Assessment of groundnut (*Arachis hypogaea* L.) genotypes for drought tolerance in Botswana

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ABSTRACT

Groundnut (*Arachis hypogaea* L.) production in Botswana is adversely affected by erratic and unpredictable rainfall resulting in various periods of drought. As part of a programme aimed at developing drought-tolerant cultivars, two field trials were conducted in the 2004-05 cropping season to evaluate 10 groundnut cultivars and 7 breeding lines from the University of Georgia, USA, together with two local varieties, for drought tolerance, using yield under stress and drought-susceptibility indices as selection indices. The trials were conducted under rain-fed and supplementary irrigation conditions at the Botswana College of Agriculture Farm, Notwane. There was a significant reduction in pod yield ($P < 0.01$), crop growth rate ($P < 0.01$) and partitioning coefficient ($P < 0.01$) due to drought stress. Pod yield across cultivars was reduced by an average of 2.3 t ha^{-1} (79.3 %) and 3.5 t ha^{-1} (88.0 %), from the irrigated to the rain-fed treatment, for the cultivars and the breeding lines, respectively. Drought susceptibility indices for pod yield (S_y), crop growth rate (S_c) and partitioning to reproductive sinks (S_p), used together, identified three cultivars (GAG, 522 and 232) and two breeding lines (C24-124 and C209-6-49) as specifically tolerant to moisture stress. The control cultivars, Nakwana and Peolwane, had the lowest specific leaf area (SLA), 135.9 and 125.8 cm^2g^{-1}, respectively, indicating high water-use efficiency (WUE) capacity. This variation in drought-tolerance traits could be exploited in a groundnut improvement programme.

Keywords: Groundnut, *Arachis hypogaea*, drought tolerance, selection indices, Botswana.

INTRODUCTION

In Botswana, groundnut (*Arachis hypogaea* L.) is a potentially important oil-seed crop. However, the crop is still grown largely as a subsistence crop under rainfed conditions. National production, characterised by low and variable yields, has decreased over the years (Mayeux and Maphanyane, 1988). A major factor limiting the production and productivity of groundnut in Botswana is the erratic and unpredictable rainfall that results in various periods of drought.

The principal agronomic strategy for mitigating the detrimental effects of drought, apart from alteration of plant architecture and biomass partitioning characteristics, is the application of supplementary irrigation (Nageswara Rao *et al.*, 1985). However, irrigation water is not always available; it is expensive and could result in serious negative long-term consequences in the form of soil salinisation, alkalinity, and zinc deficiency (Mcwilliam, 1986). A practical and economical strategy for addressing the problem of limited water availability for crop production, and ensuring the sustainability of commercial production, is the selection or development of high-yielding, drought-tolerant cultivars that can maintain high seed yield with a limited supply of water. Such a goal requires the exploration of existing useable variation in morphological and physiological traits, as well as productive potential in response to drought (Lawn, 1989).

In recent years, attempts have been made to develop drought-tolerant groundnut genotypes for Botswana conditions (Maphanyane, 1994). However, these attempts have tended to rely solely on yield performance under stress as the major selection criterion for tolerance. Conventional breeding based on yield as a sole selection criterion is now proving to be slow in achieving gains because of the need to test large numbers of genotypes in multiple seasons and locations (Nautiyal *et al.* 2002). The effective use of genetic variation in crop improvement programmes needs simple selection indices, to be used as tools to allow for more efficient, simple and practical selection of useful genotypes. Recent studies on groundnut and other annual crops have identified selection indices that can be easily measured and used to select genotypes in large breeding programmes.

Such selection indices include: water-use efficiency (WUE), carbon isotope discrimination (Δ) (Farquhar *et al.*, 1982; Wright *et al.*, 1988, 1994), specific leaf area (SLA) (Wright *et al.*, 1994; Nageswara Rao and Wright, 1994; Craufurd *et al.*, 1999; Nautiyal *et al.*, 2002; Upadhyaya, 2005), SPAD chlorophyll meter reading (SCMR) (Upadhyaya, 2005), drought susceptibility indices, and drought tolerance index (Ndunguru *et al.*, 1995; Schneider *et al.*, 1997). WUE, is widely recognised as a trait that can contribute to productivity under water-limited conditions, but it is not an easy trait to measure and, therefore, virtually impossible to include in a screening programme. However, in groundnut, variation in WUE and total dry matter has been shown to be strongly and negatively correlated with Δ in a wide range of environments (Wright *et al.*, 1994). Thus Δ is widely perceived as a useful, though relatively expensive, selection criterion for WUE. However, a number of studies have also demonstrated that Δ and WUE are positively and negatively correlated, respectively, with SLA (i.e. with leaf thickness) (Nageswara Rao and Wright, 1994; Craufurd *et al.*, 1999). SLA can be measured easily and cost effectively. Thus, as suggested by Craufurd *et al.*, (1999), it can be used as a surrogate for WUE. A number of researchers (Nageswara Rao *et al.*, 1995; Nautiyal *et al.*, 2002) have recommended low SLA as a selection criterion for improving WUE, and thus drought tolerance, in groundnut.

Drought susceptibility index, based on reduction in yield and adjusted for the drought intensity of a particular environment, has been used in attempts to identify genotypes exhibiting consistent performance across stress environments (Acosta-Gallegos and Adams, 1991; Schneider *et al.*, 1997). This index is based on the minimization of yield under drought compared to moist conditions, rather than solely on yield level under dry conditions. Ndunguru *et al.*, (1995) used drought-susceptibility indices, based on yield and yield-determining attributes, to assess groundnut genotypes for drought tolerance. The objective of the study was to assess drought-tolerance of groundnut genotypes using pod yield under drought stress, drought-susceptibility indices based on pod yield and yield-determining attributes, and SLA..

MATERIALS AND METHODS

Two field trials were conducted in the 2004-2005 cropping season under supplementary irrigation, applied during the reproductive period, and rain-fed conditions at the Botswana College of Agriculture Research farm, Notwane (24°33'S; 25°54'E, and 995 m. a.s.l.). Trial 1 was comprised of groundnut cultivars while Trial 2 consisted of groundnut breeding lines. The groundnut genotypes used in the experiment are presented in Table 1. Notwane is in the semi-arid region of the country, with an average annual rainfall of 538 mm (Bekker and de Wit, 1991). Most of the rain falls in summer (October – March/April), and temperatures may rise to about 39 °C.

Trials 1 and 2

Trial 1 consisted of 10 groundnut cultivars obtained from the core collection of the University of Georgia, USA, and two local varieties (Nakwana and Peolwane), that were used as the control. Trial 2 consisted of seven breeding lines also from the University of Georgia, USA, and the two local varieties (Table 1).

Both trials were laid out in a split-plot design with the two moisture treatments as the main plots, and genotypes in the sub-plots. The treatments were replicated five times. The groundnut genotypes were planted in four 5-m long rows per plot and spacing was 75 cm between rows and 20 cm within the row.

Table 1. Groundnut (*Arachis hypogaea* L.) genotypes used in the experiment

Genotypes		*Seed Source*
Cultivars	Breeding lines	
GAG	0027	Georgia, USA
AT201	C22-53	Georgia, USA
Tipton	C32-24	Georgia, USA
732	GK-7	Georgia, USA
522	0013	Georgia, USA
381	C24-124	Georgia, USA
232	C209-6-49	Georgia, USA
188		Georgia, USA
292		Georgia, USA
633		Georgia, USA
Nakwana		Botswana
Peolwane		Botswana

Two seeds were sown per station, and seedlings were thinned to the desired population (6.7 plants m^{-2}) at 18 days after sowing (DAS).

The two moisture treatments, rainfed and irrigated, were 10 m apart. Irrigation was initiated at flowering, and was accomplished by drip or trickle irrigation using a T-tape with outlets every 300 mm, and located between alternate rows. Plots were irrigated approximately 1 h every other day and at the rate of 6 mm of water per h. Planting was done between 13 and 16th December 2004. Plots were weeded by hand, as necessary, to keep the plots weed-free, but no pesticides were applied to control pests and diseases, and no fertilizer was applied, simulating the farmer's situation (Maphanyane, 1994). The plots were observed daily to determine the date at which 50% of the plants in the two middle rows had commenced flowering. Canopy height and canopy width were determined by averaging the distance from the ground level to the top of the plant canopy and the widest length across the row, respectively, at three spots in each plot at 85 DAS. The trial was harvested between 12 and 30th May 2005, the harvest date being determined by the maturation of the genotypes. Maturity date for each genotype was established by destructive sampling, using the internal pericarp colour as the indicator (Sanders *et al.*, 1982). Plants were harvested from a central net plot area of 3.0 m^2. The number of plants harvested was recorded for each plot, and the number of pods per plant was determined from a sample of four randomly selected harvested plants per plot. Pods were air-dried in a greenhouse floor for one week and weighed, and pod mass was adjusted for their high energy content using a coefficient of 1.65 (Duncan *et al.*, 1978). The time between sowing and maturity was converted to thermal time (°C d), which was calculated by subtracting the base temperature (10 °C) (Mohamed *et al.*, 1988) from the mean daily temperature and summing.

Dry matter production (dry weight of haulms and pods) was determined at physiological maturity from a sample of five plants per plot after oven drying to constant weight at 70 °C. Shelling percentage was determined from a 200-pod sample from each plot and was calculated as follows:

Shelling percentage = (mass of seeds / mass of seeds and shells) x 100.

Crop growth rate (CGR) and partitioning coefficient (*p*) were estimated according to the method of Williams and Saxena (1991), adjusting for the higher energy of pods (Duncan *et al.*, 1978):

$CGR = haulm\ yield + (pod\ yield \times 1.65) / T_T$;

$PGR = (pod\ yield \times 1.65) / (T_T - T_V - 15)$;

$p = PGR / CGR$;

where PGR is pod growth rate, T_T is the number of days from sowing to maturity and T_V is the duration from sowing to 50% flowering.

Drought-susceptibility indices based on pod yield (S_y), crop growth rate (S_c) and partitioning of (S_p) were calculated for each genotype as the reduction in the trait from irrigated to rain-fed conditions relative to the mean of all genotypes (Fischer and Maurer, 1978). Using pod yield as an example, the index was calculated as:

$$S = (1 - Y / Y_w) / (1 - X / X_w)$$

where, S is drought susceptibility, Y is pod yield under rain-fed conditions, Y_w is pod yield under irrigated conditions and X and X_w represent averages over all genotypes under rain-fed and irrigated conditions, respectively. The term $(1 - X / X_w)$ is defined as 'stress intensity', and S values < 1.0 indicate low susceptibility or tolerance (Ndunguru *et al.*, 1995).

Drought intensity index (DII) was calculated as:

$$DII = 1 - X_d / X_p$$

Where X_d is the mean yield averaged across genotypes in the rain-fed treatment and X_p is the mean yield averaged across genotypes in the irrigated treatment. It was calculated for each trial and averaged across trials (Fischer and Maurer, 1978).

Owing to some practical difficulties, SLA was determined on the irrigated plants only. It was determined at 85 DAS and from the dry weight of 50 leaf discs of 1.13 cm^2 per plot following the procedure of Wright (1994). Meteorological data were provided by the Department of Agricultural Research, Sebele, (Botswana). Pest infestation on the crop was also observed.

Statistical analyses

Data obtained from each trial were analyzed separately. Analysis of variance and other statistical procedures were performed on the data using STATISTIX 8 for windows (Analytical Software, Tallahassee, Florida, USA). Covariance analysis was applied to the yield data, using number of plants harvested as covariate. Associations among characters were examined by simple correlation analysis.

RESULTS AND DISCUSSION

Environment

Variation in rainfall and temperature during the growth period is presented in Fig 1. Total rainfall received was 330 mm, almost equivalent to the long-term average, but 64 % of the rainfall fell in just two months, December and April, and there was no rain in May. The monthly mean maximum and minimum temperatures ranged from 34.3 °C in February to 26.6 °C in April, and 19.8 °C in January to 6.7 °C in May 2005, respectively, .with monthly mean minimum temperatures declining consistently after January.

Infestation by termite (*Microtermes* sp.) and leaf miner (*Aproarema modicella* L.) was observed during the growing season, especially in the rain-fed treatment, and this might have affected plant growth and caused some plant mortality.

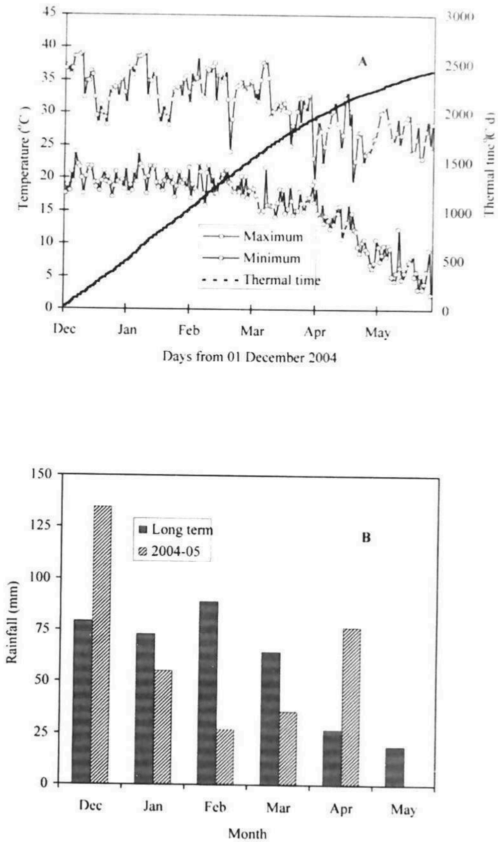

Figure 1 Variation in environmental factors at Notwane, Botswana. A: daily maximum and minimum temperature, and accumulated thermal time using a base temperature of 10°C; B: vriation in rainfall during the 2004-05 growing season, and long term.

Pod yield, growth and development

There was significant ($P < 0.05 - P < 0.001$) reduction in growth and yield of all genotypes under drought stress in both Trials (Tables 1 and 2). In Trial 1 (core collection) pod yields across cultivars was reduced by an average of 2.3 t ha^{-1} (79.3 %) from the irrigated to the rain-fed treatment. The corresponding value for the breeding lines in Trial 2 was 3.5 t ha^{-1} (88.0 %). The number of filled pods per plant, averaged across genotypes, was reduced by 6.4 and 7.8 pods per plant, in Trial 1 and Trial 2, respectively. Total dry matter, canopy width, canopy height, crop growth rate, partitioning and shelling percentage were reduced in proportions roughly similar to the reduction in pod yield and pod production in both Trials. Drought stress reduced total dry matter by 65 and 64 %, crop growth rate by 70 and 70 %, and canopy width by 51 and 48 %, in Trial 1 and Trial 2, respectively. Thus, the results of this study reveal significant reduction in growth and yield of groundnut genotypes under rain-fed conditions compared with the performance under irrigated conditions.

The reduction in pod yield under rain-fed conditions appears to be associated with reduction in the number of pods per plant. Reduced pod formation under water stress may not only be attributable to the reduction in dry matter production and its partitioning into pods, but also to the problems the pegs may have experienced in penetrating the dry soil surface (Sesay and Yarmah, 1996). The reduction in dry matter production could be accounted for, largely, by the substantial reduction in canopy development and, therefore, the associated reduction in energy interception under the rain-fed conditions (Azam-Ali *et al.*, 1989; Simmonds and Williams, 1989). However, since soil moisture determinations were not done and the effects of pests, diseases and other factors were not corrected for, we cannot attribute these reductions in plant growth, development, and productivity solely to water deficit. However, on the basis of the amount of rainfall received and its distribution during the growth period, it can reasonably be presumed that the rain-fed crop experienced severe moisture stress, and that the reduction in yield, total dry matter and crop growth rate under rain-fed conditions largely reflect the sensitivity of the crop to water deficit. Furthermore, the average drought intensity index (DII) was 0.84, across both trials, indicating high environmental stress, and strongly suggesting that the reduction in growth and pod yield, observed under rain-fed conditions in this study, was due largely to water deficit. The DII effectively quantifies the degree of stress when equipment and resources are not available for soil moisture analysis (Schneider et al., 1997). It is now well established that water deficit is highly detrimental to photosynthesis (Bhagsari *et al.*, 1976), development, dry matter production, pod formation and yield of groundnut (Azam-Ali *et al.*, 1989; Simmonds and Williams, 1989; Ravindra *et al.*, 1990; Golakiya and Patel, 1992; Ndunguru *et al.*, 1995; Sesay and Yarmah, 1996; Nautiyal *et al.*, 2002). Agro-climatologically however, drought, especially in the semi-arid tropics, is a complex combination of water deficit, high temperature and nutrient unavailability as a result of inadequate water supply. These factors, above or below critical values are independently damaging to crop growth.

development and productivity (Bjorkman *et al.*, 1980; Hall, 1992; Talwar *et al.*, 1999; Craufurd *et al.*, 2003). There is, therefore, need to undertake research to separate out the effects of water deficit, temperature and other stress factors, such as pests and diseases, in Botswana. Since the irrigation treatment was applied only during the reproductive period, the high yields obtained under irrigation are in agreement with the observation that drought during the pod-filling stage has the greatest impact on yield in groundnut (Nageswara Rao *et al.*, 1985)

With the exception of CGR in Trial 1 and pod yield and number of pods per plant in Trial 2, there was significant ($P < 0.05$ – $P < 0.001$) variation between genotypes in the parameters studied, both under irrigated and rain-fed conditions. In Trial 1 pod yield ranged from 1.5, for 633, to 4.6 t ha^{-1} for Nakwana (control cultivar), under irrigation, and from 0.2 for 732 to 1.3 for 232 under rain-fed conditions (Table 2).

Table 2. Phenological, growth and yield characteristics of groundnut cultivars grown under irrigated and rain-fed conditions in Trial 1, at Notwane, Botswana, 2004-05.

	Irrigated			Rain-fed		
Trait	Range	Mean	S.E.	Range	Mean	S.E.
Days to flowering	28.2 – 34.4	31.6	0.68	29.8 – 36,4	33.1	0.68
Days to maturity	112.4 –148.4	129.9	1.4	119.0 – 153.2	146.3	1.6
Thermal time (°C d)	1774.6 – 2137.0	1955.2	6.1	1806.3 – 2160.1	2112.3	6.1
Reproductive period (Days)	80.2 – 115.0	98.3	1.3	85.0 – 120.4	113.2	1.6
Canopy width (cm)	49.0 – 93.5	74.4	1.6	27.2 – 50.7	36.3	1.5
Canopy height (cm)	15.6 – 35.4	22.9	0.8	6.5 – 14.3	9.5	0.5
Pod yield (t/ha)	1.4 – 4.7	2.9	0.2	0.16 – 1.18	0.6	0.1
Total dry matter (t/ha)	5.2 – 9.9	8.5	0.3	2.1 – 4.1	3.0	0.2
Pods/plant	8.6 – 15.2	11.7	0.67	3.6 – 8.1	5.3	0.67
Crop growth rate (t/ha/d)	0.062 – 0.099	0.081	0.003	0.016 – 0.033	0.024	0.002
Partitioning coefficient	0.51 – 0.89	0.64	0.02	0.30 – 0.56	0.48	0.02
Shelling %	58.3 – 73.2	65.2	1.0	42.1 – 57.5	51.7	1.0

Although no statistically significant variation in yield in response to the treatments was observed in Trial 2 (Table 3), pod yield ranged from 2.7 for C209-6-49 to 5.7 t ha^{-1} for 0027 under irrigation, and from 0.3 for C22-53 and 0013 to 0.9 t ha^{-1} for C209-6-49 under rain-fed. The genotype rankings were not maintained across treatments. For example, in Trial 1, the top yielding cultivar under irrigation (Nakwana) was out-yielded by five cultivars under rain-fed conditions, and the cultivars 232 and 292, which ranked ninth and 11th, respectively, in the irrigated conditions, were first and second, respectively, in the rain-fed conditions. In Trial 2, C24-124 and C209-6-49 recorded the lowest yields under irrigation but were the top-yielding genotypes under rain-fed conditions. Only one cultivar, GAG, in Trial 1 maintained its position in the top three under both treatments. Interactions between genotype and moisture treatments were significant for pod yield in Trial 1 but not in Trial 2.

Table 3. Phenological, growth and yield characteristics of groundnut genotypes (breedinlines and two local cultivars) grown under irrigated and rain-fed conditions in Trial 2, at Notwane, Botswana, 2004-05.

	Irrigated			*Rain-fed*		
Trait	Range	Mean	S.E.	Range	Mean	S.E.
Days to flowering	25.2 – 32.8	30.5	2.2	27.4 – 34.2	32.0	2.2
Days to maturity	112.0 – 146.0	136.2	2.2	118.5 – 158.0	147.1	2.3
Thermal time (°C d)	1752.8 – 2109.8	2006.9	9.5	1830.6 – 2231.7	2122.7	9.5
Reproductive period (Days)	79.4 – 118.0	105.8	2.6	87.0 – 125.0	115.1	2.1
Canopy width (cm)	64.6 – 85.5	77.0	1.8	33.0 – 45.9	39.8	1.2
Canopy height (cm)	14.3 – 24.9	17.3	0.7	7.5 – 11.2	8.8	0.2
Pod yield (t/ha)	2.7 – 5.7	4.0	0.3	0.30 – 0.87	0.5	0.06
Total dry matter (t/ha)	4.5 – 9.2	7.0	0.4	1.7 – 3.2	2.5	0.2
Pods/plant	9.3 – 13.8	11.9	0.63	2.0 – 6.6	4.1	0.62
Crop growth rate (t/ha/d)	0.042 – 0.081	0.066	0.003	0.015 – 0.025	0.020	0.00
Partitioning coefficient	0.64 – 0.88	0.75	0.02	0.25 – 0.76	0.44	0.03
Shelling %	65.9 – 81.4	71.7	1.3	37.6 – 64.9	53.4	1.8

The difference in genotype ranking between moisture treatments for pod yield agrees with earlier reports indicating that high yield potential in unstressed conditions correlated with drought susceptibility (Nageswara Rao *et al.*, 1989).

Genotypes did not vary in time to flowering in Trial 1, but varied significantly ($P < 0.001$) in time to 50% flowering in Trial 2. However, in both trials there was a significant delay in maturity, expressed either as calendar time or thermal time, in the rain-fed conditions (Tables 1 and 2). The average thermal time totals accumulated from sowing to maturity were 1955.2 and 2112.3 °C d in Trial 1 for the irrigated and rain-fed plants, respectively, and 2006.9 and 2122.3 °C d in Trial 2 for the irrigated and rain-fed, respectively.

Table 4. Pod yield under irrigated and rain-fed conditions, drought-susceptibility indices for pod yield (S_y), crop growth rate (S_c) and partitioning (S_p), and specific leaf area (SLA) of twelve groundnut cultivars grown in Trial 1, at Notwane, Botswana, 2004-05.

Genotypes	*Pod Yield (t/ha)*		S_y	S_c	S_p	*SLA ($cm^2 g^{-1}$)*
	Irrigated	Rainfed				
GAG	3.8	0.9	0.95	90.0	0.87	144.5
AT201	3.1	0.4	1.08	1.10	0.70	147.6
Tipton	2.9	0.4	1.06	0.85	0.30	177.2
732	2.8	0.2	1.18	1.10	1.30	166.9
522	2.8	0.7	0.84	0.78	-0.67	168.2
381	2.7	0.5	1.01	0.93	0.27	157.7
232	2.5	1.3	0.60	0.92	0.12	178.8
188	2.4	0.6	0.91	1.02	1.23	153.4
292	2.4	1.2	0.59	1.07	1.30	212.4
633	1.5	0.4	0.77	1.17	-0.26	209.9
Nakwana	4.6	0.5	0.91	0.76	2.29	135.9
Peolwane	3.1	0.4	0.84	0.92	1.60	125.8
Mean	3.8	0.9	0.95	1.00	0.87	144.5
S.E.	0.1	0.1	0.13	0.14	0.55	4.5

The delay in maturity under water deficit reflects the effect of moisture deficit on growth rate, and the effect of declining temperatures on pod development during the latter part of the season (Roberts and Summerfield, 1987; Squire, 1990).

Stress susceptibility indices and specific leaf area (SLA)

The susceptibility indices for pod yield, crop growth rate and partitioning (Tables 4 and 5) indicate genotypic variation for drought tolerance capacity in both the cultivars and breeding lines. The selections of drought-tolerant genotypes, based on the various selection indices, are presented in Table 6. In using pod yield as a selection criterion or index, only genotypes with pod yields that were higher than the mean yield under rainfed conditions were selected.

The susceptibility index based on pod yield (S_Y), identified the highest number of genotypes when used alone as a selection index (Table 6). Used together, the drought-susceptibility indices identified three cultivars (GAG, 522 and 232) in Trial 1 and two breeding lines (C24-124 and C209-6-49) in Trial 2 as specifically tolerant to moisture stress, since they exhibited tolerance for susceptibility indices based on pod yield, crop growth rate and partitioning to reproductive sinks. These three cultivars and two breeding lines were also selected based on the other selection indices. The two control varieties (Nakwana and Peolwane) produced high pod yields under irrigation, but were found to be drought tolerant only in terms of pod yield and crop growth rate. However, Nakwana and Peolwane had the lowest SLA (135.9 and 125.8 $cm^2\ g^{-1}$), followed by the cultivars GAG (144.5 $cm^2\ g^{-1}$) and AT201 (147.6 $cm^2\ g^{-1}$), indicating high water-use efficiency (WUE) capacity in these genotypes.

The yield of any crop is a product of crop growth rate, the partitioning of assimilates to reproductive sinks and the duration of the reproductive phase (Duncan *et al.*, 1978). In the approach used in this study, drought tolerance was measured based on (1) the minimization of yield loss under stress, (2) the reduction in yield adjusted for the drought intensity of the environment, and (3) the effect of stress on the yield-determining processes.

Table 5. Pod yield under irrigated and rain-fed conditions and drought-susceptibility indices for pod yield (S_y), crop growth rate (S_c) and partitioning (S_p) of 7 groundnut breeding lines and 2 local cultivars grown in Trial 2, at Notwane, Botswana, 2004-05.

Genotypes	*Pod Yield (t/ha)*		S_y	S_c	S_p
	Irrigated	Rainfed			
0027	5.7	0.6	1.01	0.78	0.85
C22-53	4.9	0.3	1.04	1.09	0.86
C32-24	4.5	0.4	1.02	0.93	0.79
GK-7	4.5	0.5	1.05	0.97	1.39
0013	3.6	0.3	1.06	1.06	1.41
C24-124	2.8	0.7	0.85	0.94	0.85
C209-6-49	2.7	0.9	0.67	0.91	-0.16
Peolwane	3.8	0.4	0.94	0.84	1.13
Nakwana	3.5	0.6	0.85	0.98	1.24
Mean	4.0	0.5	0.94	0.95	0.93
S.E.	0.3	0.06	0.08	0.12	0.29

Table 6. Selections of drought tolerant groundnut genotypes based on pod yield under rainfed conditions, drought-susceptibility index (S_Y), and droughtsusceptibility indices based on yield and yield-determining processes (S_Y, S_C, S_P) at Notwane, Botswana, 2004-05.

Pod yield	S_Y	S_Y, S_C, S_P
	Core Collection	
232 (LH)*	GAG (AA)	GAG (AA)
292 (LH)	522 (LL)	232 (LH)
	232 (LH)	522 (LL)
	188 (LL)	
	292 (LH)	
	633 (LL)	
	Nakwana (HL)	
	Peolwane (HL)	
	Breeding Lines	
0027 (HH)	C24-124 (LH)	C24-124 (LH)
C24-124 (LH)	C209-6-49 (LH)	C209-6-49 (LH)
C209-6-49 (LH)	Peolwane (HL)	
Nakwana (HH)	Nakwana (HH)	

A, L and H = average, low and high, indicating in each case the yield performance under irrigation and rainfed conditions, respectively, relative to the respective overall means.

Yield under stress and the susceptibility index based on yield (S_Y) evaluate the effects of stress on the end result of the responses of the yield-determining processes. As pointed out by Ndunguru *et al.*, (1995), separating the effects of drought into the components of a yield-determination model should allow improved selection for drought responses.

Cultivars, which have an advantage in resource capture or efficiency of water use, may be expected to have superior maintenance of crop growth rate. On the other hand, cultivars with a superior maintenance of partitioning under drought could utilize a different set of mechanisms to achieve their advantage. Used together, the stress susceptibility indices evaluate the effects of drought based on the responses of the yield-determining processes and the end result of those responses (Ndunguru *et al.*, 1995; Schneider *et al.*, 1997). They should, therefore, provide a more efficient means of identifying genotypes with drought tolerance capacity, and a better understanding of the yield components contributing to performance under rainfed conditions than actual yield performance alone.

Under rain-fed conditions, correlation between pod yield and the drought susceptibility indices was significant only for S_Y ($r = -0.87$, $P < 0.001$; $n = 60$) in Trial 1, and for S_Y ($r = -0.79$, $P < 0.001$; $n = 45$) and S_P ($r = -0.46$, $P < 0.001$; $n = 45$) in Trial 2. Under irrigation, pod yield was correlated with S_Y ($r = 0.40$, $P < 0.01$; $n = 60$) and S_P ($r = 0.28$, $P < 0.05$; $n = 60$)

It is worth noting, however, that the groundnut genotypes identified as drought tolerant, on the basis of the drought susceptibility indices used together, did not have outstanding yields in the irrigated treatment. Such genotypes could be useful in the choice of parents for use in a hybridization programme designed to combine appropriate drought tolerance and high pod yield. WUE has been suggested as a desirable trait to utilise in crop improvement programmes for water-limited environments (Craufurd *et al.*, 1999). The identification of genotypes with low SLA, suggesting the existence of significant variation among the cultivars in water-use efficiency, may be useful in breeding for resistance to drought. Since the local cultivars with low SLA have reasonably good agronomic value, they can be used in breeding programmes without adversely affecting the speed of improvement resulting from epistatic effects. This study has thus demonstrated the use of selection indices that can be easily measured and used to select drought-tolerant groundnut genotypes in breeding programmes in Botswana.

REFERENCES

Acosta-Gallegos, J. A., and Adams, M. W. (1991). Plant traits and yield stability of dry bean (*phaseolus vulgaris*) cultivars under drought stress. *Journal of Agricultural Science* (Cambridge) 117: 213-219.

Azam-Ali, S. N., Simmonds, L. P., Nageswara Rao, R. C. and Williams, J. H. (1989). Population, growth and water use of groundnut maintained on stored water. III. Dry matter, water use and light interception. *Experimental Agriculture* 25: 77-86.

Bekker, R. P. and de Wit, P. V. (1991). Contribution to the soil and vegetation classification of Botswana. Field Document No. 34, FAO/UNDP/Government of Botswana Soil mapping and Advisory Services Project, 66 pp

Bhagsari, A. S., Brown, R. H. and Schepers, J. S. (1976). Effect of moisture stress on photosynthesis and some related physiological characteristics of peanut. *Crop Science*, 16: 712-715.

Bjorkman, O., Badger, M. R. and Armond, P. A. (1980). Response and adaptation to high temperature. *In*: Adaptation of plants to water and high temperature stress. Pp. 239-249. Turner N. C. and Kramer P. J. (Eds.) John Wiley & Sons, New York

Craufurd, P. Q. Wheeler, T. R., Ellis, R. H., Summerfield, R. J. and Williams, J. H. (1999). Effect of Temperature and Water Deficit on Water-Use Efficiency, Carbon Isotope Discrimination, and Specific Leaf Area in Peanut. *Crop Science* : 39, 136-142.

Craufurd, P. Q., Prasad, P. V. V., Kakani, V. G., Wheeler, T. R., and Nigam, S. N. (2003). Heat tolerance in groundnut. *Field Crops Research*, 80 : 63-77

Duncan, W. G., McCloud, D. E., Mcgraw, R. and Boote, K. J. (1978). Physiological aspects of peanut yield improvement. *Crop Science*, 18: 1015 1020.

Farquhar, G. D., O'leary, H. M. and Berry, J. A. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Australian Journal of Plant Physiology*, 9: 121-137.

Fischer, R. A. and Maurer, R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agricultural Research*, 29: 897-912.

Golakiya, B. A. and Patel, M. S. (1992). Growth dynamics and reproductive efficiency of groundnut under water stress at different phenophases. *Indian Journal of Agricultural Research*, 26: 179-186

Hall, A. E. 1992. Breeding for heat tolerance. *Plant Breeding Review*, 10: 129-168.

Lawn, R. J. (1989). Agronomic and Physiological Constraints to the Productivity of Tropical Grain Legumes and Prospects for Improvement. *Experimental Agriculture*, 25: 509-528.

Maphanyane, G. S. (1994). Selecting groundnuts for adaptation to drought under rainfed conditions in Botswana. *In*: Sustainable Groundnut Production in Southern and Eastern Africa, pp 32-36. Proceedings of ICRISAT Workshop 5-7 July 1994, Mbabane, Swaziland. Ndunguru, B. J., Hildebrand, G. L. and Subrahmanyam P. (Eds). ICRISAT, Patancheru, Andhra Pradesh, India.

Mayeux, A. and Maphanyane, G. S. (1988). Groundnut research under low-rainfall conditions in Botswana. *In*: Proceedings of the Third Regional Groundnut Workshop for Southern Africa. ICRISAT, Patancheru, Andhra Pradesh, India.

Mcwilliam, J. R. (1986). The national and international importance of drought and salinity effects on agricultural production. *Australian Journal of Plant Physiology*, 13:1-13).

Mohamed, H. A., Clark, J. A. and Ong, C. K. (1988). Genotype differences in the temperature responses of tropical crops. *Journal of Experimental Botany*, 39: 1121 – 1128.

Nageswara Rao, R. C., Williams, J. H. and Singh, M. (1989). Genotypic sensitivity to drought and yield potential of peanut. *Agronomy Journal*, 81: 887-893.

Nageswara Rao, R.C. and Wright, G. C. (1994). Stability of the relationship between specific leaf area and carbon isotope discrimination across environments in peanut. *Crop Science*, 34: 98-103

Nageswara Rao, R. C., Udaykumar, M., Farquhar, G. D., Talwar, H. S. and Prasad, T. G. (1995). Variation in carbon isotope discrimination and its relationship to specific leaf area and ribulose-1,5-bisphosphate carboxylase content in groundnut genotypes. *Australian Journal of Plant Physiology*, 22 : 545-551.

Nageswara Rao, R. C., Singh, S., Sivakumar, M. V. K., Srivastava, K. L and Williams, J. H. (1995). Effect of water deficit at different growth phases of peanut. I. Yield responses. *Agronomy Journal*, 81: 887-893.

Nautiyal, P. C., Nageswara Rao, R. and Joshi, Y. C. (2002). Moisture-deficit changes in leaf-water content, leaf carbon exchange rate and biomass production in groundnut cultivars differing in specific leaf area. *Field Crops Research*, 74: 67-79.

Ndunguru, B. J., Ntare, B. R., Williams, J. H. and Greenberg, D. C. (1995). Assessment of groundnut cultivars for end-of-season drought tolerance in a Sahelian environment. *Journal of Agricultural Science*, 125 : 79-85.

Ravindra, V., Nautiyal, P. C. and Joshi, Y. C. (1990). Physiological analysis of drought resistance and yield in groundnut (*Arachis hypogaea* L.). *Tropical Agriculture* (*Trinidad*) 67: 290-296.

Roberts, E. H. and Summerfield, R. J. (1987). Measurement and prediction of flowering in annual crops. In: Manipulation of Flowering, Pp17-50. Atherton, J. G. (Ed) Butterworths, London, UK.

Sanders, T. H., Schubert, A. M. and Patee, H. E. 1982. Maturity methodology and post-harvest physiology. *In* : *Peanut Science and Technology* P. 624-654. Patee H. E. and Young C. T. (Eds) Yoakum, Texas, American Peanut Research and Education Society.

Schneider, K. A., Rosales-Serna, R., Ibarra-Perez, F., Cazares-Enriquez, B., Acosta-Gallegos, J. A., Ramirez-Vallejo, P., Wassimi, N., and Kelly, J. D. (1997). Improving Common Bean Performance under Drought Stress. *Crop Science*, 37 : 43-50.

Sesay, A. and Yarmah, A. (1996). Growth, yield performance and market quality of groundnut (*Arachis hypogaea*) as affected by cropping season in southern Sierra Leone. *Journal of Agricultural Science*, Cambridge, 127: 201-206

Simmonds, L. P. and Williams, J. H. (1989). Population, water use and growth of groundnut maintained on stored water. II. Transpiration and evaporation from soil.*Experimental Agriculture* 25: 63-75.

Squire, R. G. (1990). The Physiology of Tropical Crop Production. Wallingford, UK: CAB International. 236 pp

Talwar, H. S., Takeda, H., Yashima, S. and Senboku, T. (1999). Growth and Photosynthetic responses of Groundnut Genotypes to High Temperature *Crop Science*, 39: 460-466.

Upadhyaya, H. R. (2005). Variability for drought resistance related traits in the Mini core collection of peanut. *Crop Science*, 45: 1432-1440.

Williams, J. H. and Boote, K.J. (1995). Physiology and Modelling - Predicting the unpredictable legume. *In*: Advances in peanut science. Pp 301-353. Pattee H. E. and Stalker H. T. (Eds.) APRES, Stillwater, Oklahoma, USA.

Williams, J. H. and Saxena, N. P. (1991). The use of non-destructive measurement and physiological models of yield determination to investigate factors determining differences in seed yield between genotypes of 'desi' chickpeas (*Cicer arietinum*). *Annals of Applied Biology* 119: 105-112.

Wright, G. C., Nageswara Rao, R. C., and Farquhar, G. D. (1994). Water-use efficiency and carbon isotope discrimination in peanut under water deficit conditions. *Crop Science*, 34: 92-97.

Wright, G. C., Hubick, K. T. and Farquhar, G. D. (1988). Discrimination in carbon isotopes of leaves correlates with water-use efficiency of field-grown peanut cultivars. *Australian Journal of Plant Physiology*, 15: 815-825.

Wright, B. C. (1994). Sampling procedures for carbon isotope discrimination and specific leaf area in groundnut. In Selection for water-use-efficiency in grain legumes. Pp 59-61. Wright, G. C. and Nageswara, R. C . (Eds) ACIAR Technical Report No. 27. ACIAR, Canberra, Australia.