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Heritability and Correlation of Drought Resistance Traits and Agronomic Traits in Peanut (*Arachis hypogaea* L.)

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Abstract: Several physio-morphological traits are related to pod yield of peanut. Improvement of these traits should lead to yield increase under drought conditions. The objective of this study was to evaluate (1) heritability of drought resistance traits, yield and yield components and (2) relationships among these traits. A cross of two parents (ICGV 98324 and KK 4) differing in physio-morphological traits was used in this study. Pot experiments of F_2 and F_3 populations were set up in the open field with rainout shelters. One hundred and twenty eight entries were subjected to water stress during 28 to 70 days after sowing and evaluation of the studied characters was conducted at appropriate time. Data were recorded for Root Dry Weight (RDW), Root Length (RL), Root Surface (RS), Root Volume (RV), Specific Leaf Area (SLA), SPAD Chlorophyll Meter Reading (SCMR), biomass, pod yield, pod number per plant, seed number per pod, 100-seed weight and Harvest Index (HI). Heritability estimates in broad sense for root characters and drought resistance traits were low to intermediate, ranging from 0.27 to 0.59. Similarly, low to intermediate heritability estimates in broad sense were found for pod yield and yield components, ranging from 0.20 to 0.57. Heritability estimates in narrow sense were much lower than in broad sense. The correlation coefficients among root characters were inter-related positively, whereas negative correlation coefficients were observed among physiological characters. Root characters were closely related to biomass production but they were not related to yield and yield components except for pod number per plant.

Key words: Breeding, inheritance, SLA, SPAD chlorophyll meter reading, water stress

INTRODUCTION

Peanut yield in rain-fed areas has been limited by drought stress because pod yield and other growth parameters have been severely affected (Pimratch *et al*., 2008; Songsri *et al*., 2008a; Awal and Ikeda, 2002; Nautiyal *et al*., 2002; Reddy *et al*., 2003; Nigam *et al*., 2005). Yield losses have been estimated to be 56-85% (Nageswara Rao *et al*., 1989), depending on crop growth stages when the crop was exposed to drought (Awal and Ikeda, 2002; Reddy *et al*., 2003), drought intensity and drought duration (Nautiyal *et al*., 2002; Nigam *et al*., 2005). Even in irrigated areas, peanut is frequently exposed to drought because water supply is not sufficient.

The use of drought-resistant varieties is an important strategy to combat the drought problem. These varieties should be able to provide higher yield under drought conditions. Genetic variability for drought resistance has been reported in peanut (Erickson and Ketring, 1985; Upadhyaya, 2005; Songsri *et al*., 2008a-c, 2009). However, breeding for drought resistance based on pod yield is lacking behind due to significant genotype×environment interactions (Wright *et al*., 1996).

Alternative breeding strategies using physiological traits as selection criteria have been proposed by some researchers. Rapid progress in drought resistance breeding has been achieved based on characters like Harvest Index (HI), Water Use Efficiency (WUE), Specific Leaf Area (SLA) and SPAD Chlorophyll Meter Reading (SCMR) (Nigam *et al*., 2005). The SLA and SCMR have been found to be highly correlated with WUE (Nageswara Rao *et al*., 2001; Sheshshayee *et al*., 2006) and have been used as surrogate traits for WUE (Nigam *et al*., 2005; Lal *et al*., 2006; Sheshshayee *et al*., 2006; Arunyanark *et al*., 2008; Jongrungklang *et al*., 2008; Pimratch *et al*., 2008). Specific leaf area and SCMR have been found to be negatively correlated (Nageswara Rao *et al*., 2001; Upadhyaya, 2005).

Earlier studies have indicated differential responses for relative water content in peanut (Painawadee *et al*., 2009) and it was positively correlated with chlorophyll

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Corresponding Author: Dr. S. Jogloy, Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Muang, Khon Kaen 40002, Thailand Tel/Fax: + 66 043 364637 content and grain yield in rice under drought conditions Pirdashti *et al*. (2009). Leaf water status is dependent on rooting density, root distribution, ability of roots to extract water, behavior of stomata closure and transpiration rate (Kramer, 1969, 1983; Gregory, 2006). Root systems play a crucial role in determining shoot water status and therefore effective water uptake is an important determinant of drought resistance (Huang *et al*., 1997; Huang, 2000; Kashiwagi *et al*., 2006). Larger root systems and deep growth of root systems into lower soil profile can take up more water to support plant growth and yield (Ludlow and Muchow, 1990; Turner *et al*., 2001). Moreover, deep and prolific root systems have been associated with enhanced avoidance of terminal drought stress in chickpea (Ludlow and Muchow, 1990; Serraj *et al*., 2004). Selections with more extensive root systems could extract more soil water from greater soil volumes than selections with limited root system. Many root characteristics have been shown to be under genetic control and quantitatively inherited (O'Toole and Bland, 1987). Genetic variation for root characters has been found among peanut genotypes (Ketring, 1984). Differences among peanut genotypes were observed and Virginia type possessed longer taproots and had faster root growth rates than Spanish type (Huang and Ketring, 1987; Maiti *et al*., 2002).

Information on the heritability of RWC, SCMR, SLA, HI, biomass, pod yield, pod number per plant, seed number per pod, 100-seed weight and root traits and the phenotypic correlations among these traits will be useful for planning suitable breeding strategies for improving drought tolerance. The effective selection for traits under improvement depends on sufficient additive genetic variation of the traits that are expressed as heritability. Phenotypic relationships among traits are also important when simultaneous selection of multiple traits is to be carried out for high yield under drought stress conditions. Therefore, the present research was undertaken to estimate the (1) heritability of drought resistance traits, yield and yield components and (2) relationships among these traits.

MATERIALS AND METHODS

Plant materials: Two parental lines (ICGV 98324 and KK 4) were used in a cross to generate an F_1 hybrid. The parents were selected because they were different in many characters such as RWC and SCMR as evaluated in one of our studies (Painawadee *et al*., 2009). ICGV 98324 is a drought resistant line from ICRISAT and it was identified as drought resistant because of high total biomass and pod yield under drought conditions (Nageswara Rao *et al*., 1992; Nigam *et al*., 2003, 2005). KK 4, a released variety in Thailand, is a Valencia bunch type with erect growth habit, early maturity (100 days), small–seeded nature and high drought tolerance index for RDW (Painawadee *et al*., 2009). The F_1 hybrid was further grown in a small plot for multiplication and generation advance. The F_2 and F_3 generations were used in the experiments.

Crop management and experimental designs: The experiment was conducted 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). One hundred and twenty eight plants in the F_2 generation were first evaluated in an un-replicated trial during December, 2006 to April, 2007 and the 128 progenies in the F_3 generation were later evaluated in a randomized complete block design with four replications during June, 2007 to October, 2007. Crop management for both trials was identical.

The plants were grown in pots with 25 cm diameter and 70 cm height under open environment and removeable rainout shelters were available if necessary. Pots were filled with soil (Yt; fine-loamy, siliceous, isohypothermic, Oxic Paleustults). The soil properties are given in Table 1.

The soil was filled into the pots in four columns of the soil profile in order to make soil bulk density uniform. Three plastic tubes were installed to supply water to each soil column from the bottom to the column below the top soil column and the top soil column was surface irrigated as detailed by Songsri *et al*. (2009) and Painawadee *et al*. (2009).

Lime at the rate of 19.2 g pot^{-1} was incorporated into the soil prior to soil filling and phosphorus fertilizer as triple superphosphate at the rate of 12.12 g P pot^{-1} and potassium fertilizer as muriate of potash (KCl) at the rate 15.26 g K pot^{-1} were applied immediately before planting.

Table 1: Soil properties for F_2 and F_3 generations experiment

	Generations	
Soil properties	F_2	F_3
Physical (%)		
Sand particle	71.00	55.00
Silt particle	20.00	29.00
Clay particle	9.00	16.00
Field capacity	10.00	10.00
1/3 available water	5.00	6.00
Permanent wilting point	3.00	4.00
Chemical		
pH (1:1 H_2O)	5.58	4.50
Organic matter (%)	0.47	0.36
Total nitrogen (%)	0.02	0.03
Available phosphorus (ppm)	7.00	2.00
Potassium (ppm)	23.50	29.50
Calcium (ppm)	216.50	215.50
Bulk density (g cm^{-3})	1.48	1.47

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 for fungal control and ethrel 48% at the rate of 2 ml L^{-1} water to break seed 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 hills before planting.

The seeds were over planted and the seedlings were thinned to one plant per hill at 14 days after sowing (DAS). Gypsum ($CaSO_4$) at the rate of 9.58 g pot^{-1} was applied at 40 DAS. The pots were kept weed free by regular manual weeding. Pests and diseases were controlled by weekly application 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}.

Uniform irrigation at field capacity was supplied to the experiments from planting to 12 DAS. Withholding of irrigation was carried out after 12 DAS to allow soil water gradually get reduced until reaching at 1/3 available water (28 DAS) and the soil moisture content was maintained at this level until 70 DAS. After 70 DAS, soil moisture level at field capacity was brought back until harvest.

The method of calculation for plant water use proposed by Songsri *et al.* (2008a-c, 2009) was followed. It was found that crop water requirement was identical to crop water loss through plant transpiration and soil evaporation. Therefore, crop water requirement is the product of evaporation (a pan) multiplied by crop coefficient for peanut. For each water level, soil moisture was controlled uniformly until harvest.

Weather parameters: Weather data were obtained from the nearest meteorological station. The maximum and minimum air temperatures ranged between 33.1 and 20°C in F_1 trial and 32.4 and 25.8°C in F_2 trial (Fig. 1). Daily pan evaporation ranged from 2.88 to 9.84 mm in F_1 trial and 0.6 to 8.9 mm in F_2 trial. The relative humidity values were 75.6% in F_1 trial and 89% in F_2 trial. The solar radiations and average sunshine hours were 18.9 MJ/m^2/day and 10 h in F_1 trial and 13.9 MJ/m^2/day and 6.4 h in F_2 trial, respectively.

Data collection:

Plant water status: Relative Water Content (RWC) was recorded on each of the four leaflets of the tetrafoliate leaf

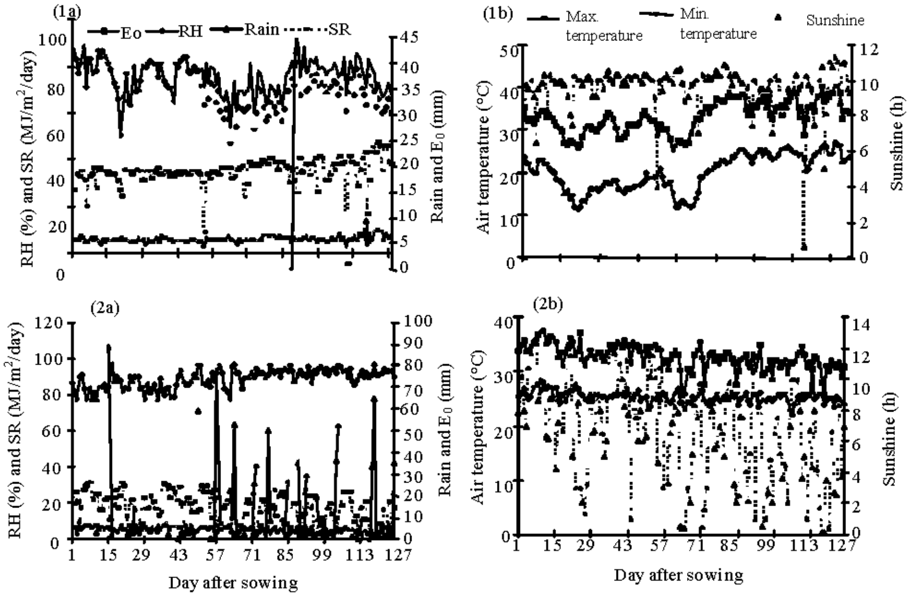

Fig. 1: Daily mean air temperature, rain fall, evaporation (E_0), relative humidity (RH), solar radiation (SR), maximum and minimum air temperature (max. and min. temp.) and sunshine (h) all season grow for experiment 1(1a, b) and experiment 2 (2a, b)

at 70 DAS. Only one fully expanded second or third leaf from the apex of the main axis of each pot was used to record RWC. Leaves were detached and kept in sealable plastic bags in ice box and transported to the laboratory and 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. The RWC was calculated based on the formula suggested by González and González-Vilar (2001) as follows:

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

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), Specific Leaf Area (SLA) and Relative Water Content (RWC) were recoded at 70 days after sowing at 9.00-10.00 AM. The second leaf from terminal bud of the main stem of each plant was detached and kept in sealable plastic bags 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 per sample. In recording the SCMR, care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and the interference from veins and midribs could be avoided. The same samples were further measured for leaf area, using a leaf area meter (LI 3100C Area meter, LI COR Inc., USA). The samples were then oven-dried at 80°C until reaching constant weight and leaf dry weight could be determined. The SLA was calculated using the following equation (Nageswara Rao *et al.*, 2001):

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

Root traits, yield and yield components: Biomass (roots and shoots included), root dry weight, shoot dry weight and harvest index were determined at harvest (120 DAS). Shoots were cut at crown level and the roots were washed in running tap water to remove the soil. The complete removal of the soil was done on a 3 mm sieve. Care was taken to recover the root system completely. The roots were thoroughly cleaned and straightened by repeated dipping and rising in buckets of clear water. Then, The root samples were put on a flatbed scanner (Epson Perfection V700 Photo, Epson Inc., Cheung Shawan, Kowloon, HK) and scanned using WinRhizo Pro 2004a (Regent instruments, Inc., Quebec, QC) at 400 dpi (Gaur *et al.*, 2008; Songsri *et al.*, 2008a). Top and bottom lighting systems were used to eliminate shadows and maximize contrast. The captured grayscale image was analyzed with WinRhizo to measure Root Surface (RS), Root Length (RL) and Root Volume (RV). Root samples and above ground samples were oven dried at 80°C until constant weights were reached. After oven drying, Root Dry Weight (RDW) and shoot dry weight were recorded. Harvest index was calculated using the following relationship (Wright and Nageswara Rao, 1994):

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

At harvest, pods were removed from shoots and immature pods were not included in any calculation of yield parameters. Pod yields were determined after air drying to approximately 8% moisture content. Pod number per plant seed number per pod and 100 seed weight were also recorded at final harvest.

Statistical analysis: The data of the F_3 generation were subjected to analysis of variance (Gomez and Gomez, 1984) and the significant variance of the progenies was further partitioned into genetic variance and error variance. Heritability estimates in broad sense (h^2_{bs}) were calculated using the following relationship (Singh *et al.*, 1993):

$$h^2_{bs} = \sigma^2_g / \left(\sigma^2_g + \sigma^2_e\right)$$

Where:
σ^2_e = M_e, σ^2_g = $(M_g - M_e)/b$,
σ^2_e = Environmental variance
M_e = Mean square of error
σ^2_g = Genotypic variance
M_g = Mean square of genotype

The Standard Error (SE) associated with broad sense heritability estimate was calculated as:

$$\text{SE}\,(h^2_{bs}) = (1-h^2)\,[1+(b-1)\,h^2]\,[2/(bf)]^{1/2}$$

Where:
b = Replication
f = Degree of freedom of error.

Heritability estimates in narrow sense (h^2_{rg}) were also calculated by parent offspring method using the data of F_3 on F_2 families as suggested in Smith and Kinman (1965):

$$h^2_{rg} = b/2r_{op}$$

Where:

b = Regression coefficient or slope

r_{op} = Relationship of parents-offspring.

Linear regression coefficients (b) were calculated by regressing of F_3 progeny means (Y_i) on F_2 plants means (X_i). Standard errors (SE) for the slope of each regression were calculated as follows (Ibrahim and Quick, 2001):

$$SE = \left[\left(Y_i^2 - (X_iY_i)2/X_i^2\right)/(n-2)X_i^2\right]/X_i^2$$

where, n is number of families.

Simple correlation coefficients based on progeny means of F_3 generation were calculated to determine the relationship between yield and yield components with drought resistance traits. All calculations were accomplished using STATISTIX 8 software program.

RESULTS

Heritability estimates for root parameters and drought resistant traits: Broad sense heritability estimates for root parameters and drought resistant traits, in general, were much higher than those in narrow sense (Table 2). Heritability estimates in broad sense ranged from 0.27 for SCMR to 0.59 for root surface and root volume, whereas heritability estimates in narrow sense ranged from 0.00 for SLA to 0.13 for root dry weight.

Heritability estimates for yield and yield components: Heritability estimates in broad sense for yield and yield components were relatively higher than those in narrow sense (Table 3). Broad sense heritability estimates ranged from 0.20 for Harvest Index (HI) to 0.57 for pod number per plant, whereas narrow sense heritability estimates ranged from 0.13 for pod yield to 0.23 for pod number per plant and 100-seed weight.

Phenotypic correlation between drought resistant traits and drought resistant traits and yield components: All root parameters (root length, root dry weight, root surface and root volume) were positively and significantly associated with the high correlation coefficients between 0.67, p≤0.01 to 0.98, p≤0.01 (Table 4). In contrast to root parameters, all traits related to drought resistance (RWC, SLA and SCMR) were negatively and significantly associated and the correlation coefficients ranged between -0.17, p≤0.05 to -0.51, p≤0.01). Root characters were also positively and significantly correlated with biomass production and in lesser extent with pod number per plant (Table 5). Most drought resistance traits (RWC, SCMR and SLA) were not correlated with pod yield and yield components except for SCMR with pod number per plant (0.20, p≤0.05).

Table 2: Broad sense and narrow sense heritability and standard errors for root dry weight (RDW), root length (RL), root surface (RS), root volume (RV), specific leaf area (SLA), relative water content (RWC) and SPAD chlorophyll meter reading (SCMR)

	Heritability	
Character	Broad sense	Narrow sense
RDW	0.34±0.03	0.13±0.01
RL	0.58±0.04	0.10±0.00
RS	0.59±0.04	0.11±0.00
RV	0.59±0.03	0.12±0.00
SLA	0.57±0.04	0.00
RWC	0.46±0.04	0.01±0.00
SCMR	0.27±0.03	0.05±0.00

Table 3: Broad sense and narrow sense heritability and standard errors for biomass, pod yield, number pod per plant, number seed per pod, 100-seed weight and harvest index (HI)

	Heritability	
Character	Broad sense	Narrow sense
Biomass	0.30±0.03	0.16±0.00
Pod yield	0.47±0.04	0.13±0.00
Pod No. plant^{-1}	0.57±0.04	0.23±0.01
Seed No. pod^{-1}	0.24±0.03	0.19±0.02
100 seed weight	0.46±0.04	0.23±0.01
HI	0.20±0.02	0.21±0.01

Table 4: Correlation coefficients among drought resistance traits for peanut in F_3 generation

	Drought resistance traits					
Drought resistance traits	RDW	RL	RS	RV	RWC	SCMR
RL	0.67**					
RS	0.71**	0.98**				
RV	0.73**	0.92**	0.97**			
RWC	0.03	-0.05	-0.00	0.04		
SCMR	0.15	0.11	0.10	0.09	-0.51**	
SLA	-0.03	0.07	0.06	0.03	-0.17*	-0.40**

*, ** Significant at the p ≤ 0.05 and p ≤ 0.01, respectively

Table 5: Correlation coefficients between yield and yield components with drought resistance traits for peanut in F_3 generation

	Yield and yield components					
Drought resistance traits	HI	Biomass	Pod yield	Pod No. plant^{-1}	Seed No. pod^{-1}	100 seed weight
RDW	-0.20*	0.65**	0.13	0.10	0.02	0.04
RL	0.04	0.43**	0.04	0.29**	0.02	0.06
RS	0.00	0.42**	0.01	0.26**	0.02	0.05
RV	-0.04	0.39**	0.04	0.17*	0.01	0.02
SLA	0.02	0.02	0.02	-0.07	0.00	-0.03
RWC	0.04	0.07	0.04	0.11	0.05	0.03
SCMR	-0.01	0.10	0.01	0.20*	0.05	0.00

*, ** Significant at the p≤0.05 and p≤0.01, respectively

DISCUSSION

The progress in breeding for drought resistance in peanut based on pod yield has been slow because of high G×E interactions (Wright *et al*., 1996). The use of surrogate traits related to drought resistance has been suggested by many authors (Nageswara Rao *et al*., 2001; Nigam *et al*., 2005) as the inheritance of these characters must be simpler than pod yield. The information on the heritability and the relationships among characters is important for plant breeders to formulate appropriate breeding strategies to achieve breeding goals. The aims of this study were to understand whether heritability estimates for characters under investigation were sufficient for further improvement of these characters and to explore whether physiological characters and other drought related characters could be used as surrogate traits for pod yield under drought conditions.

For drought resistance and physiological characters, the heritability estimates in broad sense were higher than those in narrow sense. Similar lower narrow sense heritability estimates were also observed for pod yield and its related traits. Higher broad-sense heritability estimates could be due to the inclusion of non-heritable genetic variance and variance due to G×E interactions (Falconer, 1996; Brown and Caligari, 2008). Low heritability estimates observed in this study indicate the difficulty in improving these characters.

The heritability estimates in narrow sense in this study may be under estimated because of high intra plant variation of individual plants in the F_2 generation. Single plants in the F_2 generation might be not appropriate for evaluation of narrow sense heritability estimates and the heritability estimates may be improved if more advanced generations were used with appropriate replicated trials. Root systems themselves are exceedingly complex structures, typically being composed of thousands of individual root axes. Higher narrow-sense heritability estimates for crop growth rate, reproductive duration, partitioning and yield were obtained based on F_4 on F_3 rather than based on F_3 on F_2 (Ntare and Williams, 1998).

Heritability estimates in broad sense and narrow sense for yield and yield components followed a similar pattern to those for root parameters and traits related to drought resistance. However, narrow sense heritability estimates for yield and yield components were somewhat higher than those for root parameters and traits related to drought resistance. Better improvement for these traits would be expected especially for characters with higher narrow sense heritability estimates such as pod number per plant (0.23), seed number per pod (0.19), 100-seed weight (0.23) and harvest index (0.21).

With regard to the heritability estimates, drought resistance and physiological characters were not superior to yield and yield components and therefore, the use of drought resistance and physiological characters as surrogate traits for pod yield and yield components in this population will not be effective. The disappointing results observed in this study could be due to the low genetic variability for these characters in the parental materials. However, the use of more diverse germplasm as parental materials should increase selection efficiency and these surrogate traits are still worth-exploring in peanut.

To the best of our knowledge so far, the report on the heritability for root characters in peanut has not been available in the open literature and the direct comparison of the results is not possible. In peanut, Songsri *et al.* (2008b) found rather high broad sense heritability estimates of 0.73-0.98 for biomass, pod yield, HI, SCMR and SCMR in the $F_{4:7}$ and $F_{4:8}$ generations. For other legumes, however, broad-sense heritability estimates of 0.51-0.55 for root area, 0.47-0.50 for root length and 0.51-0.61 for root mass in common bean under limited soil phosphorus supply has been reported (Araújo *et al*., 2005). In clover, broad sense heritability estimates for root characters were between 0.2 and 0.4 (Caradus and Woodfield, 1990).

The relationships of root parameters indicated that it was not necessary to evaluate all parameters and evaluation of the most convenient and less expensive characters would be sufficient. In this case, root dry weight is recommended. Ketring (1984) also found positive correlation between root volume and root dry weight in peanut and suggested to select for extensive rooting traits to develop more drought tolerant peanut cultivars. Huang and Ketring (1987) also obtained highly positive linear correlation coefficients for root dry weight with root volume and total dry weight in peanut. High inter-relationships among root characters were also observed in pea (McPhee, 2005) and common bean (Araújo *et al*., 2005). They also suggested that the high correlation between root mass and root area justifies screening genotypes based solely on root mass. However, negative correlation between root length and root dry weight were found in rice (Sasmal, 2008). This could be due to the fact that rice is normally grown under water-flooded conditions.

In contrast to root parameters, all traits related to drought resistance (RWC, SLA and SCMR) were negatively and significantly associated and the correlation coefficients ranged between -0.17, $p \leq 0.05$ to -0.51, $p \leq 0.01$). The results were in agreement with those reported under non-stressed conditions (Nageswara Rao *et al*., 2001; Upadhyaya, 2005) and end of season drought conditions (Nigam and Aruna, 2008). More recently, Songsri *et al*. (2009) found consistent relationships between SLA and SCMR under different water regimes. The significant interrelationships between

SLA and SCMR suggested that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA in peanut. Nageswara Rao *et al*. (2001) reported that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA or high Specific Leaf Nitrogen (SLN) which are surrogate measures of Transpiration Efficiency (TE) in peanut. In cowpea studied under mid-season drought, the high RWC of leaves was maintained in some of the genotypes by stomata closure and a reduction of leaf area. Drought avoidance by maintaining high leaf water content was negatively associated with SLA (Anyia and Herzog, 2004). Jongrungklang *et al*. (2008) found that the more severe the drought stresses the more was the increase in the SCMR. In fact, plant water status is related to level of soil moisture. Therefore, the results in this study showed the negative and significant relationship between SCMR and RWC. The water loss from cells might effect the concentration of chlorophyll content. During the stress period in rice, SCMR increased with stress but declined rapidly within 3 days after re-irrigation (Duy Nang, 2004). Contrastingly, in rice under drought stress conditions the correlation between SCMR with RWC was positive and significant and SCMR decreased with drought stress compared to control (Pirdashti *et al*., 2009).

However, drought resistance traits and root traits were not associated. This could be largely due to different times of evaluation between the two groups of characters. RWC, SCMR and SLA were evaluated at 70 DAS, whereas RDW, RS and RV were evaluated at harvest because of limited number of samples and evaluation of root traits being highly destructive. Furthermore, Ketring and Reid (1993) found that groundnut was able to establish both a deep and laterally spreading root system fairly early during the growing cycle, providing adaptation to drought occurrence during and later in the season. Root growth estimations at early vegetative growth stages may be of limited use considering the growth stage×genotype interaction for root growth in chickpea (Canci *et al*., 2004; Krishnamurithy *et al*., 1996).

Root characters were also positively and significantly correlated with biomass production and in lesser extent with pods number per plant. This could indicate that larger plants had larger root system and also had high number of pods. Although RDW was not significantly correlated with pod yield and pod number per plant, it was negatively and significantly correlated with harvest index. The results might suggest that the effect of roots contributed indirectly to pod yield through biomass production and subsequently through pod number per plant, but large root systems had low contribution to partitioning efficiency as indicated by negative correlation with harvest index. Similarly, McPhee (2005) observed positive correlation between total root characters and biomass and the present authors also found inter-relationships among root characters. However, Passioura (1983) hypothesized that yield could be increased by decreasing roots as they represent a high energy. Siddique *et al*. (1990) found that wheat genotypes with high HI would have lower root/shoot ratios, indicating less investment in roots. In fact, the turnover of roots can be relatively rapid, with a half life of 30-40 days in peanut (Krauss and Deacon, 1994). Therefore, even if the root/shoot ratio at a given point in time in many species is only between 10 and 40%, a complete turnover of roots in about 40 days would bring the root/shoot ratio close to 100% over the entire life cycle.

Most drought resistance traits (RWC, SCMR and SLA) were not correlated with pod yield and yield components except for SCMR with pod number per plant (0.20, $p \leq 0.05$). More greenish plants yielded more pods than did plants with lighter color under non-stress conditions. According to Wunna *et al*. (2009), number of pod per plant was significantly correlated with SCMR at 60 days after emergence, but the correlation was not significant under 1/3 available water (severe drought stress). SCMR is an indicator of the photo-synthetically active light-transmittance characteristics of the leaf, which is dependent on the unit amount of chlorophyll per unit leaf area (chlorophyll density) (Richardson *et al*., 2002). Significant and positive correlation between SCMR and chlorophyll content was observed and SCMR was also closely related with chlorophyll density (Arunyanark *et al*., 2008, 2009).

CONCLUSION

Heritability and correlation information provides a guideline for selection of characters in breeding population. In this study, broad sense heritability estimates for most characters were not high. Narrow sense heritability estimates were much lower than broad sense heritability estimates and they were expected to be under-estimated because of high intra-plant variation in the F_2 population. Based on heritability estimates, selection for RWC, SCMR, root parameters and other traits, characters related to drought resistance and agronomic traits in this population may be difficult in early segregating generation and evaluation should be carried out in more advanced generations. As there were high inter-correlations among root parameters, evaluation of root dry weight alone is sufficient because it was more simple, economical and less time-consuming.

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