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Response of Reproductive Characters of Drought Resistant Peanut Genotypes to Drought

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Abstract: The aims of this study were to evaluate genetic variations in yield and reproductive developmental characters among peanut genotypes in response to drought and relate these responses to pod yield under different soil moisture. Eleven peanut genotypes were tested under three soil moisture levels [field capacity (FC), 2/3 available soil water (AW) and 1/3AW] in field experiments. Data were recorded for number of flowers, pegs (RSs), immature pods and mature pods per plant, seed per pod, 100-seed weight and pod yield at harvest. A drought tolerance index (DTI) for pod yield was calculated as the ratio of pod yield under stress treatment to that under well-watered conditions. The differences among water regimes were significant for pod yield, number of RSs, immature pods and mature pods per plant, seed per pod and 100 seed weight and differences among genotypes were significant for all traits. Drought reduced pod yield, number of RSs, pods and mature pods per plant. Early peak of flowering is important for the formation of mature pods under drought conditions. Two different strategies were used in maintaining high pod yield under drought. High yield potential was important for ICGV 98348 and ICGV 98353, whereas low pod yield reduction was important for ICGV 98305, ICGV 98303 and ICGV 98300. Tifton 8 showed the lowest pod yield and poor seed filling. High RSs and well-filled mature pods were the most important traits contributing to high pod yield in drought resistant genotypes.

Key words: *Arachis hypogaea* L., water stress, drought resistance, yield components

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INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an economically important food legume. Most of the production areas are in arid and semi-arid tropic regions, where peanut is grown mostly under rainfed conditions (Wright and Nageswara Rao, 1994). Drought is the major abiotic stress factor affecting yield and quality of rainfed peanut worldwide (Reddy *et al*., 2003; Wright and Nageswara Rao, 1994). Therefore, the development of drought resistant cultivars is of considerable importance. Peanut cultivars that have a better ability to tolerate the effect of the reduced water supply would help stabilize yields.

The relationships between pod yield and reproductive characters may be altered by drought. So far, important characters determining pod yield under drought and those affecting the response of peanut genotypes to drought as far as reproductive characters and pod yield are concerned are not well understood. Previous studies indicated that drought during the vegetative phase has only small effect on growth and yield of peanut (Awal and Ikeda, 2002; Nautiyal *et al*., 1999) due to the ability to recover from early-season drought by initiating a flush of reproductive growth after the relief of the stress (Nautiyal *et al*., 1999; Awal and Ikeda, 2002). However, drought during the flowering and pod formation phases is severely detrimental to the yield of peanut (Nautiyal *et al*., 1999; Wright and Nageswara Rao, 1994) due to a decrease in flower production if water stress occurred at flowering phase (Awal and Ikeda, 2002). Under water deficit conditions, pod yield might be affected as a result of reduced pod growth and development (Reddy *et al*., 2003; Chapman *et al*., 1993). Drought has also been show to decrease number of mature pods and pod yield (Nautiyal *et al*., 1999).

According to Fernandez (1992), genotypes can be divided into four groups based on their response to stress conditions: (i) genotypes producing high yield under both water stress and non-stress conditions (group A), (ii) genotypes with high yield under non-stress (group B) or (iii) stress conditions (group C) and (iv) genotypes with poor performance under both stress and non-stress conditions (group D). It is still not clear if selection of drought tolerant peanuts should be carried out under conditions that favor optimum yield, or under stress conditions, or under both conditions. If selection is to be carried out under drought conditions, then more information on the extent of stress is needed.

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Pod yield can be considered as the sequential processes of flower production, peg initiation, conversion of peg to pods and pod filling. To the best of our knowledge, the contributions of reproductive characters such as number of flowers, pegs and mature pods to pod yield stability under drought have not been well researched.

Therefore, the objectives of this study were to evaluate genetic variations in yield and reproductive developmental characters among peanut genotypes in response to drought and relate these responses to pod yield under different available soil water levels. This information should provide a better understanding on how genotypes could achieve high yield under drought and could important implications on breeding for drought resistance in peanut.

MATERIALS AND METHODS

Experimental conditions and materials: The experiment was conducted under field conditions at the Field Crop Research Station of Khon Kaen University located in Khon Kaen province, Thailand (latitude 16° 28′ N, longitude 102° 48′ E, 200 m AMSL) during November 2003 to March 2004 and repeated during October 2004 to February 2005. Soil type is Yasothon Series (loamy sand, Ocix Paleustults) with the following chemical attributes: pH of 6.16-6.30, poor in organic matter (0.60-0.72%), total nitrogen (N) (0.03-0.04%), available phosphorus (P) (35.32-45.84 ppm), potassium (K) and calcium (Ca) (57.27 and 557.45 ppm, respectively).

Eleven peanut genotypes were used in this study (Table 1). Eight elite drought resistant lines obtained from ICRISAT (ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, ICGV 98330, ICGV 98348 and ICGV 98353), one (Tifton-8) drought resistant line with a large root systems (Coffelt *et al.*, 1985) received from the United States Department of Agriculture (USDA) and two (KK 60-3 and Tainan 9) released cultivars commonly grown in Thailand. The lines from ICRISAT were identified as drought resistant because they produced high total biomass and pod yield in screening tests under drought conditions (Nageswara Rao *et al.*, 1992; Nigam *et al.*, 2003, 2005) KK 60-3 is a Virginia type peanut in which pod yield is sensitive to drought and Tainan 9 a Spanish-type peanut having low dry matter production (Vorasoot *et al.*, 2003, 2004).

A split plot design with four replications was used for both years. Three soil moisture levels FC (10.55%), 2/3AW (8.48%) and 1/3AW (6.40%) were assigned as main plots and 11 peanut genotypes were laid out in subplots. Weather data for both years were obtained from a meteorological station about 30 m away from the experimental site and are presented in Fig. 1.

Crop management: Land preparation was done by plowing the field three times. Lime at 625 kg ha^{-1}, phosphorus fertilizer as triple superphosphate at 24.7 kg P ha^{-1} and potassium fertilizer as potassium chloride at 31.1 kg K ha^{-1} were applied prior to planting. Seeds were treated with captan (3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindole-1,3(2H)-dione) at the rate of 5 g kg^{-1} seed before planting and seeds of the two Virginia-type peanut cultivars (KK 60-3 and Tifton-8) were also treated with ethrel (2-chloroethylphosphonic acid) 48% at the rate of 2 ml L^{-1} water to break dormancy. Three to four seeds were planted per hill and the seedlings were thinned to two plants per hill at 14 days after sowing (DAS). Rhizobium inoculation was done by applying a water-diluted commercial peat-based inoculum of *Bradyrhizobium* (mixture of strains THA 201 and THA 205; Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) on the rows of peanut plants. Weeds were controlled by an application of alachlor (2-cholro-2',6'-diethyl-*N*-(methoxymethyl) acetanilide 48%, w/v, emulsifiable concentrate) at the rate of 3 L ha^{-1} at planting and hand weeding during the remainder of the season. Gypsum ($CaSO_4$) at the rate of 312 kg ha^{-1} was applied at 45 DAS. Carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-ylmethylcarbamate 3%

Table 1: Genotypes used and their branching patterns, growth habit, maturity and botanical type

Genotype	Botanical types	Branching patterns	Growth habit	Maturity	Source
ICGV 98300	Spanish Bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98303	Virginia Bunch	Irregular (without flower on main stem)	Semi-spreading (Decumbent-3)	Medium	ICRISAT
ICGV 98305	Virginia Bunch	Irregular (without flower on main stem)	Semi-spreading (Decumbent-3)	Medium	ICRISAT
ICGV 98308	Virginia Bunch	Irregular (without flower on main stem)	Semi-spreading (Decumbent-3)	Medium	ICRISAT
ICGV 98324	Spanish Bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98330	Spanish Bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98348	Spanish Bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98353	Spanish Bunch	Irregular (without flower on main stem)	Erect	Medium	ICRISAT
Tainan 9	Spanish	Sequential	Erect	Early	KKU
KK 60-3	Virginia	Alternate	Spreading (Decumbent-2)	Late	KKU
Tifton-8	Virginia	Alternate	Spreading (Decumbent-2)	Late	USDA

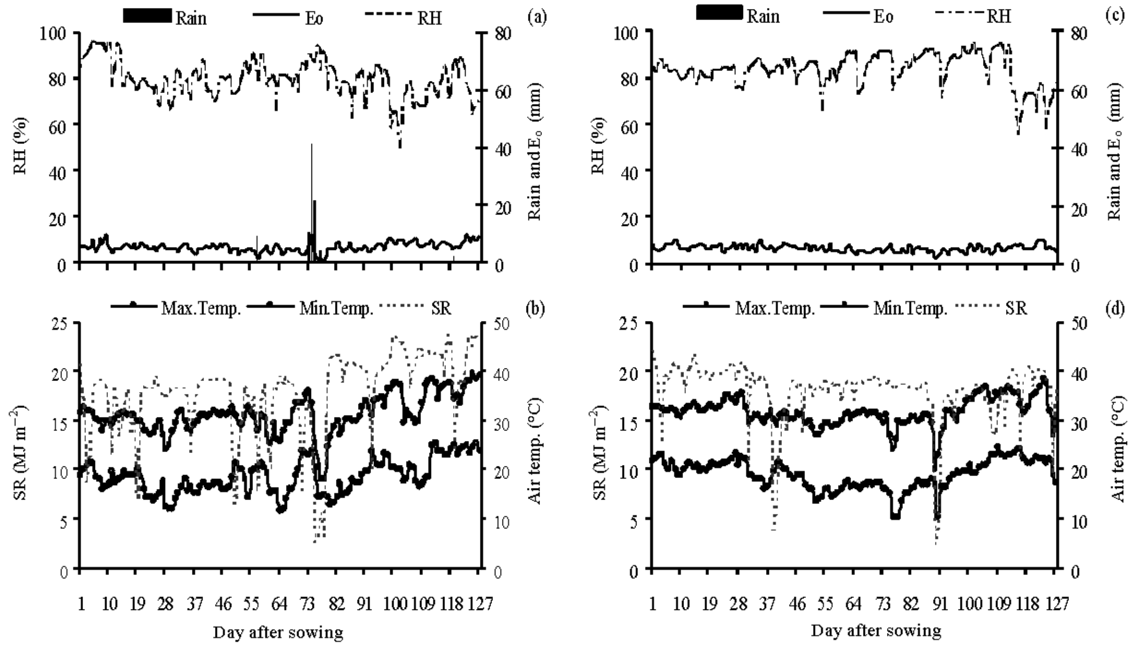

Fig. 1: Rain fall, evaporation (E_o), relative humidity (RH), maximum and minimum air temperature (Max. and Min. Temp.) and solar radiation (SR) in 2003-04 (a, b) and 2004-05 (c, d)

granular) was applied at the pod setting stage. Pests and diseases were controlled by weekly applications of carbosulfan [2-3-dihydro-2,2-dimethylbenzofuran-7-yl (dibutylaminothio) methylcarbamate 20% w/v, water soluble concentrate] at 2.5 L ha^{-1}, methomyl [*S*-methyl-*N*-((methylcarbamoyl) oxy) thioacetimidate 40% soluble powder] at 1.0 kg ha^{-1} and carboxin [5,6-dihydro-2-methyl-1,4-oxath-ine-3-carboxanilide 75% wettable powder] at 1.68 kg ha^{-1}.

Subsurface drip-irrigation system (Super Typhoon®; Netafim Irrigation equipment and Drip systems, Tel Aviv, Israel), a distance of 20 cm between emitters was installed with a spacing of 50 cm between driplines at 10 cm below the soil surface mid-way between peanut rows to supply water to the crop and fitted with a pressure valve and water meter ensured the uniform supply of measured amount of water across each plot. Soil moisture was initially maintained at field capacity (93.1 mm in 60 cm depth) until 21 DAS in all treatments to support crop establishment. After 21 DAS, stress treatments 2/3 AW and 1/3 AW were imposed by withholding irrigation until the soil moisture levels at 0-60 cm of soil depth reduced to predetermined levels of 75 and 56 mm in 60 cm depth in 2/3 AW and 1/3 AW treatments, respectively. Soil moistures in stress treatments reached 2/3 and 1/3 AW at 28 DAS and 35 DAS, respectively. The 2/3 AW and 1/3 AW water regimes were maintained not lower than 1% of the predetermined levels until harvest by controlling water input through the sub-soil drip system. In maintaining the specified soil moisture levels, water was added to the respective plots by subsurface drip-irrigation based on crop water requirement and surface evaporation which were calculated following the methods described by Songsri *et al.* (2008).

Calculation of total crop water use for each water treatment was calculated as the sum of transpiration and soil evaporation. Transpiration (T) was calculated using the formula:

$$ET_{crop} = ET_o \times K_c \quad (1)$$

Where:

ET_{crop} = Crop water requirement (mm day^{-1})
ET_o = Evapotranspiration of a reference plant under specified conditions calculated by pan evaporation method
K_c = The crop water requirement coefficient for peanut, which varies with genotype and growth stage

Surface evaporation (E_s) was calculated as:

$$E_s = \beta \times (E_o/t) \quad (2)$$

Where:

E_s = Soil evaporation (mm)

β = Light transmission coefficient measured depending on crop cover

E_0 = Evaporation from class A pan (mm day^{-1})

t = Days from the last irrigation or rain (day)

Data collections

Weather parameters: There was significant rainfall (71 mm) during 73-75 DAS in the dry season 2003-04, while the crop in the dry season 2004-05 had no interference from rain (Fig. 1). The seasonal mean maximum and minimum air temperature ranged between 31.0 and 18.0°C in 2003-04 and 32.0 and 19.0°C in 2004-05, being lower during 1-45 DAS in 2003-04. Daily pan evaporation ranged from 0.8 to 9.9 mm in 2003-04 and 2.2 to 8.3 mm in 2004-05. The seasonal mean solar radiation 17.6 in 2003-04 and 17.7 MJ m^{-2} day^{-1} in 2004-05, were observed.

Soil moisture and plant water status: Soil moisture was measured by gravimetric method at planting and harvesting at the depths of 0-5, 25-30 and 55-60 cm. The measurement at planting was for calculating the correct amount of water to be applied to the crop and the measurement at harvest was for calculating the water use of the crop. The soil water status was also monitored at 7 day intervals using a neutron moisture meter (Type I.H. II SER. N° N0152, Ambe Didcot Instruments Co. Ltd., Abingdon, Oxon, UK). An aluminum access tube was installed between rows in each plot. Sixteen-second neutron moisture meter readings were made at least weekly from a depth of 0.3 to 0.9 m at 0.3 m intervals.

Leaf water potential (LWP) and leaf relative water content (RWC) were used to evaluate plant water status and were measured at 37, 67 and 97 DAS. A pressure chamber (PMS instrument co., USA) was used to determine LWP using the second fully expanded leaf from the top of the main stem and one leaf for each plot at 1000-1200 h. At the same time as the leaf relative water content (RWC) was recorded using five leaves of the second fully expanded leaf from the top of the main stem for each plot and the formula suggested by Turner (1986) as follows:

$$\text{RWC}(\%) = [(\text{FW}-\text{DW})/(\text{TW}-\text{DW})] \times 100 \qquad (3)$$

Where:

FW = Sample fresh weight

TW = Sample turgid weight

DW = Sample dry weight

Number of reproductive parts: The number of flowers was recorded daily on five tagged plants from each plot during the morning (600-800 h, Thailand standard time) from the date of first flowering until harvest. The numbers of reproductive parts were recorded at harvest as the number of pegs (reproductive sink number; RSs = hanging pegs+pods), number of total pods (immature and mature pods) and number of mature pods per plant (mature pods was separated from immature pods, which were identified by their shriveled seeds and dark internal pericarp color). Number of seeds per pod was recorded on the plants that had been tagged for flower counts at final harvest.

Pod yield and seed size: At maturity, plots of four rows with 4.0 m in length (8 m^2) were dug by hand, roots were cut at crown level and discarded and total above-ground biological yield and marketable pod yield were determined. Mature pods were weighted after air drying to approximately 8% moisture content. Other plant parts except for mature pods were oven-dried at 80°C for 48 h and their dry weights were recorded. Seed size (100 seed weight) was determined from harvested seeds.

Drought Tolerance Index (DTI), as suggested by Nautiyal *et al.* (2002), was calculated for pod yield (DTI (PY)) as the ratio of pod yield under stressed treatments (2/3 AW or 1/3 AW) to that under well-watered (FC) condition as follow:

$$\text{DTI (PY)} = \frac{\text{Pod yield under stressed conditions}}{\text{Pod yield under non-stressed conditions}}$$

Statistical analysis: Individual analysis of variance was performed for each year followed a split plot design (Gomez and Gomez, 1984). Homogeneity of variance was tested for all characters and combined analysis of variance of two-year data was performed. Calculation procedures were done using MSTAT-C package. Due to the significance of year x genotype as well as water regime x genotype interaction (Table 2), data for each year and each water regime were analyzed separately according to a randomized complete block design (RCBD) and Duncan's multiple range test was used to compare means (Gomez and Gomez, 1984). Correlation coefficients between pod yield and DTI for pod yield and reproductive traits were calculated to assess their relationship.

Multiple-linear regression was used to determine the relative contribution of reproductive traits to pod yield under FC, 2/3 AW and 1/3 AW. The analysis was based on the following statistical model (Gomez and Gomez, 1984):

Table 2: Mean squares from the combined ANOVA for pod yield, number of flower, pegs, pods and mature pods per plant, seed per pod and 100 seed weight under three water regimes of 11 genotypes in dry seasons 2003-04 and 2004-05

SOV	DF	Pod yield	Flower No. plant^{-1}	Pegs No. plant^{-1}	Pods No. plant^{-1}	Mature pods No. plant^{-1}	Seed No. pod^{-1}	100 seed weight
Year (Y)	1	0.16	61859.40**	3856.44**	1515.36*	1419.89**	0.20	1788.91
Rep/Y	6	1.11	1457.50	216.20	127.96	35.53	0.16	372.49
Water regime (W)	2	40.14**	49.00	820.30*	98.95**	602.64**	4.51**	3524.84**
W×Y	2	3.03**	679.30*	168.81	50.44	4.29	0.75**	482.09*
Error (a)	12	0.21	166.00	184.30	56.32	21.02	0.02	88.77
Genotype (G)	10	3.07**	7251.40**	1442.93**	84.59**	171.13**	0.37**	520.54**
G×Y	10	0.31*	1156.20**	311.05**	82.82**	23.28	0.14	83.94
W×G	20	0.33**	99.30	68.57	21.88	12.89	0.06	150.91**
W×G×Y	20	0.22	218.10	77.25	29.23	10.15	0.04	80.55*
Error (b)	180	0.14	146.20	90.33	33.64	12.85	0.08	44.87

SOV = Source of variation, DF = Degree of freedom, $^*p<0.05$, $^{**}p<0.01$

$$Y_i = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \delta_i \qquad (4)$$

Where:

Y_i = Pod yield of genotype i

α = The Y intercept

X_{1i}, X_{2i}, X_{3i} and X_{4i} are number of flower, RSs, pods and mature pods of genotype i, respectively, β_1, β_2, β_3 and β_4 are regression coefficients for the independent variables X_1, X_2, X_3 and X_4 and δ_i is the associated deviation from regression.

The analysis was carried out by fitting the full model first and then determining the relative importance of the individual independent variables. A sequential fit was then performed by fitting the more important variable first. The relative contributions of the individual independent variables to pod yield under FC, 2/3 AW and 1/3 AW were determined from the percentages of regression sum of squares due to the respective independent variables to total sum of squares in the sequential fitted analysis.

RESULTS AND DISCUSSION

Monitoring of soil moisture and water status in plant: Soil water status showed reasonable management of soil moistures (Fig. 2). A clear distinction among soil moisture levels was noted at 30 cm of soil depth except in the year 2003-04, when rainfall of 71 mm at 73-75 DAS, which caused high soil moistures in the drought treatments. Soil moistures at 90 cm depth were similar among treatments because the amount of water to apply in each treatment was calculated for 0-60 cm.

Relative water content (RWC) and leaf water potential (LWP) were significantly lower in the plants experiencing soil-moisture-deficit stress than their respective controls (Fig. 3). The highest LWP and RWC were observed for soil moisture at FC followed by 2/3 AW and 1/3 AW, respectively. Observations found visual wilting in 2/3 AW and more severe wilting in 1/3 AW in the afternoon. RWC and LWP of the plants in the 1/3 AW treatment were extremely low at 97 DAS.

Effect of available soil water on pod yield: Drought significantly reduced pod yield (Table 3). The peanut genotypes were grouped depending on their similar and consistent patterns for pod yield in responses to drought. ICGV 98353 and ICGV 98348 were grouped together because they had consistently high pod yield under both FC and drought conditions (group A) (Table 3). The yield stabilizing strategies for these genotypes should be largely from their high starting yield at FC and in minor part from their relatively low reductions (high DTI). No genotype was observed to have high pod yield under non-stress conditions only (group B). ICGV 98305, ICGV 98303 and ICGV 98300 exhibited high pod yield under drought only (group C). The reductions in pod yield of these genotypes were somewhat lower than those of group A and low reduction (high DTI) in pod yield was more important for stabilizing the yield of these genotypes under drought. The genotypes with poor performance for pod yield under both non-stressed and stressed conditions were Tifton-8 and Tainan 9 (group D). These genotypes had the lowest potential yield. The reduction in pod yield of these genotypes was also relatively high, indicating that they were most sensitive to drought.

The results indicated that two possible strategies of drought resistance may be useful for explaining drought resistance in these peanut genotypes. Genotypes with high pod yield under drought conditions should be of either (i) high pod yield under well-watered conditions (e.g., ICGV 98348 and ICGV 98353) or (ii) ability to maintain a low rate of yield reduction under increasing stressed (high DTI) (e.g., ICGV 98305, ICGV 98303 and ICGV 98300). However, the strategies for maintaining high yield under mild and severe drought were quite different. Under 2/3 AW both high potential and low reduction were equally important, but in 1/3 AW low reduction strategy was more important than yield potential (Fig. 4).

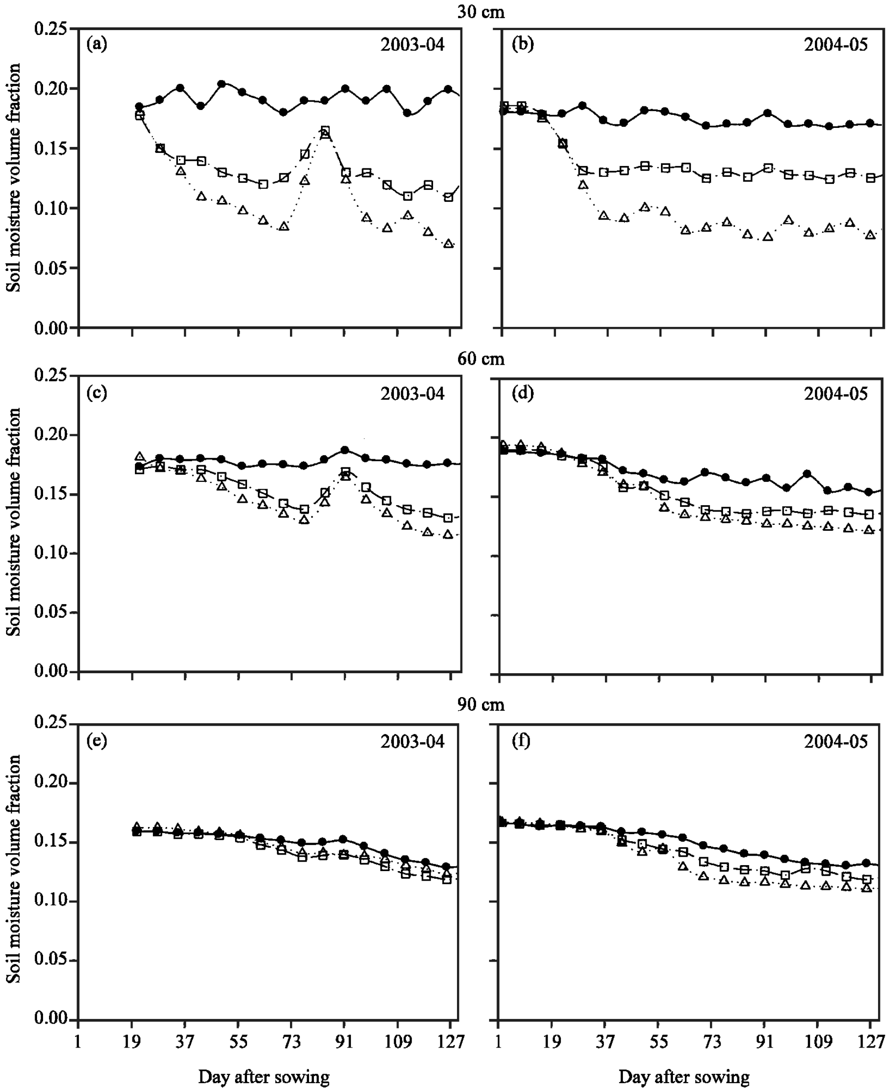

Fig. 2: Soil moisture volume fraction as measured by neutron moisture meter for three soil water regimes (FC, ●; 2/3 AW, □ and 1/3 AW, Δ) at 30 cm (a, b), 60 cm (c, d) and 90 cm (e, f) of the soil level during the 2003-04 and 2004-05 seasons

Table 3: Pod yield (t ha^{-1}) and drought tolerance index (DTI) for pod yield of 11 peanut genotypes grown under different water regimes at harvest in dry seasons 2003-04 and 2004-05

	2003-04					2004-05				
Genotype	FC	2/3 AW	1/3 AW	DTI (2/3 AW)	DTI (1/3 AW)	FC	2/3 AW	1/3 AW	DTI (2/3 AW)	DTI (1/3 AW)
ICGV 98353	3.19a	2.56a	1.81a	0.80	0.57	3.14ab	2.38ab	0.99a-d	0.76	0.32
ICGV 98348	3.00ab	2.52ab	1.79a	0.84	0.60	3.16ab	2.48a	1.00a-d	0.78	0.32
Tainan 9	2.45bc	2.22abc	1.13bc	0.91	0.46	2.57bcd	1.34de	0.74d	0.52	0.29
ICGV 98303	2.35c	2.20a-d	1.84a	0.94	0.78	3.19ab	1.83b-e	1.23a	0.57	0.39
ICGV 98324	2.41bc	2.17a-d	1.14bc	0.90	0.47	3.42a	1.75cde	1.21ab	0.51	0.35
ICGV 98305	2.27c	2.05a-d	1.67a	0.90	0.74	2.17de	2.17abc	0.96bcd	1.00	0.44
ICGV 98300	2.31c	2.03a-d	1.42ab	0.88	0.61	2.40d	2.11abc	1.22a	0.88	0.51
ICGV 98308	2.18c	1.98bcd	1.09bc	0.91	0.50	2.45cd	2.34ab	1.01abc	0.96	0.41
ICGV 98330	2.09c	1.80cd	1.09bc	0.86	0.52	2.14de	1.79b-e	0.84cd	0.84	0.39
KK 60-3	2.29c	1.62d	1.41ab	0.71	0.62	3.07abc	1.85bcd	1.00a-d	0.60	0.33
Tifton-8	1.23d	0.91e	0.70c	0.74	0.57	1.75e	1.23e	0.42e	0.70	0.24
Mean	2.34	2.01	1.37	0.85	0.59	2.68	1.93	0.97	0.74	0.36

Mean in the same column with the same letter(s) are not significantly different by DMR at $p \le 0.05$, DTI for a genotype were calculated by the ratio of stressed (2/3 AW or 1/3 AW)/non stressed (FC) conditions

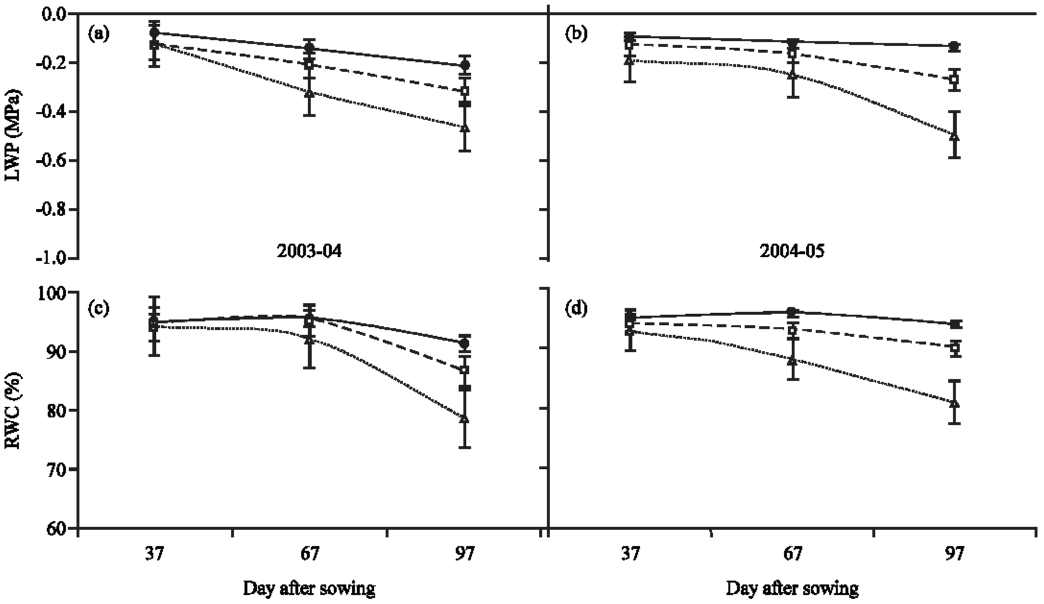

Fig. 3: Leaf water potential (LWP) (a, b) and relative water content (RWC) (c, d) in three available soil water regimes (FC, ●; 2/3 AW, □ and 1/3 AW, Δ) at 37, 67 and 97 DAS during the 2003-04 and 2004-05, seasons

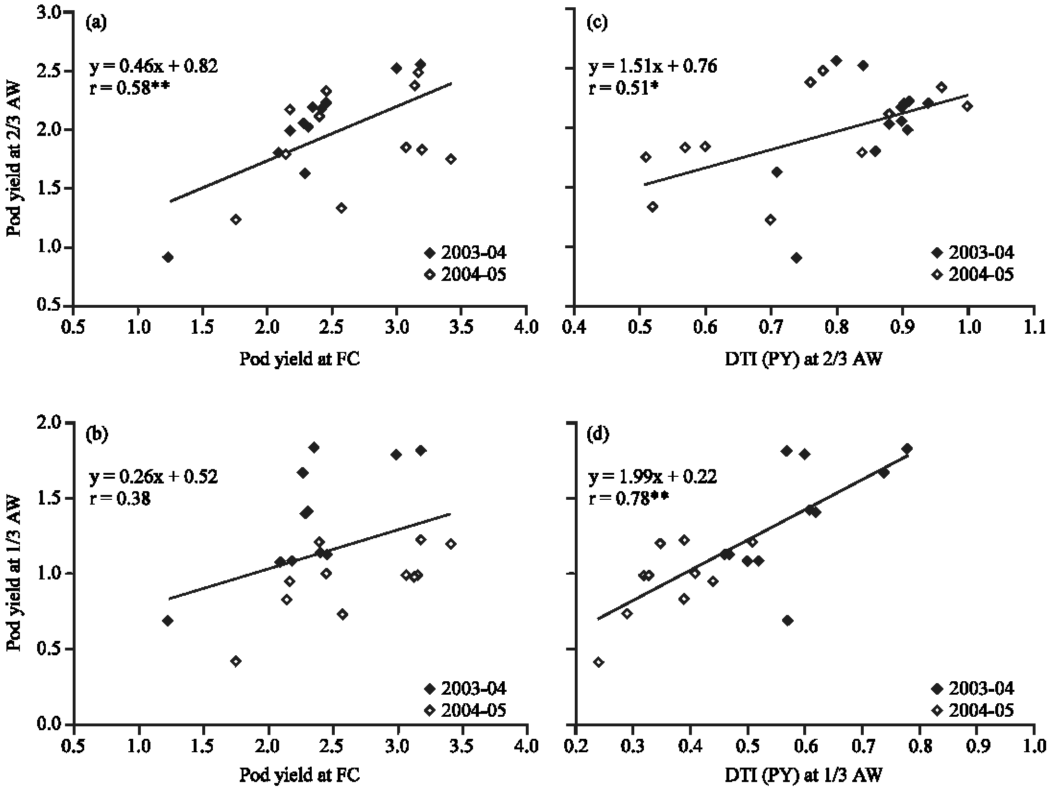

Fig. 4: Relationship between pod yield (t ha^{-1}) under FC and 2/3 AW (a) and 1/3 AW (b) and DTI for pod yield (DTI (PY)) under 2/3 AW (c) and 1/3 AW (d) of 11 peanut genotypes in 2003-04 and 2004-05

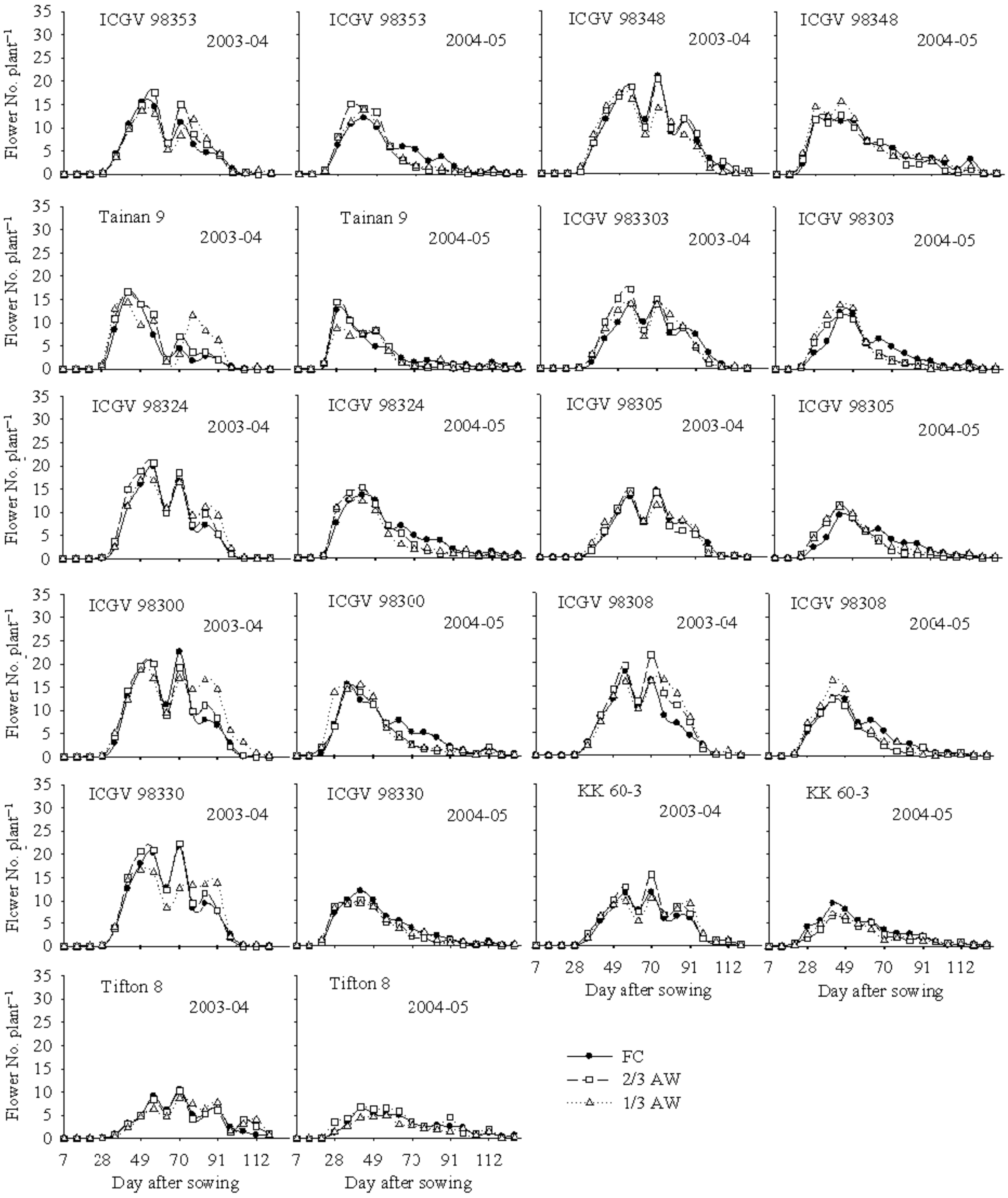

Fig. 5: Flowering patterns of 11 peanut genotypes grown under three available soil water regimes in 2003-04 and 2004-05

Effect of available soil water on flowering behaviors and reproductive parts: The flowering behaviors in 2003-04 and 2004-05 were different in both pattern and flower number. The first flowers for all genotypes in 2004-05 appeared between 21-28 DAS (Fig. 5) which was seven days earlier than observed in 2003-04. The delay of the first flowering in 2003-04 was caused by lower temperature during December and the higher number of flowers in 2003-04 was caused by higher soil moisture for a short duration because of rainfall.

The patterns of flower production for specific genotypes under different water regimes in the same year were similar, but they were different between years. Flowering patterns in 2003-04 were bi-modal, whereas flowering patterns in 2004-05 were uni-modal. The difference in the flowering patterns between years was due to rainfall during pod filling (73-75 DAS) in the year 2003-04 resulting in a second peak of flowering in all genotypes. Nautiyal *et al*. (1999) also found flush flowering of Spanish type peanuts after a relief from drought. The flowering patterns were classified into two types, (i) long duration flowering (KK 60-3 and Tifton-8) and (ii) short early peak flowering (Fig. 5). Our findings supported the typical flowering patterns of Spanish and Virginia peanuts reported by Coolbear (1994). However, the peaks of Spanish genotypes in this study were more skewed toward the left (earlier peak flowering).

When the representatives of different type peanuts were compared, Tainan 9 (Spanish) and Tifton-8 (Virginia) were similar for low flower number per plant, but they differed in flowering patterns. Tainan 9 had the shortest and earliest peak flowering, whereas Tifton-8 had lower and longer duration flowering than did Tainan 9 and other genotypes. Tainan 9 also had higher pod yield than Tifton-8 under water stress. The difference in flowering patterns might be more important than total flower number in determining pod yield under drought. Wright and Nageswara Rao (1994) also reported that reduction in flower number arising from water deficits do not directly influence pod yield since only 15-20% of flowers result in pods that contribute to yield.

Wright and Nageswara Rao (1994) reported that some genotypes with high flower production at FC did not produce high number of pegs and pods under stress, but some genotypes with lower flower production at FC could produce similar numbers of pegs and pods under drought. Pegging and pod set responses of various peanut genotypes under drought varied substantially, leading to large differences in pod yield and the reductions in pod yield also varied among peanut genotypes (Nautiyal *et al*., 1999; Nageswara Rao *et al*., 1989). However, the genotypes producing the lowest number of flowers under normal conditions rarely produced high pod yield under water stress.

Peanut genotypes differed substantially in their flowering, pegging and pod set in response to drought (Table 4). For instance, ICGV 98348, ICGV 98300 and ICGV 98330 had high flower production, number of pegs per plant and number of pods per plant under well-watered conditions in both years. ICGV 98324 and ICGV 98353 had moderate flowering production, but produced high number of pegs and pods at both stressed and well-watered levels. Under water stressed conditions, ICGV 98348 and ICGV 98353 maintained high RSs in both years and ICGV 98324 showed high RSs only in 2004-05 at 2/3AW and 1/3AW (Table 4). Tainan 9, KK 60-3 and Tifton-8 were the genotypes producing the lowest number of flowers under normal conditions and they could not produce high pod yield under drought. ICGV 98324, ICGV 98348 and ICGV 98353 were characterized by maintaining higher number of flowers and pegs under drought.

The difference in flowering behavior is also determined by their botanical groups, Spanish and Virginia. Spanish botanical type had higher total numbers and earlier peak flowering than did Virginia type (KK60-3 and Tifton-8). With regard to the production of reproductive parts contributing to yield under stressed conditions, Spanish type peanuts were in general superior to Virginia type peanuts. Spanish type peanuts were also superior to Virginia type peanuts for flowering pattern with a flush of flowers that developed to mature pods. Most flowers at latter stages did not fertilize or became hanging pegs and immature pods. In general, flowers and pegs were abundant under non-stress and stressed conditions and they did not seem to be the important characters limiting yield under drought conditions.

Effect of available soil water on yield components: Water stress reduced the number of mature pods, seeds per pod and seed size in both years (Table 5). In general, the reductions were high for mature pods and 100-seed weight (low DTI), but lower for number of seeds per pods. Higher reductions in yield and yield components were found in 2004-05 than in 2003-04. The differences between years is likely due to rainfall in 2003-04 that enhanced performance of genotypes in stressed treatments especially at 1/3 AW.

Peanut genotypes may use different strategies to develop high number of mature pods and pod yield. We related number of mature pods to flowering and pegging to understand how they reflected number of mature pods under stressed conditions. However, the division of peanut genotypes was not clear because of less divergence of the genotypes for number of mature pods and genotype x water regime interactions. As the genotypes were not significantly different for number of mature pods at FC in 2004-05, special attention was given to the performance under stressed conditions especially in 2004-05.

The genotypes with high number of mature pods under both non-stressed and stressed conditions (group A) were ICGV 98303, ICGV 98353 and ICGV 98348. These genotypes had high number of mature pods under stressed condition because of high numbers of total pods and pegs and number of mature pod at FC. ICGV 98348 also had the highest number of flowers, whereas the

Table 4: Number of flowers, pegs and pods plant^{-1} of 11 peanut genotypes grown under different water regimes at harvest in dry seasons 2003-04 and 2004-05

	2003-04			2004-05		
Genotype	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW
Number of flowers plant^{-1}						
ICGV 98353	80.17cd	87.62c	77.97d	66.50b-e	64.77bc	60.67bcd
ICGV 98348	120.01a	120.44a	106.42bc	83.60a	77.68a	92.71a
Tainan 9	62.25de	73.21c	78.71d	52.15g	51.89d	43.04def
ICGV 98303	93.39c	93.12bc	86.77cd	55.80efg	54.84cd	59.82bcd
ICGV 98324	97.47bc	110.95ab	107.34b	77.48ab	72.26ab	63.43bc
ICGV 98305	77.97cd	73.84c	77.26d	58.49d-g	49.12de	53.36cde
ICGV 98300	118.13ab	118.64a	131.49a	73.57abc	79.00a	75.23ab
ICGV 98308	93.34c	111.67ab	104.26bc	68.63bcd	57.71cd	69.60bc
ICGV 98330	118.38ab	127.48a	115.38ab	64.24c-f	54.81cd	73.53b
KK 60-3	67.03de	78.51c	68.95de	53.87fg	38.52e	37.99ef
Tifton-8	55.37e	51.80d	50.14e	55.67efg	51.13d	34.15f
Mean	89.41	95.21	91.34	64.55	59.25	60.32
Number of pegs plant^{-1}						
ICGV 98353	33.30abc	47.16ab	35.50ab	47.05abc	48.75a	39.75ab
ICGV 98348	38.75ab	40.48abc	37.88ab	54.30ab	45.30abc	44.55a
Tainan 9	23.60cd	22.92de	17.43de	31.70d	25.25e	13.60e
ICGV 98303	36.78ab	27.15cde	30.07bcd	37.10cd	40.30a-d	42.75ab
ICGV 98324	39.08ab	35.91a-d	34.05abc	54.75a	47.60ab	40.40ab
ICGV 98305	27.55bc	27.37cde	30.56bcd	41.10bcd	35.90b-e	28.50bcd
ICGV 98300	40.10a	31.96bcd	27.28bcd	39.25cd	42.40abc	38.40abc
ICGV 98308	38.69ab	35.79a-d	27.68bcd	44.85a-d	43.30abc	39.55ab
ICGV 98330	39.11ab	49.79a	44.74a	37.65cd	33.95cde	37.95a-d
KK 60-3	21.68cd	22.49de	21.42cde	41.10bcd	29.20de	24.95cde
Tifton-8	12.26d	13.12e	8.93e	39.90cd	37.95a-d	23.75de
Mean	31.90	32.19	28.69	42.61	39.08	34.01
Number of pods plant^{-1}						
ICGV 98353	21.35ab	26.54a	19.69ab	28.35b	28.45ab	23.90ab
ICGV 98348	25.80a	19.06b	21.34a	26.55b	31.25a	24.65ab
Tainan 9	19.61ab	16.38b	10.14de	19.00ab	18.05cd	8.95d
ICGV 98303	25.01a	17.95b	18.33abc	23.25ab	22.20bcd	27.35a
ICGV 98324	21.40a	16.86b	13.21bcd	34.20a	30.20ab	27.70a
ICGV 98305	21.23ab	17.25b	18.75abc	25.35b	23.10a-d	16.30bcd
ICGV 98300	24.77a	17.19b	17.58abc	23.35ab	25.70abc	21.00abc
ICGV 98308	19.82ab	20.53ab	17.95abc	27.95ab	26.85ab	20.30abc
ICGV 98330	22.36a	18.19b	18.75abc	23.45b	22.80bcd	19.10a-d
KK 60-3	14.91b	14.65b	12.78cd	22.55b	16.40d	12.15cd
Tifton-8	7.29c	6.28c	4.92e	20.45b	16.05d	9.05d
Mean	20.32	17.35	15.77	24.95	23.73	19.13

Mean in the same column with the same letter(s) are not significantly different by DMR at $p \leq 0.05$

others had somewhat lower number of flowers. High number of flowers is advantageous to produce higher mature pods, but it is not necessary for group A.

No genotype performed well for number of mature pods under non-stressed conditions only (group B) and none had high number of mature pods under stressed conditions only (group C). The genotypes with low number of mature pods under both non-stressed and stressed conditions (group D) were Tifton-8 and KK 60-3 (Table 5). These genotypes had low number of mature pods under stressed conditions due to low numbers of flowers and pegs.

There were no differences among peanut genotypes for number of seeds per pod at any water level in 2003-04, but there were significant differences at 2/3 AW and 1/3 AW in 2004-05. In 2004-05, ICGV 98353 showed high numbers of seeds per pod and Tifton-8 had the lowest number of seeds per pod under water stressed conditions (Table 5). Although the genetic variation was low, clearer differences were observed under drought conditions, indicating differences in drought sensitivity among these peanut genotypes for number of seeds per pods. Drought reduces seed filling and only the first seeds in some pods are well-filled (limited full pod load), forming taper-shaped pods in the later-developing pods (Wright and Nageswara Rao, 1994).

Using the criterion of grouping mentioned above (Fernandez, 1992), the genotypes showing the most consistent patterns for seed size in both years were grouped together. KK 60-3 was classified as group A, Tifton-8 as group B, ICGV 98324 as group C and ICGV 98348 as group D (Table 5). KK 60-3 and Tifton-8 had high seed size under non-stressed conditions. These Virginia type large-seeded peanuts also had higher rates of

Table 5: Number of mature pods plant^{-1}, seed pod^{-1} and 100 seed weight of 11 peanut genotypes grown under different water regimes at harvest in dry seasons 2003-04 and 2004-05

	2003-04			2004-05		
Genotype	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW
Number of mature pods plant^{-1}						
ICGV 98353	16.81ab	19.27a	13.46ab	12.10	10.35a	6.65ab
ICGV 98348	20.65a	12.44b	14.80a	12.15	8.10abc	7.40ab
Tainan 9	14.40bc	14.27ab	7.14cd	12.30	8.65abc	3.05cde
ICGV 98303	20.61a	14.82ab	14.42a	11.80	10.55a	9.50a
ICGV 98324	17.27ab	12.84b	9.18bc	13.25	9.60ab	5.80bc
ICGV 98305	16.31abc	13.25b	12.01abc	9.25	9.30ab	6.10bc
ICGV 98300	18.28ab	11.90b	11.41abc	9.95	11.40a	6.45ab
ICGV 98308	15.25abc	15.03ab	10.21abc	13.40	8.80abc	4.80bcd
ICGV 98330	15.49abc	12.08b	10.83abc	9.75	8.50abc	7.60ab
KK 60-3	11.05cd	9.94b	8.97bc	8.25	3.80c	1.80de
Tifton-8	5.73d	3.54c	3.45d	7.55	4.60bc	1.45e
Mean	15.62	12.67	10.53	10.89	8.51	5.51
Number of seed pod^{-1}						
ICGV 98353	1.76	1.53	1.18	1.69 a	1.63a	1.24a
ICGV 98348	1.61	1.25	1.41	1.68 a	1.37ab	1.10a
Tainan 9	1.67	1.61	1.59	1.73 a	1.47ab	1.16a
ICGV 98303	1.15	1.26	1.05	1.51 ab	1.46ab	0.89a
ICGV 98324	1.29	1.22	1.20	1.53 ab	1.40ab	1.07a
ICGV 98305	1.48	1.34	1.20	1.59 ab	1.53ab	0.82ab
ICGV 98300	1.81	1.31	1.37	1.70 a	1.50ab	1.19a
ICGV 98308	1.48	1.19	1.18	1.50 ab	1.35b	1.06a
ICGV 98330	1.68	1.30	1.24	1.52 ab	1.42ab	1.09a
KK 60-3	1.73	1.39	1.20	1.61 a	1.54ab	0.86a
Tifton-8	1.52	1.37	1.16	1.32 b	1.00c	0.39b
Mean	1.56	1.34	1.25	1.58	1.42	0.99
100 seed weight (g)						
ICGV 98353	46.42bcd	41.52ab	31.65c	38.38 bcd	35.04bc	23.99bc
ICGV 98348	40.34cd	35.14b	34.19c	36.06 cd	33.23c	24.49bc
Tainan 9	50.96abc	42.39ab	39.06bc	42.34 b	37.86abc	29.63ab
ICGV 98303	51.57abc	41.97ab	35.57bc	40.36 bc	41.44ab	27.07b
ICGV 98324	42.20cd	42.60ab	43.62ab	43.32 b	41.68ab	37.42a
ICGV 98305	38.08d	32.65b	33.73c	40.63 bc	38.58abc	25.00b
ICGV 98300	35.04d	35.98b	34.14c	34.09 d	34.35c	26.96b
ICGV 98308	46.62bcd	36.19b	31.18c	39.62 bcd	36.57abc	29.73ab
ICGV 98330	37.03d	39.43ab	35.89bc	40.11 bc	38.21abc	26.04b
KK 60-3	55.79ab	48.63a	48.62a	63.35 a	41.96a	30.26ab
Tifton-8	59.35a	50.39a	43.97ab	63.18 a	34.46c	14.66c
Mean	45.76	40.63	37.42	43.77	37.58	26.84

Mean in the same column with the same letter(s) are not significantly different by DMR at $p \leq 0.05$

reduction in seed size than did the medium-seeded genotypes under water stressed conditions. The rate of reduction in seed size of Tifton-8 was higher than that of KK 60-3, making it perform poorer under water stressed conditions. ICGV 98324 was not among the largest under non-stressed conditions, but under stressed conditions it had seed size larger than others.

Larger seeded genotypes are more sensitive to environmental changes than smaller seeded genotypes (Vorasoot *et al*., 2003). Large seeded peanuts typically have more severe reduction in seed size and yield under stressed conditions. Seed size in 2003-04 was larger than in 2004-05. Difference between years was caused by rainfall in 2003-04 that promoted seed filling of the water-starved plants. Peanut is unlike other grain legumes in that its yield depends on photo-assimilates during pod growth rather than re-translocation (Chapman *et al*., 1993).

Chapman *et al*. (1993) Observed that the number of mature pods is important for yield under most, if not all, growing conditions, while seed size is more important under stressed conditions than normal conditions. Although there are compensations among yield components, these characters might be synergistic to each other to produce higher yield. The results might also imply that the genotypes maintaining either high number of mature pods or large seed size or combination of both would be advantageous under drought conditions.

Relationship between reproductive characters and pod yield: Most correlation coefficients between pod yield and flower number per plant were not significant except under 1/3 AW conditions ($r = 0.51$; $p \leq 0.05$) and the correlation between numbers of pegs and pods per plant were significant at well-watered and 2/3 AW conditions

Table 6: Correlation coefficients among the pod yield and drought tolerance index for pod yield (DTI (PY)) and number of flowers, pegs, pods, mature pods per plant, seed per pod and 100 seed weight of 11 peanut genotypes under three water regimes grown in the field during 2003-04 and 2004-05

Trait	Flower No. plant^{-1}	Pegs No. plant^{-1}	Pods No. plant^{-1}	Mature pods No. plant^{-1}	Seed No. pod^{-1}	100 seed weight
Pod yield at FC	0.06	0.59**	0.67**	0.29	0.28	-0.30
Pod yield at 2/3 AW	0.39	0.53*	0.61**	0.63**	0.26	-0.43*
DTI (PY) at 2/3 AW	0.42	0.01	-0.02	0.44*	-0.14	-0.25
Pod yield at 1/3 AW	0.51*	0.28	0.41	0.87**	0.47*	0.38
DTI (PY) at 1/3 AW	0.51*	-0.10	-0.02	0.76**	0.45*	0.57**

* and **significant at $p\leq 0.05$ and significant at $p\leq 0.01$, respectively

Table 7: Contributions of reproductive characteristics to pod yield under FC, 2/3AW and 1/3 AW conditions of dry seasons 2003-04 and 2004-05

	Explained by regression (%)		
Trait	FC	2/3 AW	1/3 AW
Regression	55.46**	64.18**	82.26**
Flower No. plant^{-1}	15.63	0.92	4.15*
Pegs No. plant^{-1}	35.10**	0.48*	1.39
Pods No. plant^{-1}	0.49**	23.11**	0.17
Mature pods No. plant^{-1}	4.26	39.66**	76.55**

* and **significant at $p\leq 0.05$ and significant at $p\leq 0.01$, respectively

only (Table 6). Significant correlation coefficient were found for number of mature pods per plant and pod yield at mild (0.63; $p\leq 0.01$) and severe (0.87; $p\leq 0.01$) drought and correlation coefficients between mature pods number and DTI were also significant at 2/3 AW (0.44; $p\leq 0.05$) and highly significant at 1/3 AW (0.76; $p\leq 0.01$). Significant correlation coefficients were observed between DTI (PY) and seed per pod (0.45; $p\leq 0.05$) and between DTI (PY) and seed size (0.57; $p\leq 0.01$) at 1/3 AW conditions. Number of mature pods per plant seemed to play an important role in maintaining high pod yield under drought especially under severe stressed conditions (Table 7). If selection based on high yield under drought conditions is to be practiced, number of mature pods should be considered as surrogate trait for pod yield because this trait is more simple and has lower genotype by environment interaction than pod yield (Table 2). Visual screening for high number of pods can be practiced in the fields in early generations of segregating populations. However, pod yield is still necessary in more advanced generations when replicated trails are normally practiced.

In summary, High numbers of flowers and pegs are advantageous but not necessary for high yield under drought conditions. Early peak of flowering is important for the formation of mature pods and number of mature pods is the most important character determining pod yield under both non-stressed and stressed conditions. Seed size is also important for pod yield under drought but in lesser extent. High pod yield under non-stressed conditions is most important for high pod yield under drought conditions in ICGV 98348 and ICGV 98353. This is because of high fruit set and well-filled mature pods. Tifton-8 had the lowest pod yield under water stressed conditions because of both its low pod yield under normal conditions and high reduction in pod yield. Study findings showed that high pod yield under non-stressed conditions are important for high pod yield under drought conditions in some genotypes, whereas low reduction in pod yield under drought conditions is more important in others. This information should help breeders to better understand the factors that lead to higher pod yield under drought and may help breeders to formulate more effective and efficient breeding strategies for improving drought resistance in peanut.

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