



# Asian Journal of Plant Sciences

ISSN 1682-3974

**science**  
alert

**ANSI***net*  
an open access publisher  
<http://ansinet.com>

## Identification of Traits Related to Drought Resistance in Peanut (*Arachis hypogaea* L.)

M. Painawadee, S. Jogloy, T. Kesmala, C. Akkasaeng and A. Patanothai  
Department of Plant Science and Agricultural Resources, Faculty of Agriculture,  
Khon Kaen University, Muang, Khon Kaen 40002, Thailand

**Abstract:** The aim of this study was to investigate whether some root characters and physiological characters are related to drought resistance in some elite germplasm lines earlier identified as drought resistant based on pod yield. Four peanut genotypes were tested in a pot experiment under two soil moisture levels [Field Capacity (FC) and 1/3 available water (1/3 AW)]. A 2×4 factorial experiment was laid out in RCBD with six replications. Data were recorded for Relative Water Content (RWC), Specific Leaf Area (SLA), SPAD Chlorophyll Meter Reading (SCMR), root and biomass at 70 days after planting. Root characters, biomass production, pod yield and Harvest Index (HI) were recorded at harvest and Drought Tolerance Index (DTI) for these traits were also calculated. Differences between water treatments were also significant for RWC, SLA, Root Dry Weight (RDW) and biomass but not significant for SCMR, harvest index and pod yield. Drought stress reduced RWC, SLA, RDW and biomass but had no significant effect on SCMR, harvest index and pod yield. Significant differences among peanut genotypes were found for SLA at both water treatments. ICGV 98353 had the lowest SLA at both water treatments. Peanut genotypes were significantly different for RDW and RWC at 1/3 AW only. KK 4 had the highest RDW. ICGV 98324 performed best for RWC and it also had the highest DTI for RWC. ICGV 98324 also had the highest SCMR, which was significantly different among peanut genotypes at FC.

**Key words:** Breeding, Groundnut, SLA, SCMR, Water stress

### INTRODUCTION

Peanut productivity is often limited by water deficit at certain growth stages during the growing season. Yield losses due to water stress can vary depending on crop growth stages (Awal and Ikeda, 2002; Reddy *et al.*, 2003), drought intensity and drought duration (Nautiyal *et al.*, 2002; Nigam *et al.*, 2005). Although, access to irrigation should eliminate drought problem, it is not possible for most peanut growing areas. Therefore, development of drought resistant varieties, if cannot eliminate, can alleviate the problem.

Attempts have been made at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop drought resistant varieties. Several drought resistant germplasm lines have been identified and released based on high pod yield under drought stress conditions (Nageswara Rao *et al.*, 1992; Nigam *et al.*, 2003, 2005). These germplasm lines are valuable as germplasm sources to transfer drought resistance traits to high yielding well-adapted cultivars. However, selection for pod yield is difficult because of high genotype × environment interaction (G×E).

More simple and effective selection schemes have been explored using surrogate traits for drought resistance. Specific Leaf Area (SLA), SPAD Chlorophyll Meter Reading (SCMR), Water Use Efficiency (WUE), Harvest Index (HI), biomass production and Drought Resistance Index (DTI) have been used as surrogate traits for drought resistance in peanut (Nigam *et al.*, 2005; Arunyanark *et al.*, 2008; Jongrunklang *et al.*, 2008; Pimratch *et al.*, 2008). More rapid progress may be achieved by using physiological traits such as HI, WUE, SLA and SCMR (Nigam *et al.*, 2005). SLA and SCMR have been used as surrogate traits for WUE (Wright *et al.*, 1994; Nageswara Rao and Wright, 1994; Sheshshayee *et al.*, 2006; Nigam *et al.*, 2005). Water Use Efficiency was associated with SCMR, SLA and carbon isotope discrimination ( $\Delta^{13}\text{C}$ ) (Lal *et al.*, 2006) and Transpiration Efficiency (TE) was also associated with SCMR, SLA and carbon isotope discrimination (Krishnamurthy *et al.*, 2007). Nageswara Rao and Wright (1994) found that associations of SCMR and SLA were relatively stable across environments. Leaf photosynthesis is generally correlated with chlorophyll content per unit leaf area and SPAD chlorophyll

meter can provide a useful tool to screen for genotypic variation in potential photosynthetic capacity (Nageswara Rao *et al.*, 2001).

Root characters are also important for breeding for drought resistance as roots can extract water from the soil (Wright and Nageswara Rao, 1994). Deep rooting and root length density have been identified as drought-adaptive traits that can be used as selection criteria for drought resistance traits (Ludlow and Muchow, 1990; Matsui and Singh, 2003; Taiz and Seiger, 2006). Rucker *et al.* (1995) found that some peanut genotypes with large root systems under non-stress conditions gave high yield under drought conditions. Drought stress generally reduces root growth rate (Meisner and Karnok, 1992). However, Songsri *et al.* (2008c) reported that drought stress increased Root Length Density (RLD) of peanut in the deeper subsoil layers.

It would be expected that drought resistant peanut genotypes previously identified by ICRISAT might possess or be superior for some surrogate traits for drought resistance. They might perform well for root characters under drought conditions that support them to take up more water. They might retain high water content (Relative Water Content; RWC) in their leaf tissues or have greater photosynthesis apparatus (Specific Leaf Area; SLA and traits related to chlorophyll content) to support high photosynthesis under drought conditions. Identification of these drought resistance traits should facilitate selection schemes for drought resistance. Unfortunately, this useful information has not been available in the literature and further investigations are necessary. The objectives of this study was to investigate whether some root characters and physiological characters are related to drought resistance in some elite germplasm lines earlier identified as drought resistant based on pod yield.

## MATERIALS AND METHODS

**Experimental conditions and materials:** The pot experiment was conducted under open environment in the field 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 above sea level) during November 2006 to April 2007. Rainout shelters were available if necessary. Soil type is Yasothon Series (loamy sand, Oeic Paleustults) with the following soil chemical attributes: pH of 5.50-5.65, poor in organic matter (0.43-0.51%), total nitrogen (N) (0.02-0.03%), available phosphorus (P) (6.0-8.0 ppm), potassium (K) and calcium (Ca) (23.5 and 216.5 ppm, respectively).

Three peanut lines (ICGV 98303, ICGV 98305 and ICGV 98324) kindly donated from ICRISAT and a cultivar

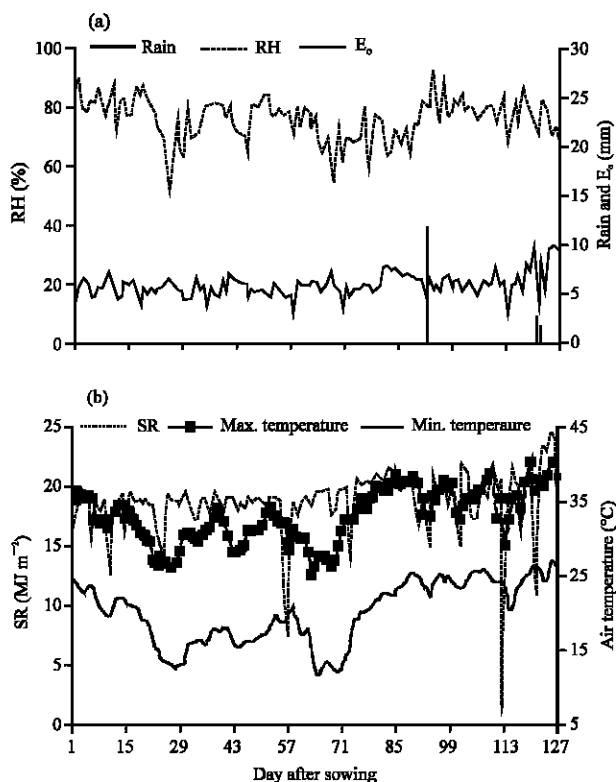


Fig. 1: Rain fall, evaporation ( $E_0$ ), Relative Humidity (RH) (a), maximum and minimum air temperature (max. and min. temp.) and Solar Radiation (SR) and (b) all season grow

(KK 4) released in Thailand were used in this study. 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). The experimental design was a 2×4 factorial in RCBD with six replications. Two soil moisture levels FC (10.28%) and 1/3 AW (5.33%) were assigned as factor A and four peanut genotypes were assigned as factor B. Weather data were obtained from a meteorological station just 50 m from the experimental site and are shown in Fig. 1.

**Crop management:** Pots with 25 cm in diameter and 70 cm in height were filled with 43.6 kg of dry soil from bottom to 10 cm below the top to create uniform bulk density. As soil pH was low and major nutrients were insufficient, lime at the rate of 19.2 g pot<sup>-1</sup> was incorporated into the soil prior to soil filling and phosphorus fertilizer as triple superphosphate at the rate of 12.12 g P pot<sup>-1</sup> and potassium fertilizer as muriate of potash (KCl) at the rate 15.26 g K pot<sup>-1</sup> were applied soon prior to planting. Seeds were treated with captan (3a, 4, 7, 7a-tetrahydro-2-

(trichloromethylthio]-1H-isindole-1, 3(2H)-dione) at the rate of 5 g kg<sup>-1</sup> seed before planting also treated with ethrel 48% at the rate of 2 ml L<sup>-1</sup> water to break dormancy. 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 holes before planting. Three to four seeds were planted per hill and the seedlings were thinned to two plants per hill at 14 Days After Sowing (DAS). Gypsum (CaSO<sub>4</sub>) at the rate of 9.58 g pot<sup>-1</sup> was applied at 40 DAS. Weeds were controlled by hands during the remainder of the season. 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<sup>-1</sup>, methomyl [S-methyl-N-((methylcarbamoyl) oxy) thioacetimidate 40% soluble powder] at 1.0 kg ha<sup>-1</sup> and carboxin [5,6-dihydro-2-methyl-1,4-oxath-ine-3-carboxanilide 75% wettable powder] at 1.68 kg ha<sup>-1</sup>.

Initial soil moisture for all water treatments was maintained at field capacity (10.28%) from planting to 14 DAS. Withholding water was initiated for stressed treatment after 30 DAS and the soil moisture were kept constant at 1/3 AW (5.33%) until 70 DAS and then was resumed at FC until harvest, whereas the non-stressed treatment was kept at FC until harvest.

The calculation for plant water use was followed the method described by Songsri *et al.* (2008a-c). Briefly, crop water requirement was identical to crop water loss through plant transpiration and soil evaporation, ignoring other losses. Therefore, crop water requirement is the product of evaporation (a pan) by crop coefficient, which depends on crop species and growth stages.

For each water treatment, soil moisture was maintained as a constant level as possible, allowing no less than 1% variation. In maintaining the defined soil moisture contents, water was filled into the pots at calculated amount at the top of the pots by surface irrigation and three levels of the soil profile through plastic tubes. This irrigation method provided uniform soil moisture to the pots.

#### Data collection

**Weather parameters:** There were three rainfalls occurring during crop growth period (Fig. 1). The first rain of 39 mm occurred at 95 DAS and the second and third rains of 9.4 and 5.7 mm occurred at 124, 125 DAS, respectively. As rainout shelters could adequately protect the crop, rainfalls did not have significant effects on the crop. The

seasonal mean maximum and minimum air temperature ranged between 20.1 and 33.2°C. Low temperature was observed during 24-34 and 64-72 DAS. Daily pan evaporation ranged from 2.9 to 9.84 mm. The seasonal mean solar radiation 18.79 MJ m<sup>-2</sup> day<sup>-1</sup> in 2006-07, were observed.

**Soil moisture and plant water status:** Soil moisture was determined by gravimetric soil analysis at 50, 60 and 70 DAS. Gravimetric soil analysis at planting was conducted to calculate correct amount of water applied to the crop for successive irrigations. Simultaneously, Relative Water Content (RWC) was recorded from four leaflets of the second fully expanded leaf from the top of the main stem for each pot. Once leaves were harvested and transported to the laboratory, leaf fresh weight was recorded. The leaf samples were then soaked in distilled water for 8 h and blotted for surface drying and water-saturated leaf weight was determined. The samples were oven-dried at 80°C until reaching constant weight and leaf dry weight could be determined. RWC was calculated based on the formula suggested by González and Gonzanlez-Vilar (2001) as follows:

$$\text{RWC (\%)} = \frac{(\text{FW} - \text{DW})}{(\text{TW} - \text{DW})} \times 100$$

where, FW is the sample fresh weight, TW is the sample turgid weight and DW is the sample dry weight.

**Leaf parameters:** SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA) were recorded at 70 days after sowing at 9.00-9.20 AM. The second leaf from terminal bud of the main stem of each plant was detached and kept in sealable plastic bag in ice box. The leaf samples were soon transported to a laboratory. Fresh weight was recorded soon after reaching the laboratory and SCMR was measured immediately by a Minolta handheld portable SCMR meter (SPAD-502 Minolta, Tokyo, Japan), using four leaflets for a sample.

The same samples were further measured for leaf area, using a leaf area meter (LI 3100C Area meter, LI COR Inc., USA). The leaf samples were then oven-dried at 80°C until reaching constant weight and leaf dry weight could be determined. SLA was calculated as following equation;

$$\text{SLA} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

**Biomass, root and Harvest Index (HI):** Because of limited samples, biomass, root and HI can be determined at

70 DAS and additional pod yield in final harvest. Plants were cut at crown level. Roots were washed in tap water to remove soil from the roots. Care was taken to recover all roots as many as possible. Root surface, root length and root volume were then determined by WINRHIZO Pro 2004a software. Root samples and above ground samples were oven-dried at 80°C for 48 h. After oven-dry, root dry weight and shoot dry weight were determined.

Drought Tolerance Index (DTI) was calculated for pod yield as suggested by Nautiyal *et al.* (2002) using the relationship as follows:

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

DTI is a ratio of the trait evaluated under drought conditions and under fully-irrigated conditions. Therefore, High DTI values indicate drought resistance and vice versa. Other DTIs were also calculated for RWC, SLA, SCMR, harvest index and biomass production.

Harvest index was also calculated using the following relationship:

$$HI = \frac{\text{Pod yield}}{\text{Pod yield} + \text{shoot and root dry weight}}$$

**Statistical analysis:** The data were subjected to analysis of variance followed a factorial experiment in a 2×4 RCBD and Duncan's multiple range test was used to compare means (Gomez and Gomez, 1984). As there were interactions between water regime and peanut genotypes, the separated analyses of each water regime were reported.

## RESULTS AND DISCUSSION

Soil water status showed reasonable management of soil moistures (Fig. 2). A clear distinction among soil moisture levels was noted at 50, 60 and 70 DAS. Soil with full irrigation therefore, the difference in RWC between fully-irrigated plants and stressed plants at 70 DAS was similar to the difference in soil moisture content. Plants could maintain leaf turgor under drought stress, but, under severe drought stress, leaf turgor was rapidly lost (Reddy *et al.*, 2003). Katam *et al.* (2007) suggested that plants respond to adopt the stress for survival through homeostasis or osmotic adjustment involving changes in physiological and biochemical processes. During the stress, plants may maintain water uptake via osmotic adjustment, which lowers the water potential of the leaf and maintains an osmotic gradient in the leaves.

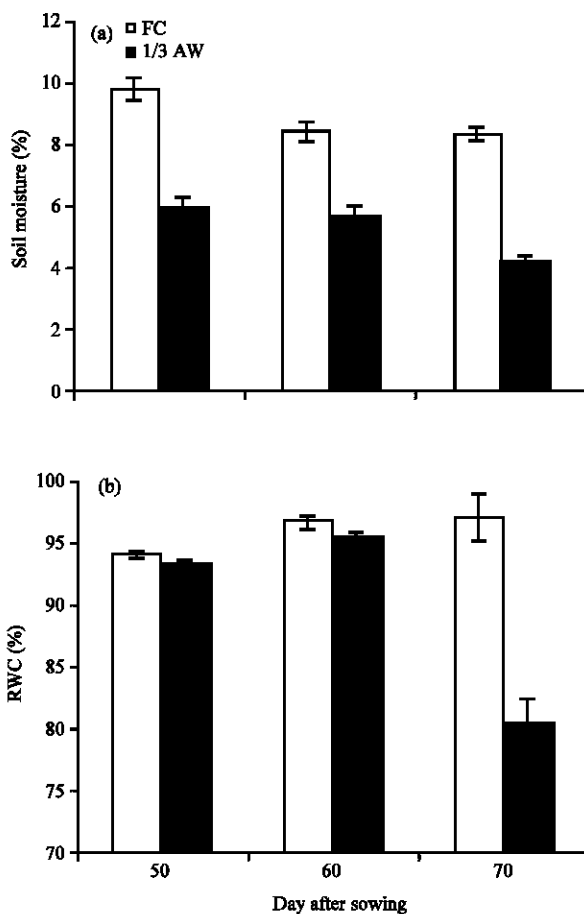


Fig. 2: Soil moisture (a) and Relative Water Content (RWC) (b) under field capacity and 1/3 available water (1/3 AW) at 50, 60 and 70 day after sowing

Ericson and Ketrang (1985) reported substantial osmotic adjustment peanut, ranging from 0.6-0.9 MPa. There was also evidence that there were significant cultivar differences in the extent of adjustment. Stirling *et al.* (1989) showed that, while substantial osmotic adjustment between 0.84-1.58 MPa occurred in expanding leaves. This response allowed expanding leaves to maintain higher turgor levels during periods of stress. The situation regarding the importance, extent and possible cultivar variation in osmotic adjustment in groundnut is therefore unclear.

### Identifying peanut genotypes with drought resistance:

The materials used in this study are peanut genotypes previously identified as drought resistant based on pod yield and biomass production under drought conditions (Nageswara Rao *et al.*, 1992; Nigam *et al.*, 2003, 2005). They were tested in pot experiment using KK 4, a well-adapted high yielding cultivar, as a drought susceptible

Table 1: Biomass, pod yield and Drought Tolerance Index (DTI) for four peanut genotypes under Field Capacity (FC) and available water (1/3 AW) condition at harvest

| Genotypes  | Biomass (g plant <sup>-1</sup> ) |        |      |            |        |      | Pod yield (g plant <sup>-1</sup> ) |        |      |
|------------|----------------------------------|--------|------|------------|--------|------|------------------------------------|--------|------|
|            | 70 DAS                           |        |      | At harvest |        |      |                                    |        |      |
|            | FC                               | 1/3 AW | DTI  | FC         | 1/3 AW | DTI  | FC                                 | 1/3 AW | DTI  |
| ICGV 98303 | 9.0                              | 7.6    | 0.88 | 16.8       | 15.5   | 0.93 | 5.79                               | 4.59   | 0.81 |
| ICGV 98324 | 11.8                             | 7.7    | 0.65 | 15.2       | 13.6   | 0.91 | 6.26                               | 5.14   | 0.93 |
| ICGV 98353 | 10.2                             | 6.5    | 0.65 | 14.7       | 13.4   | 0.92 | 4.72                               | 5.45   | 1.17 |
| KK 4       | 12.5                             | 8.7    | 0.70 | 12.6       | 13.3   | 1.06 | 4.71                               | 4.54   | 0.96 |
| Mean       | 10.9A                            | 7.6B   | 0.72 | 14.8       | 14.0   | 1.00 | 5.37                               | 4.93   | 0.97 |

For water regime comparison, Mean values in the same row with the same capital letter(s) were not significantly different by LSD at  $p \leq 0.05$  DTI for genotype were calculated by the ratio of stressed (1/3 AW)/non stress (FC) conditions

Table 2: Harvest index (HI), SPAD Chlorophyll Meter Reading (SCMR) and Drought Tolerance Index (DTI) for four peanut genotypes under Field Capacity (FC) and available water (1/3 AW) conditions at harvest

| Genotypes  | HI   |        |      | SCMR  |        |      |
|------------|------|--------|------|-------|--------|------|
|            | FC   | 1/3 AW | DTI  | FC    | 1/3 AW | DTI  |
| ICGV 98303 | 0.19 | 0.18   | 0.91 | 40.8b | 39.8   | 0.97 |
| ICGV 98324 | 0.21 | 0.21   | 1.07 | 46.1a | 44.7   | 0.98 |
| ICGV 98353 | 0.18 | 0.22   | 1.22 | 41.5b | 42.7   | 1.03 |
| KK 4       | 0.20 | 0.19   | 1.01 | 38.9b | 45.7   | 1.19 |
| Mean       | 0.20 | 0.20   | 1.05 | 41.8  | 43.2   | 1.04 |

For comparison among peanut genotypes, Mean values in the same column with the same letter(s) were not significantly different by LSD at  $p \leq 0.05$ . DTI for genotype were calculated by the ratio of stressed (1/3 AW)/non stress (FC) conditions

check. Drought stress significantly reduced biomass production from 10.9-7.6 g plant<sup>-1</sup> (Table 1). Drought stress seemed to reduce pod yield from 5.4 to 4.9 g plant<sup>-1</sup>, but the reduction was not statistically significant. Drought stress had no significant effect on harvest index. Drought Tolerance Indices (DTI) were not statistically significant for biomass production, pod yield (Table 1) and HI (Table 2). The expectation is that the ICGV genotypes should be better than KK 4 for biomass production and pod yield at least under drought conditions, but they performed similar to KK 4 for these traits. The results led to conclusion that KK 4 was tolerant to drought similar to the ICGV genotypes (based on pod yield and biomass production). This could be due to the fact that, although KK 4 has not been tested for drought resistance, it has been grown widely under rain-fed conditions in Thailand and it showed good stability for pod yield.

There was no significant genotypic difference in biomass production, HI, pod yield and DTI at any water level. This could be due to low variation for these characters. Another possible reason is that peanut genotypes responded in a similar pattern. For example, the recovery for biomass did not exceed its potential in any peanut genotypes, but full recovery was found for HI and pod yield, making no significant difference between water regimes. RWC could be recovered as early as 24 h

after re-watering in line with the recovery of leaf stomatal conductance, the electron transport rate and ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBPCO) activity (Lauriano *et al.*, 2004). Awal and Ikeda (2002) also found the relief from deficit that enabled the plants to reconstitute greater amounts of chlorophyll pigments and to regain foliar water status and stomatal conductivity simultaneously, resulting in higher amounts of gas exchange, especially through photosynthesis and thus increased water use efficiency and quantum yield. Lauriano *et al.* (1997) reported that photosystem I (PSI) and PSII activities in peanut were much higher after recovery than in controls. The capacity for rapid recovery after moisture deficit indicates that peanut has a greater ecophysiological plasticity than other crop plants, enabling it to grow well in drought-prone environments (Awal and Ikeda, 2002). Peanut plants also have a drought recovery mechanism operating at a late growth stage, but might not maintain a source-sink balance and so the yield loss may not be recoverable (Awal and Ikeda, 2002).

Therefore, it might be possible that all genotypes tested are drought resistant. The assumption underlying the experiment is that, once drought tolerant genotypes were identified, the drought tolerant genotypes should possess some root characters and/or morpho-physiological traits that are related to drought resistance. Based on the results HI did not provide useful information, but other physiological traits may help.

**Relative Water Content (RWC):** The drought stress significantly reduced RWC and significant differences among peanut genotypes for RWC at 70 DAS were observed under water stress conditions (1/3 AW) only (Table 3). ICGV 98324 performed best for this character followed by ICGV 98353 and ICGV 98303, respectively and the results were in accordance with those for its DTI. Significant differences in RWC between water regimes were also found in all peanut genotypes, in which peanut genotypes grown under FC had significantly higher RWC

Table 3: Relative Water Content (RWC), Specific Leaf Area (SLA) and Drought Tolerance Index (DTI) under Field Capacity (FC) and available water (1/3 AW) conditions at 70 days after sowing

| Genotypes  | RWC (%) |         |        | SLA (cm <sup>2</sup> g <sup>-1</sup> ) |         |      |
|------------|---------|---------|--------|--|---------|------|
|            | FC      | 1/3 AW  | DTI    | FC                                     | 1/3 AW  | DTI  |
| ICGV 98303 | 97.8    | 79.2ab* | 0.81ab | 184.0a                                 | 153.0a* | 0.83 |
| ICGV 98324 | 96.8    | 87.0a*  | 0.90a  | 156.8ab                                | 153.6a  | 0.98 |
| ICGV 98353 | 96.6    | 83.1a*  | 0.86a  | 143.5b                                 | 133.2b  | 0.94 |
| KK 4       | 97.1    | 72.6b*  | 0.75b  | 176.4a                                 | 161.6a  | 0.93 |
| Mean       | 97.1a   | 80.5b   | 0.83   | 165.2a                                 | 150.4b  | 0.92 |

For comparison among peanut genotypes, Mean values in the same column with the same letter(s) were not significantly different by LSD at  $p \leq 0.05$ . For water regime comparison, Means in the same row with the same capital letter(s) were not significantly different by LSD at  $p \leq 0.05$ . For comparison the same genotype with difference two water treatments, Mean in the same row with the symbol (\*) were significantly different by LSD at  $p \leq 0.05$ . DTI for genotype were calculated by the ratio of stressed (1/3 AW)/non stress (FC) conditions

than those grown under drought (Table 3). The visual wilting observed in genotypes exposed to water stress was also found at 70 DAS. However, peanut genotypes were not significantly different in RWC under drought at 50 and 60 DAS and the differences between water regimes at these evaluation dates were also not significant (data not showed). The results indicated that RWC was sensitive in identifying drought stress even in the same peanut genotypes with different water regimes in case of appropriate stress level. In case of mild drought stress, the use of RWC would not be appropriate because there was no significant difference between stressed and non-stressed treatments earlier than 7 DAS. This is possibly due to slow response of peanut to declining water level, whereas the response of soil to water depletion was more acute than peanut plants.

Relative water content in peanut is usually in a range of 30-100%, non-stressed plants have relative water content in a range of 85-100% (Reddy *et al.*, 2003). According to Reddy *et al.* (2003), biochemical components in leaves of stressed plants were changed although the plants could maintain relative water content as high as those for non-stressed plants and relative water content in a range lower than 85% is considered severely stressed.

In general, the RWC was decreased markedly in response to declining soil water availability. The reduction was more pronounced in sensitive varieties. In this study relative water contents of peanut experienced drought treatment and well-watered treatment were not statistically different at 50 and 60 DAS and the significant difference occurred at 70 DAS (Fig. 1). Although soil water content showed significant difference between stressed and non-stressed treatments, plants showed similar relative water content at earlier than 70 DAS. The contrasting results were reported by Arunyanark *et al.* (2008) and Pimratch *et al.* (2008), who found significant

difference in RWC between drought treatment and control treatment as early as 33-35 days after withholding water. The discrepancy of the results might be due to the difference in experimental conditions between greenhouse and field. Diurnal variation, leaf position and leaf age could affect RWC (Reddy *et al.*, 2003). However, peanut genotypes were significantly different for RWC under drought conditions. ICGV 98324 had the highest RWC and should be a promising parental line for high RWC for drought resistance breeding.

**Specific Leaf Area (SLA):** Low SLA is preferable as it indicates higher drought resistance. Drought stress significantly reduced SLA (Table 3). Peanut genotypes were also significantly different in SLA at all water regimes and ICGV 98353 showed the most consistently lower SLA than other genotypes. However, ICGV 98303 was the only one genotype that showed significant reduction in SLA. Low SLA indicated thicker leaves and could be used as an economically surrogate trait for drought resistance. In the present study, peanut genotypes were not significantly different in DTI for SLA, indicating similar responses of peanut genotypes for SLA. However, Nageswara Rao *et al.* (2001) suggested that, if SLA is to be used as a screening tool, then sampling should be performed on clear (full sunlight) days. Under high-radiation condition, variation in SLA should be largely driven by photosynthetic capacity. Thus, genotypic differences in SLA as a consequence of photosynthetic capacity may be better expressed on days with high radiation. It could be hypothesized that peanut genotypes with low SLA have more photosynthetic machinery per unit leaf area and hence potential for greater assimilation under drought stress because thicker leaves usually have a greater photosynthetic capacity compared with thinner leaves.

Although, SLA was reduced by drought stress, SLA in certain peanut genotypes under drought stress was dependent on that under well-watered conditions. For example, ICGV 98353 showed consistently low SLA under both drought and well-watered conditions. The variation and consistency of SLA make it useful for use as a selection criterion in drought resistance breeding program.

**SPAD Chlorophyll Meter Reading (SCMR):** Difference in SCMR between water treatments was not significant and significant differences among peanut genotypes were found under field capacity only (Table 2). ICGV 98324 had the highest SCMR under field capacity. DTI for SCMR was also not significantly different among peanut genotypes, indicating similar responses of peanut

genotypes for SCMR. However, the present study has also shown that, KK 4 trend to show high SCMR under drought stress conditions. Leaf photosynthesis is generally correlated with chlorophyll content per unit leaf area and hence the SPAD chlorophyll meter can provide a useful tool to screen for genotypic variation in potential photosynthetic capacity under drought conditions (Nageswara Rao *et al.*, 2001; Songsri *et al.*, 2008d).

Although, it is not significantly different between water regimes, drought seemed to increase SCMR. Similar to these results, Jongrunklang *et al.* (2008) found that drought significantly increased SCMR. The identification and use of surrogate traits for SCMR are simple and useful as a selection criterion for drought tolerance in peanut because of high heritability (Songsri *et al.*, 2008b). Nageswara Rao *et al.* (2001) found that there were significant interrelationships among SLA, specific leaf nitrogen (SLN) and SCMR and they suggested that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA or high SLN (and hence high transpiration efficiency) in breeding and peanut selection programmes. Nigam and Aruna (2008) suggested that SCMR and SLA can be recorded at any time after 60 days of the crop growth, preferably under moisture deficit conditions. However, as suggested by Serraj *et al.* (2004), these measurements should be recorded after imposition of moisture deficit and particularly at mid-way through stress.

#### Root Length (RL), Root Surface (SR), Root Volume (RV) and Root Dry Weight (RDW):

Root characters other than RDW were not significantly different among peanut genotypes for both water regimes and difference between water regimes was also not significant (data not shown). The lack of variation in root characters might be due to the difficulty in recovering roots from soil and the limitation of root growth due to the confinement of roots in the containers. However, peanut genotypes were significantly different in RDW at 1/3 AW at 70 and harvest ( $p \leq 0.10$ ), whereas at field capacity the differences among peanut genotypes were not significant (Table 4). The differences in DTI for RDW among peanut genotypes were significant at 70 DAS only. Drought stress also reduced RDW at 70 DAS but not at harvest. Increased RDW in response to drought stress was observed in peanut genotypes ICGV 98303 and KK 4. The increase in RDW in ICGV 98303 was found as early as 70 DAS, whereas the increase in RDW in KK 4 was found at harvest only. ICGV 98303 and KK 4 also showed the highest DTI for RDW. The observations showed that the varieties with low RWC tended to have a higher RDW indicating that drought stress would induce

Table 4: Root Dry Weight (RDW) and Drought Tolerance Index (DTI) under Field Capacity (FC) and available water (1/3 AW) conditions at 70 day after sowing and harvest

| Genotypes  | RDW (g plant <sup>-1</sup> )<br>at 70 DAS |        |        | RDW (g plant <sup>-1</sup> )<br>at harvest |        |      |
|------------|---|--------|--------|--|--------|------|
|            | FC  | 1/3 AW | DTI    | FC   | 1/3 AW | DTI  |
| ICGV 98303 | 1.26                                      | 1.40ab | 1.11a  | 1.82                                       | 1.92a  | 1.20 |
| ICGV 98324 | 1.90                                      | 1.40ab | 0.74b  | 1.70                                       | 1.69b  | 0.99 |
| ICGV 98353 | 1.55                                      | 1.28b  | 0.84b  | 1.84                                       | 1.77ab | 0.94 |
| KK 4       | 1.65                                      | 1.55a  | 0.95ab | 1.70                                       | 1.75ab | 1.10 |
| Mean       | 1.59a                                     | 1.41b  | 0.91   | 1.76                                       | 1.78   | 1.05 |

For comparison among peanut genotypes, Mean values in the same column with the same letter(s) were not significantly different by LSD at  $p \leq 0.10$ . For water regime comparison, Means in the same row with the same capital letter(s) were not significantly different by LSD at  $p \leq 0.10$ . DTI for genotype were calculated by the ratio of stressed (1/3 AW)/non stress (FC) conditions

increased root production such as KK 4. Del Rosario *et al.* (1988) also reported that the varieties with low leaf water potential tend to have a higher RDW indicating that severe stress would induce increased root production. Songsri *et al.* (2008c) found that RLD in the deeper subsoil level was increased in response to drought and RLD under drought conditions was not related to biomass production. However, they found that the ability to maintain the percentage of RLD (DTI for RLD (%)) was related to pod yield, DTI for pod yield and DTI for HI. The ability of peanut to maintain a viable root system during water stress may contribute to the crop's drought resistance (Reddy *et al.*, 2003).

## CONCLUSION

Drought stress reduced RWC, SLA, RDW and biomass production. Peanut genotypes were significantly different for SLA under water stress and well-watered conditions, but they were significantly different for RDW and RWC under water stress conditions only, indicating that drought stress increased variation for these traits. Peanut genotypes showed different responses for traits associated with drought resistance and the genotypes with good performance for traits associated with drought resistance could be identified. ICGV 98353 was a good genotype for SLA, whereas ICGV 98324 was a good genotype for RWC. KK 4 had high SCMR under drought stress conditions, whereas, ICGV 98303 had the highest DTI for RDW. Differential responses of peanut genotypes for these traits indicated that several drought resistance mechanisms might exist. Combining these characters in peanut breeding programs should increase drought resistance in peanut.

## ACKNOWLEDGMENTS

The authors are grateful for the financial support of the Senior Research Scholar Project of Professor Dr. Aran



Patanothai under the Thailand Research Fund and also being supported in part by the Basic Research for Supporting Groundnut Varietal Improvement for Drought Tolerance Project of Khon Kaen University Khon Kaen, Thailand. We thank the research of many people in field data collection and processing.

## REFERENCES

- Arunyanark, A., S. Jogloy, C. Akkasaeng, N. Vorasoot, T. Kesmla, R.C. Nageswara Rao, G.C. Wright and A. Patanothai, 2008. Chlorophyll stability is an indicator of drought tolerance in peanut. *J. Agron. Crop Sci.*, 194: 113-125.
- Awal, M.A. and T. Ikeda, 2002. Recovery strategies follow the imposition of episodic soil moisture deficit in stands of peanut (*Arachis hypogaea* L.). *J. Agron. Crop Sci.*, 188: 185-192.
- Del-Rosario, D.A. and F.F. Fajardo, 1988. Morphophysiological responses of ten peanut (*Arachis hypogaea* L.) varieties to drought stress. *The Philippine Agric.*, 71: 447-459.
- Erickson, P.I. and D.L. Ketrin, 1985. Evaluation of peanut genotypes for resistance to water stress *in situ*. *Crop Sci.*, 25: 870-876.
- Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons, Inc., New York, ISBN-10: 0471870927.
- González, L. and M. González-Vilar, 2001. Determination of Relative Water Content. In: Handbook of Plant Ecophysiology Techniques, Reigosa Roger, M.J. (Ed.). Springer, Netherlands, ISBN: 978-0-7923-7053-6 pp: 207-212.
- Jongrungsklang, N., B. Toomsan, N. Vorasoot, S. Jogloy, T. Kesmla and A. Patanothai, 2008. Identification of peanut genotypes with high water use efficiency under drought stress conditions from peanut germplasm of diverse origins. *Asian J. Plant Sci.*, 7: 628-638.
- Katam, R., S. Basha, H. Vasanthaiah and K. Naik, 2007. Identification of drought tolerant groundnut genotypes employing proteomics approach. *An Open Access J.*, 5: 1-4.
- Krishnamurthy, L., V. Vadez, M. Jyotsna Devi, R. Serraj, S.N. Nigam, M.S. Sheshshayee, S. Chandra and R. Aruna, 2007. Variation in transpiration efficiency and its related traits in a groundnut (*Arachis hypogaea* L.) mapping population. *Field Crops Res.*, 103: 187-197.
- Lal, C., K. Hariprasanna, A.L. Rathnakumar, H.K. Gor and B.M. Chikani, 2006. Gene action for surrogate traits of water-use efficiency and harvest index in peanut (*Arachis hypogaea*). *Ann. Applied Biol.*, 148: 165-172.
- Lauriano, J.A., P.S. Campos, J.C. Ramalho, F.C. Lidon, M.E. Guedes and M. Do-Céu-Matos, 1997. Partial decline of *Arachis hypogaea* L. photosynthesis triggered by drought stress. *Photosynthetica*, 33: 81-90.
- Lauriano, J.A., J.C. Ramalho, F.C. Lidon and M. Do-Céu-Matos, 2004. Peanut photosynthesis under drought and re-watering. *Photosynthetica*, 42: 37-41.
- Ludlow, M.M. and R.C. Muchow, 1990. A critical evaluation of traits for improving crop yield in water-limited environments. *Adv. Agron.*, 43: 107-153.
- Matsui, T. and B.B. Singh, 2003. Root characteristics in cowpea related to drought tolerance at the seedling stage. *Exp. Agric.*, 39: 29-38.
- Meisner, C.A. and K.J. Karnok, 1992. Peanut root response to drought stress. *Agron. J.*, 84: 159-165.
- Nageswara Rao, R.C., L.J. Reddy, V.K. Mehan, S.N. Nigam and D. McDonald, 1992. Drought research on groundnut at ICRISAT. Proceedings of the International Work Shop, Groundnut-a Global Perspective, Nov. 25-29, ICRISAT Center Andhra Pradesh, India, pp: 455-455.
- Nageswara Rao, R.C. and G.C. Wright, 1994. Stability of the relationship between specific leaf area and carbon isotope discrimination across environments in peanut. *Crop Sci.*, 34: 98-103.
- Nageswara Rao, R.C., H.S. Talwar and G.C. Wright, 2001. Rapid assessment of specific leaf area and leaf nitrogen in peanut (*Arachis hypogaea* L.) using chlorophyll meter. *J. Agron. Crop Sci.*, 189: 175-182.
- Nautiyal, P.C., R.C. Nageswara Rao and Y.C. Joshi, 2002. Moisture-deficit-induced changes in leaf-water content, leaf carbon exchange rate and biomass production in groundnut cultivars differing in specific leaf area. *Field Crops Res.*, 74: 67-79.
- Nigam, S.N., M.S. Basu and A.W. Cruickshank, 2003. Hybridization and description of the trait-based and empirical selection programs. Proceedings of the International Workshop on Breeding for Drought-Resistant Peanuts, Feb. 25-27, ICRISAT Centre Andhra Pradesh, India, ACIAR, Canberra, Australia, pp: 15-17.
- Nigam, S.N., S. Chandra, K. Rupa-Sridevi, A. Manohabhukta and G.S. Reddy *et al.*, 2005. Efficiency of physiological trait-based and empirical selection approaches for drought tolerance in groundnut. *Ann. Applied Biol.*, 146: 433-439.
- Nigam, S.N. and R. Aruna, 2007. Stability of soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) and specific leaf area (SLA) and their association across varying soil moisture stress conditions in groundnut (*Arachis hypogaea* L.). *Euphytica*, 160: 111-117.

- Pimratch, S., S. Jogloy, N. Vorasoot, B. Toomsan, A. Patanothai and C.C. Holbrook, 2008. Relationship between biomass production and nitrogen fixation under drought stress conditions in peanut genotypes with different levels of drought resistance. *J. Agron. Crop Sci.*, 194: 15-25.
- Reddy, T.Y., V.R. Reddy and V. Anbumozhi, 2003. Physiological responses of groundnut (*Arachis hypogaea* L.) to drought stress and its amelioration: A critical review. *Plant Growth Regul.*, 41: 75-88.
- Rucker, K.S., C.K. Kvien, C.C. Holbrook and J.E. Hook, 1995. Identification of peanut genotypes with improved drought avoidance traits. *Peanut Sci.*, 24: 14-18.
- Serraj, R., L. Krishnamurthy, M. Jyostna Devi, M.J.V. Reddy and S.N. Nigam, 2004. Variation in transpiration efficiency and related traits in a groundnut mapping population. *Int. Arach. Newslett.*, 24: 42-45.
- Sheshshayee, M.S., H. Bindumadhava, N.R. Rachaputi, T.G. Prasad, M. Udayakumar, G.C. Wright and S.N. Nigam, 2006. Leaf chlorophyll concentration relates to transpiration efficiency in peanut. *Ann. Applied Biol.*, 148: 7-15.
- Songsri, P., S. Jogloy, T. Kesmala, N. Vorasoot, C. Akkasaeng, A. Patanothai and C.C. Holbrook, 2008a. Response of reproductive characters of drought resistant peanut genotypes to drought. *Asian J. Plant Sci.*, 7: 427-439.
- Songsri, P., S. Jogloy, T. Kesmala, N. Vorasoot, C. Akkasaeng, A. Patanothai and C.C. Holbrook, 2008b. Heritability of drought resistance traits and correlation of drought resistance and agronomic traits in peanut. *Crop Sci.*, 48: 2245-2253.
- Songsri, P., S. Jogloy, N. Vorasoot, C. Akkasaeng, A. Patanothai and C.C. Holbrook, 2008c. Root distribution of drought-resistant peanut genotypes in response to drought. *J. Agron. Crop Sci.*, 194: 92-103.
- Songsri, P., S. Jogloy, C.C. Holbrook, T. Kesmala, N. Vorasoot, C. Akkasaeng and A. Patanothai, 2008d. Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. *Agric. Water Manage.* (In Press).
- Stirling, C.M., C.R. Black and C.K. Ong, 1989. The response of groundnut (*Arachis hypogaea* L.) to timing of irrigation. II. <sup>14</sup>C-partitioning and growth. *J. Exp. Bot.*, 40: 1363-1373.
- Taiz, L. and E. Zeiger, 2006. Stress Physiology. In: *Plant Physiology*, Taiz, L. and E. Zeiger (Eds.). Sinauer Associates, Inc., Sunderland, MA., pp: 671-681.
- Wright, G.C. and R.C. Nageswara Rao, 1994a. Peanut Water Relations. In: *The Peanut Crop*, Smartt, J. (Ed.). Chapman and Hall, London, ISBN: 0 412 40820 1 pp: 281-325.
- Wright, G.C., R.C. Nageswara Rao and G.D. Farguher, 1994b. Water-use efficiency and carbon isotope discrimination in peanut under water deficit conditions. *Crop Sci.*, 34: 92-97.