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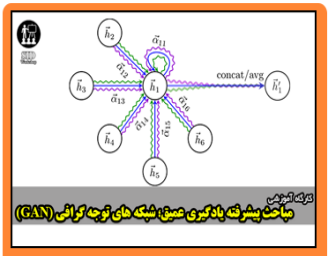

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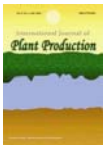

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Soil moisture affects fatty acids and oil quality parameters in peanut

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Abstract

Drought affects yield of peanut, but its effect on oleic and linoleic acids that influence its oil quality of peanut genotypes with different levels of drought resistance has not been clearly investigated. Therefore, the aims of this research were to determine whether soil water levels could affect oil quality by changes in fatty acid compositions of peanut, and to investigate the changes in oil characters in peanut genotypes with their potential drought resistance under different water regimes. Field experiments were conducted in split-plot designs with four replications during dry season for two years (2003/04 and 2004/05). Three water regimes [field capacity (FC), 2/3 available soil water (2/3 AW) and 1/3 available soil water (1/3 AW)] were assigned as main-plots, and six peanut genotypes were assigned as sub-plots. The data were recorded at maturity for fatty acid compositions and % oil. Seed samples were analyzed for % oil by Soxtec System HT, and fatty acid compositions were analyzed by gas liquid chromatography. Differences among water regimes and peanut genotypes were significant for oleic and linoleic acids content and their ratio (O/L ratio), unsaturated to saturated fatty acid ratio (U/S ratio) and iodine value (IV). Genotype × water regime interactions were also significant for all characters. Drought improved the oil quality by significant increase in oleic acid and O/L ratio, and reduced the linoleic acid, IV and U/S ratio. Peanut genotypes with different levels of drought resistance displayed similar tendency in fatty acid characters under drought conditions.

Keywords: *Arachis hypogaea* L.; Drought stress; O/L ratio; Iodine value.

Introduction

Peanut (*Arachis hypogaea* L.) is an important source of edible oil and protein worldwide, and peanut kernels are 42-49% oil and 25-29% protein (Jonnala et al., 2005). Oleic acid and linoleic acid constitute the largest portion (80%) of total fatty acids in peanut at the ranges of 35.7-82.2% for oleic acid and 2.9-40.3% for linoleic acid and there is a reverse relationship between oleic acid and linoleic acid (Andersen et al., 1998; Dwivedi et al., 1993).

The ratios of oleic acid to linoleic acid or O/L ratios determine the quality and storability of peanut oil and its products (Andersen and Gorbet, 2002). In addition, iodine value (IV) was used to determine the degree of unsaturated fatty acid and the stability of peanut oil (Andersen and Gorbet, 2002). High-oleic peanut has longer shelf-life than low-oleic peanut (O'Keefe et al., 1993; Braddock et al., 1995), and it has better flavor quality or stability than low-oleic peanut (Mugendi et al., 1998). Consumption of high-oleic peanut could reduce blood serum cholesterol and low density lipoproteins (LDL) in humans (O'Bryne et al., 1997).

Peanut is grown largely under rainfed conditions, and drought is a major constraint of peanut production worldwide (Holbrook and Stalker, 2003; Reddy et al., 2003; Songsri et al., 2008b). Drought stress can significantly reduce pod yield (Songsri et al., 2008a). The effect of drought on yield has been widely studied and is rather conclusive. Drought stress also reduced nitrogen fixation but it increased kernel infection and aflatoxin contamination (Arunyanark et al., 2012).

The effects of drought on oil characters have differed among studies. Hashim et al. (1993) observed a large reduction in percent oil and oleic acid in peanut under end-of-season drought. Another study found reduction in linoleic acid and an increase in oleic acid under end-of-season drought (Dwivedi et al., 1996). Factors other than drought conditions might explain the different results. Fatty acid compositions of peanut oil can vary with the differences in genotype, growing season (Singkham et al., 2010), location, planting date (Andersen and Gorbet, 2002), soil nutrient (Dwivedi et al., 1993), soil temperature (Golombek et al., 1995), and maturity (Hinds, 1995). However, oleic acid and linoleic acid contents had no correlation with pod yield, biomass and harvest index (HI) (Singkham et al., 2010). Therefore, yield cannot be used to predict fatty acids under drought conditions.

As oil characters affect peanut seed quality, improvement of agricultural practices might be a means to increase product quality. The questions

underlying the research project are whether (or not) drought at different severities could affect these characters of peanut genotypes with different levels of drought resistance and to what extent. A better understanding of the change of oleic acid, linoleic acid, and oil characters in peanut genotypes with different levels of drought resistance under drought conditions, and the effects of water deficits on these characters under different water regimes should be useful for selection of peanut for high yield under drought stress conditions while maintaining high oil quality. Therefore, the objective of this research was to evaluate the effects of long-term drought conditions on % oil, oleic acid and linoleic acid contents and oil characters of peanut genotypes with different levels of drought resistance.

Materials and Methods

Plant materials

Six peanut varieties (ICGV 98324, ICGV 98348, ICGV 98353, Tainan 9, KK 60-3 and Tifton-8) were selected based on different levels of drought resistance. The genotypes with ICGV number are drought resistant from ICRISAT and Tifton-8 is drought resistant (Coffelt et al., 1985) received from the United States Department of Agriculture. Tainan 9 and KK 60-3 are released cultivars in Thailand. Oleic acid content for the accessions from ICRISAT and Tifton-8 have not been reported. Tainan 9 has low oleic (40.5%), whereas KK 60-3 is intermediate oleic (59.9%) (Singkham et al., 2010). These genotypes were evaluated in a split plot design with four replications for two seasons during November 2003 to April 2004 and October 2004 to March 2005 at the Agronomy farm of Khon Kaen University. Three water regimes (field capacity; FC, 2/3 available soil water; 2/3 AW and 1/3 available soil water; 1/3 AW) were assigned as main plots and six peanut genotypes as sub-plots.

Crop managements

Soil was ploughed three times. Lime (625 kg ha^{-1}), phosphorus fertilizer as triple superphosphate (24.7 kg P ha^{-1}), and potassium fertilizer as potassium chloride (31.1 kg K ha^{-1}) were incorporated into the soil before planting. Seeds were treated with captan [3a, 4, 7, 7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindole-1, 3(2H)-dione] at the rate of 5 g kg^{-1} seed before planting and seeds of the large-seeded genotypes (KK 60-3) were also treated with ethrel (2-chloroethylphosphonic acid) 48% at the rate

of 2 mL L^{-1} water to break dormancy. Four seeds were planted per hill, and the seedlings were thinned to two plants per hill at 14 days after sowing (DAS). Rhizobium was applied to the seeds in the field by applying a water-diluted commercial peat-based inoculum of *Bradyrhizobium* (mixture of strains THA 201 and THA 205; Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) on the rows of peanut plants. Alachlor [2-cholro-2′, 6′-diethyl-*N*- (methoxymethyl) acetanilide 48%, w v^{-1}, emulsifiable concentrate] at the rate of 3 L ha^{-1} was used to control weeds at planting, and weeds were controlled manually throughout the experiment. Gypsum ($CaSO_4$) was applied at 45 DAS at the rate of 312 kg ha^{-1}. Carbofuran (2, 3-dihydro-2, 2-dimethylbenzofuran-7-ylmethylcarbamate, 3% granular) was applied at the pod-setting stage to control subterranean ants (*Dorylus orientalis*). Pests and diseases were controlled by weekly applications of carbosulfan [2-3-dihydro-2, 2-dimethylbenzofuran-7-yl (dibutylaminothio) methylcarbamate 20% w v^{-1}, water soluble concentrate] at the rate of 2.5 L ha^{-1}, methomyl [*S*-methyl-*N*-((methylcarbamoyl) oxy) thioacetimidate 40% soluble powder] at the rate of 1.0 kg ha^{-1} and carboxin [5, 6-dihydro-2-methyl-1, 4-oxathiine-3-carboxanilide 75% wettable powder] at the rate of 1.68 kg ha^{-1}.

A subsoil drip-irrigation system (Super Typhoon, Netafim Irrigation Equipment & Drip Systems, Israel) was installed at a spacing of 50 cm between drip lines and 20 cm between emitters in the drip lines. The drip lines were placed 10 cm below the soil surface between the middle of two rows. A pressure valve and a water meter were fitted for each main plot to ensure a uniform supply of water.

Soil moisture for each plot in all treatments was initially maintained at field capacity (93.1 mm in 60 cm depth) until 21 DAS to support crop establishment. After 21 DAS, the treatments of 2/3 AW and 1/3 AW were allowed to gradually decline until they reached 2/3 AW (75 mm in 60 cm depth) at 28 DAS. Then, soil moistures for the 1/3 AW treatment were further allowed to gradually decline until it reached the predetermined levels of 56 mm in 0-60 cm depth at 35 DAS. All soil moisture levels were then held at these levels until harvest. In maintaining the specified soil moisture levels, water was added to the respective plots by subsurface drip irrigation based on crop water requirement and surface evaporation, which were computed following the methods described by Doorenbos and Pruitt (1992) and Singh and Russell (1981), respectively.

Total crop water use for each water treatment was calculated as the sum of transpiration and soil evaporation. Transpiration was computed using the methods described by Doorenbos and Pruitt (1992):

$ET_{crop} = ET_o \times K_c$

Where ET_{crop} is crop water requirement (mm d^{-1}), ET_o is evapotranspiration of a reference plant under specified conditions computed by the pan evaporation method, and K_c is the crop water requirement coefficient for peanut, which varies depending on genotypes and growth stages (Doorenbos and Kassam, 1986). Surface evaporation (E_s) was computed as (Singh and Russell, 1981)

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

Where E_s is soil evaporation (mm), β is light transmission coefficient measured depending on crop cover, E_o is evaporation from class A pan (mm d^{-1}) and t is days from the last irrigation or rain.

Data collections

Weather parameters

Weather data including rain fall, evaporation, relative humidity, minimum and maximum air temperature and solar radiation were obtained throughout the experiment from a nearby meteorological station. Field trial crops were planted during the dry seasons from 23 November 2003 to 31 March 2004 and 18 October 2004 to 24 February 2005.

Soil moisture

Soil moisture was recorded by gravimetric method at planting and harvest at the depths of 0-5, 25-30 and 55-60 cm. Soil moisture at planting was used for computing the correct amount of water to be applied to the crop, and soil moisture at harvest was used for computing the water use of the crop. Soil water status was monitored at 7-day intervals using a neutron moisture meter (Type I.H. II SER, no. N0152, Ambe Didcot Instruments Co. Ltd, Abingdon, UK). An aluminium access tube was installed between rows in each plot, and the readings were obtained at the depths of 30, 60 and 90 cm.

Oil preparation and fatty acid analysis

The seeds for each plot were harvested at maturity (R8) (Boote, 1982). Groundnut oil was extracted from dried seed by Soxtec system HT, and fatty acid compositions were determined using gas liquid chromatography (GLC).

Twenty-mature seeds from each plot were ground. Ground seed samples were oven-dried at 70 ^{o}C for 15-20 h. Dried seed samples of 2 g were extracted for oil by the Soxtec extractor. Petroleum ether (50 mL) was used for solvent to extract the oil.

An oil sample of 0.01 g was used for fatty acid composition analysis. Fatty acid methyl esters (FAME) for extracted fatty acids were prepared followed Ruiz Lopez's method (Ruiz-López et al., 2003). Ruize-Lopez's solution was prepared by adding Methanol: Toluene: DMP: H_2SO_4 in the ratio of 39:20:5:2. This solution was used to hydrolyze the fatty acids and methyl groups to form FAME. The FAME were prepared by adding 1 mL of Ruize-Lopez's solution in 10 mg of dried sample and 100 µL of 0.01 g mL^{-1} heptadecanoic acid (C17:0) an internal standard. The mixture solutions were incubated in a water bath at 80 ^{o}C for 2 h. After incubation, the mixtures were added to 200 µL of 0.9% (w v^{-1}) NaCl and 200 µL heptane. Heptane was used to extract FAME. Oil sample (33 µg) was dissolved in a 1 µL of FAME. The FAME sample of 2 µL was injected in a GLC (with Flame Ionization Detector: FID). Fatty acid analysis was performed on Shimadzu Gas Chromatograph GC-14B-CR7A and SGE fort GC capillary column (30 m × 0.25 mm ID BPX70 0.25 µm). The carrier gas was helium at a flow rate of 30 mL min^{-1}. The temperature programming was from 130 ^{o}C (held 2 min) and then to 220 ^{o}C (held 8 min) at 5 ^{o}C min^{-1}. The temperatures of injector and detector were 250 and 300 ^{o}C, respectively. The standard fatty acids consisting of myristic (C14:0), palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), eicosenoic (C20:1), behenic (C22:0), erucic (C22:1) and lignoceric acids (C24:0) were used to identify the fatty acid content in peanut.

The ratio of oleic to linoleic acids (O/L ratio), the ratio of unsaturated to saturated fatty acids (U/S ratio), iodine value (IV) and % oil (Singkham et al., 2011) were computed:

O/L ratio= % oleic acid / % linoleic acid,

IV= (% oleic acid × 0.8601) + (% linoleic acid × 1.7321) + (% eicosenoic acid × 0.7854),

U/S ratio=(% oleic acid + % linoleic acid + % eicosenoic acid) / (% palmitic acid + % stearic acid + % arachidic acid + % behenic acid + % lignoceric acid)

Percentage of oil= (oil weight (g) × 100)/ground seed weight (g).

Data Analysis

Individual analysis of variance was carried out for each character in each experiment. Error variances for the two years were tested for homogeneity (Gomez and Gomez, 1984). Combined analyses of variance were performed for all characters, where error variances for the two seasons were homogeneous, and the least significant difference (LSD) was used to compare means.

Results

Weather data and monitoring of soil moisture

There was a 71 mm rainfall during 73-75 day after sowing (DAS) in the dry season 2003/04, whereas the dry season 2004/05 had no rainfall (Figure 1). The seasonal mean minimum and maximum air temperature were observed ranging from 18.0-31.0 ^{o}C in 2003/04 and 19.0-32.0 ^{o}C in 2004/05, being lower during 1-45 DAS in 2003/04. Daily pan evaporation ranged from 0.8-9.9 mm in 2003/04 and from 2.2-8.3 mm in 2004/05. The seasonal mean of solar radiation was 17.61 MJ m^{-2} day^{-1} in 2003/04 and 17.74 MJ m^{-2} day^{-1} in 2004/05.

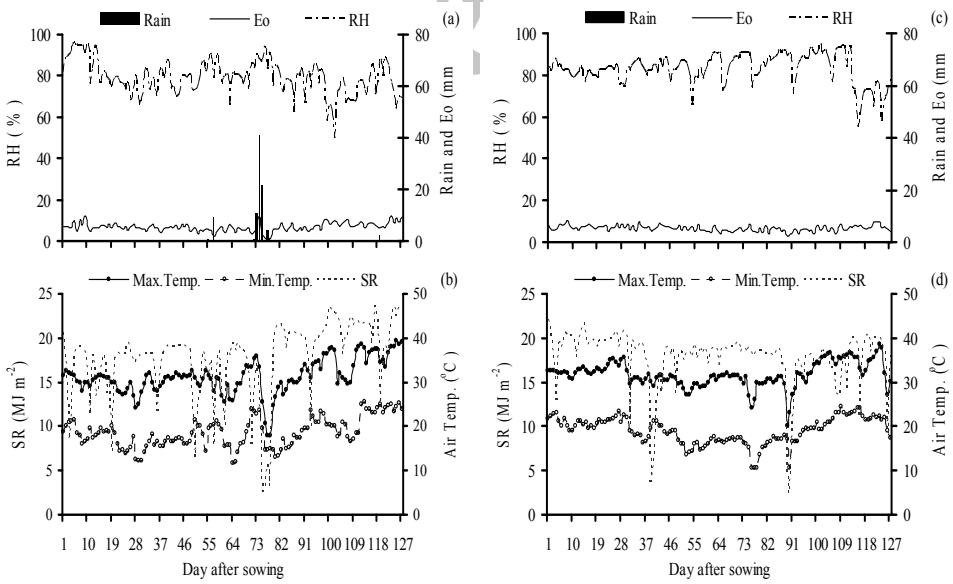

Figure 1. Rain fall, evaporation (E_0), relative humidity (RH), maximum air temperature (Max Temp.), minimum air temperature (Max and Min Temp.) and solar radiation (SR) in 2003/04 (a, b) and 2004/05 (c, d).

Soil moisture for each plot was measured using as a neutron moisture meter at 7-day intervals to harvest. The management of soil moisture under different water regimes is presented in Figure 2. The rainfall during 73-75 DAS (77 mm) caused higher soil moisture in the drought stress treatments in 2003/04.

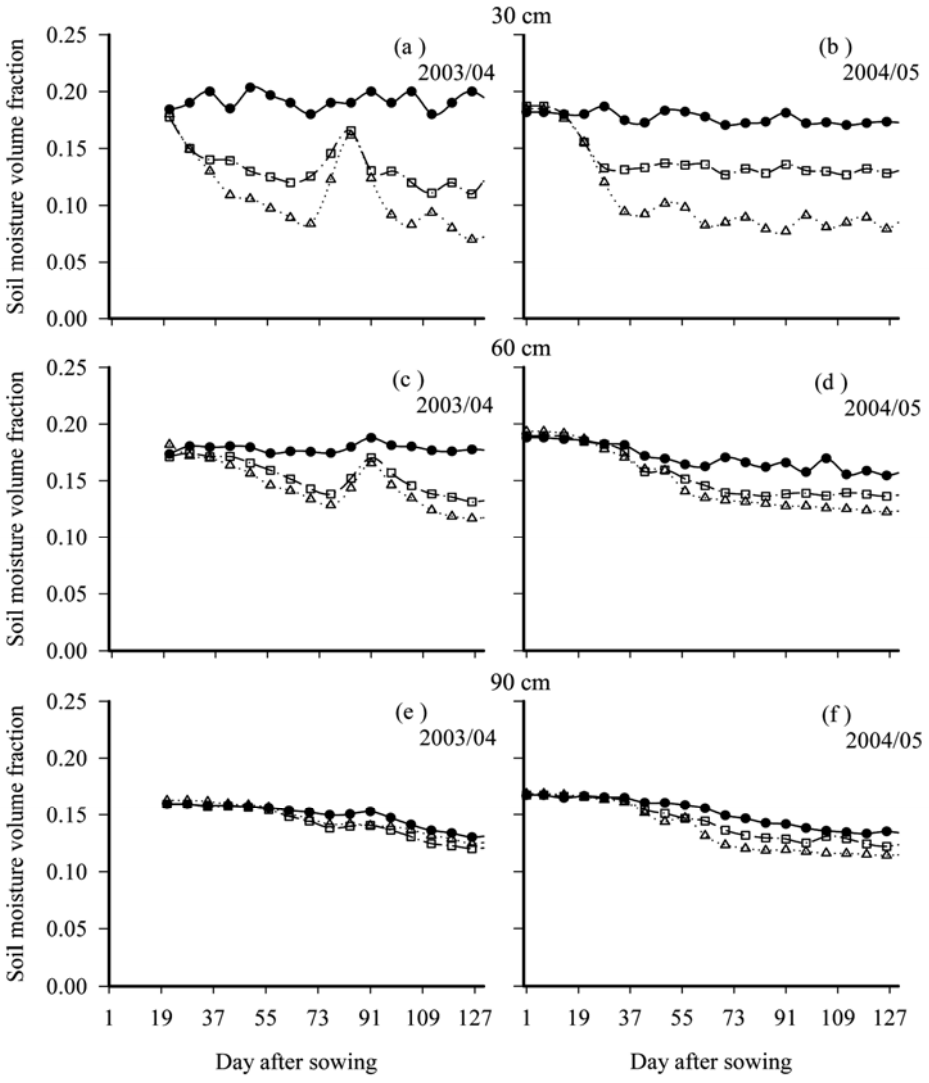

Figure 2. Soil moisture volume fraction as measured by neutron moisture meter for three soil water regimes (FC, ●, 2/3 AW, γ and 1/3 AW, Δ) at 30 cm (a, b), 60 cm (c, d) and 90 cm (e, f) of the soil level during the 2003/04 and 2004/05 in dry seasons.

Effects of available soil water on fatty acids and oil characters

Combined analysis of variance for two years showed that years, water regimes and peanut genotypes were significantly different for oleic acid, linoleic acid, % oil, oleic to linoleic acid ratio (O/L ratio), unsaturated to saturated fatty acid ratio (U/S ratio) and iodine value (IV) (Table 1). In addition, the interactions of genotype×year (G×Y), genotype×water (G×W) and genotype×year×water (G×Y×W) were highly significant for all characters.

Table 1. Mean squares from combined analysis of oleic acid, linoleic acid, oleic to linoleic acid ratio (O/L ratio), unsaturated to saturated fatty acid ratio (U/S ratio), iodine value (IV) and % oil of 6 peanut genotypes grown under different water regimes in 2003/04 and 2004/05 dry seasons.

SOV	DF	Oleic acid	Linoleic acid	O/L ratio	U/S ratio	IV	% Oil
Year (Y)	1	9.90*	133.23**	0.42*	3.30**	235.32**	93.64**
Rep/Year	3	1.20	2.05	0.01	0.02	1.38	1.75
Water (W)	2	49.90**	99.04**	0.72**	0.40**	123.27**	22.89**
Y×W	2	19.69*	18.95*	0.16**	0.12**	15.18**	26.80**
Error (b)	12	3.68	3.28	0.01	0.01	0.72	0.66
Genotype (G)	5	944.70**	709.77**	5.69**	2.79**	402.41**	31.42**
G×Y	5	9.43**	8.73**	0.15**	0.04**	6.17**	7.94**
G×W	10	4.35**	3.86*	0.05**	0.10**	7.78**	9.24**
G×Y×W	10	11.40**	7.51**	0.14**	0.05**	7.73**	3.23**
Error (c)	90	1.61	1.66	0.01	0.01	0.64	1.25
Total	143						

* and ** significant at the 5% and 1% probability levels, respectively.

Differences in water regimes were not significant for percentage of oleic acid, unsaturated to saturated fatty acids ratio (U/S ratio) and % oil in 2003/04, but the treatments were significantly different for all characters under study in 2004/05 (Table 2). Drought treatments at 2/3 AW and 1/3 AW had the highest oleic acid (48.4% for 2/3 AW and 48.9% for 1/3 AW) in 2004/05, whereas FC treatment had the highest linoleic acid, U/S ratio, iodine value (IV) and % oil (32.3%, 4.0, 96.6 and 45.4%, respectively) in 2004/05.

Percentage of oleic acid in 2003/04 ranged from 39.9-54.5, 39.3-54.3 and 40.8-54.9% under FC, 2/3 AW and 1/3 AW, respectively and in 2004/05 ranged from 38.1-50.8, 39.9-57.0 and 40.8-54.5% under FC, 2/3 AW and 1/3 AW, respectively (Table 3). KK 60-3 had the highest oleic acid and O/L ratio (54.5% and 2.3, respectively) under FC treatment in 2003/04 and had the lowest linoleic acid under FC treatment in both 2003/04 and 2004/05 (23.2 and 28.1, respectively). ICGV 98324, ICGV 98348 and KK60-3 had

higher oleic acid under water stress treatments in both 2003/04 and 2004/05 than well-watered treatment. ICGV 98348 increased oleic acid under 2/3 AW in 2003/04, but this genotype decreased oleic acid under 2/3 AW in 2004/05. Moreover, KK 60-3 under drought stress treatments had lower oleic acid than under well-watered treatment.

Table 2. Percentage of oleic acid, linoleic acid, oleic to linoleic acid ratio (O/L ratio), unsaturated to saturated fatty acid ratio (U/S ratio), iodine value (IV) and % oil of field capacity (FC), 2/3 available water (2/3 AW) and 1/3 available water (1/3 AW) in 2003/04 and 2004/05 dry seasons.

Treatment	Oleic acid	Linoleic acid	O/L ratio	U/S ratio	IV	% oil
		2003/04				
FC	48.0	29.0^{a}	1.7^{b}	3.6	92.9^{a}	42.2
2/3 AW	47.6	28.9^{a}	1.7^{b}	3.5	91.9^{b}	42.3
1/3 AW	49.5	27.0^{b}	1.9^{a}	3.5	90.8^{b}	42.1
Mean	48.4	28.3	1.8	3.5	91.8	42.2
		2004/05				
FC	46.3^{b}	32.3^{a}	1.5^{c}	4.0^{a}	96.6^{a}	45.4^{a}
2/3 AW	48.4^{a}	29.8^{b}	1.7^{b}	3.9^{b}	94.3^{b}	42.5^{c}
1/3 AW	48.9^{a}	28.6^{c}	1.8^{a}	3.7^{c}	92.3^{c}	43.5^{b}
Mean	47.9	30.2	1.7	3.8	94.4	43.8

Mean in the same column with the same letters are not significantly different by LSD (at P<0.05).

Table 3. Percentage of oleic acid, linoleic acid, oleic to linoleic acid ratio (O/L ratio) of 6 peanut genotypes grown under different water regimes in 2003/04 and 2004/05 dry seasons.

Genotypes	Oleic acid			Linoleic acid			O/L ratio		
	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW
				2003/04					
ICGV 98324	53.4^{b}	54.3^{a}	54.5^{a}	25.5^{c}	24.6^{d}	22.7^{b}	2.1^{b}	2.2^{a}	2.4^{a}
KK 60-3	54.5^{a}	52.6^{a}	53.6^{a}	23.2^{d}	25.2^{d}	23.4^{b}	2.3^{a}	2.2^{a}	2.2^{b}
Tifton-8	38.6^{e}	39.2^{c}	43.9^{c}	38.4^{a}	36.6^{a}	33.7^{a}	1.0^{e}	1.1^{d}	1.2^{d}
ICGV 98348	53.3^{b}	50.1^{b}	54.9^{a}	25.3^{c}	27.3^{c}	23.2^{b}	2.1^{b}	1.8^{c}	2.4^{a}
ICGV 98353	39.9^{d}	40.6^{c}	40.8^{d}	35.1^{b}	34.4^{b}	34.5^{a}	1.1^{d}	1.2^{d}	1.2^{d}
Tainan 9	48.9^{c}	49.1^{b}	49.0^{b}	26.7^{c}	25.4^{d}	24.7^{b}	1.8^{c}	1.9^{b}	2.0^{c}
Mean	48.1	47.6	49.5	29.0	28.9	27.0	1.7	1.7	1.9
				2004/05					
ICGV 98324	50.2^{ab}	52.3^{b}	54.5^{a}	29.9^{b}	27.5^{c}	25.4^{b}	1.7^{a}	1.9^{b}	2.3^{a}
KK 60-3	50.8^{ab}	51.4^{b}	52.2^{ab}	28.1^{c}	27.6^{c}	26.0^{b}	1.8^{a}	1.8^{c}	2.0^{b}
Tifton-8	38.6^{c}	40.0^{d}	40.8^{c}	39.2^{a}	38.0^{a}	35.4^{a}	1.0^{b}	1.1^{d}	1.2^{c}
ICGV 98348	50.8^{a}	57.0^{a}	53.2^{a}	28.7^{bc}	22.6^{d}	25.5^{b}	1.8^{a}	2.5^{a}	2.1^{a}
ICGV 98353	38.1^{c}	39.9^{d}	42.4^{c}	39.4^{a}	36.6^{b}	34.1^{a}	1.0^{b}	1.1^{d}	1.2^{c}
Tainan 9	49.0^{ab}	49.9^{c}	50.3^{b}	28.7^{bc}	26.7^{c}	25.1^{b}	1.7^{a}	1.9^{bc}	2.1^{b}
Mean	46.3	48.4	48.9	32.3	29.8	28.6	1.5	1.7	1.8

Mean in the same column with the same letters are not significantly different by LSD (at P<0.05).

ICGV 98324 had the highest U/S ratio in all water treatments in both 2003/04 and 2004/05 (Table 4). Tainan 9 had the lowest U/S ratio and IV in all water treatments in both 2003/04 and 2004/05. Most peanut genotypes decreased % oil under drought conditions in 2004/05 except for ICGV 98324.

Table 4. The ratio of unsaturated to saturated fatty acids (U/S ratio), iodine value (IV) and % oil of 6 peanut genotypes grown under different water regimes in 2003/04 and 2004/05 dry seasons.

Genotypes	U/S ratio			IV			% oil		
	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW	FC	2/3 AW	1/3 AW
2003/04									
ICGV 98324	4.0^{a}	4.1^{a}	3.7^{a}	91.8^{c}	90.2^{c}	87.2^{d}	40.4^{b}	43.8^{a}	42.0^{ab}
KK 60-3	3.7^{b}	3.6^{c}	3.6^{a}	88.7^{e}	90.9^{c}	88.8^{c}	41.2^{b}	40.6^{c}	40.5^{b}
Tifton-8	3.5^{c}	3.3^{d}	3.7^{a}	100.5^{a}	97.2^{a}	98.7^{a}	44.7^{a}	44.5^{a}	43.4^{a}
ICGV 98348	3.9^{a}	3.8^{b}	3.8^{a}	90.5^{d}	91.3^{c}	88.6^{c}	40.3^{b}	41.2^{bc}	43.7^{a}
ICGV 98353	3.1^{d}	3.2^{d}	3.3^{b}	95.3^{b}	95.3^{b}	95.7^{b}	40.9^{b}	40.9^{bc}	40.3^{b}
Tainan 9	3.3^{c}	3.2^{d}	3.0^{c}	90.3^{d}	86.4^{d}	85.7^{e}	45.5^{a}	43.0^{ab}	42.5^{ab}
Mean	3.6	3.5	3.5	92.9	91.9	90.8	42.2	42.3	42.1
2004/05									
ICGV 98324	4.3^{a}	4.4^{a}	4.3^{a}	95.4^{b}	93.8^{c}	90.3^{d}	45.1^{b}	45.2^{a}	45.6^{a}
KK 60-3	4.2^{b}	4.1^{b}	3.7^{c}	93.3^{d}	93.5^{c}	89.8^{d}	43.5^{c}	41.3^{c}	42.4^{d}
Tifton-8	3.8^{c}	3.5^{c}	3.6^{d}	101.7^{a}	100.1^{a}	97.8^{a}	46.3^{a}	43.5^{b}	42.7^{cd}
ICGV 98348	4.3^{a}	4.2^{ab}	4.0^{b}	94.4^{c}	89.0^{e}	91.6^{c}	46.1^{ab}	40.9^{c}	44.4^{b}
ICGV 98353	3.6^{d}	3.4^{e}	3.5^{d}	101.5^{a}	98.5^{b}	96.2^{b}	45.1^{b}	40.9^{c}	42.3^{d}
Tainan 9	3.6^{d}	3.6^{c}	3.2^{e}	93.2^{d}	90.6^{d}	88.1^{e}	45.9^{ab}	43.4^{b}	43.8^{bc}
Mean	4.0	3.9	3.7	96.6	94.3	92.3	45.4	42.5	43.5

Mean in the same column with the same letters are not significantly different by LSD (at P<0.05).

Discussion

In this study, well-watered condition, intermediate drought condition and severe drought condition were compared for their effects on oleic acid, linoleic acid and oil characters of peanut. Drought at 2/3 AW and 1/3 AW slightly increased oleic acid (about 1-2% increase), and it also slightly reduced linoleic acid (about 1-2% reduction). Therefore, it increased O/L ratio. Drought also reduced U/S ratio and IV. In general, drought improved fatty acid quality to a very small extent. However, KK 60-3 showed slightly reduced oleic acid under drought in 2003/04.

Results supported the findings of Dwivedi et al. (1996), who reported that end-of-season drought (80 DAS-harvest) significantly increased oleic acid content in 12 peanut genotypes, and also a peanut genotype (KK60-3) supported the conclusions of Hashim et al. (1993), who found that drought stress for 30 days during seed maturation (80 DAS) produced lower oleic acid content in three peanut genotypes. The differences might be due to various responses of peanut genotypes and genotype × environment interactions. Considering the small change in oleic acid of 1-2%, changing water regimes to improve oil quality is not practical. A more effective approach would be to grow varieties that have the high oleic character. The development of high oleic peanut with improved drought tolerance is needed since peanut is mostly grown under rainfed conditions, growing peanut genotypes with good yield performance under drought while maintaining high oil quality is highly recommended. Drought also slightly reduced % oil. Similar results were observed by Dwivedi et al. (1996), while another study found that drought did not change % oil (Musingo et al., 1989). The contrasting results were not surprising since the differences were not significant. The differences in oleic acid, linoleic acid and % oil might be caused by differences in genotypes, intensity of water stress and the environment in which grown.

Temperatures during the pod filling phase (after 80 DAS to maturity) were high in both years (Figure 1), and it was expected that the temperatures under drought conditions were higher than that of FC. In a parallel study in the same field, Arunyanak et al. (2009) reported that soil temperatures under 1/3 AW treatment at 97 DAS to harvest were higher (24-25 ^{o}C) than 2/3 AW (21-22 ^{o}C) and FC treatments (21-22 ^{o}C) in 2003/04, whereas soil temperatures in 2004/05 were higher (23-27 ^{o}C) than in 2003/04 (21-25 ^{o}C). The high temperature during pod filling phase to harvest might have reduced the activity of the enzyme that changes oleic acid to linoleic acid (Golombek et al., 1995; Dwivedi et al., 1996). Our results indicated that the combinations of water stress and high temperature during the pod filling phase could increase the oleic acid contents, and decrease linoleic acid in peanut.

The significant interaction between peanut genotype and environment makes the prediction of oil quality more difficult. Significant interactions between genotype × environment for the percentage of oleic acid, linoleic acid and oil have been observed (Anderson and Gorbet, 2002; Dwivedi et al., 1996; Singkham et al., 2010). In the present study, water regimes in long-term drought conditions, genotypes and years were important to oleic

acid, linoleic acid and oil characters, and genotype × water treatment interactions (G×W) were also significant for these characters. The significant G×W interactions were caused by the reduction of oleic acid in ICGV 98348 and KK 60-3 under drought treatments in 2003/04, whereas other peanut genotypes increased oleic acid (Table 3). Singkham et al., (2010) reported that genotypes within the intermediate and low-oleic groups had high variation for oleic acid. However, means averaged from all genotypes for percent oleic acid increased under water stress conditions. In general, the drought resistant genotypes and drought susceptible genotypes did not differ in response to drought stress for oleic acid.

Previous investigations indicated that drought reduced yield (Songsri et al., 2008a; Girdthai et al., 2010) except for early season drought (Puangbut et al., 2011) that could improve yield. Growing peanut genotypes with drought resistance can sustain yield under drought conditions and also sustain oil quality.

Conclusion

Drought slightly increased oil quality of peanut as it increased oleic acid and reduced linoleic acid and % oil. The increase in oleic acid was very small, and the genotype × environment interactions were significant for fatty acids and oil characteristics. The drought resistant and susceptible peanut genotypes reacted similarly. Therefore, the selection of drought resistant genotypes while maintaining good oil quality under drought is a strategy to sustain productivity and oil quality of peanut. The use of high oleic peanut is another promising option and more research is needed on the effect of drought on oleic acid in high-oleic peanut.

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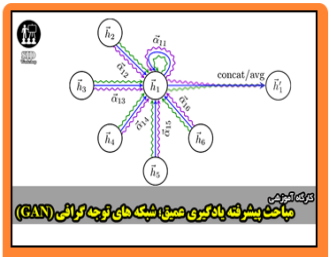

مباحث پیشرفته یادگیری عمیق؛ شبکه های توجه گرافی (Graph Attention Networks)