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GROUNDNUT IMPROVEMENT : DROUGHT STRESS AND WATER USE EFFICIENCY OF SOME PEANUT GENOTYPES GROWN UNDER NEWLY RECLAIMED SOIL

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Abstract

Water deficiency is one of the major environmental constraints, limiting agricultural productivity, and plays the major role in the distribution of plant species across different types of environments. Forty-seven peanut mutant lines were developed by γ-radiation mutagenesis of two commercial genotypes (Giza-6 and NC). The yield performance and water use efficiency, of those forty-seven peanut mutant lines and their parents, were evaluated in a field experiment, using split plot arranged in a randomized complete block design, with two replications. Two irrigation treatments (full irrigation and 50% water requirement) were applied in the main plots, and the subplots were devoted for the peanut genotypes. Stress tolerance index (STI), Stress susceptibility index (SSI), Tolerance index (TOL), Mean productivity (MP), and Geometric mean productivity (GMP) have been measured to assess the tolerance of the genotypes toward water stress. Principal component analysis (PCA) of computed drought tolerance indices, of the tested genotypes, classified the groundnut into four distinct clusters ascendingly as follows: (I) below average (16 genotypes); (II) average (parents + 23 genotypes); (III) above average (6 genotypes); and (IV) excellent performing (2 genotypes) in respect to the two different tendencies of drought tolerance indices, where GMP, MP, STI precisely corresponded to same trend. Water use efficiency (WUE) is estimated to determine the finest genotypes performance regarding severe drought deficits. The water stress treatment assorted the WUE response of genotypes from 0.236 kg/m^3 to 0.739 kg/m^3. Nine genotypes (G37, G12, G36, G27, G49, G42, G25, G35 and G7) have shown superiority over the sophisticated parent (Giza-6) regarding to WUE means in stress and non-stress conditions. STI, GMP, and MP are high positively inter correlated. Although TOL is moderately correlated toward the whole indices, Whereas SSI is negatively correlated with the previous indices, except TOL reported highly correlation with SSI.

Keywords **:** Peanut, drought indices**,** water use efficiency, mutagenesis**,** mid-season drought.

Introduction

Peanut (*Arachis hypogaea* L.) seeds are nutritionally rich food source, as they contain up to 30% protein and 56% oils as well as vitamins and minor elements, e.g. vitamin E, and magnesium (Savage and Keenan, 1994). Peanuts are widely cultivated in arid and semi-arid areas, where drought frequently occurs throughout different developmental stages, being one of the major constraints to its production. Many studies have reported the adverse effects of drought stress on pod yield and biomass production (Shinde *et al.*, 2010; Koolachart *et al.*, 2013; Dang *et al.*, 2013). Specifically, mid-season drought (MD) was shown to significantly reduce peanut yield performance, in terms of nodule dry weight, fixed nitrogen, and pod yield (Dinh *et al.*, 2013 and Nageswara Rao *et al.*, 1989). Whereas terminal drought at seed-filling stage reported to cause 56-80% yield reduction (Del Rosario and Fajardo, 1988), meanwhile, terminal drought at the end of growing season caused reduction by 24% of seed yield. (Boontang *et al.*, 2010). Moreover, terminal drought can cause increases in the incidence of aflatoxin contamination (Arunyanark *et al.*, 2009 and Girdthai *et al.*, 2010). On the other hand, early-season drought stress is not detrimental to peanut yield, however, it can even improve the yield production (Nautiyal *et al.*, 1999 and Puangbut *et al.*, 2009).

Concerning, the water use efficiency (WUE), it is a widely used characteristic which most commonly accounts for the biomass produced per unit of water transpired. Earlier studies on peanuts revealed significant differences in WUE of different varieties, due to water availability treatments (Hebbar *et al.*, 1994 and Wright *et al.*, 1994).

The wild species of peanut are found in diverse climatic environments, ranging from swamps to grass lands, to rocky ground in semi-arid conditions (Krapovickas and Gregory, 2007; Bertioli *et al.*, 2011). Hence, it is highly suggested that wild peanut species are harboring genes that confer improved performance under certain drought stress conditions. Therefore, developing drought tolerant peanut genotypes is a successful strategy adopted by peanut breeders, to alleviate water stress problems and to ensure sufficient production in drought-threatened areas (De Lima Pereira *et al.*, 2016; Pereira *et al.*, 2012; Songsri *et al.*, 2008). However, consistent inheritance of desirable traits remains a major challenge, due to high complexity of the relevant genetic background, particularly the quantitative traits, that are governed by multiple genes spread throughout the chromosomal sets of peanuts (Fonceka *et al.*, 2012). Therefore, plant breeders exert tremendous efforts to improve yield performance, of a given crop, by selecting plants with advantageous yield under drought conditions, considering different yield parameters, in order to ensure stability in inheritance and production.

Furthermore, selection of genotypes, according to multiple crop yield parameter, can result in a high variability and confusion in decision making under drought- and optimum irrigation conditions. Therefore, several drought tolerance indices (DTIs) have been proposed to assist plant breeders in selecting genotypes of high and stable performance under normal and stress conditions (Mursalova *et al.*, 2015; Fernandez,1992; Mohammadi *et al.*, 2012; and Cabello *et al.*, 2013). The stress tolerance index (STI), stress susceptibility index (SSI), yield index (YI), tolerance index (TOL), mean productivity index (MPI), and geometric mean productivity (GMP) are good examples of these selection indices and they are applied on many economic crops (Fernandez,1992; Jafari *et al.*, 2012; Singh *et al.*, 2011; Drikvand *et al.*, 2012; Cabello *et al.*, 2013).

Finally drought tolerance indices have not been yet considered for peanuts. Therefore, in this study, we aimed to investigate the effects of two different water regimes on forty-seven peanut genotypes, developed by γ-radiation mutagenesis of two commercial genotypes (Giza-6 and NC-1). The specific objectives of the study were to: (i) evaluate yield performance and water use efficiency of different genotypes under drought stress conditions; (ii) classify the tested genotypes, according to different drought tolerance indices, into sensitive and tolerant; and (iii) study the inter-relationships among the measured drought tolerance indices.

Materials and Methods

Development of peanut mutant lines

Two commercial varieties of peanuts (*Arachis hypogaea* L.), Giza-6 and NC-1, were subjected to four different doses of gamma radiation (100, 200, and 300 Gy). Forty-seven mutant lines were selected, representing the three experimented radiation doses. A mutation breeding program of groundnut has been carried out in Cairo University, Faculty of Agriculture, Agronomy Department by Prof. Dr. Saied A. Shrief for a number of years started from 2014 till now.

Experimental design and agronomic practices

The field experiments were carried out at Abo-Ghaleb area, Giza, Egypt (30°14'39.8"-30°15'45.9"N and 30°55'39.7"-30°56'50"E, with an altitude of 18 meters).The physical analysis of soil was conducted according to Klute (1986) and chemical analyses according to Page *et al.* (1982). The physical and chemical properties of soil and irrigation water are described in Table (1).

The forty-seven selected peanut mutant lines as well as their parent varieties (Giza-6 and NC-1), were assessed in a field experiment in two successive seasons, 2017 and 2018. The experimental design was a split-plot in a randomized complete block with two replications, where two irrigation treatments (optimum irrigation and 50% water requirement) were applied in the main plots, and the peanut mutant lines in the subplots. Seeds of each mutant line were planted in both sides of rows, of 3.5 m length and 0.6 cm width, with 25 cm distance intervals between seeds, i.e. hills. The net experimental unit, i.e. subplot area, was 4.2 m^2. The application of irrigation interval and amount of irrigation water given over the total growing season were calculated according to (Allen *et al.,* 1998) Table (2).

Table 1 : Soil and irrigation water properties at the experimental site in 2017 and 2018 seasons

Soil analysis	**2017**	**2018**
Physical properties		
Sand (%)	92.3	91.6
Silt (%)	4.9	5.4
Clay (%)	2.8	3.0
Texture class	Sandy	Sandy
Chemical properties		
$pH_{(1:1)}$	7.13	7.29
$Ec_{(1:1)}$ ($dS\ m^{-1}$)	2.54	2.22
Organic matter (%)	0.51	0.62
Total $CaCO_3$ (%)	3.74	2.91
Available N ($mg\ kg^{-1}$)	8.4	9.9
Available P ($mg\ kg^{-1}$)	2.65	3.04
Available K ($mg\ kg^{-1}$)	204	243
Irrigation system	Drip irrigation	Drip irrigation

Chemical properties of irrigation water										
		EC		**Ions concentration meq L^{-1}**						
Season	**pH**	**ds m^{-1}**	**Ppm**	**HCO_3^-**	**CL^-**	**SO_4^-**	**Ca^{++}**	**Mg^{++}**	**Na^+**	**K^+**
2017	7.1	2.1	1344	2.8	12.5	5.3	1.9	1.7	25.3	0.47
2018	7.3	2.2	1408	3.2	14.1	4.9	2.3	1.9	23.0	0.65

Table 2 : Months, time, stage, field capacity (kc), crop evapotranspiration (Etc), rain and amount of irrigation water in both conditions (non stress and stress)

Month	**Decade**	**Stage**	**Kc**	**Etc/day**	**Rain**	**Irrigation Request of Non stress**	**Irrigation Request of stress**
Apr	20	Initial	0.4	1.95	0.2	11.5	
Apr	30	Initial	0.4	2.13	0.2	21.1	
May	10	Development	0.4	2.32	0.1	23.1	
May	20	Development	0.54	3.38	0	33.8	
May	30	Development	0.78	5.03	0	55.3	
June	10	Development	1.01	6.86	0	68.6	
June	20	Mid	1.17	8.28	0	82.8	41.4
June	30	Mid	1.17	8.11	0	81.1	40.55
July	10	Mid	1.17	7.86	0	78.6	39.3

July	20	Mid	1.17	7.68	0	76.8	38.4
July	30	Late	1.16	7.33	0	80.6	40.3
Aug	10	Late	0.98	5.95	0	59.5	29.75
Aug	20	Late	0.75	4.4	0	44	22
Aug	30	Late	0.62	3.4	0	6.8	3.4
Total uptake of water during season (m^3/fed)						**3039.12**	**1967.7**

After 30 days of seed-cultivation, hills were thinned to include single plants. Calcium super phosphate fertilizer (15.5% P_2O_5), at the rate of 400 kg P_2O_5 ha^{-1}, was applied uniformly before the sowing. Ammonium sulphate (20.5% N), at the rate of 150 kg N ha^{-1}, was added in 5 equal doses at 6-day intervals 30 days after sowing date. Finally, Potassium sulphate (48% K_2O) was applied at the rate of 120 kg K_2O ha^{-1}. Application of K fertilizer was started at 45 days after sowing through 7 equal doses at 6-day intervals. Moreover, the preceding crop in both seasons was potato (*Solanum tuberosum L.*).

Calculation of Drought Tolerance Indices (DTIs) and Water Use Efficiency (WUE)

At maturity, above-ground biomass and pods were harvested from 2.5 m of the two center rows of each plot for a sample harvest area of 3.0 m^2. Pod yield was based on weight of the pods dried to approximately 8% moisture content. In both years, the area of each plot (3.0 m^2) was harvested to determine seed yieldplot^{-1}, under normal (Y_p) and stress (Y_s) conditions, and then converted to seed yield kgfed^{-1}. The following drought tolerance indices were calculated according to the equations presented in Table (3): stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), and stress tolerance index (STI).

Water use efficiency (WUE expressed in kg m^{-3}) on seed basis was determined by dividing the seed yield (kg fed^{-1}) by quantity of water applied (m^3fed^{-1}) (Vietes, 1965 and Lovelli *et al.*, 2007).

Reduction percentage was calculated according to (Choukan *et al.*, 2006) the following equation:

$$\text{Reduction}\% = \frac{Y_p + Y_S}{Y_p} \times 100$$

Where, Y_p and Y_s the mean yields over replications for each genotype under non-stress and stress conditions, respectively.

Table 3 : Drought tolerance indices and their abbreviation and formula:

Index name	**Outcome**	**Abbreviation and formula**	**Reference**
Stress Susceptibility Index (SSI)	The genotypes with SSI<1 are more resistant to drought stress conditions.	$SSI = \frac{1-\left(\frac{Y_S}{Y_P}\right)}{1-\left(\frac{\overline{Y}_S}{\overline{Y}_P}\right)}$	Fisher and Maurer, 1978
Tolerance index (TOL)	The genotypes with low values of this index are more desirable in two different conditions.	$TOL = Y_P - Y_S$	Rosielle and Hamblin, 1981
Mean Productivity (MP)	The genotypes with high value of this index will be more desirable	$MP = \frac{Y_S + Y_P}{2}$	
Geometric Mean Productivity (GMP)	The genotypes with high value of this index will be more desirable	$GMP = \sqrt{(Y_S)(Y_P)}$	Fernandez, 1992
Stress Tolerance Index (STI)	The genotypes with high STI values will be tolerant to drought stress	$STI = \frac{(Y_S \times Y_P)}{(\overline{Y}_P)^2}$	

Ys and Yp are the yield of all genotypes under stress and non-stress conditions, respectively.

$\overline{Y}_S$ and $\overline{Y}_P$ are the mean yield over all genotypes under stress and non-stress conditions, respectively.

Statistical analysis and data visualization

Analysis of variance (ANOVA) of split plot design (Gomez and Gomez 1984) was used to statistically analyze the collected data, using MSTAT-C software package (Freed *et al.*, 1989). Bartlett's homogeneity test (Bartlett's 1937) was carried out prior to conducting combined ANOVA analysis (Steel *et al.*, 1997). Duncan's new multiple range test (DMRT) was applied to detect the significant differences between tested treatments means (Duncan, 1955).

Further statistical analyses were carried out using R-programming language (R-CRAN, cran.r-project.org). The packages "*stats*" and "*ggplot2*" were used for constructing boxplots and plotting principal components resulted from the principal component analysis (PCA), while the package "*Performance Analytics*" was used for calculation and plotting of correlation coefficients of the computed drought tolerance indices.

Results and Discussion

The results of the combined analysis of variance for seed yield feddan^{-1} under water-stressed and non-stressed environments over two consecutive growing seasons (2017-2018) are presented in Table 4. The effects due to the irrigation regimes (A) and genotypes (B) were found to be significant at $P \leq 0.05$. The genotypes effect was the most important source of yield variation, accounting for 69.80% of the total sums of squares (TSS %) followed by irrigation regimes effect and seasons which accounted for 6.70% and 4.43% of TSS%, respectively Table 4.

Table 4 : Combined analysis of variance of a split plot design for seed yield and water use efficiency of forty-nine peanut genotypes across 2017 and 2018 seasons

S.O.V	d.f	Seed yield (kg fed^{-1})			Water use efficiency (kg m^{-3})		
		SS	MS	TSS%	SS	MS	TSS%
Years (Y)	1	755370	755370	**4.43**	0.126	0.126	**3.66**
R (Y)	2	5332	2666		0.002	0.001	
Irrigation (A)	1	1143320	1143320*	**6.70**	0.690	0.690**	**20.05**
YA	1	9199	9199		0.001	0.001	
Error$_{(a)}$	2	45871	22936		0.008	0.004	
Genotypes (B)	48	11906402	248050**	**69.80**	2.038	0.042**	**59.21**
YB	48	481589	10033		0.076	0.002	
AB	48	257765	5370		0.090	0.002	
YAB	48	516143	10753		0.082	0.002	
Error$_{(b)}$	192	1935737	10082		0.328	0.002	

**Significant at 1% level of probability, *Significant at 5% level of probability; NS: not significant, %TSS–Percentage relative to total sum of squares.

Based on results of combined analysis of variance over years for WUE presented in Table 4 pointed out highly significant at $P \leq 0.01$ to significant differences at $P \leq 0.05$ among the tested genotypes and between irrigation regime treatments respectively, thus indicating substantial variability among these genotypes for water use efficiency. Moreover, the results showed the genotypes effect was the most important source of WUE variation, accounting for 59.21% of TSS% followed by irrigation regime effect (20.05%) and years which accounted for (3.66%) of TSS%, respectively. It is obvious that, the highly significant differences among genotypes for seed yield and WUE indicate the existence of genetic variation and the possibility of selection for suitable genotype in both environments (water-stressed and non-stressed conditions).

Genotypes performance evaluation

There was a significant difference at $P \leq 0.05$among the forty-nine peanut genotypes Table 5. The results showed that seed yield varied from 1654.8 kg fed^{-1} (Genotype 7) to 539.0 kg fed^{-1} (Genotype 9) under non stress condition and from 1454.2 kg fed^{-1} (Genotype 7) to 464.9 kg fed^{-1} (Genotype 9) under stress condition. Mean of seed yield under non-stress condition was 775.4 kg fed^{-1}, while under water stress condition it was 667.4 kg fed^{-1}, indicating a reduction of 13.93% compared to non-stress conditions (full-irrigation).

According to the average seed yield under stress condition of the two years, , the genotypes can be divided into three groups: (1) tolerant genotypes (1, 5, 7, 10, 12, 14, 15, 16, 18, 19, 21, 23, 24, 25, 27, 28, 31, 33, 35, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 48, 49) thirty one genotypes producing more than 667.4 kg fed^{-1}, (2) moderately tolerant genotypes (3, 11, 13, 17, 26, 29, 38, 47) eight genotypes producing 600.0 - 667.4 kg fed^{-1} and (3) non-tolerant genotypes (2, 4, 6, 8, 9, 20, 22, 30, 32, 34) ten genotypes which are capable of producing only less than 600 kg fed^{-1}. In conclusion, considerable peanut production can be achieved under stress condition through providing selected tolerant genotypes.

Yield reduction

The results in Table 5revealed that, although, genotype 7 gave the highest seed yield and the highest WUE under both conditions, but it exhibited the medium reduction by 12.12% in seed yield under stress conditions. The lowest depression in seed yield due to stress conditions compared to the seed yield under normal irrigation has been registered for (G45, G14, G46, G1, G20, G49 and G35) genotypes by 3.55, 7.13, 5.43, 7.46, 7.96, 8.6 and 8.81%, respectively, but the highest depression recorded for G5, G8, G12, G15, G17, G23, G26, G36, G38, G39 and G42 ranged from 19.04 to 23.24%.

Water use efficiency (WUE)

The water use efficiency (WUE) is considers one of the major reliable indices for pinpointing optimal water management practices; its use has been reviewed by (Taylor *et al.,* 1983 and Musick *et al.*, 1994). The water use efficiency presented in Figure1 is expressed as (kg seeds m^{-3}) water consumed by the peanut crop. This benchmark has been used to evaluate the crop production under different applied treatments per unit of consumed water by the crop.

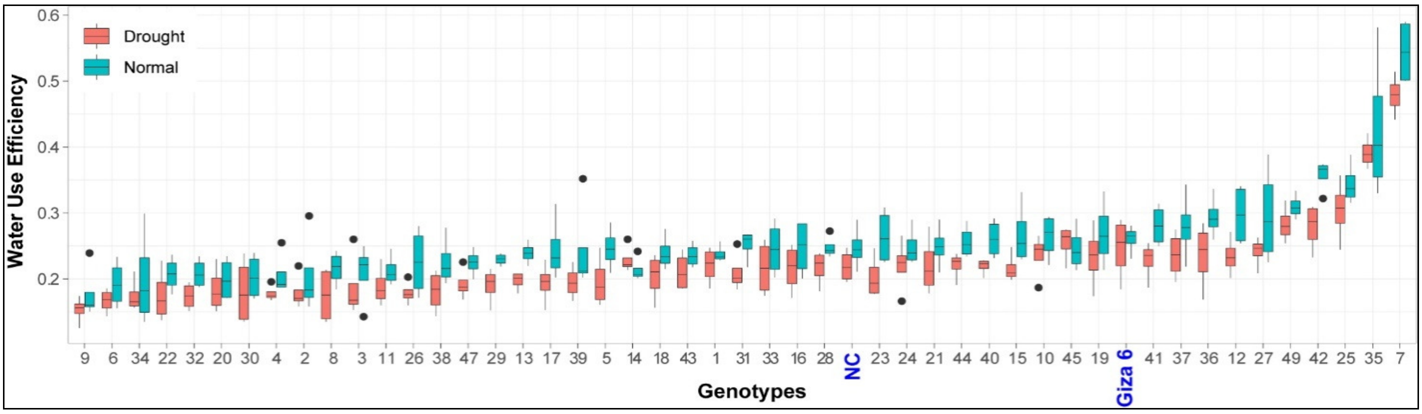

Fig. 1 : Boxplots showing the water use efficiency of genotypes of excellent and above-average yield production under normal and drought conditions, compared to the parent genotypes (NC-1and Giza-6).

The obtained results, as shown in Figure1, indicated that there were significant differences among genotypes for water use efficiency under stress conditions, it ranged from (0.236 kg m^{-3}) for G 9 to (0.739 kg m^{-3}) for G 7. Also, the results showed that, the genotypes (G7, G25, G35 and G42) which exhibited the highest seed yield under both conditions, exhibited also the highest values of WUE under stress and non-stress conditions. Moreover, the results in Figure1 showed a predominance of WUE values under stress conditions as compared to normal conditions. Several studies reported that the water use efficiency (WUE) values were higher under water deficit as compared to the full irrigation condition, especially when irrigation is applied in the critical growth stages of plant (Khalili *et al.*, 2012, Shamsi *et al.*, 2010 and Cabello *et al.*, 2013).

Breeding for drought tolerance has been a paramount approach pursued by researchers to alleviate the water stress damages and to secure the production in environments exposed to drought (Songsri *et al.*, 2008).

Drought tolerance indices

To compare the seed yield of genotypes under stress condition Y_S along with their seed yield under normal conditions Y_P: SSI, STI, TOL, MPI and GMP were calculated over both growing season, as shown in (Figure 2& Table 6). The principle component analysis categorized the genotypes into four main groups based on yield parameter as following (I) Below average genotypes (II)Average genotypes group that contain the parents (Giza-6, NC-1) and 23 other genotypes (III) Above average genotypes G12, G25, G27, G36, G42, G49 (IV) Excellent genotypes G7, G35. The drought tolerant genotypes G7, G25, G35, and G49 which yielded well under both irrigation treatments, exhibited high values for the Y_S, Y_P, STI, MPI & GMP and below average values for the SSI and TOL. On the contrary, the drought sensitive genotypes G5, G12, G17, G23, G26, G39 and G42 the yield of which declined by more than 20% under stress condition as shown in Table 5. Generally, the genotypes whose yield declined by more than 20% under stress condition registered the highest values for the SSI and TOL, and the lowest values for the other indices. The genotypes that yielded very low under both irrigation treatments exhibited the lowest values for STI, MPI and GMP, and the highest values for SSI and TOL. Drought-stressed plants lose moisture from pods, thus can lead to decline in the physiological activity of the seeds, therefore affecting both yield and nutritional quality (Songsri *et al.*, 2008).

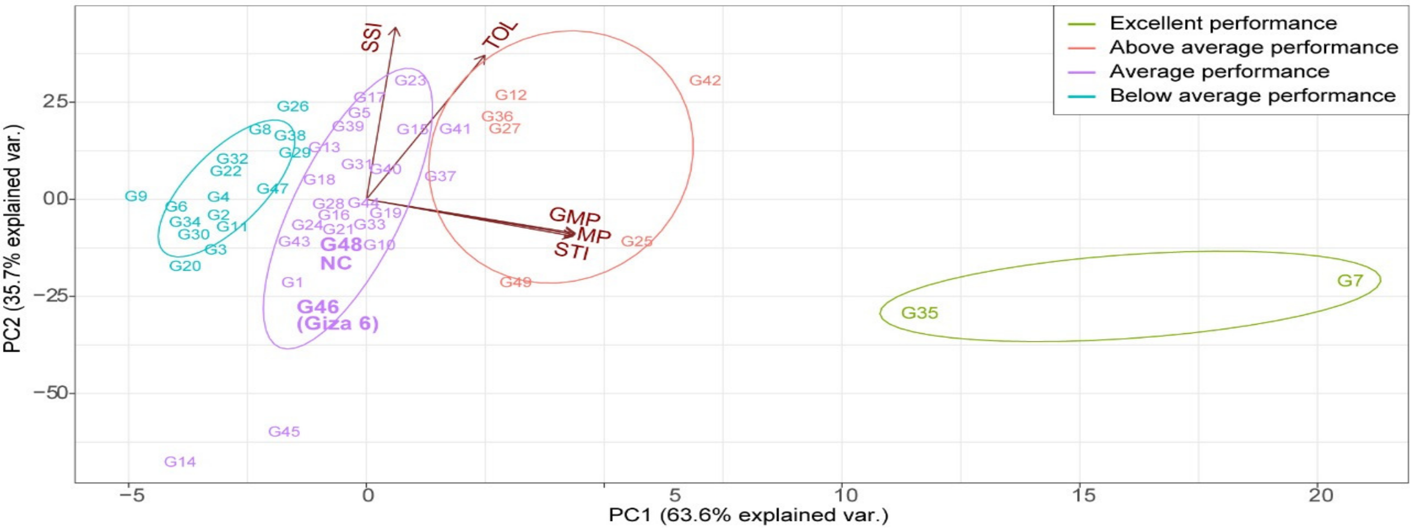

Fig. 2 : Principal Component Analysis (PCA) of drought tolerance indices of the tested 49 peanut genotypes over two consecutive seasons. Colored circles indicate 4 different clusters according to k-means method. STI, Stress tolerance index; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric Average productivity; SSI, Stress susceptibility index

Ranking method for screening drought tolerant genotypes

Statistical analysis of the data reported that drought indices set out different ranks for genotypes, and consequently could be classified into two groups according to the genotypes discriminations, the first one contain stress susceptibility index (SSI) along with tolerance index (TOL), the second contain potential seed yield (Y_p), stress yield (Y_s) $plot^{-1}$, mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI).

The drought tolerance indices (DTI) and their ranks based on the indices over two seasons are presented in (Figure 2 & Table 7). According to DTI-based genotype ranking, the tolerant genotypes was found independently separated from one drought resistance index to another, the indices distinguish drought tolerant genotypes concerning yield parameter. To determine the ultimate drought tolerant genotypes according to the all indices, mean rank ($\bar{R}$), and standard deviation of ranks (SDR) of all drought tolerance pattern were calculated. In consideration to all indices, genotypes G7, G25, G35 and G42, exhibited the best mean rank and almost medium standard deviation of rank.

Ranking method has been used for screening drought tolerant genotypes by (Farshadfar and Elyasi (2012); Farshadfar *et al.* (2012); Abd El-Mohsen *et al.* (2015); and Khalili *et al.* (2012); Drikvand *et al.*, 2012 and Cabello *et al.*, 2013.)

Correlation Analysis

To determine the most desirable drought tolerant pattern, the Spearman's correlation coefficients between Y_p, Y_s and other quantitative indices of drought tolerance were calculated as presented in Figure3. In other words, correlation analysis between seed yield and drought tolerance indices can be a fine pattern for screening the best genotypes and indices used. The mean yields of genotypes in both conditions were correlated to all studied traits at $P \leq 0.01$ except SSI. The method of STI, SSI, TOL, MP, GMP, Y_s and Y_p were highly correlated $P \leq 0.01$, which indicated that one of this method could be used as alternative for the others in evaluation on peanut genotypes. Yield in stress (Y_s) condition was significantly and positively correlated with TOL, MP and GMP. Yield in non-stress (Y_p) condition was significant and positively correlated with MP and GMP indicating that these criteria were more effective in identifying high yielding genotypes under different water conditions.

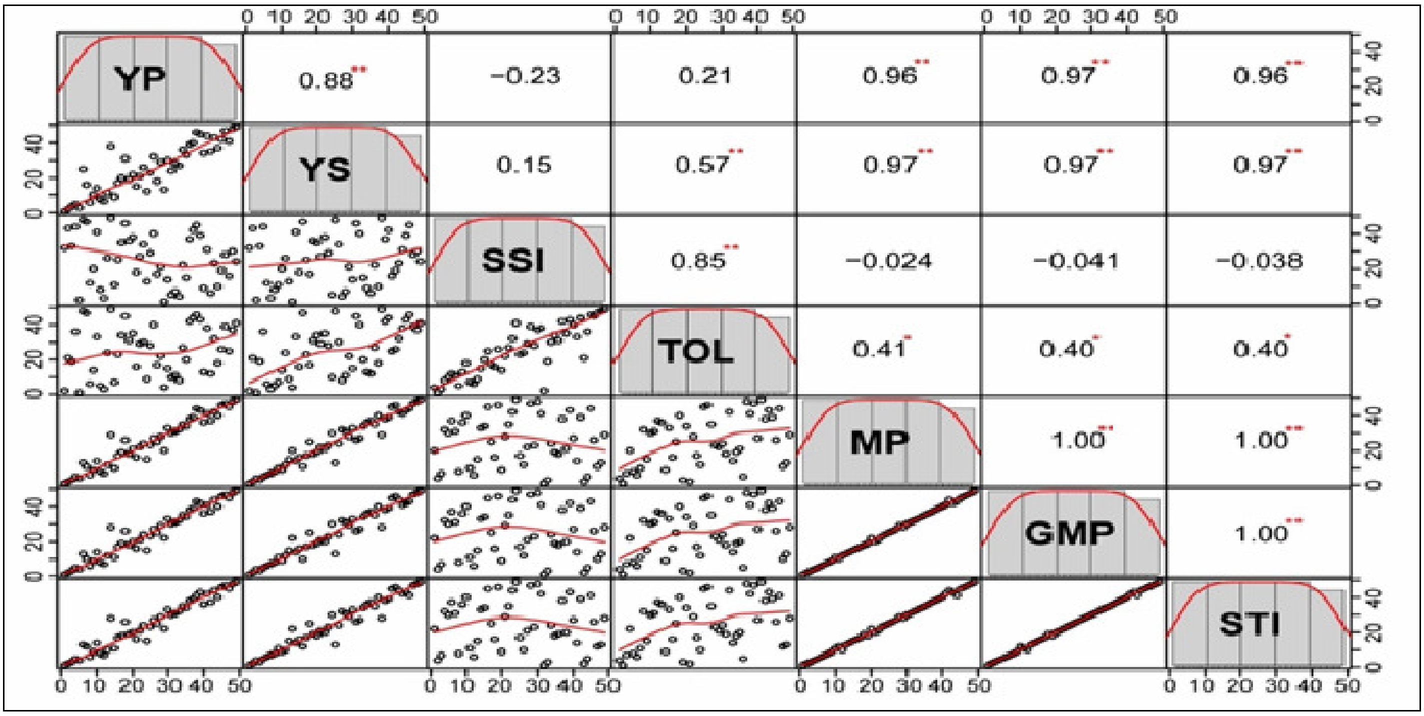

Fig. 3 : Spearman's rank correlation coefficients matrix of drought tolerance indices with seed yield of the tested 49 peanut genotypes over two consecutive seasons. Red asterisks indicate significance levels (**, highly significant at 0.01 and *, significant at 0.05). YP, yield under non-stress condition; YS, yield under water stress condition; STI, Stress tolerance index; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric Average productivity; SSI, Stress susceptibility index.

Toorchi *et al.* (2012) and Akcura and Ceri (2011) reported that correlation between MP, GMP, Ys and Yp was positive. Malekshahi *et al.* (2009) reported that GMP, MP and STI were significantly and positively correlated with stress yield. In a correlation study carried out by Songsri *et al.* (2008) involving traits associated to drought tolerance and pod production, authors found high magnitude correlations among drought tolerance index (DTI) and pod yield.

Table 5 : Seed yield and yield reduction of the forty-nine peanut genotypes under non-stress and stress conditions.

Genotypes	Seed yield (kg fed^{-1})		Mean	Seed yield reduction%	Genotypes	Seed yield (kg fed^{-1})		Mean	Seed yield reduction%
	Non-stress condition	Stress condition				Non-stress condition	Stress condition		
G1	723.2	669.3	696.2	7.46	G26	685.0	543.0	614.0	20.74
G2	623.4	545.8	584.6	12.44	G27	902.9	732.8	817.8	18.83
G3	634.5	568.8	601.6	10.34	G28	753.9	659.3	706.6	12.55
G4	627.5	540.6	584.1	13.85	G29	697.5	577.4	637.4	17.23
G5	748.2	595.0	671.6	20.48	G30	617.5	550.5	584.0	10.85
G6	584.6	506.5	545.5	13.36	G31	764.1	637.5	700.8	16.57
G7	1654.8	1454.2	1554.5	12.12	G32	633.1	527.5	580.3	16.69
G8	656.4	531.4	593.9	19.04	G33	746.9	658.0	702.4	11.90
G9	539.3	464.9	502.1	13.80	G34	606.0	530.0	568.0	12.55
G10	801.9	715.8	758.8	10.74	G35	1304.4	1189.5	1246.9	8.81
G11	646.2	573.3	609.7	11.28	G36	894.0	715.8	804.9	19.94
G12	902.8	711.9	807.3	21.15	G37	849.0	717.0	783.0	15.56
G13	727.1	599.0	663.0	17.61	G38	685.8	550.4	618.1	19.74
G14	649.8	696.1	673.0	7.13	G39	742.8	592.3	667.5	20.26
G15	812.0	656.8	734.4	19.11	G40	792.9	666.0	729.4	16.01
G16	750.6	656.0	703.3	12.60	G41	853.8	692.9	773.3	18.85
G17	744.2	588.3	666.3	20.95	G42	1085.3	848.2	966.8	21.85
G18	728.2	618.0	673.1	15.13	G43	716.8	641.7	679.2	10.47
G19	817.1	710.7	763.9	13.02	G44	779.6	669.9	724.8	14.07
G20	607.0	558.8	582.9	7.94	G45	747.8	774.4	761.1	3.55

G21	757.8	669.2	713.5	11.69	G46	791.1	748.1	769.6	5.43
G22	629.3	530.6	579.9	15.69	G47	683.2	584.6	633.9	14.43
G23	802.5	615.9	709.2	23.24	G48	751.5	666.5	709.0	11.31
G24	755.5	669.4	712.4	11.39	G49	941.0	860.1	900.5	8.60
G25	1046.2	923.9	985.0	11.68	Mean	775.4	667.4		13.93

L.S.D. value at 0.05: Irrigation (A): sig Genotypes (B): 99.02 Interaction (AB): 140

Table 6 : Resistance indices of forty-nine peanut genotypes under stress and non-stress environments for grain yield over two years.

Genotypes	Stress Susceptibility Index (SSI)	Tolerance index (TOL)	Mean Productivity (MP)	Geometric Mean Productivity (GMP)	Stress Tolerance Index (STI)
G1	0.53	54.00	696.2	695.7	0.81
G2	0.88	77.53	584.6	583.3	0.57
G3	0.71	65.63	601.6	600.6	0.61
G4	0.97	86.94	584.1	582.3	0.57
G5	1.50	153.22	671.5	666.4	0.75
G6	0.89	78.09	545.5	543.8	0.50
G7	0.87	200.63	1554.5	1551.1	4.00
G8	1.36	125.00	593.9	590.5	0.58
G9	0.96	74.41	502.1	500.7	0.42
G10	0.75	86.16	758.8	757.5	0.96
G11	0.80	72.88	609.7	608.3	0.62
G12	1.52	190.91	807.3	800.9	1.07
G13	1.26	128.03	663.0	659.9	0.72
G14	0.52	46.31	673.0	672.5	0.75
G15	1.34	155.20	734.4	729.4	0.89
G16	0.90	94.63	703.3	701.3	0.82
G17	1.51	155.91	666.3	661.7	0.74
G18	1.09	110.19	673.1	670.8	0.75
G19	0.93	106.41	763.9	762.0	0.99
G20	0.58	48.22	582.9	582.4	0.58
G21	0.82	88.59	713.5	712.0	0.85
G22	1.13	98.69	579.9	577.4	0.56
G23	1.67	186.50	709.2	703.0	0.82
G24	0.83	86.06	712.4	711.0	0.85
G25	0.86	122.25	985.0	982.9	1.62
G26	1.49	142.06	614.0	609.9	0.62
G27	1.36	170.06	817.8	813.4	1.10
G28	0.91	94.63	706.6	704.8	0.83
G29	1.23	120.16	637.4	634.2	0.67
G30	0.78	67.00	583.9	582.9	0.57
G31	1.16	126.56	700.8	696.6	0.81
G32	1.20	105.66	580.3	577.9	0.56
G33	0.85	88.91	702.4	700.9	0.82
G34	0.90	76.03	568.0	566.7	0.54
G35	0.63	114.94	1246.9	1245.5	2.59
G36	1.40	178.22	804.9	799.0	1.06
G37	1.12	132.09	783.0	780.2	1.01
G38	1.38	135.44	618.0	613.7	0.63
G39	1.43	150.47	667.5	663.1	0.74
G40	1.15	126.91	729.4	726.6	0.88
G41	1.36	160.97	773.3	769.0	0.99
G42	1.57	237.09	966.7	959.4	1.53
G43	0.75	75.06	679.2	678.1	0.76
G44	0.94	109.72	724.7	720.9	0.86
G45	0.25	26.53	761.1	760.9	0.96
G46	0.39	42.94	769.6	769.3	0.98
G47	1.03	98.56	633.8	631.5	0.66
G48	0.79	85.03	709.0	707.5	0.83
G49	0.63	80.91	900.5	899.5	1.35

Yp = yield under optimal conditions; Ys = yield under stress conditions; SSI = stress susceptibility index; TOL = tolerance index; GMP = geometric mean productivity; MP = mean productivity; STI = stress tolerance index.

Table 7 : Rank, rank mean ($\overline{R}$), and standard deviation of ranks (SDR) of drought tolerance.

Genotypes	Y_P	Y_S	SSI	TOL	MP	GMP	STI	$\overline{R}$	SDR
G1	18	31	4	5	26	26	26	19.4	10.9
G2	41	44	19	12	41	41	42	34.3	13.0
G3	37	40	8	6	39	39	39	29.7	15.6
G4	43	43	27	18	42	44	44	37.3	10.5
G5	31	24	45	40	30	30	30	32.9	7.1
G6	48	48	20	13	48	48	48	39.0	15.5
G7	1	1	18	48	1	1	1	10.1	17.9
G8	44	37	38	32	40	40	40	38.7	3.7
G9	49	49	26	9	49	49	49	40.0	16.1
G10	10	14	9	17	14	14	14	13.1	2.7
G11	36	39	13	8	38	38	38	30.0	13.4
G12	12	7	47	47	7	7	7	19.1	19.1
G13	30	30	36	35	33	33	33	32.9	2.3
G14	14	38	1	1	29	28	28	19.9	14.7
G15	24	12	37	41	15	15	15	22.7	11.8
G16	25	23	21	21	23	23	23	22.7	1.4
G17	33	27	46	42	32	32	32	34.9	6.6
G18	28	29	29	28	28	29	29	28.6	0.5
G19	13	11	24	26	12	12	10	15.4	6.6
G20	38	46	5	4	44	43	41	31.6	18.7
G21	19	19	14	19	18	18	19	18.0	1.8
G22	45	42	31	24	46	46	46	40.0	8.9
G23	29	13	49	46	20	22	22	28.7	13.7
G24	17	20	15	16	19	19	18	17.7	1.8
G25	3	4	17	31	3	3	3	9.1	10.9
G26	42	35	44	38	37	37	37	38.6	3.2
G27	8	6	39	44	6	6	6	16.4	17.2
G28	22	21	23	22	22	21	21	21.7	0.8
G29	35	33	35	30	34	34	34	33.6	1.7
G30	39	45	11	7	43	42	43	32.9	16.4
G31	27	18	33	33	25	25	25	26.6	5.2
G32	47	41	34	25	45	45	45	40.3	8.0
G33	23	26	16	20	24	24	24	22.4	3.4
G34	46	47	22	11	47	47	47	38.1	15.1
G35	2	2	6	29	2	2	2	6.4	10.1
G36	11	8	42	45	8	8	8	18.6	17.1
G37	9	10	30	36	9	9	9	16.0	11.7
G38	40	34	41	37	36	36	36	37.1	2.5
G39	32	28	43	39	31	31	31	33.6	5.3
G40	21	15	32	34	16	16	16	21.4	8.2
G41	15	9	40	43	10	11	11	19.9	14.9
G42	5	3	48	49	4	4	4	16.7	21.7
G43	26	32	10	10	27	27	27	22.7	8.9
G44	16	17	25	27	17	17	17	19.4	4.5
G45	6	25	2	2	13	13	13	10.6	8.1
G46	7	16	3	3	11	10	12	8.9	4.8
G47	34	36	28	23	35	35	35	32.3	4.9
G48	20	22	12	15	21	20	20	18.6	3.6
G49	4	5	7	14	5	5	5	6.4	3.5

Yp = yield under optimal conditions; Ys = yield under stress conditions; SSI = stress susceptibility index; TOL = tolerance index; GMP = geometric mean productivity; MP = mean productivity; STI = stress tolerance index.

References

Akcura, M. and Ceri, S. (2011). Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions. Zemdirbyste-Agriculture, 98(2): 157-166.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9): D05109.

Arunyanark, A., Jogloy, S., Wongkaew, S., Akkasaeng, C., Vorasoot, N., Wright, G.C., Rachaputi, R.C. and Patanothai, A. (2009). Association between aflatoxin contamination and drought tolerance traits in peanut. Field Crops Research, 114(1): 14-22.

Bartlett, M.S. (1937). Properties of sufficiency and statistical tests. Proceedings of the Royal Society of London. Series A-Mathematical and Physical Sciences, 160(901): 268-282.

Bertioli, D.J., Seijo, G., Freitas, F.O., Valls, J.F., Leal-Bertioli, S.C. and Moretzsohn, M.C. (2011). An overview of peanut and its wild relatives. Plant Genetic Resources, 9(1): 134-149.

Boontang, S., Girdthai, T., Jogloy, S., Akkasaeng, C., Vorasoot, N., Patanothai, A. and Tantisuwichwong, N. (2010). Responses of released cultivars of peanut to terminal drought for traits related to drought tolerance. Asian Journal of Plant Sciences, 9(7): 423.

Cabello, R., Monneveux, P., De Mendiburu, F. and Bonierbale, M. (2013). Comparison of yield based drought tolerance indices in improved varieties, genetic stocks and landraces of potato (*Solanum tuberosum* L.). Euphytica, 193(2): 147-156.

Cabello, R., Monneveux, P., De Mendiburu, F. and Bonierbale, M. (2013). Comparison of yield based drought tolerance indices in improved varieties, genetic stocks and landraces of potato (*Solanum tuberosum* L.). Euphytica, 193(2): 147-156.

Choukan, R., Taherkhani, T., Ghanadha, M.R. and Khodarahmi, M. (2006). Evaluation of drought tolerance in grain maize inbred lines using drought tolerance indices.

Dang, P.M., Chen, C.Y. and Holbrook, C.C. (2013). Evaluation of five peanut (*Arachis hypogaea*) genotypes to identify drought responsive mechanisms utilising candidate-gene approach. Functional Plant Biology, 40(12): 1323-1333.

De Lima Pereira, J.W., Albuquerque, M.B., Melo Filho, P.A., Nogueira, R.J.M.C., de Lima, L.M. and Santos, R.C. (2016). Assessment of drought tolerance of peanut cultivars based on physiological and yield traits in a semiarid environment. Agricultural Water Management, 166: 70-76.

Del Rosario, D.A. and Fajardo, F.F. (1988). Morphophysiological responses of ten peanut (*Arachis hypogaea* L.) varieties to drought stress. Philipp. Agric, 71(447): p.e459.

Dinh, H.T.; Kaewpradit, W.; Jogloy, S.; Vorasoot, N. and Patanothai, A. (2013). Biological nitrogen fixation of peanut genotypes with different levels of drought tolerance under mid-season drought. SABRAO Journal of Breeding and Genetics, 45(3): 491-503.

Drikvand, R.; Doosty, B. and Hosseinpour, T. (2012). Response of rainfed wheat genotypes to drought stress using drought tolerance indices. Journal of Agricultural Science (Toronto), 4(7): 126-131.

Duncan, D.B. (1955). Multiple range and multiple F tests. Biometrics, 11(1): 1-42.

El-Mohsen, A.A.A.; El-Shafi, M.A., Gheith, E.M.S. and Suleiman, H.S. (2015). Using different statistical procedures for evaluating drought tolerance indices of bread wheat genotypes. Advance in Agriculture and Biology, 4(1): 19-30.

Farshadfar, E. (2012). Application of integrated selection index and rank sum for screening drought tolerant genotypes in bread wheat. International Journal of Agriculture and Crop Sciences, 4(6): 325-332.

Farshadfar, E. and Elyasi, P. (2012). Screening quantitative indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) landraces. European Journal of Experimental Biology, 2(3): 577-584.

Fernandez, G.C. (1992). Effective selection criteria for assessing plant stress tolerance. In Proceeding of the International Symposium on Adaptation of VegeFigures and other Food Crops in Temperature and Water Stress, Aug. 13-16, Shanhua, Taiwan, 257-270.

Fernandez, G.C.J. (1992). Effective selection criteria for assessing plant stress tolerance. In: Kuo, C.G. (Ed), Proceedings of the International Symposium on Adaptation of VegeFigures and Other Food Crops in Temperature and Water Stress, Publication, Tainan, Taiwan.

Fischer, R.A. and Maurer R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. Australian J. Agric. Res., 29: 897-912.

Fonceka, D., Tossim, H.A., Rivallan, R., Vignes, H., Lacut, E., De Bellis, F., Faye, I., Ndoye, O., Leal-Bertioli, S.C., Valls, J.F. and Bertioli, D.J. (2012). Construction of chromosome segment substitution lines in peanut (*Arachis hypogaea* L.) using a wild synthetic and QTL mapping for plant morphology. PLoS One, 7(11).

Freed, R., Einensmith, S.P., Guets, S., Reicosky, D., Smail, V.W. and Wolberg, P. (1989). User's guide to MSTAT-C analysis of agronomic research experiments. Michigan State University, USA.

Girdthai, T., Jogloy, S., Vorasoot, N., Akkasaeng, C., Wongkaew, S., Holbrook, C.C. and Patanothai, A. (2010). Heritability of, and genotypic correlations between, aflatoxin traits and physiological traits for drought tolerance under end of season drought in peanut (*Arachis hypogaea* L.). Field crops research, 118(2): 169-176.

Girdthai, T., Jogloy, S., Vorasoot, N., Akkasaeng, C., Wongkaew, S., Holbrook, C.C. and Patanothai, A. (2010). Associations between physiological traits for drought tolerance and aflatoxin contamination in peanut genotypes under terminal drought. Plant Breeding, 129(6): 693-699.

Golabadi, M., Arzani, A. and Maibody, S.M. (2006). Assessment of drought tolerance in segregating populations in durum wheat. African Journal of Agricultural Research, 1(5): 162-171.

Gomez, K.A. and Gomez, A.A. (1984). Statistical procedures for agricultural research. John Wiley & Sons.

Hebbar, K.B., Sashidhar, V.R., Udayakumar, M., Devendra, R. and Rao, R.N. (1994). A comparative assessment of water use efficiency in groundnut (*Arachis hypogaea*) grown in containers and in the field under water-limited conditions. The Journal of Agricultural Science, 122(3): 429-434.

Jafari, A., Paknejad, F.A.R.Z.A.D. and Jami, A.A., 2012. Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. International Journal of Plant Production, 3(4): 33-38.

Jongrungklang, N., Toomsan, B., Vorasoot, N., Jogloy, S., Boote, K.J., Hoogenboom, G. and Patanothai, A. (2013). Drought tolerance mechanisms for yield responses to pre-flowering drought stress of peanut genotypes with different drought tolerant levels. Field crops research, 144: 34-42.

Jongrungklang, N., Toomsan, B., Vorasoot, N., Jogloy, S., Boote, K.J., Hoogenboom, G. and Patanothai, A. (2011). Rooting traits of peanut genotypes with different yield responses to pre-flowering drought stress. Field Crops Research, 120(2): 262-270.

Khalili, M., Naghavi, M.R., Aboughadareh, A.P. and Talebzadeh, S.J. (2012). Evaluating of drought stress tolerance based on selection indices in spring canola cultivars *(Brassica napus* L.). Journal of Agricultural Science, 4(11): 78.

Klute, A. (1986). Methods of soil analysis, part 1 physical and mineralogical methods, Arnold Klute ed. Agronomy. 9, (part 1).

Koolachart, R., Jogloy, S., Vorasoot, N., Wongkaew, S., Holbrook, C.C., Jongrungklang, N., Kesmala, T. and Patanothai, A. (2013). Rooting traits of peanut genotypes with different yield responses to terminal drought. Field crops research, 149: 366-378.

Krapovickas, A., Gregory, W.C., Williams, D.E. and Simpson, C.E. (2007). Taxonomy of the genus Arachis (Leguminosae). Bonplandia, 16: 7-205.

Lovelli, S., Perniola, M., Ferrara, A. and Di Tommaso, T. (2007). Yield response factor to water (Ky) and water use efficiency of *Carthamus tinctorius* L. and *Solanum melongena* L. Agricultural water management, 92(1-2): 73-80.

Malekshahi, F., Dehghani, H.A.M.I.D. and Alizadeh, B.A.H.R.A.M. (2009). A study of drought tolerance indices in canola (*Brassica napus* L.) genotypes. Journal of Science and technology of agriculture and natural resources, 13(48 (B)): 77-90.

Mohammadi, R., Armion, M., Kahrizi, D. and Amri, A. (2012). Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. International Journal of Plant Production, 4(1): 11-24.

Mursalova, J., Akparov, Z., Ojaghi, J., Eldarov, M., Belen, S., Gummadove, N. and Morgounov, A. (2015). Evaluation of drought tolerance of winter bread wheat genotypes under drip irrigation and rain-fed conditions. Turkish Journal of Agriculture and Forestry, 39: 1-8.

Musick, J.T., Jones, O.R., Stewart, B.A. and Dusek, D.A. (1994). Water yield relationships for irrigated and dryland wheat in the US southern plains. Agronomy Journal, 86(6): 980-986.

Nautiyal, P.C., Ravindra, V., Zala, P.V. and Joshi, Y.C. (1999). Enhancement of yield in groundnut following the imposition of transient soil-moisture-deficit stress during the vegetative phase. Experimental Agriculture, 35(3): 371-385.

Page, A.I., R.H. Miller, and Keeny, D.R. (1982). Methods of Soil Analysis Part II. Chemical and Microbiological Methods (2nd ed.), American Society of Agronomy, Madison, WI, USA, pp. 225-246.

Puangbut, D., Jogloy, S., Vorasoot, N., Akkasaeng, C., Kesmalac, T. and Patanothai, A. (2009). Variability in yield responses of peanut (*Arachis hypogaea* L.) genotypes under early season drought. Asian Journal of Plant Sciences, 8(4): 254.

Rao, R.C., Williams, J.H. and Singh, M. (1989). Genotypic sensitivity to drought and yield potential of peanut. Agronomy Journal, 81(6): 887-893.

Rosielle A.A. and Hamblin J. (1981). Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci., 21: 943-946.

Savage, G.P. and Keenan, J.I. (1994). The composition and nutritive value of groundnut kernels. In The groundnut crop (pp. 173-213). Springer, Dordrecht.

Shamsi, K., Petrosyan, M., Noor-Mohammadi, G. and Haghparast, R. (2010). The role of water deficit stress and water use efficiency on bread wheat cultivars. Journal of Applied Biosciences, 35: 2325-2331.

Shinde, B.M., Limaye, A.S., Deore, G.B. and Laware, S.L. (2010). Physiological responses of groundnut (*Arachis hypogaea* L.) varieties to drought stress. Asian Journal of Experimental Biological Sciences (Spl issue), 65-68.

Singh, B.U., Rao, K.V. and Sharma, H.C. (2011). Comparison of selection indices to identify sorghum genotypes resistant to the spotted stem borer *Chilo partellus* (Lepidoptera: Noctuidae). International Journal of Tropical Insect Science, 31(1-2): 38-51.

Songsri, P., Jogloy, S., Vorasoot, N., Akkasaeng, C., Patanothai, A. and Holbrook, C.C. (2008). Root distribution of drought‐resistant peanut genotypes in response to drought. Journal of Agronomy and Crop Science, 194(2): 92-103.

Songsri, P., Jogloy, S., Vorasoot, N., Akkasaeng, C., Patanothai, A. and Holbrook, C.C. (2008). Root distribution of drought‐resistant peanut genotypes in response to drought. Journal of Agronomy and Crop Science, 194(2): 92-103.

Steel, R.G. (1997). Principles and procedures of statistics a biometrical approach (No. 519.5 S8).

Taylor, H.M. (1983). Managing root systems for efficient water use: An overview. Limitations to efficient water use in crop production, 87-113.

Toorchi, M., Naderi, R., Kanbar, A. and Shakiba, M.R. (2012). Response of spring canola cultivars to sodium chloride stress. Annals of Biological Research, 2(5): 312-322.

Vietes, F.G. (1965). Increasing water use efficiency by soil management in plant environment. J. Amer. Soc. Agron., 26: 537- 546.

Wright, G.C., Rao, R.C. and Farquhar, G.D. (1994). Water-use efficiency and carbon isotope discrimination in peanut under water deficit conditions. Crop Science, 34(1): 92-97.