to the local check, GG 2, the top four entries registered significantly higher kernel yields. These entries also had significantly greater HI than the lowest among the top 20 entries for yield.

Similarly, when kernel yields of the top 20 entries were compared with their respective parents, no entry except JUG 24 (GG2 x ICGV86031), exhibited significantly higher kernel yield.

Other genotypes having significantly higher HI over the lowest one among the top 20 were, TIR 39, JUG 37, ICR 45, JUG 22, TIR 48, ICR 09, ICR 4 and JUG 38. Thirteen and fourteen genotypes registered significantly higher TE and T respectively, when compared to the lowest ones observed in the top 20 entries.

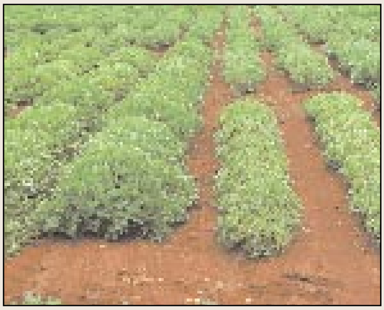
The genotype TAG 24, having the highest kernel yield, had the lowest estimated water use (T).

Conclusion

In both seasons the empirical and trait-selection methods were found to be equally effective. The empirical method is comparatively easy; so because a breeder has freedom to have their own selection procedures, the empirical method appears to be desirable for isolating superior genotypes.

Three genotypes ICR 20, ICR 40 and JUG 27 were common in both the seasons in the top 20 genotypes. These genotypes, which exhibited stability over seasons, need to be further tested at multiple locations for their wider adaptability

Breeding lines with high yield potential under drought conditions compared to the local checks were developed through this project.



Multi-location trials at QDPI, Kingaroy, Qld, Australia.

Plants from a breeding block at ICRISAT Centre, Andhra Pradesh, India.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at Jalgaon, Maharashtra, India

M.P. Deshmuk, A.M. Mahalle, R.B. Patil, T.R. Patil and Y.M. Shinde[1]

Introduction

PEANUT IS ONE of the most drought-resistant of all the grain legumes, as is evidenced by its widespread production in many of the world's semi-arid cropping regions.

It is grown over 20 per cent of the total cropping area of oilseed (0.49 M ha) in the state of Maharashtra. Two distinct peanut-production zones have been identified. The area receiving rains from the south-west monsoon (Jalgaon, Nasik, Dhule, Pune, Nagpur and part of Marathwada) grows non-dormant, bunch peanut varieties maturing in 90–100 days. The area receiving rains from the south-west and north-east monsoon (Sangli, Satara, Kolhapur, Solapur and part of Marathwada region) grows dormant, semi-spreading varieties maturing in 125–140 days.

The rainy season (rainfed) peanut is cultivated on 80 per cent (400,000 ha) of the total peanut-growing area. Rain-fed peanut cultivation faces intermittent dry spells, so there is a need for drought-resistant genotypes. Indeed the development of high-yielding drought-resistant cultivars is a priority issue in India. Transpiration efficiency (TE) is one of the traits that can contribute to higher productivity when water availability is limited. Genotypes possessing high water-use efficiency (TE), harvest index (HI) and transpiration (T) are also useful in this respect. Thus, in the current project, the crosses were made involving genotypes possessing high levels of these traits.

In line with the second objective of the current project, we report the evaluation of 192 selected progenies in the Jalgaon region of Maharashtra.

Materials and Methods

Rainy season 2000 ($F_{2:6}$ MLT)

During rainy season 2000, heavy rainfall (303 mm) was received during the 23rd standard week in the month of June, which delayed the sowing of peanut. The crop was sown on 4–5 July to exploit the stored soil moisture. In the second week of July (28th standard week) heavy rainfall of 345 mm was received in seven days, which adversely affected germination.

[1] Oilseeds Research Station, MPKV, Jalgaon-425 001, Maharashtra, India.

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Gap-filling was done in the 29th standard week, which received 37.4 mm rainfall. Plant spacing was 0.3 x 0.1 m. Plots were 4.0 x 1.2 m. This was followed by a fortnight of dry weather. During the vegetative to flowering stage, rainfall distribution was quite satisfactory and crop condition was good. During the peg penetration period, there was a dry spell of two weeks, which necessitated a supplementary irrigation to the crop. During the pod formation stage, 8.8 mm of rainfall was received in the last week of September. After this, no rainfall was received until the harvest of the crop. Protective irrigations were applied on: 1–2 August; 20–22 August; 12–13 September; 4–6 October. Fertilisers applied at sowing were 20 kg/ha N and 40 kg/ha P.

Recommended cultural practices were followed. Three passes of hand-weeding and hoeing were made at intervals of 15 days. The final hoeing was done before 45 DAS. Once pegging had commenced, no cultivating was done.

Pests and diseases

The activity of the major insect pests *Spodoptera* and leafminer was very low throughout the crop growth period.

The infestation of sucking pests (jassids and thrips) was quite severe during all the critical growth stages of the crop. The abundance of nymphal population of jassids was recorded from the 31st to the 44th standard week.

The peak activity of thrips (19.0 nymphs/plant) observed during the 36th standard week was governed by optimum temperature (30ºC) coupled with high humidity (90%), followed by less precipitation.

The mean incidence of Peanut Bud Necrosis Disease (PBND) was 4–60 per cent in the various test entries. Warm and dry conditions followed by low sunshine hours were favourable for the incidence of PBND.

The severity and intensity of the foliar diseases late leafspot and rust was 0–20 per cent. The incidence of soil borne diseases was very low i.e. below 1%. Other major diseases were not observed during the season. The crop was protected against all diseases and pests by prophylactic sprays.

Sampling and measurements

Ten plants were selected from the middle two rows of each plot for recording of SPAD on 19–23 August (43–47 DAS). Yield samples were obtained from the middle two rows from 23 October to 10 November. Plants falling in a one-metre row out of one of the two middle rows were uprooted for the air and oven-dry weight. Plants left in the remaining seven-metre rows were used for recording of yield and other observations.

Summer 2001 ($F_{2:7}$ MLT)

The sowing of the summer peanut trial was done on 23–24 January. During this period the maximum and minimum temperatures were 31.9–32.3ºC and 11.1–17.2ºC, respectively. Emergence was delayed by 6–7 days because of the low temperatures (8.5–13.4ºC) prevailing during January and the first half of February. Germination, plant stand and crop growth were quite satisfactory. Plant spacing of 0.3 x 0.1 m was achieved. Plots were 4.0 x 1.2 m. No severe incidence of pests and diseases was noticed during the crop growth period.

Crop growth and vigour were quite good up to mid-April, as the availability of irrigation water was adequate during this period. Thereafter, due to an acute shortage of irrigation water coupled with severe high temperatures, the crop faced severe moisture stress, which coincided with the pod development and pod filling stages. Irrigation was provided on: 26–28 January; 6–8 February; 20–22 February; 3–4 March; 19–20 March; 30–31 March; and 20–22 April. Fertilisers applied at sowing were 20 kg/ha N and 40 kg/ha P. Recommended cultural practices were followed. Three passes of hand-weeding and hoeing were made at intervals of 15 days. The final hoeing was done before 45 DAS. Once pegging had commenced, no cultivating was done.

Sampling and measurements

Ten plants were selected from the middle two rows for recording SPAD on 19–21 March (56–58 DAS). Yield samples were obtained from the middle two rows. Plants falling in a one-meter row in one of the two middle rows were uprooted for air-dry and oven-dry weights. Plants left in the remaining seven-metre rows were used for recording observations. Harvest was conducted on 17–25 May 2001.

Design and analysis

The Jalgaon trial was an alpha design with three replicates. The data were analysed in alpha design. Genstat 5 release 4.1 developed by Lawes Agricultural Trust (Rothamsted Experimental Station), and compatible with Windows 98, was used.

Results

Rainy season 2000 ($F_{2:6}$ MLT)

The results of the rainy season multi-location trial are given in Table 1. Variations observed in kernel yield among different selections (out of 192) were significant. Kernel yield was 911–1643 kg/ha for the rainy season. Among the top 20 selections, 13 selections were from empirical selection and six were from trait-based selection (kernel yield kg/ha basis).

The kernel yield of the top 15 selections (out of 192) were significantly greater than the parental means (1187 kg/ha). The top ranking selection JAL-30 (1643 kg/ha) had high HI, SPAD and TE values. This selection has an increment of 2.2 for SPAD and 25mm for T over the highest-ranking parent (ICGS-44). The selection JUG-45 (1429 kg/ha) had high HI, TE, SPAD but low T. According to Passioura (1977), genotypes with high TE, T, and HI are considered to be drought-tolerant. Selections JAL-13, JAL-27, ICR-36, TIR-31 and ICR-48 had comparatively higher values of T, TE & HI among the top 20.

Post-rainy season 2001 ($F_{2:7}$ MLT)

Variations in kernel yield among the different selections were significant. Kernel yield was 514–2495 kg/ha. Among the top 20 selections, eleven were from empirical selection and nine were from trait-based selection on the basis of kernel yield (kg/ha) (Table 2). The top eight selections had significantly higher kernel yield than the best-yielding parent (K-134). The selection ICR-40 ranked first for kernel yield (2495 kg/ha) with a high T value (1258 mm). Selections JAL-08, ICR-48, ICR-46, ICR-42 and ICR-45 had comparatively higher values of T, TE & HI among the top twenty genotypes.

The selection JAL-08 (2067 kg/ha) had comparatively good yield and also moderate values of TE, T and HI. The pedigree of this selection is ICGV 86031 x TAG-24. The former parent had high TE, and the latter had high HI.

Table 1. Performance of the top 20 genotypes and eight parents for kernel yield and for other traits in MLT during rainy season 2000.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
JAL 30	EMP	1643	0.20	2.328	377
JAL 13	IRR	1620	0.17	2.296	440
ICR 13	IRR	1559	0.19	2.315	381
JUG 43	EMP	1500	0.17	2.268	398
TIR 31	EMP	1471	0.16	2.313	421
ICR 26	EMP	1470	0.18	2.302	381
ICR 48	EMP	1442	0.15	2.311	421
ICR 43	EMP	1442	0.18	2.253	377
ICR 39	EMP	1441	0.19	2.231	363
JUG 28	EMP	1432	0.18	2.318	363
TIR 13	DRO	1432	0.19	2.277	352
JUG 45	EMP	1429	0.20	2.350	316
JUG 16	IRR	1426	0.16	2.258	412
TIR 14	DRO	1424	0.18	2.279	362
TIR 41	EMP	1424	0.18	2.306	364
ICGS 44	P	1421	0.18	2.256	352
ICR 24	IRR	1415	0.18	2.295	363
ICR 36	EMP	1407	0.15	2.258	426
JAL 27	EMP	1403	0.14	2.308	428
ICR 47	EMP	1398	0.19	2.312	341
ICGS 44		1421	0.18	2.256	352
ICGS 76		1339	0.15	2.317	390
TAG 24		1231	0.18	2.241	330
JL-220		1050	0.14	2.272	315
CSMG 84-1		1271	0.14	2.227	389
ICGV 86031		1082	0.12	2.260	382
GG2		1147	0.15	2.285	334
K134		958	0.12	2.264	313
Mean of Parents		1187	0.15	2.265	3510
SE		233.8	0.02618	0.04401	48.25

Table 2. Performance of the top 20 genotypes and eight parents for kernel yield and other traits in MLT during post-rainy season 2001.

Geno-ID	Selection	Yield (kg/ha)	HI (g/kg)	TE (g/kg)	T
ICR 40	EMP	2495	0.17	1.162	1258
JAL 41	EMP	2130	0.16	1.188	1115
ICR 09	DRO	2097	0.21	1.197	859
JAL 35	EMP	2076	0.20	1.175	875
JAL 08	DRO	2067	0.13	1.171	1346
JAL 33	EMP	2065	0.16	1.154	1125
ICR 39	EMP	2021	0.21	1.163	870
ICR 42	EMP	2004	0.14	1.172	1201
JAL 18	IRR	1990	0.16	1.189	1035
TIR 39	EMP	1985	0.20	1.175	865
ICR 24	IRR	1926	0.15	1.185	1132
JUG 38	EMP	1921	0.20	1.180	810
JUG 11	DRO	1904	0.19	1.198	833
ICR 45	EMP	1889	0.14	1.171	1187
JAL 30	EMP	1873	0.19	1.189	837
ICR 48	EMP	1872	0.13	1.179	1274
ICR 19	IRR	1854	0.22	1.158	755
JUG 21	IRR	1846	0.17	1.165	934
ICR 18	IRR	1840	0.17	1.174	966
JAL 07	DRO	1831	0.20	1.179	800
ICGS 44		1409	0.11	1.176	1113
ICGS 76		1805	0.13	1.184	1186
TAG 24		1443	0.11	1.148	1166
JL-220		1370	0.17	1.182	657
CSMG 84-1		1491	0.15	1.173	867
ICGV 86031		1146	0.09	1.176	1051
GG2		1558	0.19	1.148	739
K134		1823	0.13	1.194	1201
Mean of Parents		1506	0.14	1.172	998
SE		180.3	0.01712	0.01701	68.85

Conclusions

Response to selection methodology

Two selection methods, trait-based and empirical, were used and their suitability was assessed. It was observed that both methods performed equally well under Jalgaon condition. However, when all top 20 genotypes (out of 192) were considered, the ratio of empirical to trait-based selections was 3:2 for both rainy seasons and summer seasons. This suggests that both methods of selection were effective under Jalgaon conditions. Considering local conditions, the available resources may have the greatest influence over the method. However, since trait-based selection is based on detailed observations, its reliability and acceptability may be more authentic.

Relative performance of top 20 selections and parents or checks

Data on pod yield and other important traits of the top ten selections for rainy season 2000 and summer 2001 are given in Tables 1 and 2, respectively. All the selections were significantly superior to the local checks, JL-220 and TAG-24, during both seasons. The selection JAL-30 (1643 kg/ha) ranked first, followed by JAL-13 (1620 kg/ha) and ICR-13 (1559 kg/ha) during the rainy season. Similarly, selections ICR-40 (2495 kg/ha) ranked first, followed by JAL-41 (2130 kg/ha) and JAL-35 (2076 kg/ha) during the summer season. These selections out-yielded the parental means in both seasons.

Future plans and fate of the superior performers

A multi-location trial of elite selections developed in this project at Jalgaon has been prepared as a prerequisite for release in the Maharashtra state program during summer 2002. The sites for the evaluation will be: 1) Jalgaon; 2) Rahuri (Dist.A'Nagar); and 3) Digraj (Dist. Sangli).

The best performing selections for yield and physiological traits (HI and T) were JAL-30, JUG-45, JAL-13, JAL-27, ICR-36, TIR-31 and ICR-48 during the rainy season and the selections ICR-40, JAL-41, JAL-08, ICR-48, ICR-46, ICR-42 and ICR-45 during the summer under Jalgaon conditions They have been selected for high TE and moderately–high HI. After considering performance of these selections in both seasons across the above locations, the selections with the greatest potential will be evaluated in multi-location trials to identify the best performing cultivar, which can be recommended for general cultivation in the bunch peanut growing area. The best cultivars will also be evaluated in the fields of innovative farmers so as to judge their performance in an on-farm situation. This will help to increase the production of peanut both in terms of area and productivity. This evaluation exercise is critical to exploit the research outcomes of the collaborative project.

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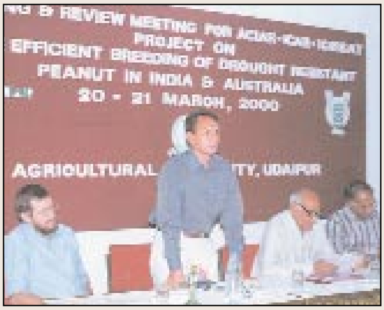

Project review and planning meeting at Udaipur, Rajasthan, India.


SPAD chlorophyll meter used in the WUE studies.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at Udaipur, Rajasthan, India

A.K Nagda[1], B. Manohar[2], K. Rupa Sridevi[2] and S.N. Nigam[2]

Introduction

PEANUT IN RAJASTHAN is mainly grown as a rain-fed crop on 0.27 M ha, with an in-shell production of 0.26 M tonnes. The productivity of peanut in Rajasthan is 964 kg/ha (Rajasthan State Agricultural Marketing Board, 2000), which is slightly higher than the national average of 833 kg/ha (Dept. of Agric. & Coop., 2000) Drought is the most important constraint affecting productivity of rain-fed agriculture in Rajasthan. Therefore varieties efficient in water-use can raise productivity of rain-fed agriculture throughout the State.

Udaipur in Rajasthan was chosen as one of the locations for the multi-environment evaluation of trait-based and empirical selections developed under the ACIAR-ICAR-ICRISAT collaborative project 'More efficient breeding of drought resistant peanuts in India and Australia'.

Materials and Methods

Udaipur is situated at 579.5 m above sea level, at latitude 24.35ºN and longitude 74.30ºE. The climate of this region is sub-humid, with an average annual rainfall of 637 mm. Most of the rainfall is received during the monsoon season, which extends from July to October.

The experimental materials consisted of eight parents (ICGS 76, CSMG 84-1, ICGS 44, ICGV 86031, TAG 24, GG 2, JL 220, and K 134) and 192 progenies, which were selected as described elsewhere in these Proceedings.

The experiment was laid out in an incomplete block design (alpha design) with three replications. Each replication had 50 blocks, 48 for selections and two for parents, each with four plots. Each plot consisted of four four-metre rows. The inter-row and intra-row spacing were 30 and 10 cm, respectively. The basal dose of fertilisers consisted of 44 kg urea (20kg N) and 375 kg single super phosphate (60 kg P_2O_4) per hectare. Before sowing, the seeds were treated with 1% ethrel solution to break any seed dormancy. For protection from fungi and insects, seeds were treated with Bavistin (3 g/kg of seed) and chlorpyriphos 20 EC (1.5 litres/100 kg of seed). At 35–40

[1] Rajasthan Agricultural University, Udaipur, Rajasthan, India
[2] ICRISAT, Patancheru, Andhra Pradesh, India

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days after sowing, chlorpyriphos 20 E.C. was again applied to the soil to control termites. Other agronomic practices were followed as per local recommendations.

Following the procedures described elsewhere in these proceedings, the observations recorded on each treatment included SPAD chlorophyll meter reading, plant number, vegetative weight, pod weight and kernel weight.

Results and Discussion

After good rains in the initial stages, the crop faced intermittent dry spells during the season and suffered severe end-of-season drought. The maximum temperature was around 30º C and the minimum around 25º C until 38 DAS. After that, the maximum temperature gradually increased and the minimum decreased as the season progressed. The radiation also showed an increase from 37 DAS and reached 20MJ/m^2 around 43 DAS.

Data corresponding to the 200 genotypes (192 progenies + 8 parents) for kernel yield (kg/ha), kernel HI, TE and T were subjected to a simple-analysis, assuming genotypic effects to be random. Genotypes showed significant differences in all the four traits mentioned above.

The top 20 genotypes for kernel yield consisted of nine trait-based and 11 empirical selections (Table 1). Among the top 20 genotypes, the kernel yield was 3411–4662 kg/ha, HI 0.39–0.47, TE 2.01–2.16 g/kg and T 377–492 mm. Five genotypes (JAL 17, JUG 11, ICR 39, ICR 23 and JAL 24, four from trait and one from empirical selection method) showed a significant improvement (from 12.7 to 28.1%) for kernel yield over the highest-yielding parent at this location (TAG 24, 3639 kg/ha). For these five genotypes, an increase over TAG 24 in HI (0.4%–3.2%) for four, in TE (1.2%) for three and in T (10.5%–27.6%) for all five genotypes was found. JAL 17, ICR 39, and ICR 23 had an increase in all the three traits over the control. TIR 17 and ICR 05, in spite of their having the highest increase in TE over the control, could not score in kernel yield because of their lower values for HI and T. An optimal combination of HI, TE and T is required to achieve higher yields.

Ignoring statistical significance, 10 genotypes of the 20 for kernel yield, 5 for HI, 11 for TE and 16 for T had a positive increase over the best-yielding parent TAG 24. For three genotypes, HI, TE and T showed a positive improvement. For six genotypes, a combination of HI and T (in two cases) or TE and T (in four cases) were positive. The HI and T combination was able to bring about a positive increase in kernel yield, but not the TE and T combination (except in one case). The remaining 11 genotypes had a positive increase in either T (in seven cases) or TE (in four cases) alone over TAG 24, of which four genotypes with positive increase in T showed a positive increase in kernel yield.

Table 1. Top 20 genotypes for kernel yield, HI, Transpiration efficiency (TE) and Transpiration (T) in the 2000 rainy season, Udaipur.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
JAL 17	IRR	4662	0.47	2.10	460
JUG 11	DRO	4456	0.46	2.01	492
ICR 39	EMP	4196	0.46	2.10	426
ICR 23	IRR	4171	0.46	2.10	430
JAL 24	IRR	4103	0.45	2.06	443
JAL 43	EMP	3940	0.44	2.02	455
JAL 32	EMP	3924	0.46	2.07	411
JAL 21	IRR	3794	0.43	2.11	414
JAL 46	EMP	3746	0.42	2.01	459
JUG 40	EMP	3686	0.41	2.07	434
TIR 17	IRR	3517	0.43	2.16	377
JAL 12	DRO	3516	0.40	2.05	433
TIR 38	EMP	3504	0.42	2.04	419
JUG 35	EMP	3501	0.39	2.10	423
JAL 29	EMP	3460	0.42	2.14	380
TIR 40	EMP	3425	0.42	2.10	381
ICR 16	IRR	3414	0.40	2.10	401
ICR 05	DRO	3411	0.40	2.16	386
JAL 37	EMP	3411	0.41	2.14	384
ICR 44	EMP	3402	0.42	2.05	403
ICGS 44	P	2856	0.37	2.10	375
ICGS 76	P	2350	0.32	2.17	334
CSMG 84-1	P	3221	0.40	2.08	400
ICGV 86031	P	3075	0.38	2.17	371
TAG 24	P	3639	0.46	2.07	386
JL 220	P	3231	0.42	2.02	401
GG 2	P	3336	0.41	2.04	416
K 134	P	2345	0.36	2.03	340
Grand mean		2786	0.37	2.11	355
LSD		400.8	0.031	0.108	38.7

Conclusions

At the Udaipur location, the progenies with the best kernel yield were from the trait-based selection approach. The superiority in kernel yield was accompanied with superiority in HI, TE, and T, either alone or in combination. For achieving maximum yield, an optimum combination of these traits is required.

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Dr Ray Shorter and Dr R.C.N. Rachaputi discussing project trials near an on-farm trial site at Tirupati, Andhra Pradesh, India.

Plants from a breeding block at at ICRISAT Centre, Andhra Pradesh, India.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at the Agricultural Research Station, Anantapur, Andhra Pradesh, India

Vasundhara, S. and Yellamanda Reddy, T.[1]

Introduction

GROUNDNUT IS THE MAJOR oilseed cash crop grown in 0.75 M ha in the Anantapur district of Andhra Pradesh under rain-fed conditions. The agricultural production of rain-fed regions varies from year to year due to variations in climate, in particular rainfall. The crop is frequently subjected to drought resulting in lower yields and poor seed quality. Hence, growing of drought-resistant varieties is appropriate in these areas. The drought-resistant lines developed at ICRISAT (Patancheru), NRCG (Junagadh), MPKV-ORS (Jalagaon) and ANGRAU-RARS (Tirupati) were evaluated at the Agricultural Research Station, Anantapur during the 2000 rainy season.

Materials and Methods

The crop was raised under rain-fed conditions during the 2000 rainy season. The experimental soils were red sandy loams, with pH 4.92, 35% water-holding capacity, and EC of 0.035. These soils are low in nitrogen, medium in phosphorous and high in potassium. The trial, involving evaluation of 192 selections developed in the ACIAR project, was laid out in an Alpha design with three replications. Inter-row spacing of 30 cm and plant spacing of 10 cm within a row was applied. The crop was sown on 14 July after 17 mm of rainfall on 12–13 July. The recommended dose of fertilisers (20 N: 40 P_20_5: 40 K_20) and gypsum 500 kg/ha were applied at sowing.

The crop received 221 mm rainfall in 16 rainy days during the growth period. It experienced two dry spells: 14 July to 4 August (22 days); and 25 August to 15 September (23 days), which coincided with the vegetative and pod development stages. Insecticide (monocrotophos) was applied by spray on 31 August.

The weekly mean values of maximum and minimum temperature were 29.2–35.8ºC and 18.9–23.7ºC, respectively. The mean weekly bright sunshine hours per day was 8.0. The seasonal mean relative humidity was 73% and 35% at 0720 hrs and 1420 hrs, respectively. The wind velocity during the crop season was

[1] ANGRAU, Anantapur, Andhra Pradesh, India

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generally high, at around 13.3 km/h. The seasonal mean daily evaporation was 8.7 mm/day. The crop was harvested, after accumulating 1800 GDD, on 23–30 October 2000.

SPAD meter readings were recorded at 60 DAS following protocols described by Bindu Madhava *et al*. (2003). Plants from one metre (one of the two middle rows) length were harvested for determining the oven-dry vegetative, pod and kernel weights. From the rest of the centre two rows (4 + 3 m), pod, kernel yield and 100 seed weight were recorded. The analysis was conducted at ICRISAT using the GENSTAT package.

Table 1. Kernel yield, HI,TE and T of the 20 highest-yielding selections during 2000 rainy season at Anantapur.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
ICR 37	Emp	1341	0.36	2.38	167
JAL 05	Trait	1331	0.34	2.31	174
JUG 01	Trait	1306	0.35	2.08	179
ICR 46	Emp	1298	0.32	2.41	171
JUG 24	Trait	1296	0.37	2.24	168
ICR 19	Trait	1287	0.36	2.35	167
ICR 08	Trait	1278	0.31	2.35	177
JUG 13	Trait	1267	0.33	2.41	170
TIR 18	Trait	1263	0.33	2.27	170
TIR 48	Emp	1254	0.33	2.37	169
JUG 47	Emp	1252	0.35	2.35	166
TIR 43	Emp	1246	0.35	2.37	163
JUG 37	Emp	1245	0.34	2.34	167
JUG 06	Trait	1242	0.33	2.25	171
ICR 24	Trait	1241	0.35	2.36	165
JAL 13	Trait	1238	0.33	2.30	170
ICR 10	Trait	1236	0.31	2.43	169
JAL 46	Emp	1235	0.32	2.26	172
ICR 32	Emp	1235	0.32	2.17	177
ICR 02	Trait	1234	0.30	2.43	174
ICGS 44		1029	0.29	2.32	160
ICGS 76		1183	0.32	2.44	166
CSMG 84-1		1102	0.26	2.30	179
ICGV 86031		1133	0.28	2.37	170
TAG 24		1035	0.31	2.19	158
JL 220		1079	0.29	2.01	174
GG 2		1150	0.32	2.05	171
K 134		1166	0.33	2.13	168
Grand mean		1108	0.30	2.30	166
LSD		323.4	0.079	0.215	29.0

Results and Discussion

Among the top 20 entries, based on kernel yield, the yield was 1234–1341 (kg/ha), harvest index 0.30–0.37, transpiration efficiency 2.08–2.43 (g/kg) and transpiration from 163–179 mm (Table 1).

HI was highest for JUG 24 (0.37), followed by ICR 37 and ICR 19 (0.36). The kernel yield was highest for ICR 37 (1341 kg/ha), followed by JAL 05 (1331) and JUG 01 (1306). TE was the highest for ICR 10 & ICR 02 (2.43 g/kg) followed by ICR 46 & JUG 13 (2.41) and ICR 37 (2.38). Transpiration (T) was highest for JUG 0l (179 mm) followed by ICR 08 & ICR 32 (177) and JAL 05 & ICR 02 (174).

Among the top 20 genotypes, eight were from ICRISAT, six from Junagadh and three each from Jalgaon and Tirupati. ICR 37 showed the highest kernel yield and HI of 0.36, TE of 2.38 g/kg and T of 167.

The observed variations were due to the response of the genotypes to a set of growing conditions. Harvest index, transpiration efficiency and transpiration did not show a trend similar to that of kernel yield. The genotypes with the highest harvest index, transpiration efficiency and transpiration could not produce the highest kernel yield and vice versa, and there was no obvious trend for these characters.

In general, transpiration efficiency was higher at ICRISAT than the other breeding centres.

Conclusion

Among the top 20 genotypes, eight were from empirical and 12 from trait-based selection approaches. Traits including kernel yield, harvest index, transpiration efficiency and transpiration were independent in their expression among the genotypes.

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From left: Mr Jim Page, Ms Michelle Robbins, Dr R.C.N. Rachaputi, Dr S.N. Nigam and Dr Graeme Wright attending a project planning meeting at QDPI, Kingaroy, QLD, Australia.

WUE collaborators during the Year 3 Review and Planning meeting at Pondicherry, South India.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at Vriddhachalam, Tamil Nadu, India

K. Subburamu[1] and P. Vindhiya Varman[2]

Introduction

PEANUT IS AN IMPORTANT oilseed crop in Tamil Nadu. The crop is grown in an area of about 1.2 M ha of which 0.8 M ha are grown under rain-fed conditions and raised during June-July with the onset of the South West Monsoon. The production of kharif peanut is highly influenced by the vagaries of the monsoon. 'Spanish bunch type' cultivars dominate, occupying some 90 per cent of the area.

The shorter growing season for these cultivars means they are more vulnerable to mid-season drought due to reduced capacity to recover after drought. Further, no cultivar presently under cultivation has been specifically bred for drought-resistance. The reliable and simple scoring methods available for screening genotypes against biotic stresses are virtually absent in the case of abiotic stresses, especially for screening against drought. This might be the reason for the absence of a major breakthrough in this field. However, as a result of the concerted effort taken in ACIAR-ICRISAT-ICAR collaborative projects, some useful traits to develop drought-resistant genotypes have been identified. Genotypes selected on the basis of such traits were used in a breeding project and selections made by 'trait-based' or 'empirical' selection approaches. This paper reports on the evaluation of the 192 selections developed in the collaborative project at the Vriddhachalam site in Tamil Nadu, India.

Materials and Methods

The peanut progenies developed from crosses among drought-resistant genotypes were supplied by the four breeding centres ICRISAT, National Research Centre for Groundnut (NRCG), Regional Research Station at Jalgaon, and the Andhra Pradesh Agricultural University at Tirupati. The selections were produced in the respective breeding centres over a period of time by either of two selection procedures, empirical or trait-based. With aim of evaluating the yield performance of the 192 entries developed from the proj-

[1] Horticulture College and Research Institute, Periyakulam, Tamil Nadu, India.
[2] Regional Research Station, Vriddhachalam 606 001, Tamil Nadu, India.

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ect for their adaptation under the peanut-growing conditions of Tamil Nadu, field trials were conducted at Vriddhachalam under moisture stress conditions using an advanced statistical alpha design with a 4 x 48 block pattern and three replicates, following the specification given by the ICRISAT centre.

The 2000 rainy season experimental crop was planted on 30 June. Each genotype was raised in plots of four rows by four metres, by adopting a row-to-row spacing of 30 cm and plant-to-plant spacing of 10 cm. The soil was ploughed to a fine tilth and 12.5 tonnes of farmyard manure were incorporated with the final ploughing. A basal fertiliser dose of 17.5 N: 35 P_2O_5: 52.5 K_2O kg/ha was applied, along with 200 kg/ha of gypsum. A similar dose of gypsum was again applied as a top dressing at 45 DAS, as earthing up was done. The field was kept free from weeds by hand weeding at 15, 25, 40 and 60 DAS. Leaf hopper, leaf miner and Spodoptera were prevented by spraying monocrotophos, Dichlorvos, quinalphos, endosulphan and chlorpyriphos. Two irrigations were given at 0 and 13 DAS. However, 189 mm of rainfall was received on 18 rainy days during the cropping period and probably mitigated the stress treatment to some extent. The rainy season crop was harvested on 13 October. The post-rainy summer 2000-01 crop was planted on 10 January 2001 and harvested on 14–18 April. The same cultural practices were followed for the rainy season crop. Irrigations (each of 360 mm) were given at 0, 6, 13, 19, 32, 45, 65, 70 and 91 DAS; there was also a total of 62 mm rainfall between 92 and 94 DAS.

The observations recorded were:

- SPAD readings at 59–61 DAS during rainy season, 2000 and at 40–42 DAS during post-rainy summer season, 2000-01;
- one-metre growth sample within the middle 2 x 4 m row for plant number, vegetative, kernel and pod weight (both air dry and oven dry); and
- seven-metre sample within the 2 x 4 m row for vegetative, pod and kernel air dry weight.

Table 1. Yield, HI, TE and T of the 20 highest-yielding genotypes during rainy season 2000 at Vriddhachalam.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
ICR 16	IRR	2336	0.10	1.68	1337
ICR 26	EMP	2120	0.15	1.69	846
JAL 48	EMP	2112	0.13	1.52	1088
ICR 08	DRO	2103	0.11	1.73	1090
TIR 36	EMP	2099	0.12	1.61	1088
JUG 44	EMP	2092	0.16	1.62	793
TIR 33	EMP	2090	0.12	1.62	1055
ICR 22	IRR	2088	0.15	1.64	870
ICR 36	EMP	2082	0.12	1.67	1047
ICR 40	EMP	2077	0.09	1.54	1551
JAL 09	DRO	2075	0.13	1.68	988
JUG 15	IRR	2066	0.13	1.74	930
ICR 28	EMP	2045	0.14	1.74	828
JAL 05	DRO	2044	0.13	1.66	953
JAL 20	IRR	2033	0.12	1.62	1072
JAL 40	EMP	2032	0.11	1.61	1109
TIR 06	IRR	2003	0.11	1.50	1268
TIR 29	EMP	1993	0.10	1.63	1176
ICR 12	DRO	1981	0.16	1.64	773
JUG 06	DRO	1979	0.14	1.64	860
JL 220	P	1832	0.11	1.55	1061
Grand mean		1576	0.11	1.65	890
SED (±)		69.9	0.006	0.016	38.1
LSD (<0.05)		137.0	0.011	0.031	74.8

Table 2. Yield, HI, TE and T of the 20 highest-yielding genotypes during post-rainy season 2001 at Vriddhachalam.

Geno-ID	Selection	Yield (kg/ha)	HI	TE (g/kg)	T (mm)
JAL 15	IRR	3396	0.17	2.14	914
JAL 14	IRR	3153	0.17	2.10	865
TIR 35	EMP	2868	0.16	1.98	878
JAL 10	DRO	2706	0.15	1.74	1008
JUG 36	EMP	2617	0.15	2.04	826
ICR 40	EMP	2615	0.15	1.68	1020
JUG 20	IRR	2571	0.16	1.88	851
JUG 42	EMP	2531	0.16	1.97	819
JUG 01	DRO	2509	0.16	2.00	765
TIR 07	DRO	2480	0.15	2.01	841
TIR 22	IRR	2479	0.15	1.78	948
JAL 05	DRO	2477	0.15	1.94	819
ICR 07	DRO	2439	0.15	1.98	812
ICR 13	IRR	2418	0.16	2.06	724
ICR 42	EMP	2416	0.16	1.97	765
ICR 48	EMP	2408	0.17	2.00	714
TIR 16	IRR	2406	0.16	1.94	792
TIR 03	DRO	2394	0.16	1.90	804
JUG 15	IRR	2388	0.16	2.12	689
TIR 01	DRO	2383	0.15	1.93	822
TAG 24	P	2311	0.14	1.83	884
Grand mean		1917	0.15	1.93	675
SED (±)		35.9	0.003	0.038	19.5
LSD (<0.05)		70.3	0.006	0.075	38.2

Results and Discussion

The data were subjected to statistical analysis at ICRISAT Centre, and the results for kernel yield, harvest index, total transpiration and transpiration efficiency are presented in Tables 1 and 2.

During the 2000 rainy season, all top 20 selections significantly exceeded the best parent, JL 220 for kernel yield. The maximum kernel yield was recorded by the selection ICR 16 (2336 kg/ha). The yield increase ranged from 8.0 to 27.5 per cent (Table 1). With respect to the drought-resistance traits, selections JUG 44 and ICR 12 recorded significantly higher kernel harvest index (0.16), JUG 15 and ICR 28 recorded significantly higher transpiration efficiency (1.74 g/kg) and selections ICR 12, JUG 44, ICR 28 and ICR 26 recorded significantly lower total transpiration rates (773–846 mm). As mentioned above, rainfall reduced the impact of moisture stress in this season.

During the post-rainy season, all top 20 selections significantly out-yielded the best parent, TAG 24 in kernel yield. The maximum kernel yield was recorded by the selection JAL 15 (3396 kg/ha). The yield increase ranged from 3.1 to 46.9 per cent (Table 2). Regarding component traits, selections JAL 15, JAL 14 and ICR 48 recorded significantly higher kernel harvest index (0.17), JAL 15, JUG 15, JAL 14 and ICR 13 recorded significantly higher transpiration efficiency (2.06–2.14 g/kg) and JUG 15, ICR 48 and ICR 13 recorded significantly lower total transpiration rate (689–724 mm) compared to the other selections.

Conclusions

The selections identified as having superior drought-resistance, based on yield and other physiological characters, were:

- Kernel yield — JAL 15 & ICR 16
- Kernel harvest index — JAL 14, JAL 15, ICR 48 JUG 44 & ICR 12
- Transpiration efficiency — JAL 15, JUG 15, JAL 14 & ICR 13
- Total transpiration — JUG 15, ICR 48 & ICR 13.

Some of the lines will be utilised in the local breeding program for further improvement of yield. The elite genotypes identified in this project will be further screened and the best will be made available to the farming community as released varieties.

WUE collaborators during the Year 3 Review and Planning meeting at Pondicherry, South India.

F4 progeny rows showing good variation for drought tolerance traits at QDPI, Kingaroy, QLD, Australia.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at Tirupati, Andhra Pradesh, India

P.V. Reddy, M. Asalatha, R.P. Vasanthi, D. Sujatha and V. Jayalakshmi[1]

Introduction

IN ANDHRA PRADESH state of India about 2.2 M ha are sown to peanut. The productivity in the rainy season ranges from 500 to 1200 kg/ha depending on the vagaries of rainfall and the incidence of pests and diseases during the crop growth period. Peanut productivity in the irrigated situation is 1500–3000 kg/ha. Identification of traits for drought-resistance and breeding for drought-resistant peanuts is a research priority.

A field experiment was conducted involving 192 selections, the seed material of which was supplied by ICRISAT.

Method

Details of field layout and observations recorded are common with other centres in the multi-location trials (MLT); for example, see Vasundhara and Yellamanda (2003).

At Tirupati centre the peanut was sown on 3 July. The total number of treatments (genotypes) was 200 (192 + 8 parents). The experiment was laid out in 5 x 40 alpha designs with three replications. After sowing, one irrigation was given to ensure optimum germination.

During the crop growth period a total of 531 mm of rainfall was received in 29 rainy days. There was a dry spell of 24 days duration from 4–28 DAS, but the crop did not face any further dry spells >10 days.

The crop was protected against all diseases and pests by prophylactic sprays and kept weed-free. Specific leaf area and SPAD were recorded at 60 DAS.

The crop was harvested beginning on 11–19 October 2000. Plants in one-meter length from the two middle rows (0.5 m in each row) were harvested separately followed by the effective row harvest. The number of plants in one-metre and seven-metre row length were counted and recorded.

The MLT with the same treatments and experimental details as that of the rainy season 2000 experiment was repeated in the post-rainy season under

[1] Regional Agricultural Research Station, Tirupati 517 502, Andhra Pradesh, India

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irrigation. The crop was sown on 1 December 2000 and harvested on 7–31 March 2001. The crop was protected from pests and diseases with prophylactic sprays.

Results and Discussion

The project has made significant progress in breeding drought-resistant peanut genotypes. The research highlights of the rainy season 2000 and post-rainy season 2000-01 trials are summarised below.

Rainy season 2000 ($F_{2:6}$ MLT)

During the rainy season 2000, the genotypes ICR-17, JAL-30, TIR-44,TIR-42, JAL-03, ICR-12, TIR-17, JAL-14, JUG-18 & ICR-26 were superior to the local check Vemana in terms of kernel yield. Increases in kernel yield (38–51%) and kernel harvest index (17–50%) were observed in the top ten selections. Six of the selections were from the trait-based selection method and four from the empirical method.

During the post-rainy season 2000-01 genotypes JAL-25, JAL-06, TIR-16, ICR-45, JAL-02, JUG-06, JUG-03, JAL-28, JAL-18 & JAL-29 were significantly superior to the local check Vemana in both pod and kernel yield. The increase in kernel yield was 16–48 per cent, while kernel harvest index was 6–27 per cent. Six of the selections were from the trait method and four from the empirical method.

Among the three model component traits included in the selection index, there was a major gain for HI (6–50%) compared to T (<0–12%) and TE (<0–25%) in the top 10 genotypes in both rainy and post-rainy season MLTs.

The data pertaining to the top ten genotypes (on a seven-metre row kernel yield basis), are shown in Table 1. Among the top ten genotypes, six were from the trait method and four from the empirical method. Four of the genotypes were Spanish type and six belong to the Virginia group.

The data presented in the Tables 1 and 2 show that there was a large and significant gain in the selected genotypes in terms of kernel yield and kernel harvest index. There was marginal improvement in TE and moderate gain in T in the top ten genotypes, as compared to the local check and parental mean.

The differences between the methods of selection were not significant for any of the traits (Tables 3 and 4). Among the crosses, the improvement in kernel yield and total transpiration was superior in lines developed from a trait-based selection method in C3 (ICGV 86031 x TAG-24), C6 (JL-220 x TAG-24), C4 (ICGS-44 x ICGS-76), and C8 (TAG-24 x ICGV86031).

The breeding project has resulted in genotypes with higher kernel yields compared to the local checks. In the trait method, marginal gain was observed in TE compared to the empirical method.

Table 1. Percent increase in kernel yield (KY) and HI in the top ten selected genotypes (7 m basis) over the local check (LC) and parental mean (PM), Tirupati centre, rainy season 2000.

Geno-ID	Cross	Yield (kg/ha)	KY Over LC (%)	KY Over PM (%)	HI	HI Over LC (%)	HI Over PM (%)
ICR 17	C-2	1687	51	28	0.24	33	20
JAL 30	C-1	1623	45	22	0.23	28	21
TIR 44	C-7	1610	44	43	0.27	50	42
TIR 42	C-3	1585	15	37	0.26	44	44
JAL 03	C-1	1572	41	18	0.21	17	11
ICR 12	C-4	1565	40	13	0.24	33	14
TIR 17	C-3	1562	40	35	0.24	33	33
JAL 14	C-1	1553	39	17	0.21	17	11
JUG 18	C-2	1545	38	17	0.23	28	15
ICR 26	C-1	1543	38	16	0.22	22	16
K-134		1119			0.18		
ICGS-76		1402			0.20		
ICGS-44		1374			0.21		
CSMG.84-1		1262			0.18		
ICGV.86031		1175			0.16		
TAG.24		1136			0.20		
GG-2		1066			0.17		
JL.220		1023			0.17		
Grand Mean		1280			0.20		
SED		193.6			0.026		

Table 2. Percent increase in TE and T in the top ten selected genotypes (7 m basis) over the local check (LH) and parental mean (PM), Tirupati centre, rainy season 2000.

Geno-ID	Cross	TE (g/kg)	TE Over LC (%)	TE Over PM (%)	T (mm)	T Over LC (%)	T Over PM (%)
ICR 17	C-2	2.41	0	0	302	11	9
JAL 30	C-1	2.49	3	1	290	7	3
TIR 44	C-7	2.31	-4	-4	267	-2	3
TIR 42	C-3	2.39	-1	-1	261	-4	-3
JAL 03	C-1	2.49	3	1	301	11	7
ICR 12	C-4	2.43	1	-2	279	3	2
TIR 17	C-3	2.44	1	1	272	0	2
JAL 14	C-1	2.51	4	2	299	10	6
JUG 18	C-2	2.41	0	0	289	6	4
ICR 26	C-1	2.42	0	-2	293	8	4
K-134		2.41			272		
ICGS-76		2.51			277		
ICGS-44		2.42			271		
CSMG.84-1		2.41			285		
ICGV.86031		2.41			289		
TAG.24		2.4			247		
GG-2		2.41			251		
JL.220		2.29			252		
Grand Mean		2.42			270		
SED		0.034			29.8		

Table 3. Percent increase in KY, HI, TE and T in empirical and trait selection methods (7 m basis), Tirupati centre, rainy season 2000.

	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
Empirical	1277	0.198	2.41	270
Trait	1291	0.200	2.43	271
Overall	**1284**	**0.199**	**2.42**	**271**

Table 4. Percent increase in KY, HI, TE and T cross-wise in empirical and trait selection methods (7 m basis), Tirupati centre, rainy season 2000.

Cross	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
Cross-1	**(ICGS76 x CSMG84-1)**			
E	1336	0.20	2.46	277
T	1348	0.20	2.47	281
Cross-2	**(ICGS44 x CSMG84-1)**			
E	1323	0.20	2.41	282
T	1296	0.20	2.40	277
Cross-3	**(ICGV86031 x TAG24)**			
E	1195	0.19	2.40	264
T	1236	0.19	2.43	268
Cross-4	**(ICGS44 x ICGS76)**			
E	1285	0.20	2.43	266
T	1396	0.22	2.46	269
Cross-5	**(JL220 x TAG24)**			
E	1205	0.18	2.31	278
T	1243	0.20	2.32	265
Cross-6	**(GG2 x ICGV86031)**			
E	1154	0.19	2.44	249
T	1182	0.21	2.43	246
Cross-7	**(K134 x TAG24)**			
E	1318	0.23	2.38	251
T	1231	0.21	2.41	255
Cross-8	**(TAG24 x ICGV86031)**			
E	1255	0.21	2.40	256
T	1317	0.22	2.42	263

Post-rainy season 2000-01 ($F_{2:7}$ MLT)

The results of the post-rainy season trial are presented in Tables 5 and 6. In the top ten genotypes ranked on the basis of kernel yield, eight genotypes were virginias and only two were spanish types. There was a 16–48 per cent increase in kernel yield in the top ten selections compared to the local check (Table 5). The trait method was superior in improving kernel yield in only two crosses: (ICGV 86031 x TAG-24); and (JL220 x TAG-24) (Table 6). No clear improvement in traits was discernable in the trait method (Tables 7 & 8).

Table 5. Percent increase in KY and HI in the top ten selected genotypes (7 m basis) over local check (LC) and parental mean (PM), Tirupati centre, post-rainy season 2000-01.

Geno-ID	Cross	Kernel Yield (kg/ha)	KY Over LC (%)	KY Over PM (%)	HI	HI Over LC (%)	HI Over PM (%)
JAL 25	C-1	3780	48	41	0.39	15	18
JAL 06	C-2	3388	32	29	0.43	27	30
TIR 16	C-3	3332	30	33	0.38	12	3
ICR 45	C-4	3330	30	18	0.44	29	22
JAL 02	C-1	3293	29	23	0.37	9	12
JUG 06	C-2	3255	27	24	0.40	18	21
JUG 03	C-1	3179	24	19	0.37	9	12
JAL 28	C-1	3131	22	17	0.36	6	9
JAL 18	C-2	3069	20	17	0.39	15	18
JAL 29	C-1	2999	17	12	0.36	1	9
K-134		2561			0.34		
ICGS-76		2874			0.36		
ICGS-44		2766			0.35		
CSMG.84-1		2488			0.30		
ICGV.86031		2887			0.35		
TAG.24		2123			0.39		
GG-2		2178			0.32		
JL.220		1899			0.34		
Grand Mean		2457			0.34		
SED		274.5			0.027		

Table 6. Percent increase in TE and T in the top ten selected genotypes (7 m basis) over local check (LC) and parental mean (PM), Tirupati centre, post-rainy season 2000-01.

Geno-ID	Cross	TE (g/kg)	TE Over LC (%)	TE Over PM (%)	T (mm)	T Over LC (%)	T Over PM (%)
JAL 25	C-1	2.22	19	2	433	10	15
JAL 06	C-2	1.90	2	-8	409	4	5
TIR 16	C-3	2.01	8	1	441	12	28
ICR 45	C-4	2.12	13	0	361	-8	-5
JAL 02	C-1	2.16	16	-1	414	5	10
JUG 06	C-2	1.89	1	-8	432	10	11
JUG 03	C-1	2.34	25	7	370	-6	-2
JAL 28	C-1	2.20	18	1	403	2	7
JAL 18	C-2	2.03	9	-2	386	-2	-1
JAL 29	C-1	2.15	15	-1	393	0	5
K-134		1.87			394		
ICGS-76		2.23			363		
ICGS-44		2.00			394		
CSMG.84-1		2.12			388		
ICGV.86031		2.02			413		
TAG.24		1.96			277		
GG-2		1.96			343		
JL.220		1.88			293		
Grand Mean		2.06			352		
SED		0.057			26.3		

Table 7. Percent increase in KY, HI, TE and T in empirical and trait selection methods (7 m basis) Tirupati centre, post-rainy season 2000-2001.

	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
Empirical	2458	0.34	2.05	351
Trait	2455	0.34	2.07	353
Overall	**2457**	**0.34**	**2.06**	**352**

Table 8. KY, HI, TE and T in empirical and trait methods of selections cross-wise (7 m basis), Tirupati centre, post-rainy season 2001.

Cross	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
Cross-1	**(ICGS76 x CSMG84-1)**			
E	2532	0.33	2.15	353
T	2455	0.33	2.17	349
Cross-2	**(ICGS44 x CSMG84-1)**			
E	2425	0.33	2.03	361
T	2445	0.33	1.99	369
Cross-3	**(ICGV86031 x TAG24)**			
E	2359	0.34	2.02	345
T	2531	0.35	2.05	357
Cross-4	**(ICGS44 x ICGS76)**			
E	2665	0.36	2.09	357
T	2466	0.35	2.13	331
Cross-5	**(JL220 x TAG24)**			
E	2278	0.34	1.94	343
T	2402	0.34	1.95	366
Cross-6	**(GG2 x ICGV86031)**			
E	2422	0.37	2.09	322
T	2369	0.34	2.07	338
Cross-7	**(K134 x TAG24)**			
E	2490	0.36	1.96	350
T	2368	0.35	2.00	336
Cross-8	**(TAG24 x ICGV86031)**			
E	2573	0.36	2.02	359
T	2494	0.36	2.12	330

Table 9. Range of percent increase in traits over the local check Vemana, from the top ten selections.

Trait	Rainy season 2000	Post-rainy season 2000-01
KY	38–51	16–48
HI	17–50	6–27
TE	<0–4	1–5
T	<0–11	<0–12

Conclusions

Andhra Pradesh state has 14 M ha available for rainfed peanut production. Crop yields in this situation largely depend on the amount and distribution of rainfall during the growing season. Any improvement in peanut genotypes' drought-resistance traits will go a long way to mitigating the effects of drought on peanut production. The selections made in the present project are likely to improve the productivity in the rainfed situation.

All the top ten genotypes were superior to the local check Vemana in both rainy and post-rainy seasons, as shown in Table 9. As seen from the mean values for the traits in the Empirical and Trait approaches no significant gains are evident from the trait method in terms of T and TE. It would be interesting to investigate the nature of expression of these traits under water-limited situations.

Benefits and Future Activities

The peanut breeding program for drought tolerance in the State has benefited immensely from this project due to access to new germplasm, technical skills and creation of infrastructure facilities. Acquisition of a SPAD meter and a computer with internet capacity also contributed to infrastructure at the University.

The scientists in the project were trained in Australia in mini-lysimeter technology and packages for analysis of multi location variety evaluation trials. Frequent visits to ICRISAT and visits by the scientists from Australia and ICRISAT resulted in exchange of valuable information.

Fifteen selections from Tirupati centre are now included in an AICORPO Multi-location trial in ten centres across the country. Water-use-efficient peanut genotypes suitable for moisture-limited situations are likely to be released if their continued superiority is established under further multi-location testing.

Capacity-building of the participating scientists

Dr. P.V. Reddy visited the Peanut Research Station in Kingaroy, Australia and received training in Multi-location data analysis.

The project supplied capital equipment such as SPAD meters to all collaborating centres. Pot culture facilities for measuring water-use efficiency were developed in the project.

Two Ph.D. (Plant Physiology) students and three M.Sc. (Agriculture) students from the University utilised the facilities in the project for thesis work.

Ms. M. Asalatha, Scientist in the project, was awarded a fellowship for Ph.D. studies at UQ, Brisbane, Australia.

The expertise gained in the project resulted in our institute obtaining further grants from the National funding bodies to pursue basic and strategic work on water-use efficiency in field crops.

Two selections from the study are in mini-kit testing in the farmer's fields. University officials, farmers, and State Department of Agriculture officials have on various occasions visited the experimental fields and showed a keen interest in the final outcomes of the project.

Several research papers have been published from the project work.

After the completion of the AICORPO multi-location trial and the MLTs conducted by the University, it is expected that a group of high-yielding drought-resistant peanut genotypes belonging to both Virginia and Spanish groups will be available for release to the farmers.

A new ACIAR project, PHT2000/080 aimed at identifying low-aflatoxin-risk genotypes in peanut has also been initiated at Tirupati Regional Agricultural Research Station. The 200 drought-resistant genotypes selected in the present project will provide a good resource for such a study, as drought-resistance is often associated with low aflatoxin production.

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Drs N.C. Rachaputi and S.N. Nigam discussing results with Technical Officer Mr Manohar at ICRISAT Centre, Andhra Pradesh, India.

Multi-location trial plots at Tirupati, Andhra Pradesh, India.

Evaluation of Trait-based and Empirical Selections for Drought Resistance at ICRISAT Centre, Patancheru, Andhra Pradesh, India

S.N. Nigam, S. Chandra, B. Manohar, H.S. Talwar, A.G.S. Reddy and Rupa Kanchi[1]

Introduction

PEANUT IS CULTIVATED on 25.5 M ha worldwide with a total in-shell production of 35.1 million tons (Food & Agriculture Organisation of the UN 2001). Production of peanut is concentrated in developing countries of Asia and Africa, which account for 95 per cent of the world peanut area and about 93 per cent of total production. Peanut is grown in these countries mostly by smallholders under rain-fed conditions with almost no inputs other than land and labour. More than 80 per cent of the world's peanut production comes from rain-fed agriculture where productivity is much lower (<1.0 t/ha) than the developed world (2.9 t/ha).

Drought is a major abiotic stress affecting yield and quality of rain-fed peanut. Yield losses due to drought are highly variable in nature depending on its timing, intensity, and duration coupled with other location-specific environment factors such as irradiance and temperature (Nigam *et al*. 2001). On a global basis, the estimated annual loss in peanut production caused by drought alone is equivalent to US$520 million in 1994 prices. ICRISAT's mid-term plan (1994–98) projected that half of the losses (US$208 million) could be recovered through genetic enhancement for drought-resistance with a benefit:cost ratio of 5:2 (Johansen and Nigam 1994).

The present study is of global significance and its results will help developing countries to alleviate the adverse effects of drought on peanut production by reorienting their peanut-breeding programs.

Materials and Methods

ICRISAT Centre, Patancheru is located at 17.53ºN, 78.27ºE and 545 m above mean sea level. The soils of the experimental sites are lithic rhodustalf with high clay and silt contents. The Centre receives, on average, 781 mm annual rainfall. Most of the rains are received from mid-June to mid-October with erratic distribution.

[1] ICRISAT, Patancheru, Andhra Pradesh, India

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The experiment was conducted in 2000 rainy and 2000-01 post-rainy seasons with 192 lines selected following trait-based and empirical approaches and eight parents in an Alpha design with three replications. For details of the materials and selection methods, see elsewhere in these Proceedings; for example, see Vasundhara and Yellamanda Reddy (2003). The plot size consisted of four four-metre rows 30 cm apart. In the 2000 rainy season, the experiment was grown under both rain-fed and irrigated conditions. In the 2000-01 post-rainy season, it was grown with full irrigation and also under imposed mid-season drought conditions (irrigation was withheld from 40 DAS to 80 DAS).

The experiment received single super phosphate at 375 kg/ha as a basal dose and gypsum at 400 kg/ha at the time of peak flowering. Weeds were controlled by pre-emergence application of *Alachlor* and two manual weedings at 60 and 90 DAS. Intensive measures were taken to protect the crop from diseases and insect damage.

The 2000 rainy season experiment was sown on 3 July. The irrigated treatment received seven irrigations of 50 mm applied using overhead sprinklers on 19 & 29 July, 8 August, 4 & 11 September, and 4 & 15 October, while the rain-fed treatment received no irrigation. The post-rainy season experiment was sown on 2 December 2000, in which the irrigated treatment received 15 sprinkler irrigations, one each on 2, 8, 18, & 31 December, 6, 13, & 27 January, 8 & 19 February, 6, 17, & 26 March, 10 & 21 April, and 6 May, 2001. In the mid-season drought treatment, drought was imposed by withholding from the full irrigation schedule described earlier irrigations scheduled on 8 & 19 February and 6 & 17 March.

In each plot observations were recorded on SPAD chlorophyll meter reading, specific leaf area (SLA), plant number, vegetative weight; pod weight, and kernel weight. The SPAD observations were recorded during 50 to 70 DAS. In each plot, eight randomly selected second leaves from the top of the main stem were sampled from the middle two rows. These leaves were plucked and brought to the laboratory for further observations in plastic bags. On each leaflet, two readings were taken. For each genotype, 64 observations were averaged. These leaves were also used to measure specific leaf area. The leaves were soaked in water for three hours; then, after drying them with blotting paper, their leaf area was measured. Subsequently, these leaves were oven-dried at 60ºC for two days, and their dry weight measured. From these two observations, SLA values were derived. For other observations at final harvest, one-metre row length was selected from the middle two rows and plants were counted and harvested. Then, plants were separated into vegetative parts (including pegs) and pods. The vegetative and pod fresh weights were recorded. Samples were oven-dried at 60ºC for 24 hours. The dry vegetative, pod, and seed weights were recorded. HI, T, and TE were derived from these and other observations.

Weather

2000 rainy season

The total rainfall during the cropping season was 899.9mm but it was very unevenly distributed. There were three unusually heavy downpours during the 32nd week (105.8 mm), the 34th week (517.3 mm), and 38th week (117.2 mm) (Figure 1). Of the total 899.9 mm rainfall received during the cropping season, 740.3 mm were received in these three downpours, resulting in very uneven distribution. The maximum temperature was 27.5–32.8ºC and the minimum was 17.5–20.2ºC during the cropping season. The solar radiation during the rainy season averaged 15.8 MJm^{-2} per day and ranged between 9.6 MJm^{-2} and 20.8 MJm^{-2}.

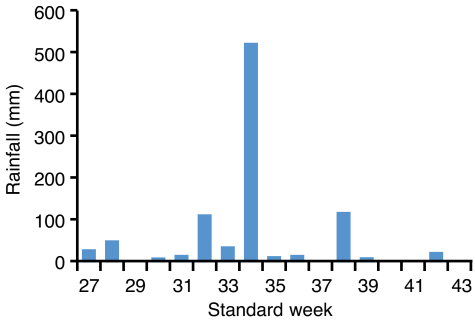

Figure 1. Rainfall distribution during July to October 2000 at ICRISAT.

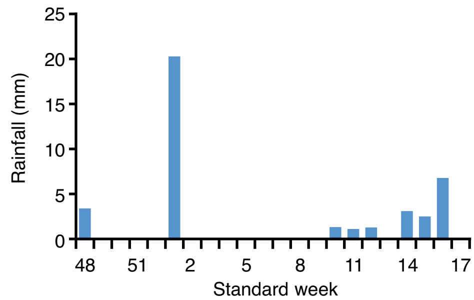

Figure 2. Rainfall distribution during December 2000 to May 2001 at ICRISAT Centre, Patancheru.

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2000-01 post-rainy season

The rainfall was very low during the cropping season (32.9 mm). The highest rainfall of 20 mm was received during the 1st standard week (Figure 2). Near absence of rains created conducive conditions for applying mid-season stress to one of the experiments. The maximum temperature was 26.5–39.0ºC and the minimum 9.1–23.7ºC, with maximum and minimum temperatures increasing gradually as the crop season progressed. The solar radiation averaged 18.0 MJm^{-2} per day and ranged between 11.8 MJ m^{-2} and 23.2 MJ m.

Statistical analyses

For individual experiment analysis, observation Y_{ijk} on genotype i recorded in block j of replication k was modelled as:

$$Y_{ijk} = \mu + r_k + b_{jk} + g_i + \Sigma_{ijk}$$

where:

μ, r_k, b_{jk}, g_i, and Σ_{ijk}, respectively, denote the general mean, effect of replication k, effect of block j within replication k , effect of genotype i, and the residual effect.

For combined analysis over experiments, observation Y_{ijkl} on genotype i recorded in block j of replication k in experiment l was modelled as:

$$Y_{ijkl} = \mu + e_l + r_{kl} + b_{jkl} + g_i + (ge)_{il} + \Sigma_{ijkl}$$

where:

μ, e_l, r_{kl}, b_{jkl}, g_i, $(ge)_{il}$, and Σ_{ijkl}, respectively, denote the general mean, effect of experiment l, effect of replication k within experiment l, effect of block j within replication k within experiment l, effect of genotype i, effect of interaction of genotype i with experiment l, and the residual effect.

All the terms in the model, except μ, were assumed to be random. Each random effect was assumed to be identically and independently normally distributed with a mean of zero and a constant variance. The unbiased estimate of variance component and best linear unbiased predictions (BLUPs), the latter where necessary, for each random effect were obtained using the restricted maximum likelihood (ReML) method in GenStat computing software.

The plant population was used as a covariate to adjust the estimates for varying plant populations. The statistical significance of estimates of variance components was tested using their respective standard errors assuming an asymptotic normal distribution.

Results and Discussion

Irrigated experiment, 2000 rainy season

The genotypic differences for kernel yield, HI, TE, and T were highly significant (Table 1a). The top 20 genotypes for kernel yield consisted of 11 trait-based and 9 empirical selections (Table 1b). Although these genotypes showed superiority in kernel yield (2.5–16.0%) over the highest-yielding parent ICGS 76, the differences were not significant. Similarly for HI, the differences were not significant. No genotype showed significant superiority over ICGS 76 for TE. On the other hand, eight genotypes recorded significantly lower TE than the parent. Trait-based and empirical selections were equally represented in this group. However, for T, four genotypes showed significant superiority over ICGS 76 with equal number of genotypes coming from the two selection methods. This superiority of T in four genotypes however was not translated into significantly greater kernel yield.

Ignoring statistical significance, 20 genotypes for kernel yield, 12 for HI, 4 for TE, and 19 for T showed positive increases over ICGS 76. T in six genotypes and HI in one genotype were positive. In the rest, it was a positive combination of HI, TE, or T in pairs or trios. Both trait-based and empirical selections were equally represented among the 12 positive genotypes for HI. For TE, three were trait-based and one empirical; for T, ten were trait-based and nine empirical among the genotypes showing positive improvement for these traits. No selection method showed superiority in selecting for kernel yield, HI, TE, or T.

Rain-fed experiment, 2000 rainy season

The genotypic differences for all the traits were highly significant (Table 2a). The top 20 genotypes for kernel yield comprising 12 trait-based and 8 empirical

Table 1a. Variance components, Irrigated experiment, ICRISAT Centre, 2000 rainy season.

Variance Component	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
σ_G^2	71027***	1148***	61.29 x 10^{-3}***	0.99 x 10^{-3}***
Se	17038	208	7.22 x 10^{-3}	0.19 x 10^{-3}
σ_e^2	253301	2280	28.90 x 10^{-3}	2.34 x 10^{-3}
Se	20640	190	2.47 x 10^{-3}	0.19 x 10^{-3}

Notes: G = genotype, e = error, SE = standard error, ***P < 0.001

Table 1b. Performance of the highest-yielding 20 genotypes for kernel yield (KY), harvest index (HI), transpiration efficiency (TE), and transpiration (T), Irrigated experiment, ICRISAT Centre, 2000 rainy season. Percentage change in these traits over parent ICGS 76 is also presented.

Geno-ID	Selection	KY (kg/ha)	HI	TE (g/kg)	T (mm)	Percent change over ICGS 76			
						KY	HI	TE	T
ICR 07	TRT	2563	0.35	2.89	275	16.0	7.2	1.4	9.7
TIR 47	EMP	2446	0.34	2.41	309	10.7	3.2	-15.4	23.0
ICR 09	TRT	2443	0.35	2.72	272	10.5	6.8	-4.3	8.4
TIR 36	EMP	2432	0.29	2.73	330	10.0	-10.3	-4.0	31.3
JAL 32	EMP	2416	0.35	2.53	286	9.3	7.8	-11.1	14.1
TIR 19	TRT	2408	0.33	2.53	297	9.0	2.3	-11.2	18.1
ICR 14	TRT	2398	0.31	2.76	295	8.5	-3.6	-3.2	17.6
TIR 31	EMP	2386	0.35	2.67	274	8.0	6.3	-6.4	9.0
ICR 17	TRT	2373	0.31	2.51	320	7.4	-4.9	-11.8	27.6
JUG 38	EMP	2342	0.34	2.54	281	6.0	4.2	-10.7	12.0
ICR 16	TRT	2341	0.29	2.48	337	5.9	-10.2	-12.9	34.2
JAL 29	EMP	2339	0.32	2.85	275	5.8	-1.5	0.2	9.6
JAL 02	TRT	2333	0.34	2.95	254	5.6	5.8	3.6	1.0
ICR 29	EMP	2326	0.30	2.64	316	5.2	-8.3	-7.4	25.9
ICR 08	TRT	2316	0.37	2.73	251	4.8	12.3	-4.3	0.0
JUG 25	EMP	2308	0.36	2.55	262	4.4	10.7	-10.3	4.5
ICR 44	EMP	2287	0.33	2.79	265	3.5	1.7	-1.9	5.5
TIR 22	TRT	2275	0.36	2.28	285	2.9	10.1	-20.0	13.3
JAL 13	TRT	2272	0.30	2.96	271	2.8	-7.2	4.1	7.8
ICR 24	TRT	2266	0.31	2.84	266	2.5	-4.8	-0.3	6.1
ICGS 44		1996	0.31	2.59	250				
ICGS 76		2210	0.33	2.85	251				
CSMG 84-1		2129	0.31	2.68	275				
ICGV 86031		1878	0.27	2.69	248				
TAG 24		1932	0.29	2.38	284				
JL 220		1962	0.30	2.48	267				
GG 2		1886	0.29	2.50	256				
K 134		1976	0.31	2.16	289				
Grand Mean		2033	0.30	2.58	265				
SED		279.9	0.030	0.133	31.2				
LSD		548.6	0.058	0.261	61.1				

Table 2a. Variance components, Rainfed experiment, ICRISAT Centre, 2000 rainy season.

Variance Component	Kernel Yield (kg/ha)	HI	TE(g/kg)	T(mm)
σ_G^2	51069***	551***	62.6 x 10-3***	1.29 x 10-3***
Se	11739	150	8.08 x 10-3	0.18 x 10-3
σ_e^2	171296	2441	45.6 x 10-3	1.51 x 10-3
Se	13950	197	3.89 x 10-3	0.13 x 10-3

Notes: G = genotype, e = error, SE = standard error, ***P < 0.001

selections did not differ significantly from ICGS 76 (Table 2b). Similarly, differences for HI and T for these genotypes and ICGS 76 were non-significant. However, four of these genotypes had significantly lower TE than ICGS 76. Ignoring statistical significance, genotypes showed positive improvement over ICGS 76 for: kernel yield (2 = 1 trait-based + 1 empirical); HI (10 = 6 + 4), TE (3 = 1 + 2), and T (10 = 6 + 4). Among these genotypes, only five had the positive combination of both HI, TE, or T. Under rain-fed conditions also, no selection method showed superiority in selecting for kernel yield, HI, TE, and T.

Irrigated experiment, 2000-01 post-rainy season

Like the 2000 season experiments, the genotypic differences for the traits studied were significant in this experiment (Table 3a). However, the top 20 genotypes for kernel yield did not differ significantly from the parent ICGS 76 (Table 3b). Similarly, these genotypes did not differ significantly for TE and T with ICGS 76. However, seven genotypes (3 trait-based + 4 empirical) showed significantly greater HI than ICGS 76. But these positive gains in HI were not translated into significantly greater kernel yield.

Table 2b. Performance of the highest-yielding 20 genotypes for kernel yield (KY), harvest index (HI), transpiration efficiency (TE), and transpiration (T), Rainfed experiment, ICRISAT Centre, 2000 rainy season. Percentage change in these traits over parent ICGS 76 is also presented.

Geno-ID	Selection	KY (kg/ha)	HI	TE (g/kg)	T (mm)	Percent change over ICGS 76			
						KY	HI	TE	T
JAL 15	TRT	2187	0.32	2.91	250	4.7	6.7	-2.2	1.8
TIR 34	EMP	2101	0.28	2.69	278	0.6	-9.2	-9.5	13.3
ICR 03	TRT	2080	0.29	2.77	276	-0.4	-5.6	-6.9	12.3
ICR 10	TRT	2054	0.31	2.51	264	-1.6	3.3	-15.7	7.4
TIR 31	EMP	2036	0.30	3.03	236	-2.5	0.0	1.7	-4.1
ICR 11	TRT	2013	0.29	2.94	246	-3.6	-3.7	-1.2	0.0
ICR 02	TRT	2001	0.29	2.91	246	-4.2	-4.0	-2.3	0.0
ICR 25	EMP	1991	0.30	2.76	249	-4.6	-2.1	-7.3	1.4
ICR 14	TRT	1956	0.27	2.77	259	-6.3	-11.4	-6.8	5.5
JAL 35	EMP	1951	0.31	2.46	249	-6.6	2.0	-17.4	1.5
ICR 48	EMP	1947	0.34	2.71	230	-6.8	11.4	-9.1	-6.5
TIR 19	TRT	1943	0.31	2.46	262	-6.9	3.6	-17.3	6.8
JAL 20	TRT	1936	0.27	2.88	250	-7.3	-10.9	-3.2	1.9
JAL 14	TRT	1921	0.28	3.05	235	-8.0	-6.8	2.5	-4.4
ICR 46	EMP	1914	0.31	2.54	245	-8.3	2.5	-14.6	-0.1
ICR 43	EMP	1895	0.33	3.03	219	-9.2	9.7	1.6	-10.7
JAL 29	EMP	1892	0.27	2.88	249	-9.4	-12.3	-3.2	1.3
ICR 09	TRT	1892	0.32	2.82	227	-9.4	5.0	-5.1	-7.4
TIR 17	TRT	1887	0.31	2.91	228	-9.6	2.8	-2.3	-7.3
ICR 23	TRT	1886	0.32	2.82	226	-9.7	4.2	-5.4	-8.0
ICGS 44		1627	0.31	2.64	213				
ICGS 76		2088	0.30	2.98	246				
CSMG 84-1		1731	0.26	2.78	239				
ICGV 86031		1882	0.26	2.74	260				
TAG 24		2003	0.34	2.39	254				
JL 220		1762	0.31	2.18	252				
GG 2		1546	0.29	2.57	215				
K 134		1373	0.25	2.36	215				
Grand Mean		1689	0.28	2.63	231				
SED		233.5	0.027	0.164	25.7				
LSD		457.7	0.053	0.321	50.4				

Table 3a. Variance components, Irrigated experiment, ICRISAT Centre, 2000/01 post-rainy season.

Variance Component	Kernel Yield (kg/ha)	HI	TE	T (mm)
σ_G^2	350913***	6532***	3.45×10^{-3}***	3.11×10^{-3}***
Se	44093	842	0.47×10^{-3}	0.39×10^{-3}
σ_e^2	253697	4731	3.41×10^{-3}	2.28×10^{-3}
Se	21303	403	0.28×10^{-3}	0.19×10^{-3}

Notes: G = genotype, e = error, Se = standard error, ***p < 0.001

Table 3b. Performance of the highest-yielding 20 genotypes for kernel yield (KY), harvest index (HI), transpiration efficiency (TE), and transpiration (T), Irrigated experiment, ICRISAT Centre, 2000-01 post-rainy season. Percentage change in these traits over parent ICGS 76 is also presented.

Geno-ID	Selection	KY (kg/ha)	HI	TE (g/kg)	T (mm)	Percent change over ICGS 76			
						KY	HI	TE	T
JAL 15	TRT	3826	0.41	1.75	527	9.5	20.0	3.6	-13.3
JAL 28	EMP	3662	0.39	1.71	543	4.8	13.3	1.5	-10.5
JUG 01	TRT	3657	0.36	1.63	626	4.6	3.9	-3.7	3.1
JAL 01	TRT	3648	0.38	1.74	538	4.4	11.7	3.0	-11.4
TIR 01	TRT	3632	0.34	1.61	662	3.9	-0.9	-4.5	9.0
JUG 14	TRT	3618	0.42	1.71	491	3.5	22.7	1.2	-19.2
JAL 02	TRT	3615	0.37	1.74	570	3.4	7.3	3.0	-6.1
JAL 26	EMP	3536	0.40	1.67	533	1.2	17.7	-0.8	-12.3
JAL 29	EMP	3529	0.42	1.70	476	1.0	23.6	0.5	-21.6
JAL 03	TRT	3514	0.39	1.75	514	0.5	13.9	3.6	-15.3
JUG 03	TRT	3450	0.40	1.74	494	-1.3	16.0	3.0	-18.7
JUG 13	TRT	3413	0.37	1.73	532	-2.3	7.9	2.3	-12.4
JUG 30	EMP	3387	0.41	1.69	485	-3.1	20.6	0.3	-20.2
JAL 18	TRT	3380	0.42	1.62	486	-3.3	23.3	-4.1	-20.0
ICR 28	EMP	3377	0.35	1.70	565	-3.4	0.9	0.9	-7.0
TIR 28	EMP	3371	0.34	1.61	613	-3.5	-1.7	-4.4	1.0
ICR 45	EMP	3310	0.44	1.65	452	-5.3	28.8	-2.2	-25.6
ICR 43	EMP	3264	0.43	1.65	456	-6.6	26.1	-2.0	-24.9
JUG 27	EMP	3258	0.37	1.61	542	-6.8	9.2	-4.6	-10.8
JAL 04	TRT	3255	0.35	1.60	582	-6.9	2.0	-5.3	-4.2
ICGS 44		2787	0.41	1.60	430				
ICGS 76		3495	0.34	1.69	607				
CSMG 84-1		2470	0.29	1.64	505				
ICGV 86031		2883	0.31	1.68	538				
TAG 24		1925	0.35	1.55	362				
JL 220		1965	0.28	1.60	432				
GG 2		1615	0.27	1.55	382				
K 134		1406	0.20	1.54	444				
Grand Mean		2530	0.33	1.63	479				
SED		369.6	0.035	0.041	52.8				
LSD		724.4	0.069	0.081	103.5				

Ignoring statistical significance, genotypes showed positive improvement over ICGS 76 for: kernel yield (10 = 7 trait-based + 3 empirical); HI (18 = 10 + 8), TE (11 = 7 + 4), and T (3 = 2 + 1). There was a preponderance of trait-based genotypes which showed positive gains over ICGS 76. In the top 20 genotypes for kernel yield, eight showed superiority only in one trait and the remaining 12 in two of the three traits associated with kernel yield, HI, TE, and T. As stated earlier, these positive gains in traits associated with kernel yield did not result in significant increase in kernel yield of the genotypes. No selection method was superior in selecting for kernel yield, HI, TE, and T.

Table 4a. Variance components, Imposed mid-season drought experiment, ICRISAT Centre, 2000-01 post-rainy season.

Variance Component	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
σ_G^2	77872***	2678***	2.79 x 10^{-3}***	2.78 x 10^{-3}***
Se	16110	395	0.46 x 10^{-3}	0.38 x 10^{-3}
σ_e^2	217385	3517	4.9 x 10^{-3}	2.56 x 10^{-3}
Se	17740	291	0.4 x 10^{-3}	2.16 x 10^{-3}

Notes: G = genotype, e = error, SE = standard error, ***P < 0.001

Table 4b. Performance of the highest-yielding 20 genotypes for kernel yield (KY), harvest index (HI), transpiration efficiency (TE), and transpiration (T), Imposed mid-season drought experiment, ICRISAT Centre, 2000-01 post-rainy season. Percentage change in these traits over parent ICGS 76 is also presented.

Geno-ID	Selection	KY (kg/ha)	HI	TE (g/kg)	T (mm)	Percent change over ICGS 76			
						KY	HI	TE	T
TIR 31	EMP	3032	0.43	1.67	457	19.0	20.3	0.5	5.5
JUG 26	EMP	2881	0.45	1.69	413	13.1	24.4	1.6	-4.6
ICR 24	TRT	2819	0.44	1.65	418	10.6	21.1	-0.8	-3.4
JAL 29	EMP	2788	0.37	1.69	466	9.4	3.0	1.4	7.5
JUG 15	TRT	2786	0.46	1.67	399	9.3	27.5	0.1	-8.0
JAL 13	TRT	2767	0.44	1.70	395	8.6	22.7	2.0	-8.8
ICR 25	EMP	2724	0.43	1.66	414	6.9	19.0	-0.5	-4.5
ICR 04	TRT	2707	0.38	1.59	487	6.2	5.0	-4.8	12.5
ICR 26	EMP	2688	0.39	1.64	446	5.5	8.2	-1.3	2.9
JAL 25	EMP	2668	0.41	1.68	414	4.7	12.9	1.1	-4.5
JAL 05	TRT	2665	0.45	1.55	416	4.6	24.8	-7.0	-3.8
ICR 38	EMP	2664	0.36	1.64	476	4.6	-0.2	-1.6	10.0
JAL 03	TRT	2660	0.37	1.67	455	4.4	2.0	0.3	5.0
JAL 26	EMP	2645	0.38	1.69	434	3.8	5.0	1.5	0.3
ICR 13	TRT	2626	0.41	1.65	409	3.1	12.9	-0.9	-5.5
JUG 01	TRT	2616	0.39	1.64	426	2.7	9.5	-1.4	-1.6
ICR 23	TRT	2616	0.44	1.68	385	2.7	21.2	0.6	-11.0
TIR 16	TRT	2608	0.38	1.67	430	2.4	5.8	0.0	-0.7
ICR 08	TRT	2597	0.39	1.63	426	1.9	9.2	-2.0	-1.6
JUG 03	TRT	2585	0.44	1.69	371	1.5	22.4	1.5	-14.3
ICGS 44		2408	0.36	1.65	405				
ICGS 76		2548	0.36	1.67	433				
CSMG 84-1		2288	0.29	1.65	465				
ICGV 86031		2266	0.28	1.67	485				
TAG 24		1997	0.41	1.62	300				
JL 220		2060	0.34	1.64	353				
GG 2		2490	0.38	1.61	426				
K 134		2603	0.35	1.60	481				
Grand Mean		2327	0.35	1.63	413				
SED		275.5	0.037	0.045	40.4				
LSD		540.0	0.073	0.089	79.2				

Table 5a. Combined analysis: Variance components, ICRISAT Centre, 2000 rainy and 2000-01 post-rainy seasons.

Variance Component	Kernel Yield (kg/ha)	HI	TE (g/kg)	T (mm)
σ_E^2	113922	12493	311.9 x 10^{-3}	0.93 x 10^{-3}
Se	94687	10260	257.2 x 10^{-3}	0.78 x 10^{-3}
σ_G^2	57047***	989***	15.6 x 10^{-3}***	0.99 x 10^{-3}***
Se	9931	177	2.2 x 10^{-3}	0.15 x 10^{-3}
σ_{GE}^2	81216***	1748***	16.98 x 10^{-3}***	1.06 x 10^{-3}***
Se	9478	173	1.44 x 10^{-3}	0.11 x 10^{-3}
σ_e^2	225463	3256	20.6 x 10^{-3}	0.22 x 10^{-3}
Se	9245	136	0.87 x 10^{-3}	0.09 x 10^{-3}

Notes: E = environments (experiments), G = genotype, GE = genotype x environment interaction, e = error, SE = standard error, ***P < 0.001

Mid-season drought experiment, 2000-01 post-rainy season

The genotypic differences for the traits studied were also significant in this experiment (Table 4a). The top 20 genotypes for kernel yield (12 trait-based and 8 empirical) did not differ significantly from ICGS 76 for kernel yield, TE, and T (Table 4b). However, 7 genotypes (6 + 1) did show significant superiority over ICGS 76 for HI. As in earlier experiments, the superiority in HI in this experiment was not translated into significantly greater kernel yield in these genotypes.

Ignoring statistical significance, genotypes showed positive improvement over ICGS 76 for: kernel yield (20 = 12 trait-based + 8 empirical); HI (19 = 11 + 8), TE (10 = 5 + 5), and T (7 = 2 + 5). Many genotypes had positive gains in two or three traits (HI, TE, or T), but this did not result in any significant gains for them in kernel yield. Although, there was preponderance of trait-based genotypes among the 20 genotypes in this experiment also, no method showed superiority in selecting for kernel yield, HI, TE, and T.

Combined analysis

The combined analysis over all experiments showed significant differences among genotypes for kernel yield, HI, TE, and T (Table 5a). Similarly, genotype x experiment (environment) interaction was also significant for all the traits.

The kernel yield of the top 20 genotypes did not differ significantly from the highest yielding parent ICGS 76 (Table 5b). Fifteen of these genotypes were trait-based and five empirical. Only three of these genotypes (two empirical and one trait-based) had greater kernel yield (statistically non-significant) than ICGS 76. Preponderance of trait-based genotypes among the top 20 test genotypes for kernel yield suggests the effectiveness of the Selection Index

Table 5b. Performance of the highest-yielding 20 genotypes for kernel yield (KY), harvest index (HI), transpiration efficiency (TE), and transpiration (T), combined analysis ICRISAT Centre, 2000 rainy and 2000-01 post-rainy seasons.

Geno-ID	Selection	KY (kg/ha)	HI	TE (g/kg)	T (mm)
TIR 31	EMP	2912	0.37	2.29	385.8
JAL 29	EMP	2801	0.35	2.31	376.7
JAL 15	TRT	2771	0.36	2.37	356.0
JAL 01	TRT	2643	0.37	2.38	344.8
JAL 02	TRT	2639	0.34	2.37	372.9
JAL 03	TRT	2636	0.35	2.33	361.9
JAL 26	EMP	2625	0.35	2.37	355.3
ICR 24	TRT	2617	0.37	2.24	341.3
JUG 01	TRT	2568	0.33	2.18	387.1
ICR 07	TRT	2565	0.34	2.30	346.6
TIR 16	TRT	2559	0.38	2.04	355.0
JUG 15	TRT	2538	0.38	2.38	315.3
ICR 09	TRT	2526	0.38	2.23	329.2
ICR 14	TRT	2525	0.31	2.22	390.7
JUG 03	TRT	2519	0.37	2.36	316.2
ICR 10	TRT	2505	0.34	2.16	371.4
JAL 13	TRT	2502	0.36	2.38	323.7
ICR 48	EMP	2496	0.38	2.21	337.0
JUG 26	EMP	2493	0.35	2.42	331.3
JAL 14	TRT	2469	0.32	2.41	352.2
ICGS 44		2204	0.35	2.12	318.3
ICGS 76		2719	0.34	2.32	389.6
CSMG 84-1		2180	0.29	2.20	379.2
ICGV 86031		2235	0.27	2.21	394.8
TAG 24		1959	0.35	1.97	302.3
JL 220		1905	0.31	1.95	330.6
GG 2		1864	0.30	2.04	315.0
K 134		1814	0.27	1.89	358.9
Grand Mean		2145	0.32	2.12	346.8
SED		450.2	0.046	0.151	56.58
LSD		342.0	0.035	0.115	42.98

(described elsewhere in these proceedings) in picking up high yielding genotypes, however the Selection Index was not effective enough in picking up genotypes that were higher yielding than the highest yielding parent. Four genotypes (three trait-based and one empirical) for HI and one trait-based genotype for T showed significant positive gains over ICGS 76. But eight other genotypes for T and three genotypes for TE had significant decrease relative to ICGS 76. Most of these selections were trait-based. This requires a reconsideration of the Selection Index and weighting given to its constituents (HI, TE, and T).

Conclusions

Results from the present experiments did not show significant superiority of trait-based selection over the empirical selection method for yield under either limited-moisture or normal-moisture conditions. However, there was a strong trend for increased kernel yield in trait-based genotypes among the top 20 genotypes, although the yield gains were statistically non-significant when compared with the highest-yielding parent ICGS 76. Even so there were significant yield gains among the top 20 genotypes compared to the other five parents.

These results suggest that that the inclusion in peanut breeding programs of some of the constituent traits of the Selection Index, or their easily measurable surrogate traits, would be useful. The Selection Index used in the present studies needs revision and improvement.

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Evaluation of Trait-based and Empirical Selections for Drought Resistance at Kingaroy, Queensland, Australia

A. Cruickshank, N.C. Rachaputi, G.C. Wright and D. Fresser[1]

Introduction

IN AUSTRALIA there was only one breeding centre and seed could not be rapidly exchanged with the Indian programs due to quarantine restrictions. So only selections from Kingaroy were evaluated. All testing of selections occurred in the 2000-01 summer season. The multi-environment testing (MET) of the selections used seven environments: six in the Burnett region and one on the Atherton Tableland in North Queensland. Three selections were made by both the empirical and trait-based methods. These were excluded from comparisons between the methods. One selection had insufficient seed for all sites; Streeton filler plots were substituted at the other two sites. This line was also excluded from the major factor comparisons. Each trial was a row-column design with 84 entries and four replicates; unit plots were two rows by 5–6m, 0.9m apart.

Results

Generally kernel yield, T and HI did not differ between selection methods (Table 1). The higher TE of the trait-selected group was consistent across sites. At the J4 site the empirical selections had a significantly greater HI, and at the G3 site the empirical selections had a significantly greater T than the trait selections. The reasons for these interactions are not clear. It is notable that the empirical selections expressed a greater T at the G3 site but not in the adjacent irrigated G4 site.

Comparison of sites

Trial mean kernel yields varied from 1.6 t/ha at Coalstoun Lakes to 3.1 t/ha at Block J4, Redvale (Table 2). Trial sites with higher yield potential generally expressed higher HI and T. Proportionally, the greatest variation was in T. While there were site effects for TE, they do not clearly relate to the yield potential of the environment. Kairi and M4 had TE values over three, and then the next highest values were at the driest site, Coalstoun Lakes.

Individual Sites — Redvale J4 and Coalstoun Lakes

Cluster analysis of kernel yield suggested that most sites elicited a similar genotype response pattern and that J4 and Coalstoun Lakes sites were the most disparate.

[1] Agency for Food and Fibre Sciences, QDPI, Kingaroy, Queensland, Australia

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Table 1. Site means for empirical and trait-based selections for Kernel Yield (KY), HI, T and TE.

	Redvale G4	Redvale G3	Taabinga J4	Taabinga M4	Wooroolin	Coalstoun Lakes	Kairi
KY (kg/ha)							
Empirical	3120	2116	3087	2393	1734	1530	2184
Trait-based	3052	2073	2982	2349	1680	1533	1977
HI							
Empirical	0.290	0.269	**0.326**	0.290	0.305	0.204	0.217
Trait-based	0.283	0.276	**0.303**	0.284	0.286	0.209	0.199
T (mm)							
Empirical	447	**359**	491	218	254	293	487
Trait-based	441	**326**	483	213	258	286	483
TE (g/kg)							
Empirical	**2.50**	**2.28**	**1.99**	**3.70**	**2.37**	**2.77**	**3.38**
Trait-based	**2.57**	**2.34**	**2.04**	**3.77**	**2.43**	**2.84**	**3.44**

Note: Sections of the table with significant differences (P<0.05) are highlighted by bold type.

Table 2. Site means for Kernel Yield (KY), HI, T and TE.

Site	KY (kg/ha)	HI	T (mm)	TE (g/kg)
G4	3133[a]	0.29	444[a]	2.53
J4	3096[a]	0.32	477[a]	2.02
M4	2419	0.29	218[b]	3.74[a]
G3	2135	0.28	372	2.31
Kairi	2110	0.19	486[a]	3.42[a]
Wooroolin	1742	0.30	251[b]	2.40
C. Lakes	1558	0.21	269[b]	2.81
Grand Mean	**2313**	**0.27**	**359**	**2.75**

Note: Means in a column with the same letter are not significantly different (P<0.01).

The 20 selections with the highest kernel yield (and checks from within that range) from each of these two sites are presented and compared.

The top 20 selections in J4 included 12 empirical and 8 trait-based selections; also 3 checks fell within this range (Table 3). Eleven selections and the three checks were not significantly lower than the highest yielding selection AX1-253 (4395 kg/ha). Only one of these selections (AX3-77, 4026 kg/ha) was not from cross AX1 (Streeton x CSMG 84-1). AX1-216 had the highest HI (0.47) among the 20 highest yields; five selections, and the parent Streeton, were not significantly lower than it. AX1-253 was just outside this group.

AX3-77 had the highest TE among the top 20 selections; the check Conder and four other selections were not significantly lower. All six of these lines had significantly higher TE than Streeton and NC 7. AX1-262 had the highest T of the top 20 with 8 other selections (including AX1-253), NC 7 and Conder not significantly lower. AX1-262 and AX4-628 both had significantly greater T than Streeton. NC 7 and Conder had significantly greater kernel size than all the top 20 selections in J4. Eleven of the top 20 selections had significantly smaller kernel yield than Streeton. No line among the top 20 kernel yields had a high proportion of (through-sieve) oil-grade kernel; the highest being only 1.9 per cent (AX1-216).

At the Coalstoun Lakes sites the top 20 selections for kernel yield included 10 from the top 20 at Redvale J4 (Table 4); of which AX1-156 had the highest yield (2196 kg/ha). The top 20 selections included 12 empirical and eight trait-based selections. Twelve selections and five parents/checks were not significantly lower in yield than AX1-156. AX2-87 had the highest HI (0.39) and only AX1-156 (0.32) was not significantly lower. AX2-19 had the highest TE; four selections and the check B185-2-p11-4 were not significantly lower than it. Ten selections and three checks (B185-2-p11-4, NC 7 and VB 97) had significantly greater TE than Streeton. AX3-77 had the highest T but twelve other top 20 selections and four checks (NC 7, Conder, Streeton and B185-2-p11-4) were not significantly lower. NC 7, B185-2-p11-4, VB 97 and Conder had significantly larger kernel than any selection in the top 20. NC 7 was significantly greater than the other checks also.

Examination of the 20 highest-yielding selections in individual trials shows no significant difference between empirical and trait-based selection. The highest-yielding selections do not consistently have a particular combination of the three-model component

Table 3. Top 20 Selections and Checks at the Redvale J4 site – 2000–01.

	Selection	Kernel Yield	Total K (%)	Oil K (%)	Wt50k	HI	TE (g/kg)	T (mm)
AX1-253	Emp	4395	72.3	1.2	38.0	0.38	1.97	580
AX1-227	Trait	4342	73.7	0.6	40.0	0.40	1.95	536
AX1-216	Emp	4209	73.2	1.9	33.5	0.47	1.88	483
NC 7		4120	71.4	0.5	55.5	0.36	1.92	606
AX1-134	Emp	4110	73.0	1.3	38.5	0.45	1.87	454
Streeton		4051	73.1	0.9	43.8	0.39	1.92	498
AX3-77	Trait	4026	71.2	1.2	38.7	0.42	2.10	489
Conder		3991	69.4	0.5	53.2	0.34	2.05	602
AX1-256	Trait	3988	72.0	0.9	39.7	0.35	1.96	553
AX1-188	Trait	3983	71.8	1.7	38.7	0.36	1.96	555
AX1-73	Emp	3959	71.4	0.7	44.4	0.40	1.90	480
AX1-18	Emp	3934	72.6	1.2	43.3	0.36	1.85	562
AX1-147	Emp	3924	66.9	1.0	41.7	0.38	1.98	504
AX1-262	Trait	3889	72.4	1.1	41.6	0.28	1.96	654
AX1-156	Emp	3879	74.6	0.5	45.2	0.32	1.95	594
AX1-185	Trait	3763	70.4	1.2	40.1	0.31	2.02	582
AX1-193	Emp	3707	72.4	0.6	45.3	0.33	1.96	571
AX1-31	Emp	3672	70.4	1.5	37.0	0.34	2.04	532
AX4-390	Trait	3577	73.2	0.6	40.2	0.39	2.00	460
AX1-170	Trait	3562	70.4	0.7	43.6	0.35	2.04	483
AX4-133	Emp	3415	66.7	1.1	43.6	0.36	2.00	489
AX4-628	Emp	3314	66.5	0.8	47.1	0.26	2.07	629
AX3-191	Emp	3308	67.6	1.1	37.7	0.33	1.95	499
LSD P<0.05		535	2.4	0.6	2.7	0.09	0.09	114

Total K% = All kernel as a % of pod weight; Oil K % = Most immature kernel grade as % of pod weight;
Wt50k = Weight in grams of 50 mature kernels.

Table 4. Top 20 Selections and Checks at the Coalstoun Lakes site – 2000–01.

	Selection	Kernel Yield	Total K (%)	Oil K (%)	Wt50k	HI	TE (g/kg)	T (mm)
AX1-156	Emp	2196	67.8	1.8	38.7	0.32	2.68	272
Conder		2046	62.1	0.8	43.6	0.24	2.78	307
AX2-92	Trait	2018	64.8	5.5	28.4	0.29	2.89	242
AX1-18	Emp	1998	68.2	2.4	39.7	0.24	2.66	322
NC 7		1923	64.1	0.7	50.9	0.22	2.90	311
AX1-134	Emp	1917	67.1	3.1	36.5	0.22	2.85	322
AX1-216	Emp	1904	67.3	5.4	32.0	0.21	2.77	320
AX1-253	Emp	1903	68.0	2.7	38.1	0.23	2.91	315
B185-2-p11-4		1866	63.9	0.7	45.9	0.26	2.98	261
Streeton		1853	67.3	1.2	39.4	0.24	2.67	305
AX2-99	Trait	1851	68.5	6.4	26.3	0.30	2.81	219
AX4-390	Trait	1832	67.8	1.7	37.0	0.22	2.95	280
AX1-227	Trait	1831	66.4	2.6	36.1	0.22	2.94	297
AX2-243	Emp	1826	68.6	1.2	36.3	0.27	2.87	246
AX4-940	Emp	1822	68.1	2.4	34.5	0.24	2.93	262
VB 97		1807	59.5	0.9	44.3	0.31	2.84	220
AX4-810	Trait	1796	69.9	2.1	34.1	0.22	2.80	292
AX2-87	Emp	1792	70.2	1.3	33.4	0.39	2.81	192
AX4-47	Emp	1769	68.5	2.2	34.5	0.27	2.78	239
AX2-19	Trait	1769	64.2	2.3	30.1	0.21	3.05	273
AX4-133	Emp	1761	64.4	1.7	37.4	0.21	2.72	318
AX3-77	Trait	1760	67.0	1.5	39.2	0.19	2.84	335
AX2-72	Trait	1760	67.2	1.2	35.7	0.27	2.76	243
AX1-73	Emp	1759	66.0	1.7	41.8	0.20	2.76	321
AX2-83	Emp	1755	67.7	1.8	33.6	0.22	2.85	284
LSD P<0.05		427	1.8	1.3	3.1	0.08	0.14	79

traits. Whereas the highest-yielding selections at the J4 site were dominated by cross AX1, at Coalstoun Lakes the highest-yielding selections included more from other crosses and cross AX2 in particular. The influence of cross warrants closer examination.

Comparison of crosses

Across sites, cross AX1 achieved the highest mean kernel yield (Table 5), the highest T and equal highest HI. In spite of having the highest TE and equal highest HI, AX2 had the lowest mean yield. The performance of crosses is consistent with the performance of their parents: AX1 is the product of the two parents with the highest T values and AX2 the opposite (Table 5). All the evaluation trials were conducted under 90 cm row spacing. The small plant stature of TAG 24 and ICGV 86031 (indicated here by low T values) is much better suited to narrower row spacing and higher plant density. The low T may have imposed a 'maximum yield ceiling' on all progeny in cross AX2, and many progeny in AX3 and AX4, when grown in the wide row arrangement. This suggests that the choice of parents for those three crosses was not the most suitable for the target cropping system.

Crosses AX2 and AX4 had the highest TE. ICGV 86031, the common parent in those crosses, had significantly greater TE than the other three parents. The trait performance of all parents in the multi-site evaluation was as expected on the basis of previous work (Rachaputi and Wright 2003):

- ICGV 86031 — high TE
- TAG 24 — high HI and moderate TE
- CSMG 84-1 — high T and moderate TE
- Streeton — high T and moderate HI.

Table 5. Means of crosses for Kernel Yield (KY), HI, T and TE.

	Kernel Yield	HI	T (mm)	TE (g/kg)
Crosses				
AX1 (Streeton x CSMG 84-1)	2732	0.28^{a}	409^{a}	2.70^{c}
AX2 (ICGV 86031 x TAG 24)	2088^{c}	0.28^{a}	312	2.80^{a}
AX3 (TAG 24 x CSMG 84-1)	2102^{c}	0.25^{b}	352^{c}	2.72^{c}
AX4 (Streeton x ICGV 86031)	2269	0.26^{b}	367^{b}	2.75^{b}
Parents				
CSMG84-1	2270^{b}	0.23	419^{a}	2.76^{b}
ICGV86031	1990^{c}	0.26	321^{b}	2.90^{a}
Streeton	2920^{a}	0.30^{b}	412^{a}	2.62^{c}
TAG24	2009^{c}	0.33^{a}	255^{c}	2.73^{b}

Note: Means in the same section, with the same letter are not significantly different (P<0.01).

Quality attributes

The value of germplasm to the Australian peanut breeding program is influenced by quality characteristics, particularly aflatoxin risk, fatty acid composition and blanchability. Fatty acid composition is not an issue with the material in this project as no high oleic acid parents were available and suitable for the purposes of this study. However it appears there is useful variation for aflatoxin risk factors and blanchability in the selected material.

Three replicates from the Coalstoun Lakes site were analysed for aflatoxin (Table 6). Thirteen test lines, two parents (Streeton and TAG 24) and one check line (B185-2-p11-4), had three replicates with less than 20 ppb aflatoxin. So 16 out of 84 trial entries may have lower aflatoxin risk. Given the unpredictable nature of aflatoxin contamination, it is not unusual to see some low or nil results in a high-risk environment; but the large number of such results supports the conclusion that there is genetic variation present for traits that reduce the risk of aflatoxin contamination. Elucidating the mechanisms of reduced risk is considerably more difficult. Some of these lines are ultra-early maturing, for example TAG 24 and AX2-92. Perhaps the mechanism in these lines is associated with escaping the aflatoxin risk through escape of end-of-season drought. Other lines such as Streeton, which is known to have lower aflatoxin risk, are not early maturing and cannot be simply escaping

Table 6. Aflatoxin content (ppb) of kernels from Coalstoun Lakes site.

Geno-ID	Rep 1	Rep 3	Rep 4	Mean
AX2-19	0	0	0	**0**
AX2-92	0	0	0	**0**
AX4-155	0	0	0	**0**
AX4-565	0	0	0	**0**
AX3-29	0	1	0	**0**
AX2-34	1	0	1	**1**
AX2-100	0	3	0	**1**
TAG 24	0	2	1	**1**
Streeton	15	0	0	**5**
B185-2-p11-4	9	7	3	**6**
ICGV 86031	29	0	50	**26**
AX2-99	64	0	20	**28**
CSMG 84-1	0	1	88	**30**
AX1-156	180	0	20	**67**
Conder	140	160	9	**103**
NC 7	240	70	81	**130**
AX2-243	64	150	360	**191**
AX1-147	850	340	410	**533**

aflatoxin contamination, but rather must possess other physiological and/or biochemical traits conferring resistance.

While cross AX1 (Streeton x CSMG 84-1) produced some of the highest-yielding selections in this project, no lines from this cross were among the low to nil aflatoxin group, and some were among the highest levels of toxin found.

Blanching, the removal of the testa from kernel by a heating/cooling cycle, followed by mild abrasion, is an important value-adding step for most Australian-grown peanuts. Heritable differences exist among commercial varieties and the development of varieties with high blanchability is a high priority for the Australian program.

Table 7. Blanchability of kernels from the paired sites: G4 and G3.

Genotype	Mean of Both Trials		Blanched %	
	Blanched %	Unblanched %	G4 Irrigated	G3 Rainfed
TAG 24	94.4	2.6	93.6	95.2
AX2-92	93.7	2.6	94.0	93.4
AX2-100	92.2	4.2	92.8	91.6
Conder	92.0	4.7	90.6	93.3
AX3-29	89.0	7.7	85.5	92.5
AX2-34	88.6	7.8	88.6	88.6
AX2-243	88.0	8.9	84.9	91.1
Streeton	81.3	15.7	85.2	77.4
CSMG 84-1	79.6	17.7	76.6	82.6
ICGV 86031	79.4	17.2	71.3	87.5
AX1-156	76.2	21.2	76.6	75.8
AX2-19	72.1	24.5	69.7	74.4
AX1-147	70.9	26.5	75.3	66.6
LSD (5%)	4.7	4.9	6.7	6.7
LSD (1%)	6.3	6.4	8.9	8.9

To test the blanchability of selections from this project and demonstrate the effect of drought stress on the blanchability of kernels, selections were tested from the adjacent G3 and G4 trials. The two environments differ only in the provision of irrigation of the G4 site. A subset of 26 genotypes (including checks, high yielding lines and putative low aflatoxin risk lines) was evaluated. TAG 24 and some of the AX2 lines blanched as well as Conder (Table 7), the best commercial check variety.

Both TAG 24 and AX2-92 are good prospective parents, having early maturity, moderate yield potential, good blanchability and possibly traits conferring lower aflatoxin risk. Parent ICGV 86031 is not consistent across the two environments. The reasons for this are not clear, but some AX2 lines blanched badly and may have inherited this feature from ICGV 86031. This is therefore a concern if ICGV 86031 is used as a parent to donate high TE to breeding populations in Australia.

Streeton and CSMG 84-1 both blanched poorly, so the poor blanchability of the AX1 lines is to be expected. This is disappointing given the excellent yield potential of some of these lines.

Integration into Core Breeding Program

Lines such as TAG 24 and CSMG 84-1 have been used in the core breeding program since 1998. Since then many of the selections from this project have entered the breeding program (Table 8), in particular as ultra-early maturity lines (all from AX2

Table 8. Details of some recent crosses featuring elite progenies from Project CS97/114.

Year	Cross #	Female	Male	'Purpose' of Cross
2001	B336	AX1-280	Streeton	Streeton x better TE
2001	B337	AX1-280	TKG 19A	Early, drought traits
2001	B338	AX2-92	TKG 19A	Early, drought traits
2001	B339	AX3-77	TKG 19A	Early, drought traits
2001	B340	AX4-590	Streeton	Streeton x better TE
2001	D161	AX2-92	D123-p31	Early, drought traits
2001	D162	AX3-77	D123-p31	Early, drought traits
2001	D166	D106-p7	AX1-280	hiO Streeton x traits
2001	D167	D106-p7	AX4-590	hiO Streeton x traits
2002	D175	D48-4-p4-2	AX2-92	hiO early
2002	D176	D91-p8-11	AX2-92	hiO early
2002	D181	D48-4-p4-2	AX1-227	hiO Streeton + traits
2002	D182	D48-4-p4-2	AX3-77	hiO Streeton + traits

ICGV 86031 x TAG 24) and lines with high yield potential (mostly from AX1 Streeton x CSMG 84-1). Most are being crossed to high oleic parents (considered a mandatory requirement for the Australian peanut industry).

In addition, trait-based index selection is being employed for the first time in the core breeding program, with a high oleic breeding population based on Streeton x Conder germplasm. This will only be used in cases where the parents are known to differ substantially in T, TE or HI. The index in this case will be composed of kernel yield, TE and possibly kernel-grade characteristics.

Reference

Rachaputi, N.C. and Wright, G.C. 2003. The physiological basis for selection of peanut genotypes as parents in breeding for improved drought resistance. These Proceedings.

Multi-location Analysis and Cost-benefit Analysis

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Environmental characterisation of experimental sites

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Multi-environment analysis for Indian sites

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Multi-environment analysis for Queensland sites

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Cost-benefit analysis

Multi-location trials at Coalstoun Lakes
in S.E. Queensland, Australia.

Multi-location trials at ICRISAT Centre, Andhra Pradesh, India.

Aflatoxin genotype resistance screening plots at ICRISAT Centre, Andhra Pradesh, India.

Environmental Characterisation of Experimental Sites in India and Australia

N.C. Rachaputi[1]

Introduction

IN INDIA AND AUSTRALIA the peanut crop is grown in geographically and environmentally diverse agro-climates. In the present ACIAR project, breeding and selection centres are located at four locations in India (Tirupati, ICRISAT, Jalgaon and Junagadh) and one location in Queensland, Australia (Kingaroy), which represents a major peanut production region. However, the evaluations of final selections were carried out in a wider range of target environments in India (14) and Australia (7) (Table 1).

As described in other papers in these Proceedings, for example Basu *et al*. (2003), there was a significant variation in yield within and across locations, which represented significant 'environmental' effects. In the Multi-location Trial (MLT) sites, peanut crops have been protected from nutrient and biotic stresses, and hence, water is considered to be the major environmental factor contributing to the observed variation in yield. However, even in 'irrigated' trials, water requirements of the crops have often not been fully met, resulting in moderate to severe crop water

Table 1. Experimental sites used for Multi-location Location Trials during 2000 and 2001 growing seasons in India and Australia.

India		Australia
Rainy season (June–Nov 2000)	**Post-rainy – Irrigated (Dec 2000–Apr 2001)**	**Summer-autumn (Nov 2000–May 2001)**
Vriddhachalam (RF)	Vriddhachalam (IRR)	Tabinga-G3 (IRR)
Tirupati (RF)	Tirupati (IRR)	Tabinga-G4 (RF)
Anantapur(RF)		Redvale-M4 (RF)
ICRISAT(RF)	ICRISAT (IRR)	Redvale-J4 (RF)
ICRISAT(Irr)	ICRISAT (Mid Drt)	C. Lakes (RF)
Jalgaon (RF)		Jalgaon (IRR)
Wooroolin (RF)		
Junagadh (RF)	Junagadh (IRR)	Kairi (RF/IRR)
Udaipur (RF)		
Total Envs = 8	Total Envs = 6	Total Envs = 7

Notes: RF = rain-fed; IRR = irrigated;
MidDrt = mid-season drought imposed by withholding irrigation.

[1] QDPI, Kingaroy PO Box 23, Kingaroy, Queensland, Australia

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deficits. Therefore, to gain a better understanding of G x E effects on yield, it is necessary to characterise the water availability at each site and assess how the variations in water availability patterns may have influenced the G x E interaction for pod yield.

The focus of this paper is to characterise the plant-extractable water pattern at each site and explore the possibility of clustering the MLT environments based on similar water stress patterns.

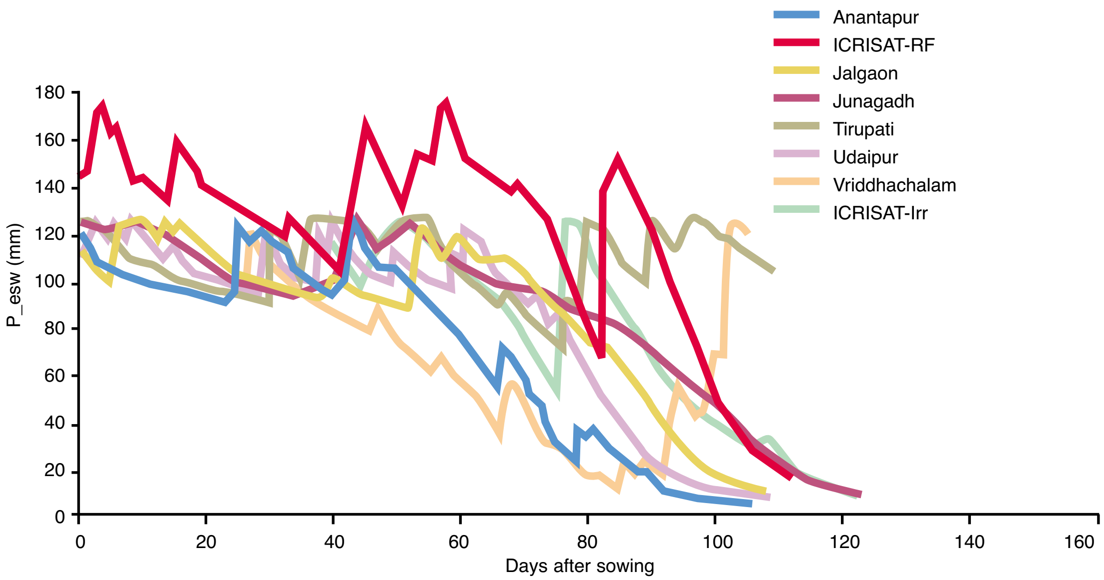


Figure 1. Plant Extractable Soil Water (P_esw) patterns at MLT sites in India during the 2000 season.

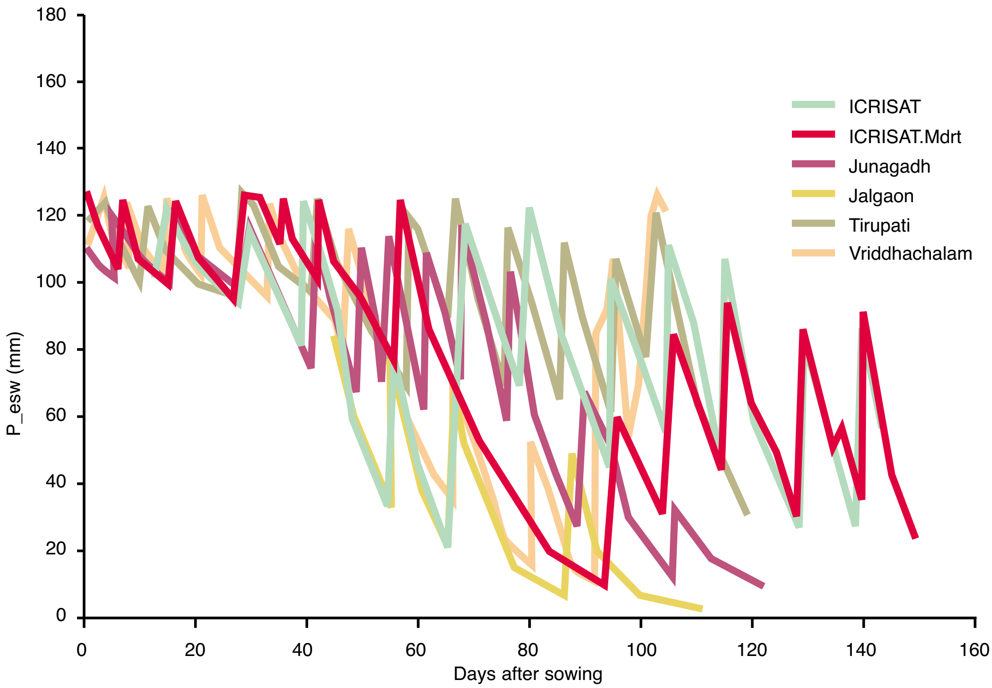
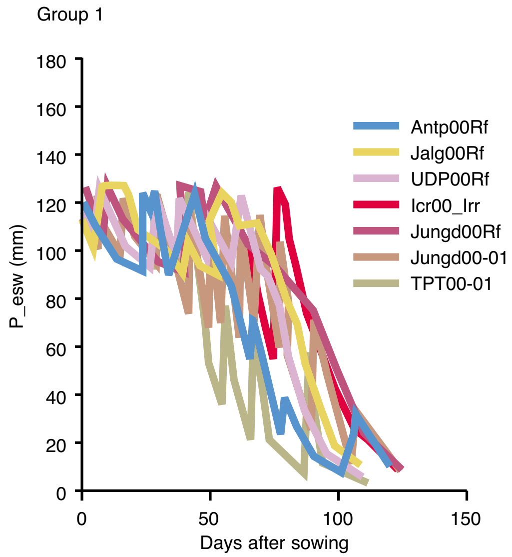


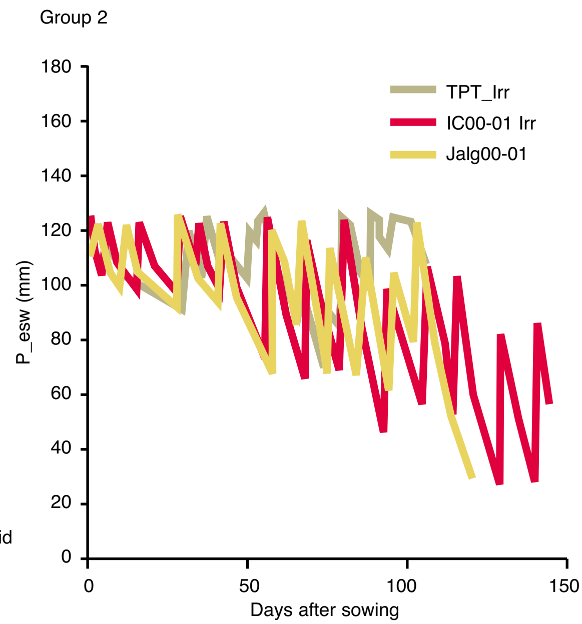
Figure 2. Plant Extractable Soil Water (P_esw) patterns at MLT sites in India during the 2000-01 season.

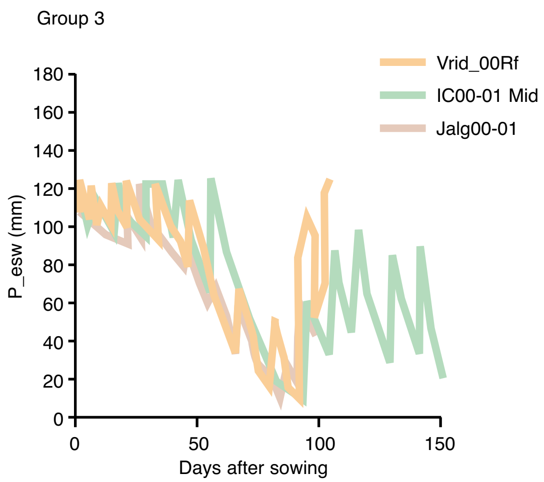


Methods

Analysis of plant-extractable soil water

The APSIM peanut model (Hammer *et al*. 1995) was used to compute daily changes in plant extractable soil water (P_esw) at each site, by using climate parameters (ambient temperature, radiation, rainfall or irrigation amounts), soil hydraulic parameters and crop parameters (planting and harvest dates).





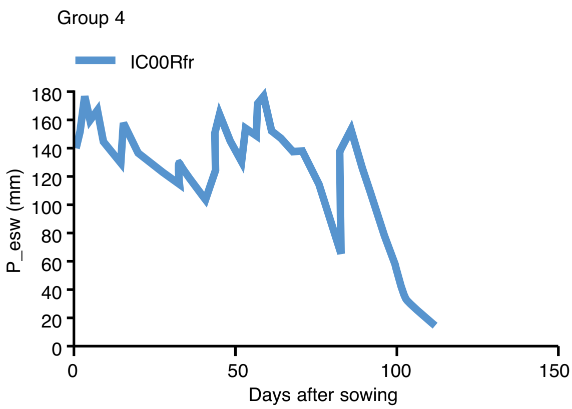


Figure 3. Cluster analysis of the P_esw patterns in MLTs in India during the 2000 rainy and 2000-01 post-rainy seasons. P_esw patterns in MLTs within each of the four groups are presented.

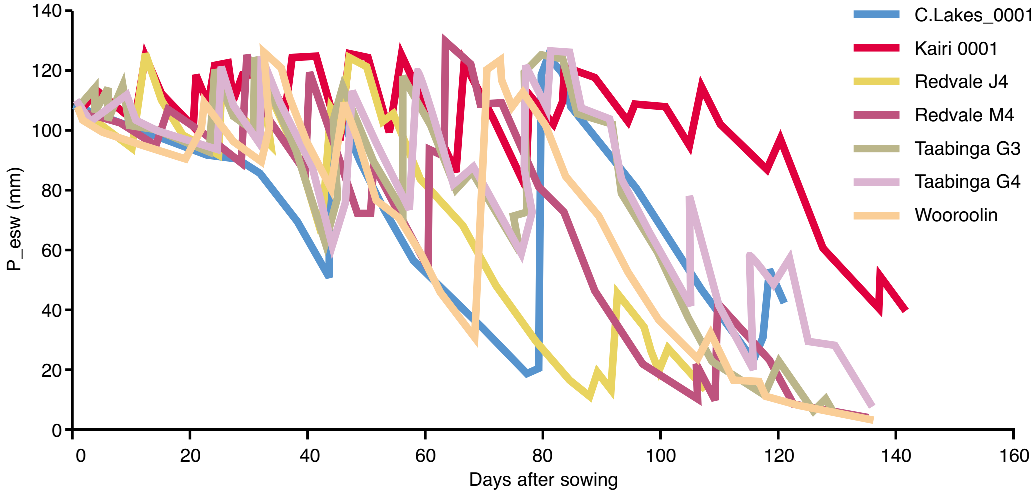


Figure 4: Plant Extractable Soil Water (P_esw) patterns at MLT sites in Australia during the 2000-01 growing season.

Table 2. Membership of each of four groups identified based on P_esw pattern experienced by the crops during July 2000 to May 2001 seasons in Multi-location sites in India and Australia.

Clusters	**India (14 Environments) 2000 & 2000-01 seasons**	**Australia (7 Environments) 2000-01 season**
Group 1	Anantapur-00RF	Tabinga-G3
	Jalgaon 00RF	Kairi
	Udaipur 00RF	Tabinga G4
	ICRISAT-00 IRR	
	Junagadh-00RF	
	Junagadh 00-01	
	Tirupati 00-01	
Group 2	Tirupati-00RF	Coalstoun Lakes
	ICRISAT 00-01 IRR	
	Jalgaon-00-01 IRR	
Group 3	Vriddhachalam 00RF	Redvale M4
	ICRISAT00-01Mdrt	Wooroolin
	Vriddhachalam 00-01 IRR	
Group 4	ICRISAT-00RF	Redvale J4

Notes: RF = rain-fed; IRR = irrigated;
MidDrt = mid-season drought imposed by withholding irrigation.

Statistical analysis

The relationship between daily changes in P_esw during the growing season was quantified for each site-season combination by using polynomial equations. The regression coefficients were used to cluster environments with similar P_esw patterns, using techniques described by Muchow *et al*. (1996).

Results and Discussion

MLT Environments in India

In India, multi-location trials were conducted at eight locations during the 2000 rainy season, and six locations during the 2000-01 post-rainy season. The environments differed widely in amount and distribution of rainfall during both seasons, resulting in significant variation in P_esw patterns between locations (Figures 1 and 2).

Although the trials in the 2000-01 post-rainy season were irrigated, the P_esw curves show that there were periods when crops experienced significant deficits in water availability. Such periods depended on timing and amount of irrigation and also evaporative demand. The result was severe drought stress conditions for many of these crops (Figure 2).

The P_esw curves generated for the 14 Indian MLT environments (8 rainy + 6 post-rainy seasons) were subjected to principal component analysis and cluster analysis in order to identify groups of environments with similar P_esw patterns. The clustering analysis showed that 96 per cent of the variation could be accounted for by clustering them into four groups (Table 2). As an example, the similarity in P_esw patterns within each group is illustrated in Figure 3.

MLT Environments in Australia

In Australia, the multi-location experiment was conducted during the 2000-01 season at seven sites (Table 1). The P_esw was computed using APSIM peanut model (Figure 4), and the P_esw patterns were subjected to cluster analysis. The analysis revealed

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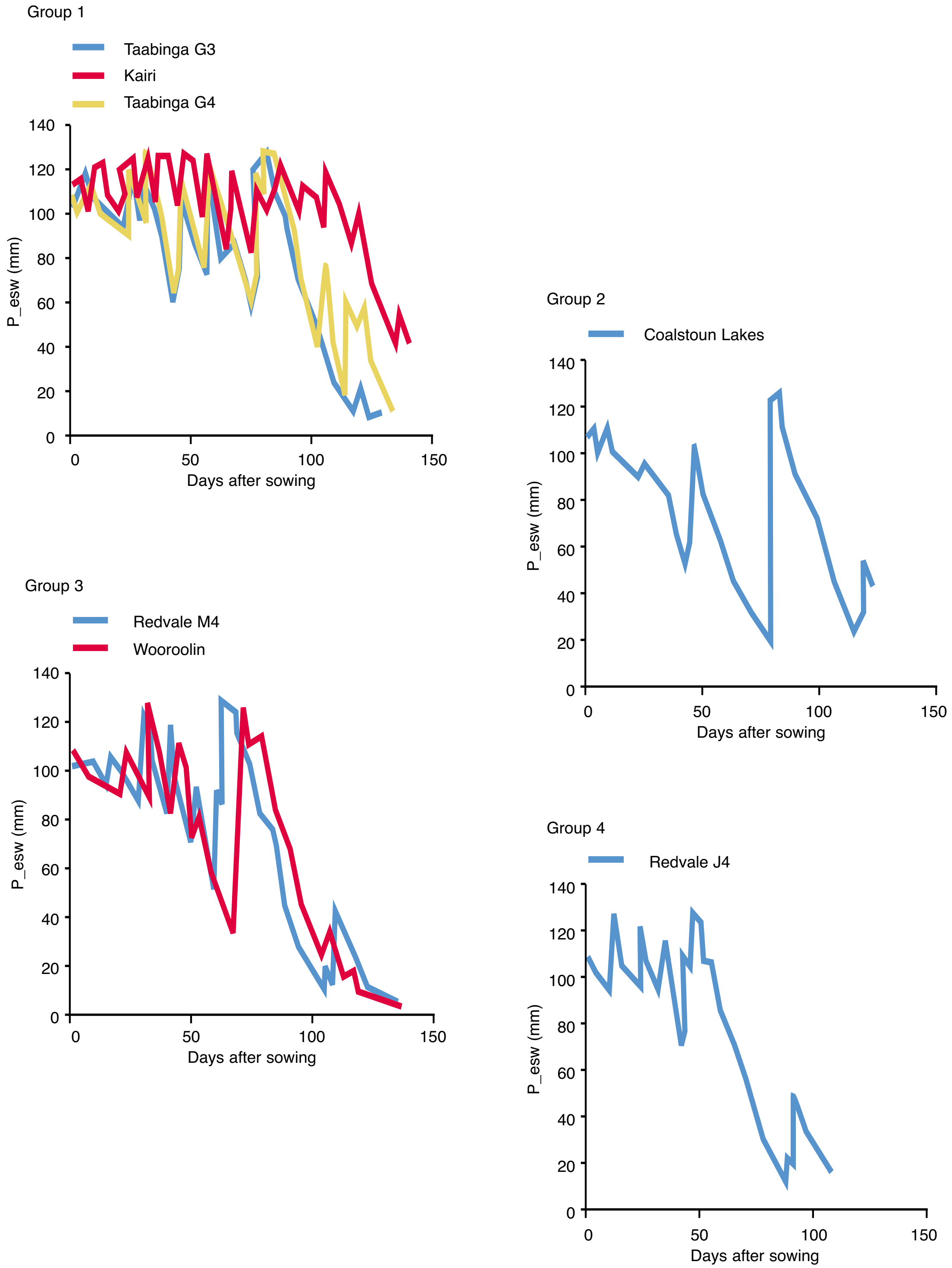

Figure 5. Cluster analysis of the P_esw patterns in MLTs in Australia during the 2000-01 growing season. P_esw patterns in MLTs within each of the four groups are presented.

that the seven environments could be clustered into four groups which accounted for at least 98 per cent of the variation (Table 2 and Figure 5).

Conclusion

The results from the P_esw characterisation of experimental sites has clearly shown that the crops grown in MLTs have experienced a wide variation in timing, intensity and duration of crop water-deficits during the growing season. It is expected that quantification of the P_esw during the growing season and clustering of environments based on P_esw patterns can assist in understanding the basis of G x E interactions for yield between clusters, and to examine the effect of breeding methods on yield variation within each of the clusters.

Acknowledgments

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F4 progeny rows showing good variation for drought tolerance traits at QDPI, Kingaroy, QLD, Australia.

At the inauguration ceremony for the new ACIAR-funded boundary fence at Jalgaon Oilseeds Research Station, Maharashtra, India (*from left*: Dr M.P. Deshmuck, Dr R.B. Patil, Dr G.C. Wright).

Multi-environment Analysis for Indian Sites

S.N. Nigam, S. Chandra, K. Rupa Sridevi and Manohar Bhukta[1]

Introduction

GENOTYPE-BY-ENVIRONMENT interactions (GEI) are ubiquitous for quantitative traits of economic importance. Significant GEI tends to hinder genetic progress in a breeding program; in particular, the crossover type of GEI makes it difficult to unambiguously select promising materials that perform consistently better across a wide range of environmental conditions. The first step to deal with the consequences of the presence of GEI is to assess its relative importance through a pooled analysis of data across the testing sites.

Method

Pooled analysis over Indian environments was performed for kernel yield (KY), total transpiration (T), transpiration efficiency (TE), and harvest index (HI) to assess the relative importance of different sources of variation, in particular that of the interaction of major factors like genotypes (G), selection methods (S) and crosses (C) with environments (E). There were 14 environments in total, eight in the kharif (rainy) season and six in the rabi (post-rainy) seasons. These were stratified into four clusters based on water availability as indicated by Rachaputi (2003). Pooled analyses were conducted clusterwise over all 14 environments.

Using the genetic concept of predicted response to selection, predicted selection efficiency of trait-based selection relative to empirical selection was computed:
- for each environment;
- over all 14 environments; and
- for each cluster of environments.

This was used as a measure of potential for further improvement by selection among progenies.

[1] ICRISAT, Patancheru, Andhra Pradesh, India

Biometric analysis

Observation Y_{ijkl} on genotype i recorded in block j of replication k in environment l was modelled as:

$$Y_{ijkl} = \mu + e_l + r_{kl} + b_{jkl} + g_i + (ge)_{il} + e_{ijkl}$$

where:

μ, e_l, r_{kl}, b_{jkl}, g_i, $(ge)_{il}$, and e_{ijkl}, respectively, denote: the general mean; effect of environment, l; effect of replication k within environment l; effect of block j within replication k within environment l; effect of genotype I; effect of interaction of genotype i with environment l; and the residual effect.

All terms in the model, except μ, were assumed to be random. Each random effect was assumed to be identically and independently normally distributed, with a mean of zero and a constant variance. The unbiased estimates of variance components for each random effect were obtained using the restricted maximum likelihood (ReML) method in GenStat computing software. Where necessary, best linear unbiased predictions (BLUPs) were obtained. The plant population was used as a covariate to adjust the estimates for varying plant populations.

As the 192 genotypes were bred from two selection methods (S) and eight crosses (C), with S and C being cross-classified, the genotypes were appropriately grouped into S and C to assess the differences among selection methods and crosses and their interaction (SxC). These effects were assumed to be fixed. Their best linear unbiased estimates (BLUEs) were obtained using ReML. Interaction effects of S and C with E, with E assumed as random, become random. The unbiased estimates of variance components of these random interaction effects were obtained using ReML.

The statistical significance of estimates of variance components was tested using their respective standard errors assuming an asymptotic normal distribution. The significance of differences among levels of a fixed-effects-factor was tested using the Wald statistic that follows an approximate χ^2 distribution.

Results and Discussion

Components of variance

Table 1 presents the estimates of variance components for the four traits for environments (σ_e^2), genotypes (σ_g^2), GxE (σ_{ge}^2) and residuals (σ_e^2) obtained from data from 14 environments and 192 $F_{2.6}$ progenies. All traits exhibited significant variation among environments, genotypes, and genotype-by-environment interactions. The environments represented the major source of variation, followed by genotype-by-environment interactions, and then genotypes. This is in line with what

Table 1. Estimates of variance components (VC) based on 14 environments and 192 $F_{2:6}$ progenies.

VC	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_e^2	302726*	9x10-3**	215x10-3**	60025*
σ_g^2	17571***	0.6x10-3***	6x10-3***	805***
σ_{ge}^2	107769***	1x10-3***	7x10-3***	6994***
σ_e^2	129046	1.5x10-3	10x10-3	3069

Notes: *P<0.05, **P<0.01, ***P<0.001

Table 2. Estimates of variance components for Cluster 3 (Vriddhachalam-rainy, Vriddhachalam-post-rainy, ICRISAT-post-rainy-Midseason) based on 192 $F_{2:6}$ progenies.

VC	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_e^2	132485ns	17x10-3ns	28x10-3ns	56062ns
σ_g^2	14802**	0.1x10-3*	4x10-3***	1725*
σ_{ge}^2	77076***	1x10-3***	3x10-3***	12305***
σ_e^2	77272	0.9x10-3	2.5x10-3	2078

Notes: ns:non-significant at .05 level of significance; *P<0.05, **P<0.01, *** P<0.001

Table 3. Estimates of variance components for Cluster 1 (Anantapur-rainy, ICRISAT-rainy-irrigated, Jalgaon-rainy, Junagadh-rainy, Udaipur-rainy, Junagadh-post-rainy, Tirupati-post-rainy) based on 192 $F_{2:6}$ progenies.

VC	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_e^2	455424ns	8x10-3ns	159x10-3ns	22813ns
σ_g^2	22156***	0.9x10-3***	7x10-3***	255**
σ_{ge}^2	102913***	0.8x10-3***	7x10-3***	2346***
σ_e^2	139418	1.7x10-3	12x10-3	2733

Notes: ns : non-significant at 0.05 level of significance; **P<0.01, ***P<0.001

Table 4. Estimates of variance components for Cluster 2 (Tirupati-rainy, ICRISAT-post-rainy-irrigated, Jalgaon-post-rainy) based on 192 $F_{2:6}$ progenies.

VC	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_e^2	319362ns	11.0x10-3ns	387x10-3ns	100703ns
σ_g^2	10257ns	0.5x10-3***	1x10-3***	1703**
σ_{ge}^2	174458***	1.0x10-3***	1x10-3***	14304***
σ_e^2	132506	1.0x10-3	2x10-3	4715

Notes :ns: non-significant at 0.05 level of significance; **P<0.01, ***P<0.001

Table 5. Difference among selection methods, crosses, and their interactions, and estimates of variance components based on 14 environments and 192 $F_{2:6}$ progenies for KY.

Effect	Wald Statistic	VC Estimate
S	ns (P>0.05)	-
C	P<.001	-
SxC	ns (P>0.05)	-
σ_e^2	-	271 419*
σ_{Se}^2	-	0.64×10^{-3ns}
σ_{Ce}^2	-	35 878***
σ_{SCe}^2	-	0.14×10^{-3ns}

Note: ^{ns}: non-significant at 0.05 level of significance; *P<0.05, **P<0.01, ***P<0.001

has usually been observed in multi-environment trials in most crops. The results were similar when the variance components were estimated from 200 genotypes.

Results of cluster-wise pooled analysis for three multiple-environment clusters (Rachapuh, 2003) are presented in Tables 2–4. Results of Cluster 4 are not shown as it had only a single environment (ICRISAT rain-fed, rainy season).

As a result of environmental classification, the variation among environments within clusters became non-significant in all clusters for all four traits. This outcome needs to be viewed with caution, as sample size (the number of environments) in individual clusters is small giving a less precise estimate of variance

Table 6. Top 20 Progenies or Parents' Mean over all Indian sites.

Rank	Progeny or Parent	Selection Method	KY (kg/ha)	HI	TE (g/kg)	T (mm)
1	JAL 30	Emp	2153	0.27	2.16	438.60
2	JAL 01	Trait	2111	0.26	2.15	460.70
3	TIR 31	Emp	2096	0.26	2.10	470.00
4	JAL 29	Emp	2095	0.25	2.14	477.70
5	ICR 24	Trait	2093	0.28	2.07	454.50
6	ICR 39	Emp	2084	0.28	1.93	455.80
7	ICR 09	Trait	2083	0.29	2.09	424.30
8	ICR 45	Emp	2079	0.29	2.03	438.60
9	ICR 43	Emp	2077	0.28	2.09	472.70
10	JAL 13	Trait	2073	0.26	2.17	457.10
11	TIR 16	Trait	2072	0.28	1.98	440.70
12	ICR 40	Emp	2070	0.27	1.99	531.60
13	TIR 18	Trait	2068	0.27	1.98	452.40
14	ICR 07	Trait	2064	0.27	2.11	451.00
15	JUG 13	Trait	2055	0.26	2.20	450.00
16	JAL 15	Trait	2044	0.26	2.19	431.60
17	ICR 13	Trait	2034	0.25	2.06	488.10
18	JAL 02	Trait	2027	0.24	2.17	473.60
19	JUG 03	Trait	2019	0.27	2.18	435.00
20	JAL 05	Trait	2014	0.27	1.97	474.10
	ICGS 76		2046			
	ICGS 44		1949			
	TAG 24		1853			
	CSMG 84-1		1766			
	ICGV 86031		1765			
	GG 2		1744			
	JL 220		1702			
	K 134		1645			
	LSD (5%)		148.6	24.44	0.044	0.017
	Mean	Emp (n = 7)	2093	469.30	2.06	0.27
		Trait (n = 13)	2058	453.30	2.10	0.26
	Maximum	Emp	2153	531.60	2.16	0.29
		Trait	2111	488.10	2.20	0.29
	Minimum	Emp	2070	438.60	1.93	0.25
		Trait	2014	424.30	1.97	0.24

component σ_e^2. The general trend of relative magnitude of variation for E, GxE, and G remained nearly similar to that in Table 1 for all 14 environments analysed together. A casualty of clustering was the absence of significant genetic variation for KY in Cluster 4.

Methods, crosses, and interactions

The results of statistical significance of difference among selection methods, crosses, and their interactions with environments, and estimates of variance components for SxE, CxE, and SxCxE are presented in Table 5 for KY for 14 environments and 192 $F_{2.6}$ progenies.

The two selection methods, trait-based and empirical, did not significantly differ from each other. There were large and significant differences among the eight crosses. There was no significant interaction between selection methods and crosses. The crosses significantly interacted with environments. The two selection methods, however, did not exhibit significant interaction with environments, indicating a similar performance of the two methods in each of the 14 environments.

Empirical v trait-based selection

The top 20 progenies (ca.10% of 192) for KY that were significantly superior (P<0.05) to parents are listed in Table 6. The first-ranked progeny JAL 30, an empirical selection, had KY of 2153 kg/ha, whereas the 20th ranked progeny JAL 05, a trait-based selection, had KY of 2014 kg/ha. The frequency of empirical and trait-based progenies among these top 20 progenies was 7/20 for empirical and 13/20 for trait-based. The eight parents/checks differed in their KY from 1645 kg/ha (K 134) to 2046 kg/ha (ICGS 76). None of the top 20 progenies differed significantly (P>0.05) from ICGS 76. Only the first-ranked and second-ranked progenies (JAL 30 & JAL 01) had significantly higher KY (P<0.05) than the second best

Table 7. Predicted Relative efficiency of trait-based selection (RE_T) for KY in 14 Indian environments for 96 $F_{2:6}$ progenies.

Parameter	*ATP-K*	*ICR-IR-K*	*ICR-RF*	*JAL-K*	*JUN-K*	*TIR-K*	*UDAI-K*
$\sigma_g^2(E)$	26 159**	68 760**	32 591^{ns}	48 542**	62 339**	65 038***	295 619***
$\sigma_g^2(T)$	19 608^{ns}	55 353*	49 736**	56 389***	82 339***	57 945***	280 031***
$h^2(E)$	0.449	0.422	0.300	0.456	0.503	0.583	0.948
$h^2(T)$	0.330	0.365	0.440	0.524	0.630	0.574	0.924
RE_T	**0.742**	**0.834**	**1.495**	**1.155**	**1.286**	**0.937**	**0.961**

Parameter	*VRI-K*	*ICR-IR-R*	*ICR-MD*	*JAL-R*	*JUN-R*	*TIR-R*	*VRI-R*
$\sigma_g^2(E)$	84 398***	267 176***	99 210***	166 677***	201 914***	138 816***	90 755***
$\sigma_g^2(T)$	89 001***	390 542***	53 487*	152 826***	251 083***	162 425***	129 201***
$h^2(E)$	0.973	0.754	0.583	0.912	0.854	0.724	0.995
$h^2(T)$	0.974	0.810	0.405	0.918	0.915	0.752	0.994
RE_T	**1.028**	**1.254**	**0.612**	**0.961**	**1.154**	**1.103**	**1.192**

Notes: ^{ns}: non-significant at 0.05 level of significance; * P<0.05, **P<0.01, ***P<0.001; E = empirical. T = trait-based.

Table 8. Relative efficiency of trait-based selection (RE_T) for KY in pooled environments for 96 $F_{2:6}$ progenies.

Parameter	Rainy season	Post-rainy season	All 14	Cluster 1	Cluster 2	Cluster 3	Cluster 4
$\sigma_g^2(E)$	9 053*	29 333***	16 289***	32 591^{ns}	13 105^{ns}	18 022**	7 712^{ns}
$\sigma_g^2(T)$	12 346**	21 529**	18 676***	49 736**	14 488^{ns}	25 761***	9 486^{ns}
$\sigma_{ge}^2(E)$	77 260***	131 924***	103 614***	-	78 470***	102 965***	159 553***
$\sigma_{ge}^2(T)$	74 776***	168 994***	114 006***	-	76 097***	104 042***	191 440***
$h^2(E)$	0.367	0.501	0.606	0.300	0.277	0.453	0.099
$h^2(T)$	0.451	0.378	0.625	0.440	0.295	0.543	0.106
RE_T	**1.29**	**0.744**	**1.087**	**1.495**	**1.086**	**1.308**	**1.144**

Notes: ^{ns}: non-significant at 0.05 level of significance; *P<0.05, **P<0.01, ***P<0.001; Cluster 1: ICR-RF; Cluster 2: VRI-K, ICR-MD, VRI-R; Cluster 3: ATP-K, JAL-K, UDA-K, ICR-K, JUN-K, JUN-R, TIR-R; TIR-K, ICR-R, JAL-R; RE_T.: Efficiency of T relative to E.

parent (ICGS 44, KY = 1949 kg/ha). All top 20 progenies, however, had significantly higher KY ($P<0.05$) than the other parents (CSMG 84-1, TAG 24, ICGV 86031, GG 2, JL 220 and K 134).

Mean T, TE, and HI for the top 20 high-yielding progenies are presented in Table 6. On average, the seven empirical progenies had higher KY, higher T, lower TE, and nearly equal HI relative to the 13 trait-based progenies. The maximum and minimum values of T (531.6 - 438.6 = 93.0 mm) for empirical progeny were higher than that (488.1 - 424.3 = 63.8 mm) for trait-based progenies. The reverse was true for TE, with trait-based progenies having generally higher TE values. The range of HI values was similar for both trait and empirical progenies. Thus, trait-based progenies had relatively lower KY, but generally exhibited higher TE values than empirical progenies.

Potential for Further Improvement

The predicted selection efficiencies for KY, based on predicted response to selection, are presented in Table 7 for individual environments and in Table 8 for environments pooled or clustered in different ways.

Grouping of 14 environments into two classes – rainy season and post-rainy season – shows that the trait-based selection method has more potential for improvement in the rainy season, but not in the post-rainy. This happens because in the rainy season this material generates a higher genetic variance, lower GxE interaction variance, and hence higher heritability. Taken over all 14 environments, the two selection methods more-or-less perform the same with RE_T being 1.087. Classification of the 14 environments into four clusters according to pattern of water availability shows trait-based selection to be generally superior to empirical. This is because of an increase in genetic variance and heritability under trait-based selection resulting from this water-availability-based grouping of the environments.

This predictable outcome is consistent with the raison d'être of the project – trait-based selection would be expected to select genotypes that will express greater genetic variance and less GEI over environments differing in available water.

Reference

Rachaputi, N.C. (2003). Environmental characterisation of experimental sites in India and Australia. These Proceedings.

Taking biomass samples from QDPI, Kingaroy, QLD, Australia.

Boundary fence installed by the project at Jalgaon Oilseeds Research Station, Maharashtra, India.

Multi-environment Analysis for Queensland Sites

A.W. Cruickshank, G.C. Wright, N.C. Rachaputi and S. Foster[1]

Introduction

SELECTIONS WERE EVALUATED over multiple sites because of the importance of genotype-by-environment interaction in genetic improvement of peanuts. Therefore it is important to assess whether differences among selections are consistent across peanut production environments. The sample of environments used in the Queensland evaluation did not include all peanut production regions. Six of the seven sites were in the Burnett region of southern Queensland, where most of the Australian rain-fed peanut production occurs. The seventh site, at Kairi in North Queensland, differs in latitude and altitude, but has a similar soil-type to the Burnett sites. Irrigation and planting date were used to create environmental variation among close trial sites at the Kingaroy research station in the Burnett.

Cross-site Factor Analysis

At each site spatial analysis was used to increase precision of comparison of genotypes. Factor analysis was employed to include all the spatial information in the analysis of the MET. The best-fit spatial model for each site was included in a complex factor model together with: selection method; environment within the trait selection method; cross; site; and all interactions. There were significant differences among genotypes for all traits (Kernel Yield per hectare, HI, T and TE) at all sites. In addition to the testing for differences between selections from different breeding methods, the data was also tested for differences between crosses, sites and the interaction of them with breeding methods.

Probabilities of type-1 error for these sources of variation are presented in Table 1. Both sites and crosses influenced all traits significantly. The average performance of all selections unique to the empirical method versus those unique to the trait method did not differ significantly for Kernel Yield, HI and T but there was a highly significant difference in TE. There were significant interactions between site and selection method for HI and T.

[1] Agency for Food and Fibre Sciences, QDPI, Kingaroy, Queensland, Australia

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Table 1. Probabilities of Type 1 Error for different factors from the MET.

Source/Factor	KY (kg/ha)	HI	TE (g/kg)	T (mm)
Site	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Cross	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Selection method	0.448	0.239	**<0.001**	0.328
Selection environment	0.320	0.707	0.744	0.390
Site: Selection method	0.098	**0.032**	0.148	**0.015**
Site: Selection environment	0.143	0.944	0.562	0.630
Cross: Selection method	0.231	0.995	0.307	0.321
Cross: Selection environment	0.760	0.959	0.837	0.273
Site: Cross: Selection method	0.360	0.980	0.934	0.798
Site: Cross: Selection environment	0.703	0.279	0.480	0.508

Note: Significant probabilities are highlighted by bold type (P<0.01).

The unique trait selections exceeded the unique empirical ones in TE (Table 2). This indicates that the two breeding methods were equally efficient in selecting for yield, HI and T, but the trait-based approach was more efficient in selecting for higher TE. This is not simply an artefact of greater precision in TE, as the probabilities for the other traits are nowhere near significant, and that for TE is highly significant.

Many earlier studies have highlighted the negative association between TE and HI (and hence frequently a negative association between TE and yield). It appears that the selection index in the trait-based method was able to retain genotypes that were rejected in early generations by empirical selection for yield. The next logical question is: Why doesn't this difference result in a significant yield improvement? There are small non-significant differences in mean HI and T that counter-balance the increase in TE. A greater sample from the target population of environments would be required to state with assurance that there are no environments where higher TE would confer a yield advantage or disadvantage, but it is unlikely that the mean yield in all environments would become significantly different with a larger sample.

Table 2. Means of selection methods and trait selection environments.

	KY (kg/ha)	HI	TE (g/kg)	T (mm)
Empirical	2309[a]	0.27[a]	2.71	362[a]
Trait	2235[a]	0.26[a]	2.78[a]	354[a]
Trait-Rain-fed	2288[a]	0.27[a]	2.77[a]	353[a]
Trait-Irrigated	2241[a]	0.26[a]	2.77[a]	356[a]

Note: Means in a column with the same letter are not significantly different (P<0.01).

In no circumstance or interaction was the difference between trait-based and empirical selection in a rain-fed or irrigated environment significant. Lack of effect of selection environment is an encouraging result, indicating that the trait-based approach doesn't require a carefully managed environment to achieve similar progress in all traits.

Examination of Variance Components

To calculate classical variance components the following linear model was used;

$$Y_{ijkl} = \mu + e_l + r_{kl} + b_{jkl} + g_i + (ge)_{il} + \varepsilon_{ijkl}$$

where:

μ, e_l, r_{kl}, b_{jkl}, g_i, $(ge)_{il}$, and ε_{ijkl}, respectively, denote: the general mean; effect of environment, l; effect of replication k within environment l; effect of block j within replication k within environment l; effect of genotype I; effect of interaction of genotype i with environment l; and the residual effect.

All terms in the model, except μ, were assumed to be random. Each random effect was assumed to be identically and independently normally distributed with a mean of zero and a constant variance. To meet this assumption and to restrict inference to the selected material, the checks and parents were excluded. The unbiased estimates of variance components for each random effect were obtained using the restricted maximum likelihood (ReML) method in GenStat computing software.

In all cases the variance due to site was greater than that due to genotypes, which was in turn greater than the variance due to interaction of genotype and site. For HI and yield, σ_G^2 was less than twice σ_{GE}^2. For TE and T, σ_G^2 was more than twice σ_{GE}^2. This was consistent with earlier reports of traits (particularly TE) being more stable over environments than kernel yield (Table 3).

Table 3. Variance components from the multi-site analysis (checks excluded).

Variance Component	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_E^2	323 042	2.81×10^{-3}	342.6×10^{-3}	8 674
SE	190 177	1.67×10^{-3}	217.2×10^{-3}	5 585
σ_G^2	96 447	0.64×10^{-3}	4.56×10^{-3}	2 064
SE	17 800	0.13×10^{-3}	0.89×10^{-3}	383
σ_{GE}^2	58 961	0.37×10^{-3}	1.82×10^{-3}	644
SE	5 954	0.09×10^{-3}	0.45×10^{-3}	138
σ_e^2	112 366	3.47×10^{-3}	14.92×10^{-3}	4 414
SE	4 149	0.13×10^{-3}	0.59×10^{-3}	175

Notes: σ_E^2: Variance component due to Environments as a source of variation

σ_G^2: Variance component due to Genotypes (Genetic variance)

σ_{GE}^2: G x E interaction variance

σ_e^2: Residual or Error variance

SE: standard error of the corresponding variance component

Table 4. Variance components from the cluster 1 sites (checks excluded).

Variance Component	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_E^2	291 733	3.907×10^{-3}	296.2×10^{-3}	1 480
SE	302 511	4.01×10^{-3}	362.4×10^{-3}	3 416
σ_G^2	72 448	0.314×10^{-3}	3.845×10^{-3}	2 424
SE	17 772	0.12×10^{-3}	0.92×10^{-3}	548
σ_{GE}^2	66 717	0.277×10^{-3}	3.33×10^{-3}	996
SE	11 822	0.14×10^{-3}	0.59×10^{-3}	315
σ_e^2	134 697	3.321×10^{-3}	6.02×10^{-3}	5 653
SE	7 526	0.18×10^{-3}	0.36×10^{-3}	335

When the same variance components were calculated for Environment Clusters (see Rachaputi 2003) it was thought that σ_{GE}^2 and σ_E^2 would be minimised. Within cluster 1 (Kairi, Taabinga irrigated and Taabinga rain-fed) σ_E^2 was not significant for any trait (Table 4), σ_G^2 and σ_{GE}^2 were of similar magnitude for all except T, where σ_G^2 was greater. Within cluster 3 (Redvale M4 and Wooroolin) σ_E^2 was not significant for any trait (Table 5), σ_{GE}^2 was small to negligible for all traits. The characterisation using environmental data successfully grouped two sites with similar patterns of genotypic performance in the case of cluster 3, but not in the case of cluster 1.

Examination of variance components can also indicate the variation available for further selection. The within group σ_G^2 and σ_{GE}^2 for the two selection methods was used to calculate a predicted relative efficiency of selection. This is just a ratio measure of

Table 5. Variance components from the cluster 3 sites (checks excluded).

Variance Component	KY (kg/ha)	HI	TE (g/kg)	T (mm)
σ_E^2	140 235	0.0004×10^{-3}	872.2×10^{-3}	1 184
SE	202 683	0.07×10^{-3}	1247.05×10^{-3}	1 799
σ_G^2	146 489	0.94×10^{-3}	7.59×10^{-3}	1 120
SE	27 556	0.25×10^{-3}	3.05×10^{-3}	242
σ_{GE}^2	21 402	0.1×10^{-3}	0.005×10^{-3}	0.1874
SE	6 974	0.18×10^{-3}	3.17×10^{-3}	124
σ_e^2	79 978	3.69×10^{-3}	48.26×10^{-3}	1 874
SE	5 531	0.25×10^{-3}	4.04×10^{-3}	157

the potential for further improvement in each group of selections and can be calculated for a group of environments, or a single environment. The potential in the two groups is similar except in Cluster 1, where there appears to be much more potential among the trait selections (Table 6). This appears to be driven by the two Taabinga environments (Table 7). There is no apparent reason for greater expression of genetic variation in these environments, either from theory or examination of the data.

The 20 best selections for kernel yield came equally from the two selection methods (Table 8) and were dominated (16/20) by selections from cross AX1: Streeton x CSMG 84-1. There was one line from AX3 and three from AX4. Despite the success of some AX2 cross material at Coalstoun Lakes, there were no AX2 selections in the overall top 20. Four checks (Conder, NC 7, Streeton and B185-2-p11-4) fell within the range of the top 20 selections. No selections showed significant yield improvement over Streeton (the highest-yielding parent), NC 7 and Conder. Only five selections (all from AX1) were not significantly lower-yielding than Conder.

Among the top 20 for kernel yield, AX1-156 had the highest HI (0.32). Nine selections and the four checks were not significantly lower in HI (Table 8). Neither trait nor empirical selections dominated this group. AX1-253 had the highest TE of the top 20. Three checks and five trait selections were not significantly lower in TE than AX1-253 (which was an empirical selection). Ten selections (3 empirical, 7 trait) were significantly greater than Streeton in TE. AX1-262 (trait) had the highest estimated transpiration, with eight selections (5 empirical, 3 trait) and three checks not significantly lower.

Examination of the top 20 yielding lines supports the conclusion from analysis of all data: that TE is the only trait where the selection methods have had a differential impact.

Table 6. Kernel yield genetic variances within selection methods and relative predicted response to selection – Environmental Clusters.

	Cluster 1	Cluster 3	Cluster 2	Cluster 4	All Sites
σ_G^2 (emp)	34 900	138 244	56 562	236 911	**78 169**
SE	16 859	36 188	17 817	62 263	**20 461**
σ_G^2 (trt)	117 522	157 174	33 681	329 171	**117 542**
SE	35 628	43 025	13 558	88 601	**31 148**
σ_{GE}^2 (emp)	68 726	19 620	-	-	**53 310**
SE	17 154	9 379	-	-	**7 883**
σ_{GE}^2 (trt)	57 463	23 477	-	-	**60 190**
SE	15 311	10 394	-	-	**8 680**
RE_T	**2.327**	**1.071**	**0.7091**	**1.202**	**1.252**

Genotype Clustering using Yield Data

A pattern analysis was conducted on the '83 genotype by 7 environment' kernel yield matrix (the selection which was not at all sites was removed from the data set). Hierarchical clustering was performed using the group average strategy and Squared Euclidean Distance as the dissimilarity measure. The clustering was stopped at the 24 x 7 level, where 97 per cent of the genotype sums of squares and 80 per cent of the genotype-by-environment sums of squares were retained between groups. Membership of groups (Table 9) was compared against selection method and cross.

There were no groups that originated predominantly from either selection method. There were groups that aligned with crosses. Six groups each had two members, both from the same cross. Group 52 consisted of ICGV 86031 and five lines from cross AX2. Nine of the 11 lines in Group 58 were from AX1, the other two being AX3-77 and NC 7. The conclusion that parentage has more impact on the adaptation of lines than selection method is consistent with the argument above that progeny of different crosses had differing potential to be adapted to the cropping system in which they were selected and then evaluated.

Table 7. Kernel yield genetic variances within selection methods and relative predicted response to selection – Individual Sites.

	Kairi (Cluster 1)	Taabinga G4 (Cluster 1)	Taabinga G3 (Cluster 1)	Wooroolin (Cluster 3)	Redvale M4 (Cluster 3)
σ_G^2 (emp)	128832	111184	70650	101632	213841
SE	38299	36639	21746	26776	54369
σ_G^2 (trt)	125852	261841	132197	97932	261120
SE	38598	70237	38996	28513	66768
RE_T	**1.005**	**1.726**	**1.445**	**0.9606**	**1.131**

Table 8. Promising selections over all sites.

	Selection	KY (kg/ha)	Total K*(%)	Oil K*(%)	Wt50k*	HI	TE (g/kg)	T (mm)
Conder		2977	65.7	0.8	45.2	0.30	2.66	416
AX1-156	Emp	2973	70.8	1.1	41.9	0.32	2.51	398
AX1-147	Emp	2961	66.3	1.3	40.3	0.32	2.59	388
Streeton		2957	69.6	1.4	39.5	0.30	2.52	417
NC 7		2948	66.8	0.7	50.4	0.29	2.66	422
AX1-227	Trait	2880	68.1	1.9	35.9	0.30	2.67	391
AX1-253	Emp	2836	69.0	2.3	35.1	0.29	2.70	399
AX1-256	Trait	2802	68.8	1.7	37.1	0.30	2.59	391
AX3-77	Trait	2794	68.4	1.7	37.7	0.29	2.64	398
AX1-18	Emp	2783	69.3	2.0	38.2	0.28	2.58	415
AX1-73	Emp	2771	68.4	1.5	40.5	0.30	2.54	405
B185-2-p11-4		2762	66.4	1.1	45.5	0.31	2.68	356
AX1-134	Emp	2708	68.4	2.2	36.1	0.29	2.62	387
AX1-193	Emp	2699	68.4	1.1	41.4	0.28	2.56	419
AX1-216	Emp	2674	69.0	3.9	30.0	0.29	2.52	403
AX1-262	Trait	2668	67.7	2.3	35.4	0.25	2.59	436
AX1-280	Trait	2666	68.1	1.5	39.5	0.28	2.67	379
AX1-31	Emp	2638	66.9	1.9	33.9	0.27	2.55	409
AX1-185	Trait	2635	66.9	1.5	36.0	0.27	2.67	408
AX1-188	Trait	2618	67.2	2.7	32.6	0.25	2.59	410
AX1-170	Trait	2594	67.8	1.2	40.5	0.28	2.62	379
AX4-390	Trait	2584	69.3	1.6	37.6	0.29	2.61	350
AX4-133	Emp	2556	64.4	1.7	38.4	0.28	2.61	375
AX4-793	Trait	2526	64.7	2.0	36.8	0.26	2.63	405
Grand Mean		2280				0.27	2.73	344
LSD (P<0.05)		151	3.3	1.1	6.7	0.03	0.05	31

*Total K% = All kernel as a % of pod weight; Oil K % = Most immature kernel grade as % of pod weight;
Wt50k = Weight in grams of 50 mature kernels.

TABLE 9. Members of some groups at the 24 group level for genotypes.

Group	No.	Members
Group 2	2	AX1-156 Conder
Group 11	2	AX1-170 AX1-280
Group 15	2	AX4-221 AX4-277
Group 25	2	AX1-147 Streeton
Group 49	5	AX1-100 AX3-98 CSMG 84-1 AX3-191 AX3-248
Group 52	6	AX2-114 AX2-165 AX2-19 ICGV86031 AX2-33 AX2-119
Group 56	4	AX2-92 AX4-47 AX4-253 TAG24
Group 58	11	AX1-134 AX1-262 AX1-193 AX1-73 AX1-185 AX1-188 AX1-18 AX1-256 AX1-227 AX3-77 NC7

A group-by-environment ANOVA was conducted for yield, HI, T and TE (i.e. using the groups from the kernel yield pattern analysis as a source of variation for analysis of all variables). All three component traits show significant effects for groups and sites but only HI and T have significant group by site interaction (Table 10). The highly significant results for groups supports the underlying thesis of this project: that the adaptation of genotypes is associated with heritable differences in these three yield components. The lack of group-by-site interaction for TE once again shows the stability of this trait over environments.

Table 10. Probabilities of a Type 1 Error from ANOVA of TE, HI, and T.

Source	TE	T	HI
Genotype Groups	<0.001	<0.001	<0.001
Sites	<0.001	<0.001	<0.001
Groups x Sites	0.222	0.003	<0.001

Reference

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Cost-benefit Analysis for ACIAR Project CS 97/114: More Efficient Breeding of Drought Resistant Peanuts in India and Australia

R. Strahan[1], G.C. Wright[2], N.C. Rachaputi[2], A.W. Cruickshank[2] and J.R. Page[3]

Introduction

This chapter presents the economic analysis for the joint India/Australia ACIAR project 'More Efficient Breeding of Drought Resistant Peanuts in India and Australia', as outlined in objective 3 of the original project proposal, which aimed

> *to make a quantitative assessment of the cost-benefit of using indirect selection methods compared to conventional yield selection approaches for the identification of drought resistant cultivars.*

The purpose of the analysis is to assess the economic costs and benefits of the two breeding methodologies used during this peanut breeding research. A comparison of the traditional empirical approach was made with the trait-based approach. The costs and resulting trial site yields for these two methods were assessed in both India and Australia at various sites with varying water availability, and under both dryland and irrigated farming systems.

This report also provides an analysis of the research project's breeding program costs and benefits for Indian and Australian peanut industries based upon the yield gains achieved over the trial sites.

The report provides three assessments:

Assessment 1 — Comparison between the Empirical and Trait Breeding Methods

Assessment 2 — Potential Benefit of the Research project to the Indian Peanut Industry

Assessment 3 — Potential Benefit for the Australian Peanut Industry

Background

The peanut industry in Australia produces approximately 35 000 tonnes of kernel per annum, at an on-farm value of A$32m. In India, the peanut industry produces some 5.25 million tonnes of kernel annually over an area of 7.5 million hectares, valued at over 130 billion Rupees (A$4.8b) on farm. Peanut production in both India and Australia is predominantly rain fed and therefore subject to a range of drought conditions. The development of high-yielding, drought-resistant cultivars to ameliorate the effect of drought is an industry priority in both countries.

QDPI, [1] Toowoomba, [2] Kingaroy and [3] Nambour, Queensland, Australia

The yield of peanut in India and Australia is usually severely limited by water deficits during crop growth, arising from unpredictable rainfall, high evaporation and production on soils with a low water-holding capacity. India, which has the world's largest production of peanut, grows most of its crop primarily under rain-fed conditions, where drought can result in very large fluctuations in total production. Similarly, Australian production is mainly based on summer-dominant rain-fed systems, with drought causing substantial reductions in yield and total productivity. Peanut is an important grain legume crop in north-eastern Australia, and its production and market potential are expanding; however the industry has had major problems in maintaining continuity of supply due to drought events.

Traditional breeding methods utilise an empirical approach based on selection for high yield under drought stress conditions in a range of target environments. While such an approach has been successful, it requires large investments in land, labour and capital structure to manage the large numbers of progenies required to identify optimal genetic combinations of drought-adaptive traits.

Yields – Indian & Australian Trial Sites

The economic analysis was performed using gross estimates of kernel yield gain in each test environment from: selections made using trait versus empirical breeding approaches; and yield gain from both T and E selections versus the local checks.

The approach we used involved calculation of a yield gain estimate from each MET (in India and Australia) by:

- empirical v trait-based — taking the 'mean' of the group consisting of 1 x Least Significant Difference (LSD) of the top-yielding selections from both 'trait-based' and 'empirical' breeding methods, and subtracting trait from empirical;
- trait selections v local check — taking the 'mean' of the group consisting of 1 x LSD of the top-yielding selections from trait-based breeding method, and subtracting trait from local checks.

The rationale behind this approach was that the LSD method is a way of being conservative (rather than picking the best few selections), and represents selections that would have been kept after one cycle of multi-environment evaluation. In effect we have assumed that the METs are a third cycle of selection. We argue that any eventual variety releases would most likely be in the top 1 x LSD range, hence a mean of this group represents a reasonable estimate for comparison of 'yield gain'.

A summary of kernel yield results from the MET in India is presented in Table 1 and for the Australian studies in Table 2. The trial sites were selected in different locations in order to sample a variety of growing conditions representative of the peanut industries in both India and Australia. The sites varied in climatic and soil conditions, as well as for seasonal variations, which included both dryland and irrigated cropping systems. A more detailed analysis of the climatic conditions experienced at each site is provided by Rachaputi 2003.

Table 1. Kernel Yields — Indian trial sites (kg/ha).

Research Site	Season	Empirical Yield	Trait-based Yield	Trait – Empirical Difference	Local Check Yield	Average Yield Gain
Anatapur	Rainy season	1220	1220	0	1260	-40
ICRISAT (dry)	Rainy season	2080	2080	0	2560	-480
ICRISAT (dry)	Post-rainy season	2960	2890	-70	2750	140
ICRISAT (irr)	Rainy season	2370	2380	10	2430	-50
ICRISAT (irr)	Post-rainy season	3450	3460	10	3760	-300
Jalgaon	Rainy season	1550	1520	-30	1030	490
Jalgaon	Post-rainy season	2250	2170	-80	1140	1030
NRCG (Junagadh)	Rainy season	2180	2200	20	1650	550
NRCG	Post-rainy season	2010	2040	30	1750	290
Tiriputi	Rainy season	1510	1510	0	990	520
Tiriputi	Post-rainy season	3750	3580	-170	2590	990
Udaipur	Rainy season	4340	4560	220	3720	840
Vriddhachalam	Rainy season	2140	2360	220	1760	600
Vriddhachalam	Post-rainy season	2870	3400	530	2190	1210
Totals		34680	35370	690	29580	5790
Averages		2477.1	2526.4	49.3	2112.9	413.57

India

For India, the trial results demonstrate that the average yields for both the empirical and trait-based methods are significantly higher than that of the average of the yields achieved in the local check plots. The average yield gain over the 14 environments for the trait method over the average of local checks was 413 kg/ha (Table 1).

Expected yield benefit of trait method over empirical method

The average kernel yield difference between the trait and empirical methods across all of the trial sites was 49.3 kg/ha (Table 1). The average of the yields obtained in the local check plots was significantly higher than the average industry kernel yield of 700 kg/ha. In order to determine the economic benefit for the Indian peanut industry of the trait method over the empirical method, it was necessary to express the research results in terms of the industry yield. For this reason the average industry kernel yield (700 kg/ha) was divided by the average local check yield (2113 kg/ha) giving a scaling factor of 0.3313. The kernel yield difference between the trait and empirical methods (49.3 kg/ha) was then multiplied by 0.3313 to express this observed yield difference in terms of an overall industry yield benefit. Thus, the average increase of the trait over the empirical method could then be expressed as an industry yield gain of 16.3 kg/ha, as demonstrated below.

Calculating trait method benefit

Average Industry Kernel Yield (Av KY) = 700 kg/ha
Average Local Check (Av LC) = 2113 kg/ha
Av KY / Av LC = 0.33
Trait minus empirical (from trial results) = 49.3 kg/ha
Trait method gain over empirical method = 16.3 kg/ha (expected commercial gain).

Determining the benefit of the research project to the Indian peanut industry

The average kernel yield derived from the trait selection approach (2526 kg/ha) was 19.6 per cent greater than the average yield of the local checks (2113 kg/ha) (Table 1). In order to determine the benefit of this yield gain to the Indian peanut industry, this analysis assumed that this percentage yield gain could be achieved by the industry. Therefore a 19.6 per cent increase to the average industry kernel yield of 700 kg/ha would result in a yield increase of 137 kg/ha, as demonstrated below. However, the total industry benefit would also depend upon the rate of adoption of the new variety.

Calculating industry benefit

Average Industry Yield = 700 kg/ha kernel yield
Trait method Yield Increase over Local Check = 19.6%
Yield Gain for Industry = Av Industry Yield x Yield Increase % = 137 kg/ha.

Australia

Table 2 presents the kernel yield results for the Australian trial sites. The average yields for both the empirical and trait methods are lower than the average yields achieved in the local check plots. Also, the average kernel yield results for the empirical method are higher than the average kernel yield results for the trait method. This result is inconsistent with the results obtained in the Indian trial sites and may be explained by the fact that the germplasm used in the research was of Indian origin and may not have been as adapted to Australian conditions as local parent material. This issue is discussed more comprehensively earlier in these proceedings (Cruickshank *et al*. 2003).

Table 2. Kernel Yields — Australian trial sites (kg/ha).

Environment	Empirical Yield	Trait-based Yield	Trait – Empirical Difference	Local Check Yield	Average Yield Gain
Red M4	3300	3263	-37	3451	-188
Red J4	4219	4136	-83	4066	70
Taab Irr	3575	3615	40	3902	-287
Taab Dry	2552	2542	-10	2793	-251
Wooroolin	2444	2344	-100	2257	87
C. Lakes	1982	1858	-124	1698	160
Kairi	2845	2594	-251	2941	-347
Totals	20917	20352	-565	21108	-756
Averages	2988.1	2907.4	-80.71	3015.43	-108.00

Research Costs

The costs associated with conducting the two peanut breeding methods were recorded for each of the breeding centres in India and Australia. These are summarised in Table 3.

Assumptions

Determining the area able to be planted to a new variety

With the development of any new peanut variety there is a time lag until commercial production, due to the time needed to produce adequate seed supplies. Table 4 demonstrates the time period necessary and the number of hectares that are possible to plant to a new peanut variety based on a planting rate of 75 kg/ha and a seed increase multiplication rate of 20:1.

Adoption rates

It was noted above that the total industry benefit would depend upon the rate of adoption of the new peanut variety. The following economic assessments consider three possible adoption rates. The scenarios are:

- Scenario 1 — adoption to a maximum of 12.5% of the total cropped area achieved over 6 years.
- Scenario 2 — adoption to a maximum of 25% of the total cropped area achieved over 6 years.
- Scenario 3 — adoption to a maximum of 50% of the total cropped area achieved over 6 years.

Table 5 provides details of the adoption rates for the three scenarios. The first year of adoption is the first year of commercial planting that follows the necessary seed production time in order to plant the area denoted by the adoption rate.

Yield Benefits used in Assessments

Industry Kernel Yield Benefit of Trait over Empirical Breeding Method = 16.3 kg/ha
Industry Kernel Yield increase from new varieties = 137 kg/ha.

Indian Industry Assumptions

On-farm Peanut Kernel Price = 25Rs/kg = 25,000 Rs/tonne
1 Rs Lakh = 100 000 Rs = A$4000
Indian Industry Total Area = 7.5 M hectares.

Economic Analysis Measures (Costs and Benefits)

Net Present Value (NPV) measures the sum of discounted net cash flows of an investment discounted at a nominated discount rate over a period of time. Benefit /Cost Ratio (B/C) measures the ratio of the NPV of benefits to the NPV of costs — how many dollars are gained for each dollar spent over the life of an investment in today's values.

Table 3. Summary of research costs (Rupees, except for AUD at Kingaroy)

	ICRISAT	Tirupati	Junagadh	Jalgaon	Total India	Kingaroy
Trait	1 640 805	607 563	617 150	644 850	3 510 368	65 450
Empirical	1 173 420	218 173	431 150	421 830	2 244 573	21 366
Totals					**5 754 941**	**86 816**
Cost Difference of Trait and Empirical Research Methods (Rs)						
Trait – Emp	467 385	389 390	186 000	223 020	1 265 795	(Rs over 3yrs)
Trait/Empirical	1.4	2.8	1.4	1.5	1.6	3.1

Note:* Total costs of both methods over the project life (3 years)

Table 4. Determining the area able to be planted to a new variety.

Time	Generation	Weight of seed(t)	Hectares
Year 1	1	0.005	0
	2	0.1	1
Year 2	3	2	27
	4	40	533
Year 3	5	800	10 667
	6	16 000	213 333
	7	320 000	4 266 667

Notes: Planting rate = 75 kg/ha
Seed multiplication rate = 20x

Table 5. Adoption Rates expressed as a percentage of total industry cropped area.

Year of Commercial Planting	Scenario 1 Low Rate	Scenario 2 Intermediate Rate	Scenario 3 High Rate
1	0.63	1.2	2.5
2	1.88	3.7	7.5
3	3.75	7.5	15.0
4	6.25	12.5	25.0
5	10.0	20.0	40.0
6	12.5	25.0	50.0
7+	12.5	25.0	50.0

Assessment 1 – Benefit of the Trait Selection Method to the Indian Peanut Industry

The benefit to the Indian peanut industry of the trait versus the empirical method was determined from the difference in costs between the two methods and the average difference in the yield benefit, determined as 16.3 kg/ha. Cost differences were calculated for the three years of research from each of the research sites. The total costs for each year were:

- year 1 — 126 516 Rs;
- year 2 — 506 990 Rs; and
- year 3 — 632 290 Rs.

Table 6 shows the number of hectares commercially planted to the new variety, the extra yield and the extra cash flow according to the adoption rate for Scenario 1.

Table 7 calculates the NPV and B/C ratios for Scenario 1. Included are the activities (research costs, seed production, commercial planting), the adoption rate, the cash flow, the discount factor (assumed at 10%) and the present values of the cashflow values for each year (net cashflow multiplied by the discount factor for each year). Following the three years of research, there is a period of three years required for seed production of the new variety followed by commercial planting in year seven, and following years at the adoption rate, as per Table 5 for each scenario.

It was considered that the net cost or benefit attributed to the seed production phase would be negligible, because this is a function performed by the Indian government involving substituting the new seed variety for a former variety.

The calculation of the Net Present Value and the Benefit/Cost ratio was based on a total of 15 years

Table 6. Scenario 1 — Trait Method benefits to Indian industry.

Year	Adoption Rate (%)	Area (ha)	Extra Yield (t)	Extra Income (Rs Lakh)
1	0.63	46 875	764	191
2	1.88	140 625	2 292	573
3	3.75	281 250	4 584	1 146
4	6.25	468 750	7 641	1 910
5	10.00	750 000	12 225	3 056
6	12.50	937 500	15 281	3 820
7+	12.50	937 500	15 281	3 820

Table 7. Scenario 1 — NPV Calculation of Trait Method benefits to Indian industry.

Year	Activity	Adoption Rate (%)	Cash Flow (Rs Lakh)	Discount Factors	Present Value (Rs Lakh)
0			0	1	0
1	Research Phase 2		-1.27	0.9091	-1.1501
2	Research Phase 2		-5.07	0.8264	-4.1900
3	Research Phase 2		-6.32	0.7513	-4.7505
4	Seed Production		0.00	0.6830	0
5	Seed Production		0.00	0.6209	0
6	Seed Production		0.00	0.5645	0
7	Commercial Planting	0.63	191.02	0.5132	98.0212
8	Commercial Planting	1.88	573.05	0.4665	267.3306
9	Commercial Planting	3.75	1146.09	0.4241	486.0556
10	Commercial Planting	6.25	1910.16	0.3855	736.4479
11	Commercial Planting	10.00	3056.25	0.3505	1071.1970
12	Commercial Planting	12.50	3820.31	0.3186	1217.2693
13	Commercial Planting	12.50	3820.31	0.2897	1106.6085
14	Commercial Planting	12.50	3820.31	0.2633	1006.0077
15	Commercial Planting	12.50	3820.31	0.2394	914.5524

Notes: Discount Rate = 10%
NPV = 6 893
Rs Lakh = $27.60 M $AUD
B/C Ratio = 684

starting from the beginning of the research phase. The analysis includes three scenarios based upon the three different rates of adoption. The analysis assumes that obtaining the extra yield of 16.3 kg/ha does not incur any extra variable costs. In reality some extra costs would be incurred for activities such as harvesting and cartage; however it was considered that these would be negligible and would not alter the general outcome of the results.

The NPV is calculated by summing all the present values of the net annual cash flows. The B/C Ratio is calculated by dividing the sum of the NPVs of the benefits by the sum of the NPVs of the costs. The results of Scenario 1 are presented in Table 7.

Table 8. Scenario 2 — Trait Method benefits to industry.

Year	Adoption Rate (%)	Area (ha)	Extra Yield (t)	Extra Income (Rs Lakh)
1	1.25	93750	1528	382
2	3.75	281250	4584	1146
3	7.50	562500	9169	2292
4	12.50	937500	15281	3820
5	20.00	1500000	24450	6113
6	25.00	1875000	30563	7641
7+	25.00	1875000	30563	7641

Notes: Discount Rate = 10%
NPV = 13,797
B/C Ratio = 1,368

Table 9. Scenario 3 — Trait Method benefits to industry.

Year	Adoption Rate (%)	Area (ha)	Extra Yield (t)	Extra Income (Rs Lakh)
1	2.50	187500	3056	764
2	7.50	562500	9169	2292
3	15.00	1125000	18338	4584
4	25.00	1875000	30563	7641
5	40.00	3000000	48900	12225
6	50.00	3750000	61125	15281
7 +	50.00	3750000	61125	15281

Notes: Discount Rate = 10%
NPV = 27,604
B/C Ratio = 2,737

Table 10. Assessment 1 — Summary of Results.

	NPV (Rs Lakh)	B/C Ratio	NPV (A$m)
Scenario 1	6 893	684	27.6
Scenario 2	13 797	1 368	55.2
Scenario 3	27 604	2 737	110.4

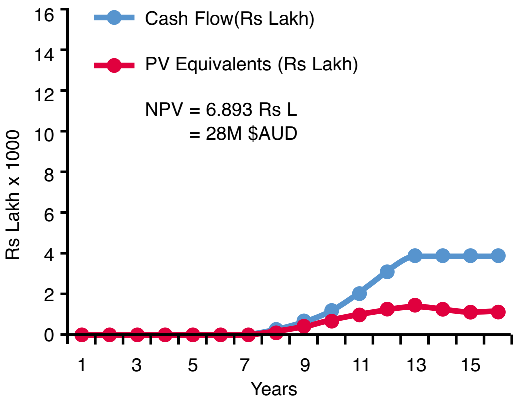

Figure 1. Assess 1 (Trait benefit) – Scenario 1.

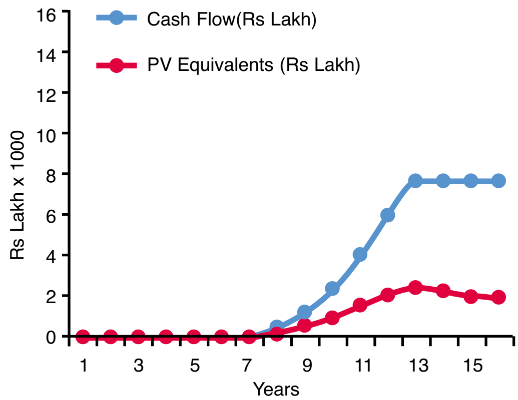

Figure 2. Assess 1 (Trait benefit) – Scenario 2.

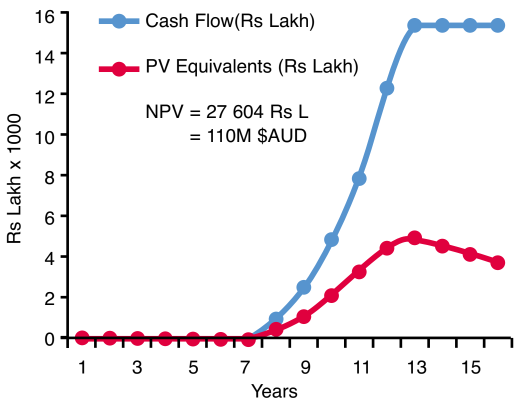

Figure 3. Assess 1 (Trait benefit) – Scenario 3.

Table 8 presents the results for the intermediate adoption rate. The NPV and B/C ratio are calculated in the same manner as for the low adoption rate.

Table 9 provides the results for the high adoption rate. The NPV and B/C ratio are calculated in the same manner as for the low adoption rate.

Table 10 provides a summary of the results for Assessment 1.

Figures 1–3 present results of the cash flows and the present value equivalents of Scenarios 1–3. Note the effect that discounting has on the cashflow values.

Figure 4 illustrates the Present Value Equivalents of each of the three scenarios for Assessment 1. Note that the higher the rate of adoption, the greater the benefit that the project delivers.

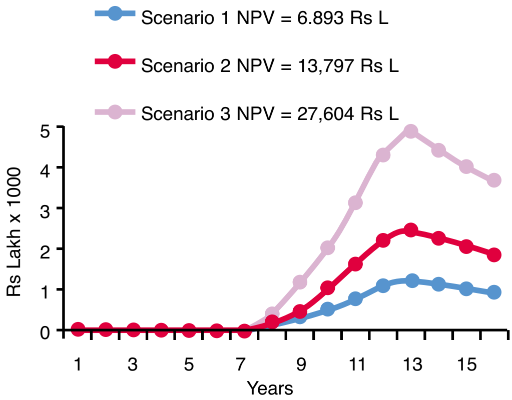

Figure 4. Assess 1 (Trait benefit) – PV Equivalents – Scenario Comparisons.

Assessment 2 — Benefit of the Research Project to the Indian Peanut Industry

The costs include both phases of the Drought Resistance Breeding Projects (PN9216 – 1993 – 1997; CS97/114 – 1998-2001). The costs of phase 2 of the research project (CS97/114 – last 3 years) include the total costs from each of the breeding centres, for both trait and empirical research methods.

The benefits are based on a yield gain of 137 kg/ha of selected lines over the local check. The NPVs and B/C ratios are calculated for three scenarios each with different adoption rates. (These adoption rates are the same as used in Assessment 1; see Table 5).

Table 11 calculates the NPV and B/C ratios for Scenario 1. Included are the activities (research costs, seed production, commercial planting), the adoption rate, the cash flow, the discount factor (10%) and the present values of the cashflows for each year (cashflow x discount factor for each year). Following the eight years of research there is a period of three years required for seed production of the new variety followed by commercial planting in year 12, and following years at the adoption rate calculated in Table 5 for each scenario. It was considered that the net cost or benefit attributed to the seed production phase would be negligible because this is a function performed by the Indian government involving substituting the new seed variety for a former variety.

The calculation of the Net Present Value and the Benefit/Cost ratio was based on a total of 20 years starting from the beginning of research in the first phase of the project (PN9216). The analysis includes three scenarios based upon the three different rates of adoption (Refer Table 5). The analysis assumes that obtaining the extra yield of 137 kg/ha does not incur any extra costs. In reality some extra variable costs would be incurred for activities such as harvesting and cartage; however it was considered that these would be fairly negligible and would not alter the general outcome of the results.

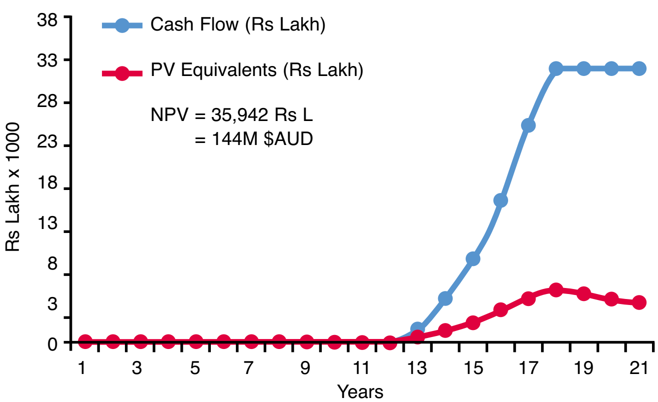

Figure 5. Assess 2 (Industry benefit) – PV Equivalents – Scenario 1.

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Table 11. Scenario 1 — NPV Calculation of benefits of research to Indian industry.

Year	Activity	Adoption Rate (%)	Cash Flow (Rs Lakh)	Discount Factors	Present Values (Rs Lakh)
0			0.00	1	0
1	Research Phase 1		-29.55	0.9091	-26.86
2	Research Phase 1		-15.20	0.8264	-12.56
3	Research Phase 1		-12.50	0.7513	-9.39
4	Research Phase 1		-6.25	0.6830	-4.27
5	Research Phase 1		-6.25	0.6209	-3.88
6	Research Phase 2		-8.28	0.5645	-4.67
7	Research Phase 2		-27.25	0.5132	-13.98
8	Research Phase 2		-22.02	0.4665	-10.27
9	Seed Production		0	0.4241	0
10	Seed Production		0	0.3855	0
11	Seed Production		0	0.3505	0
12	Commercial Planting	0.63	1 605	0.3186	511.55
13	Commercial Planting	1.88	4 816	0.2897	1395.14
14	Commercial Planting	3.75	9 633	0.2633	2536.62
15	Commercial Planting	6.25	16 055	0.2394	3843.36
16	Commercial Planting	10.0	25 688	0.21763	5590.35
17	Commercial Planting	12.5	32 109	0.19784	6352.67
18	Commercial Planting	12.5	32 109	0.17986	5775.15
19	Commercial Planting	12.5	32 109	0.16351	5250.14
20	Commercial Planting	12.5	32 109	0.14864	4772.85

Notes: Discount Rate = 10%
NPV = 35 942
B/C Ratio = 419

Table 12. Assessment 2 — Summary of Results.

	NPV (Rs Lakh)	B/C Ratio	NPV (A$m)
Scenario 1	35 942	419	143.8
Scenario 2	71 970	839	287.9
Scenario 3	144 025	1 678	576.1

The NPV is calculated by summing all the present values of the cash flow. The B/C Ratio is calculated by dividing the sum of the NPVs of the benefits by the sum of the NPVs of the costs. The results of Scenario 1 are shown in Table 11.

The results from each of the three Scenarios are calculated in the same manner. Figures 5–7 illustrate the Cash Flow and Present Value equivalents for each of the three scenarios.

Figure 8 illustrates the Present Value Equivalents of each of the three scenarios for Assessment 2. Note that the higher the rate of adoption the greater the benefit that the project delivers.

Assessment 3 — Potential Benefits for the Australian Peanut Industry

Assessment 3 is an analysis of the costs and potential benefits that the research project could achieve if similar yield gains as achieved in the Indian trial sites were achieved in Australia.

The assumptions used in Assessment 3 were:

- Average Industry Tonnage = 35 700 tonnes
- Total cropped area = 25 500 hectares
- Average industry yield = 1400 Kernel kg/ha
- On-farm value of industry = 32.1 A$m
- Average On-farm Peanut Kernel Price = A$900/tonne
- Discount rate = 7%.

Adoption rates as above are used to compare industry yield increases of 10% and 19.6 % (in the same way as the achieved average yield increase in the Indian trial results). Therefore:

- 10% industry yield increase = 140 Kernel kg/ha
- 19.6% industry yield increase = 274.4 Kernel kg/ha.

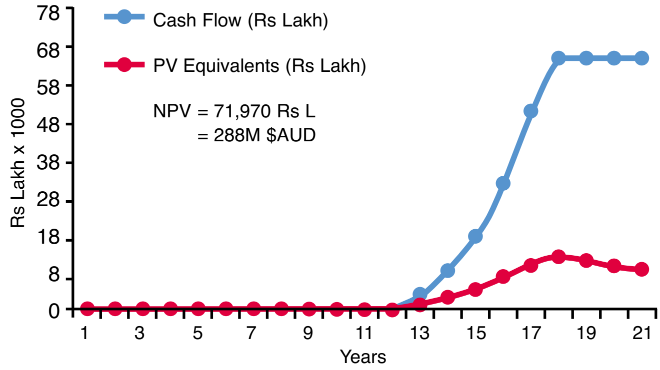

Figure 6. Assess 2 (Industry benefit) – PV Equivalents – Scenario 2.

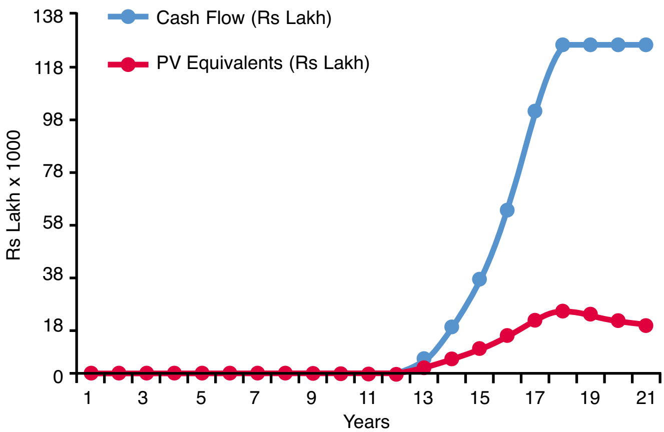

Figure 7. Assess 2 (Industry benefit) – PV Equivalents – Scenario 3.

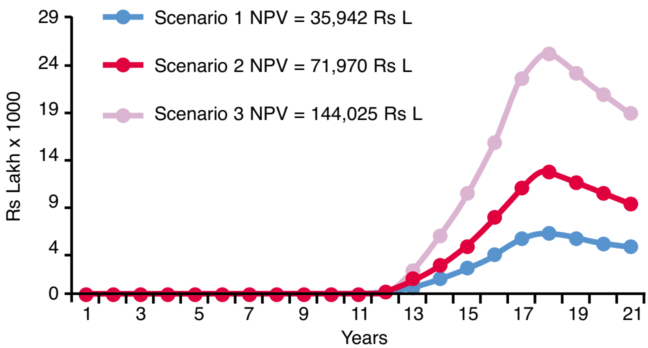

Figure 8. Assess 2 (Project industry benefit) – PV Equivalents Scenario Comparisons.

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Table 13 summarises the results for the Australian industry. The results of each of the scenarios are calculated in the same manner as the previous assessments. The calculations of the Net Present Values and the Benefit/Cost ratios were based on a total of 15 years starting from the beginning of the research phase. The only difference from previous assessments is that the seed production time period was only two years as this was sufficient time to provide adequate seed for the adoption rates used in the analysis. It was considered that the net cost or benefit attributed to the seed production phase would be negligible because in Australia this is a function performed by seed supply companies substituting the new seed variety for a former variety.

Figures 9 and 10 illustrate the Present Value Equivalents derived from 10% and 19.6% yield increases for each of the two scenarios for Assessment 3:

- Scenario 1 – adoption to a maximum of 12.5% of the total cropped area achieved over 6 years.
- Scenario 2 – adoption to a maximum of 25% of the total cropped area achieved over 6 years.

Limitations of the Analysis

A major limitation is the translation of trial results to commercial performance across the entire industry. In this analysis experimental yield gains have been significantly discounted and a range of adoption rates have been assumed. The outcomes calculated are only useful if these assumptions are realistic.

The analysis did not account for possible changes to the production of peanut fodder available for livestock consumption or as green manure crops.

The analysis did not taken into account any macroeconomic effects of shifts in the supply of peanuts. For example, what effect would increased peanut supply have on farm and consumer prices? Significant supply increases may cause reduced prices for producers, thus reducing the expected benefits to producers. However, increased supply could result in lower prices to the consumers, thus shifting the benefit from the producers to the consumers.

The apparent inconsistency between the Indian and Australian trait and empirical selection comparison results raises questions addressed elsewhere.

Conclusions

The average kernel yield increase of the trait selection approach in India was only marginally higher than the empirical approach. However, the comparison of the trait and empirical selection approaches demonstrated that even small yield gains per hectare have significant economic benefits to the Indian industry, and that the benefit-cost ratios were very high.

Both the empirical and the trait methods developed lines that achieved significant kernel yield gains over the local check varieties. It is reasonable to believe that the elite drought resistant parents used in the breeding study were a significant contributing factor to this yield increase with superior-yielding lines being generated under both empirical and trait selection approaches.

The economic analysis showed that costs associated with the breeding research program are relatively

Table 13. Potential research benefits for Australian industry.

	Yield Increase (%)	NPV (A$m)	B/C Ratio
Scenario 1	10.0	$1.16	16.6
	19.6	$2.34	32.5
Scenario 2	10.0	$2.39	33.1
	19.6	$4.75	64.9

Note: Discount Rate = 7%

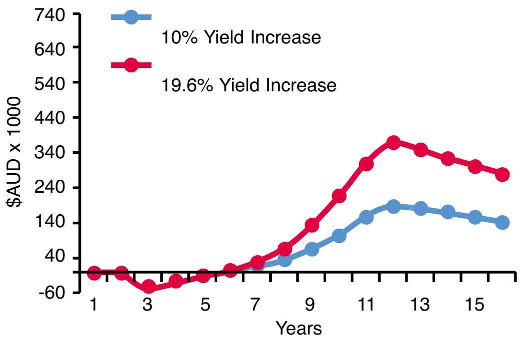

Figure 9. Assess 3 (Australian Industry) – Scenario 1. PV Equivalent of Yield Increase Comparison.

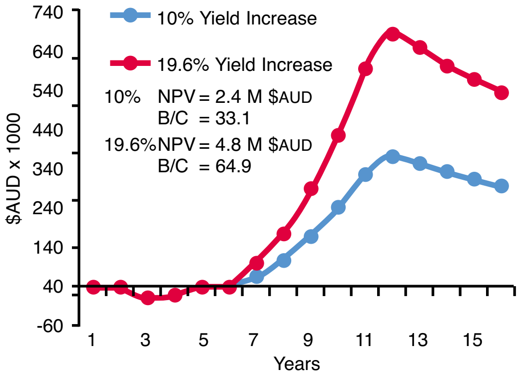

Figure 10. Assess 3 (Australian Industry) – Scenario 2. PV Equivalent of Yield Increase Comparison.

insignificant, even if only slight gains in industry yields are attained, especially in India.

The direct costs associated with trait-based selection approach are higher than the empirical approach. However, the empirical approach relies on existing resources and extensive infrastructure for large numbers of plant progenies that are required to allow for optimal genetic combinations. It seems that both methods have a useful contribution to make to plant breeding.

The high net present values and benefit/cost ratio results of the analysis endorse ongoing research investment into peanut breeding programs.

Recommendations

There is a need to consider the continuation of both trait and empirical approaches in peanut breeding programs, because each approach has generated useful yield gains.

There is a need to maintain the resources and infrastructure within breeding programs, because the payoffs for small gains in yield and quality become very significant when adopted within such a large industry.

Although the results from the Australian trial sites were inconsistent with that obtained in India, it is necessary to apply the same research approach to germplasm more suited to Australian peanut production systems to determine if similar percentage yield increases can be obtained.

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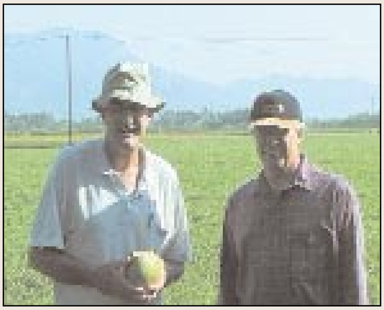
Rachaputi, N.C. 2003. Environmental characterisation of experimental sites in India and Australia. These Proceedings.

Conclusions



Drs Colin Piggin and Ray Shorter inspecting multi-location trials at the Regional Agricultural Station, S.V. Agricultural College Campus, Turapti, Andhra Pradesh, India.

Group discussion of multi-location trials at a farm near Tirupati, Andhra Pradesh, India.

Participants at the final review meeting for ACIAR project CS97/114 held at ICRISAT Centre, Andhra Pradesh, India.

Where To from Here?

S.N. Nigam[1], A.W.Cruickshank[2], N.C. Rachaputi[2], G.C.Wright[2] and M.S. Basu[3]

WATER IS GROWING in importance as a limiting factor in agriculture due to the unpredictable nature of rainfall and increasing competition for it from human and industrial uses. To sustain agricultural productivity, water-use-efficient systems are required. Transpiration-efficient cultivars are an important component of such systems.

Yield is a complex character and is an integrated expression of several physiological processes and their interactions within plant and whole-crop systems. Passioura (1977) gave a simplified expression of this complex phenomenon in the model Y = T*TE*HI as described by Bindu Madhava *et al*. (2003). This simple model generated a lot of interest among plant scientists wishing to address the issue of yield through its physiological components. Further studies leading to the identification of simple surrogate measures of physiological traits difficult to measure in the field, have encouraged interest in pursuing the trait-based approach for improving crop yield.

The present study, however, failed to establish a clear superiority of the trait-based selection approach over the empirical selection approach for yield improvement in peanut. There could be several reasons for these inconclusive results: failure of the simple yield model to capture all physiological 'happenings' in the plant system; an imperfect selection index; negative associations among various yield-related physiological traits; and failure of surrogate traits to fully explain the association between yield and its physiological components. Whatever the reason, a logical expectation of the superiority of trait-based approach over empirical approach was not realised from the present study.

So, where do we go from here? To pursue the issue of trait-based versus empirical approach further, we may need to look closer at the model traits, for example at the molecular level. Precise characterisation of parental and breeding materials for yield-related physiological traits, identification of appropriate markers and QTLs, and marker-assisted selection should help to resolve this issue. The QDPI sorghum research into 'stay-green' provides a good model for

[1] ICRISAT, Patancheru, Andhra Pradesh, India
[2] QDPI, Kingaroy, Queensland, Australia
[3] NRCG, Junagadh, Gujarat, India

such an approach. Integrated breeding and physiological research has laid a platform of knowledge and germplasm for current research into the molecular biology determining the 'stay-green' trait. Similarly, this project has provided knowledge and germplasm which will facilitate research into the molecular biology of expression of drought-resistance traits in peanut.

The association of SPAD chlorophyll meter readings with specific leaf area and carbon isotope discrimination — and therefore, with transpiration efficiency — is of interest to peanut breeders. The SPAD meter provides an easy-to-use practical tool for use in breeding programs. The SPAD measurements should be integrated with other parameters in the selection scheme. Results from the Australian studies clearly demonstrated that trait-based selection for high TE (via SPAD) was more efficient than empirical yield selection for improvement in TE. The challenge remains to be able to concurrently select for high levels of the three yield component traits (T, TE, HI) to generate genotypes with superior yield under drought conditions.

The present study has generated and identified much promising breeding material through multi-location testing in diverse environments. These promising lines are now entering the national testing system for their ultimate release to farmers. In some cases, particularly the Australian program, material identified in this project is broadening the genetic base of the core breeding program.

End-of-season drought is a major cause of aflatoxin contamination of peanut kernel. There is evidence that peanut genotypes with lower aflatoxin risk maintain kernels at higher water activity. Water-use-efficient lines are likely to have better inherent ability to drive seed and plant physiological processes that would discourage *Aspergillus* spp. infection and aflatoxin production. This hypothesis needs to be further tested under field conditions.

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Appendixes

Dr N.C. Rachaputi and Dr S.N. Nigam inspecting a commercial crop of peanuts near Kingaroy, Qld, Australia.

Appendix 1 – Publications Arising from CS 97/114

Anon. 1998. Drought Resistant Peanut Varieties. Country Life (10/9/98).

Anon. 1999a. Research Project on Groundnut. Business Line (New Delhi) (11/2/99).

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Anon. 2001a. ACIAR Project Visit to Oilseeds Research Station, Jalgaon. Lokmat (3/4/01).

Anon. 2001b. ACIAR Project Visit to Oilseeds Research Station, Jalgaon. Tarun Bharat (3/4/01).

Anon. 2001c. ACIAR Project Visit to Oilseeds Research Station, Jalgaon. Sakal (6/4/01).

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Appendix 2 – Parents and selection method of all selections in the Indian multi-environment trial

Genotype ID Code	Parentage of Cross	Selection Approach	Breeding Site	Cross Abbreviation
ICGS_44	ICGS 44	-	-	-
ICGS_76	ICGS 76	-	-	-
TAG_24	TAG 24	-	-	-
JL_220	JL 220	-	-	-
CSMG_84-1	CSMG 84-1	-	-	-
ICGV_86031	ICGV 86031	-	-	-
GG_2	GG 2	-	-	-
K_134	K 134	-	-	-
ICR_01	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_02	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_03	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_04	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_05	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_06	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_07	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_08	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_09	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_10	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_11	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_12	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_13	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_14	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_15	ICGS 76 x CSMG 84-1	TRT	ICRISAT	xA
ICR_16	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_17	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_18	ICGS 44 x CSMG 84-1	TRT	ICRISAT	xB
ICR_19	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_20	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_21	TAG 24 x ICGV 86031	TRT	ICRISAT	xH
ICR_22	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_23	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_24	ICGS 44 x ICGS 76	TRT	ICRISAT	xG
ICR_25	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_26	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_27	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_28	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_29	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_30	ICGS 76 x CSMG 84-1	EMP	ICRISAT	xA
ICR_31	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_32	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_33	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_34	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_35	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_36	ICGS 44 x CSMG 84-1	EMP	ICRISAT	xB
ICR_37	TAG 24 x ICGV 86031	EMP	ICRISAT	xH
ICR_38	TAG 24 x ICGV 86031	EMP	ICRISAT	xH

Genotype ID Code	Parentage of Cross	Selection Approach	Breeding Site	Cross Abbreviation
ICR_39	TAG 24 x ICGV 86031	EMP	ICRISAT	xH
ICR_40	TAG 24 x ICGV 86031	EMP	ICRISAT	xH
ICR_41	TAG 24 x ICGV 86031	EMP	ICRISAT	xH
ICR_42	TAG 24 x ICGV 86031	EMP	ICRISAT	xH
ICR_43	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
ICR_44	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
ICR_45	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
ICR_46	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
ICR_47	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
ICR_48	ICGS 44 x ICGS 76	EMP	ICRISAT	xG
JAL_01	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_02	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_03	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_04	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_05	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_06	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_07	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_08	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_09	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_10	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_11	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_12	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_13	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_14	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_15	ICGS 76 x CSMG 84-1	TRT	Jalgaon	xA
JAL_16	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_17	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_18	ICGS 44 x CSMG 84-1	TRT	Jalgaon	xB
JAL_19	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_20	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_21	ICGV 86031 x TAG 24	TRT	Jalgaon	xC
JAL_22	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_23	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_24	JL-220 x TAG 24	TRT	Jalgaon	xE
JAL_25	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_26	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_27	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_28	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_29	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_30	ICGS 76 x CSMG 84-1	EMP	Jalgaon	xA
JAL_31	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_32	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_33	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_34	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_35	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_36	ICGS 44 x CSMG 84-1	EMP	Jalgaon	xB
JAL_37	ICGV 86031 x TAG 24	EMP	Jalgaon	xC
JAL_38	ICGV 86031 x TAG 24	EMP	Jalgaon	xC
JAL_39	ICGV 86031 x TAG 24	EMP	Jalgaon	xC
JAL_40	ICGV 86031 x TAG 24	EMP	Jalgaon	xC
JAL_41	ICGV 86031 x TAG 24	EMP	Jalgaon	xC
JAL_42	ICGV 86031 x TAG 24	EMP	Jalgaon	xC

Genotype ID Code	Parentage of Cross	Selection Approach	Breeding Site	Cross Abbreviation
JAL_43	JL-220 x TAG 24	EMP	Jalgaon	xE
JAL_44	JL-220 x TAG 24	EMP	Jalgaon	xE
JAL_45	JL-220 x TAG 24	EMP	Jalgaon	xE
JAL_46	JL-220 x TAG 24	EMP	Jalgaon	xE
JAL_47	JL-220 x TAG 24	EMP	Jalgaon	xE
JAL_48	JL-220 x TAG 24	EMP	Jalgaon	xE
JUG_01	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_02	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_03	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_04	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_05	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_06	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_07	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_08	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_09	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_10	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_11	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_12	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_13	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_14	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_15	ICGS 76 x CSMG 84-1	TRT	Junagadh	xA
JUG_16	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_17	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_18	ICGS 44 x CSMG 84-1	TRT	Junagadh	xB
JUG_19	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_20	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_21	ICGV 86031 x TAG 24	TRT	Junagadh	xC
JUG_22	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_23	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_24	GG 2 x ICGV 86031	TRT	Junagadh	xD
JUG_25	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_26	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_27	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_28	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_29	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_30	ICGS 76 x CSMG 84-1	EMP	Junagadh	xA
JUG_31	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_32	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_33	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_34	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_35	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_36	ICGS 44 x CSMG 84-1	EMP	Junagadh	xB
JUG_37	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_38	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_39	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_40	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_41	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_42	ICGV 86031 x TAG 24	EMP	Junagadh	xC
JUG_43	GG 2 x ICGV 86031	EMP	Junagadh	xD
JUG_44	GG 2 x ICGV 86031	EMP	Junagadh	xD
JUG_45	GG 2 x ICGV 86031	EMP	Junagadh	xD
JUG_46	GG 2 x ICGV 86031	EMP	Junagadh	xD

Genotype ID Code	Parentage of Cross	Selection Approach	Breeding Site	Cross Abbreviation
JUG_47	GG 2 x ICGV 86031	EMP	Junagadh	xD
JUG_48	GG 2 x ICGV 86031	EMP	Junagadh	xD
TIR_01	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_02	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_03	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_04	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_05	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_06	ICGS 44 x CSMG 84-1	TRT	Tirupati	xB
TIR_07	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_08	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_09	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_10	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_11	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_12	ICGS 76 x CSMG 84-1	TRT	Tirupati	xA
TIR_13	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_14	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_15	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_16	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_17	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_18	ICGV 86031 x TAG 24	TRT	Tirupati	xC
TIR_19	K134 x TAG 24	TRT	Tirupati	xF
TIR_20	K134 x TAG 24	TRT	Tirupati	xF
TIR_21	K134 x TAG 24	TRT	Tirupati	xF
TIR_22	K134 x TAG 24	TRT	Tirupati	xF
TIR_23	K134 x TAG 24	TRT	Tirupati	xF
TIR_24	K134 x TAG 24	TRT	Tirupati	xF
TIR_25	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_26	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_27	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_28	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_29	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_30	ICGS 44 x CSMG 84-1	EMP	Tirupati	xB
TIR_31	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_32	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_33	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_34	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_35	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_36	ICGS 76 x CSMG 84-1	EMP	Tirupati	xA
TIR_37	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_38	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_39	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_40	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_41	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_42	ICGV 86031 x TAG 24	EMP	Tirupati	xC
TIR_43	K134 x TAG 24	EMP	Tirupati	xF
TIR_44	K134 x TAG 24	EMP	Tirupati	xF
TIR_45	K134 x TAG 24	EMP	Tirupati	xF
TIR_46	K134 x TAG 24	EMP	Tirupati	xF
TIR_47	K134 x TAG 24	EMP	Tirupati	xF
TIR_48	K134 x TAG 24	EMP	Tirupati	xF

Appendix 3 – Parents and selection method of all selections in the Queensland multi-environment trial

Genotype ID Code	Parentage of Cross	Selection Approach
Streeton	Parent/Local Check	-
CSMG 84-1	Parent	-
ICGV 86031	Parent	-
TAG 24	Parent	-
Conder	Local Check	-
NC 7	Local Check	-
B185-2-p11-4	Local Check	-
VB 97	Local Check	-
AX1-18	Streeton x CSMG84-1	Empirical
AX1-31	Streeton x CSMG84-1	Empirical
AX1-73	Streeton x CSMG84-1	Empirical
AX1-100	Streeton x CSMG84-1	Trait-Irrigated
AX1-108	Streeton x CSMG84-1	Empirical
AX1-134	Streeton x CSMG84-1	Empirical+Rainfed
AX1-147	Streeton x CSMG84-1	Empirical
AX1-156	Streeton x CSMG84-1	Empirical
AX1-170	Streeton x CSMG84-1	Trait-Rainfed
AX1-185	Streeton x CSMG84-1	Trait-Irrigated
AX1-188	Streeton x CSMG84-1	Trait-Irrigated
AX1-193	Streeton x CSMG84-1	Empirical
AX1-216	Streeton x CSMG84-1	Empirical
AX1-227	Streeton x CSMG84-1	Trait-Rainfed
AX1-253	Streeton x CSMG84-1	Empirical+Rainfed
AX1-256	Streeton x CSMG84-1	Trait-Irrigated
AX1-262	Streeton x CSMG84-1	Trait-Rainfed
AX1-280	Streeton x CSMG84-1	Trait-Irrigated
AX2-19	ICGV 86031 x TAG 24	Trait-Rainfed
AX2-27	ICGV 86031 x TAG 24	Empirical
AX2-33	ICGV 86031 x TAG 24	Trait-Irrigated
AX2-34	ICGV 86031 x TAG 24	Empirical
AX2-68	ICGV 86031 x TAG 24	Trait-Irrigated
AX2-72	ICGV 86031 x TAG 24	Trait-Irrigated
AX2-83	ICGV 86031 x TAG 24	Empirical
AX2-87	ICGV 86031 x TAG 24	Empirical
AX2-92	ICGV 86031 x TAG 24	Trait-Rainfed
AX2-99	ICGV 86031 x TAG 24	Trait-Rainfed
AX2-100	ICGV 86031 x TAG 24	Trait-Rainfed
AX2-103	ICGV 86031 x TAG 24	Empirical
AX2-114	ICGV 86031 x TAG 24	Trait-Irrigated
AX2-119	ICGV 86031 x TAG 24	Empirical
AX2-133	ICGV 86031 x TAG 24	Empirical
AX2-134	ICGV 86031 x TAG 24	Trait-Rainfed

Genotype ID Code	Parentage of Cross	Selection Approach
AX2-165	ICGV 86031 x TAG 24	Empirical
AX2-224	ICGV 86031 x TAG 24	Trait-Irrigated
AX2-243	ICGV 86031 x TAG 24	Empirical
AX2-260	ICGV 86031 x TAG 24	Empirical
AX3-5	TAG 24 x CSMG 84-1	Empirical
AX3-29	TAG 24 x CSMG 84-1	Trait-Rainfed
AX3-50	TAG 24 x CSMG 84-1	Empirical+Irrigated
AX3-77	TAG 24 x CSMG 84-1	Trait-Rainfed
AX3-88	TAG 24 x CSMG 84-1	Trait-Irrigated
AX3-98	TAG 24 x CSMG 84-1	Empirical
AX3-116	TAG 24 x CSMG 84-1	Trait-Irrigated
AX3-121	TAG 24 x CSMG 84-1	Empirical
AX3-137	TAG 24 x CSMG 84-1	Empirical
AX3-153	TAG 24 x CSMG 84-1	Empirical
AX3-165	TAG 24 x CSMG 84-1	Trait-Rainfed
AX3-178	TAG 24 x CSMG 84-1	Trait-Rainfed
AX3-184	TAG 24 x CSMG 84-1	Trait-Irrigated
AX3-191	TAG 24 x CSMG 84-1	Empirical
AX3-193	TAG 24 x CSMG 84-1	Empirical
AX3-213	TAG 24 x CSMG 84-1	Trait-Irrigated
AX3-225	TAG 24 x CSMG 84-1	Empirical
AX3-248	TAG 24 x CSMG 84-1	Trait-Rainfed
AX3-255	TAG 24 x CSMG 84-1	Empirical
AX4-45	Streeton x ICGV 86031	Empirical
AX4-47	Streeton x ICGV 86031	Empirical
AX4-89	Streeton x ICGV 86031	Empirical
AX4-133	Streeton x ICGV 86031	Empirical
AX4-155	Streeton x ICGV 86031	Empirical
AX4-170	Streeton x ICGV 86031	Trait-Rainfed
AX4-221	Streeton x ICGV 86031	Empirical
AX4-253	Streeton x ICGV 86031	Empirical
AX4-277	Streeton x ICGV 86031	Trait-Irrigated
AX4-390	Streeton x ICGV 86031	Trait-Irrigated
AX4-400	Streeton x ICGV 86031	Trait-Irrigated
AX4-561	Streeton x ICGV 86031	Empirical
AX4-565	Streeton x ICGV 86031	Trait-Irrigated
AX4-590	Streeton x ICGV 86031	Trait-Rainfed
AX4-628	Streeton x ICGV 86031	Empirical
AX4-750	Streeton x ICGV 86031	Trait-Rainfed
AX4-793	Streeton x ICGV 86031	Trait-Irrigated
AX4-810	Streeton x ICGV 86031	Trait-Rainfed
AX4-940	Streeton x ICGV 86031	Empirical+Rainfed

Appendix 4 – The Practice of Selection — Tirupati as an Example

Selection as it was approached in this project is illustrated by its practice at the Tirupati Centre in the:

- Post-rainy season 1998-99 ($F_{2:3}$ selection);
- Rainy season 1999 ($F_{2:4}$ selection); and
- Post-rainy season 1999-2000 ($F_{2:5}$ seed increase).

During the post-rainy season 1999-2000 the selections were sown for seed increase for the ensuing multi-location-trial (MLT). Details of the other two periods follows.

Post-rainy season 1998-99 ($F_{2:3}$ selection)

The F_3 generation was planted on 9–16 December 1998 and harvested 7 April 1999. Results for this trial are presented in Table 1.

In the empirical method, the breeder selected 50 genotypes in each cross following the local method of visual evaluation at harvest. In some cases single plants were selected, and in others off types were removed from progeny rows.

In the trait method, the top 50 progenies were selected from the F3 generation utilising the selection index. It can be seen that the gain made was greater in terms of kernel yield, total dry matter and total transpiration. The gain in terms of transpiration efficiency is marginal. In the $F_{2:3}$ the trait selection index appears to have resulted in more gain in kernel yield, marginal gain in T and little gain in TE.

Table 1. Trait data 1998-99 *Post-rainy season* season $F_{2:3}$ Tirupati centre.

Parent or Progeny ID	TDM/pl (g)	PY/pl (g)	KY/pl (g)	SLA (g/cm²)	TE (g/kg)	T (mm)
K-134 x TAG 24						
Selections	43.3	25.5	18.4	176.1	2.2	20.5
General Means	**29.8**	**16.9**	**11.6**	**179.0**	**2.1**	**14.3**
ICGV86031 x TAG 24						
Selections	41.5	25.5	18.2	160.6	2.4	17.8
General Means	**30.5**	**17.4**	**12.0**	**167.5**	**2.3**	**12.6**
ICGS 76 x CSMG84-1						
Selections	46.3	16.4	10.3	120.4	3.1	11.7
General Means	**29.4**	**10.3**	**6.5**	**126.9**	**3.0**	**9.2**
ICGS 44 x CSMG84-1						
Selections	36.6	13.4	7.9	121.1	3.1	11.9
General Means	**28.4**	**7.5**	**4.0**	**126.8**	**3.0**	**9.2**

Rainy season 1999 ($F_{2:4}$ selection)

The F_4 generation was planted on 14–16 July 1999 and harvested 15–20 November 1999. Results for this trial are presented in Table 2.

During the rainy season 1999, the $F_{2:4}$ progenies were allotted 25 progenies to each of rainfed and irrigated treatments (odd numbers to irrigated and even numbers to rainfed treatment). Three top-ranking progenies from each cross by treatment combination were selected, utilising the selection index. The selections are shown in Table 2.

Table 2. Summary of the trait parameters compared with the parents.

Parent or Progeny ID	TDM/pl (g)	PY/pl (g)	KY/pl (g)	SLA (g/cm²)	TE (g/kg)	T (mm)	HI
Cross: K134 x TAG24							
Rainfed							
26	36.8	12.6	7.5	153.7	2.60	14.1	0.20
34	44.3	11.8	6.1	150.9	2.64	16.8	0.14
14	43.5	11.4	6.7	155.1	2.58	16.8	0.15
K-134	26.2	7.5	4.4	127.3	2.95	8.9	0.17
TAG24	20.5	7.4	3.8	121.0	3.03	6.8	0.19
General Means	**33.2**	**9.7**	**5.5**	**165.3**	**2.45**	**13.6**	**0.17**

Parent or Progeny ID	TDM/pl (g)	PY/pl (g)	KY/pl (g)	SLA (g/cm²)	TE (g/kg)	T (mm)	HI
Irrigated							
11	49.8	9.3	4.8	140.7	2.74	18.1	0.20
9	45.7	9.1	4.5	140.4	2.75	14.6	0.24
1	48.5	10.5	5.8	145.9	2.68	18.1	0.21
K134	35.0	9.0	5.1	138.0	2.78	12.6	0.15
TAG 24	32.2	10.4	7.2	138.9	2.77	11.7	0.22
General Means	**34.9**	**9.3**	**5.1**	**139.5**	**2.76**	**12.7**	**0.18**
Cross: ICGV 86031 X TAG 24							
Rainfed							
30	33.0	9.1	5.1	120.1	2.76	12.0	0.16
22	27.3	8.1	3.9	119.5	2.77	9.8	0.14
20	40.3	9.6	5.8	141.3	2.43	16.6	0.14
86031	30.3	7.6	3.6	101.6	3.04	10.6	0.10
TAG 24	20.5	7.4	3.8	121.0	2.75	7.5	0.14
General Means	**30.9**	**7.2**	**3.8**	**140.2**	**2.45**	**12.6**	**0.12**
Irrigated							
21	37.9	12.5	7.7	120.6	2.53	15.0	0.20
33	37.8	12.2	7.3	122.5	2.50	15.2	0.19
37	40.7	10.8	6.7	121.1	2.52	16.1	0.17
86031	32.3	8.3	4.0	113.9	2.64	12.2	0.11
TAG 24	32.3	10.4	7.2	138.9	2.21	14.6	0.11
General Means	**36.2**	**9.1**	**5.2**	**125.1**	**2.45**	**14.8**	**0.14**
Cross: ICGS 44 X CSMG 84-1							
Rainfed							
14	57.7	16.1	8.6	174.7	2.50	23.1	0.21
4	56.2	15.6	7.8	176.4	2.48	22.6	0.21
8	57.9	18.8	7.5	184.8	2.38	24.4	0.21
ICGS44	26.2	9.1	5.2	129.9	3.04	8.6	0.20
CSMG-84	23.6	12.2	6.4	135.0	2.98	7.9	0.27
General Means	**42.2**	**12.0**	**6.2**	**178.6**	**2.45**	**17.2**	**0.19**
Irrigated							
15	72.4	18.5	10.5	133.3	2.56	28.3	0.21
33	53.9	16.4	8.8	140.7	2.45	22.0	0.21
21	34.5	9.1	5.2	133.5	2.56	13.5	0.24
ICGS 44	30.5	11.0	6.6	138.3	2.49	12.3	0.22
CSMG 84-	35.3	14.6	7.6	133.5	2.56	13.8	0.22
General Means	**40.9**	**11.9**	**6.8**	**140.5**	**2.45**	**16.7**	**0.18**
ICGS 76 X CSMG 84-1							
Rainfed							
4	47.0	12.4	6.7	133.4	2.63	17.8	0.21
12	40.1	14.8	7.4	134.6	2.62	15.3	0.21
32	46.2	13.8	8.6	139.6	2.54	18.5	0.21
ICGS 76	26.6	8.6	5.2	125.4	2.75	9.7	0.20
CSMG 84-	23.6	12.2	6.4	135.0	2.61	9.0	0.27
General Means	**35.3**	**12.3**	**7.0**	**145.8**	**2.45**	**14.4**	**0.20**
Irrigated							
25	37.4	12.8	7.6	127.2	2.59	14.5	0.21
29	45.5	15.7	8.6	131.3	2.52	18.0	0.20
11	44.8	10.0	5.1	121.9	2.67	16.8	0.14
ICGS 76	31.9	10.2	6.2	124.1	2.63	12.1	0.19
CSMG 84-	35.3	14.6	7.6	133.5	2..49	14.2	0.22
General Means	**36.4**	**12.4**	**7.1**	**133.7**	**2.48**	**14.7**	**0.19**

In the $F_{2:4}$ trait selections, the gain made in terms of T was higher with moderate to no gain in the traits of HI and TE.

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