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Biomass, shoot and pod dry weight, and harvest index of Valencia peanut genotypes under terminal drought

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ABSTRACT: This research work aimed to investigate the effects of terminal drought (TD) on growth, pod yield, and harvest index and to identify the high potential of pod yield (PP) genotypes and low reduction of pod yield (RP) genotypes. A 2 × 10 factorial in randomized complete block design (RCBD) was undertaken in a greenhouse with four replications at Khon Kaen University (KKU), Thailand, from February to May 2018 and 2019. Factor A included two water regimes, field capacity (FC), and 1/3 available water (1/3 AW) at 60 days after planting (DAP) until harvest. Factor B included 10 Valencia peanut genotypes. The data were recorded of total biomass, shoot dry weight, pod dry weight, and harvest index (HI). Under TD conditions, total biomass, shoot and pod dry weights and HI were reduced. The pod yield under TD was contributed by the larger portion of the RP, whereas the PP (at FC) contributed a smaller portion. From the two years result, the low RP genotypes were PI365564 and ICG8517, whereas the high PP genotypes were ICG10092 and ICG10890. The distinct groups with high PP and low RP could be selected as parental lines and generated progenies in varietal improvement program, aiming to develop peanut varieties with high PP and low RP under TD.
Keywords: water stress, biomass production, pod dry weight, high yield potential genotype, low yield reduction

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Introduction

Peanut (*Arachis hypogaea* L.) is an oil crop grown mostly in the semi-arid tropical regions including Africa, Asia, and America (Revoredo and Fletcher, 2002). Peanut is rich in oil, protein, and carbohydrate, and it contains significant amounts of minerals, several vitamins, antioxidants, biologically active polyphenols, flavonoids and isoflavones (James Yaw et al., 2008; Janila et al., 2013). Peanut provides health benefits as it reduces the risk of cardiovascular disease, antioxidants, and antimicrobial (Barbour et al., 2015; De Camargo et al., 2017). In tropical and semi-tropical regions, the peanut is at risk of drought because of poor rainfall and rain distribution (Chakraborty et al., 2015).

The effect of drought is more severe in sandy soil with low water holding capacity. Growth, yield, and quality of the product are severely reduced under drought during the last 30 to 45 days before harvest (TD) (Kambiranda et al., 2011). Furthermore, drought stress is implicated in causing low biomass production, yield, seed quality, seed sizes, poor seed grades, germination, nitrogen fixation, and aflatoxin contamination (Kambiranda et al., 2011; Pimratch et al., 2010; Boontang et al., 2010; Junjittakarn et al., 2014). TD reduces the yield of about 14-50% and increases aflatoxin of 0.5-8.8% because it occurs at seed-filling stages when the crop is susceptible to *Aspergillus flavus* infection and aflatoxin contamination (Craufurd et al., 2006; Koolachart et al., 2013).

The major eco-agro systems of peanut in Thailand include upland early rainy season, upland late rainy season, and lowland in the dry season after the rice harvest. Peanut is also grown on the river banks after the reduction of water level in the dry season with or without irrigation. The eco-agro systems described in Thailand and Asian countries are also similar to those in other peanut producing countries in the world. TD can occur in all eco-agro systems because of uneven rainfall and poor rain distribution even under irrigation when water resources are not sufficient.

The reported of the responses of Valencia peanut genotypes to TD is limited. Only one study in one season has been reported for growth, pod yield, yield components, flower distribution, biomass, drought tolerance index (DTI), relative water content (RWC), SPAD chlorophyll meter reading (SCMR) and specific leaf area (SLA) (Carvalho et al., 2017; Manjonda et al., 2018). The information on the responses of Valencia peanut to TD for biomass and pod yield of Valencia peanut is still lacking. This research work aimed to investigate the effects of terminal drought (TD) on growth, shoot and pod dry weight and harvest index and to identify the high PP and low RP genotypes for using as parental genotypes in breeding programs for the improvement of resistance to TD variety.

Materials and Methods

The experiment was conducted in the pot, in a greenhouse during February - May in 2018 and repeat during February - May in 2019 at the Research Station of KKU (latitude 16° 28´ N, longitude 102° 48´ E, and 200 m above mean sea level)

Plant Materials and Experimental Design

Ten peanut genotypes were used in this study. Eight Valencia peanut genotypes (ICG10092, ICG10890, ICG14127, ICG6888, ICG8517, PI536121, ICG14106, and PI365564) were kindly donated from New Mexico State University (NMSU) and the International Crops Research Institute for the Semi-arid Tropics (ICRISAT). KS2 is a commercial Valencia type peanut for Thailand and ICGV98324 is a Spanish type peanut from ICRISAT used as a drought tolerance check. ICGV98324 had high SCMR, RWC, HI, DTI, low SLA, high yield components and best genotypes for nutrient uptake under drought condition (Painawadee et al., 2009; Songsri et al., 2009; Koolachart et al., 2013; Htoon et al., 2014).

The genotypes were planted in pots under two water regimes (FC and 1/3 AW) from 60 DAP to harvest. Two water regimes and 10 peanut varieties were assigned as factor A, and as factor B, respectively. The treatments of 2×10 factorial were arranged in an RCBD with four replications. There were 6 pots per experimental unit.

Preparation of Pots

The dry soil of 45.5 kg was filled into each pot with 24 cm in inner diameter and 70 cm in height. The soil bulk density of 1.55 g/cm^3 in the pot was uniform and it was the same as that in the field. The soil in the pot was divided into five layers. Four layers from the bottom had 15 cm in thickness and one layer on the top has 5 cm in thickness. Four tubes were installed in the pot at the spacing of 15 cm from the bottom, and eight small holes were made in the tubes for water outlets. Four cones were installed on the tubes for supplying water to the pots. A day before planting, the experimental pots were supplied with water at the FC level. Water that was replenished to the pots after planting was calculated base on the crop water requirement of peanut at different growth stages.

Crop Management

The seeds were treated with captan (N-(trichlomethylthio) cyclohexyl-4-ene-1, 2-diboximide 50% WP) at the rate of 5 g/kg seeds to control stem rot (*Aspergillus niger*) and inoculated with *Bradyrhizobium sp.* (mixture of strains THA 201 and THA 205; Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) for symbiotic nitrogen fixation. Chemical fertilizer formula 12-24-12 of N-P_2O_5-K_2O was applied to the pots at the rate of 1.41 g/pot before planting. The seeds were planted at the rate of three seeds per pot at 5 cm below the soil surface and two seedlings were maintained in each pot at 14 DAP. Diseases were treated with mancozeb ((1,2-ethanediyl-bis-(carbamdithioato)) (2-)) manganese, mixture with ((1,2-ethanediylbis-(carbam-dithioato))(2-)) zinc and insect pests were controlled with carbosulfan (2,3-dihydro-2,2-dimethyl-benzofuran-7-yl (dibutylaminothio) methylcarbamate). At flowering, gypsum ($CaSO_4$) at the rate of 1.42 g/pot was applied to the crop for a better pod setting.

Before planting, water was uniformly supplied to the pot at the FC level. Water at FC was maintained until 60 DAP when water treatments (FC and 1/3 AW) were started. For 1/3 AW treatment, water application was stopped at 60 DAP and soil moisture decreased to reach 1/3 AW level then maintained at this level until harvest. For FC treatment, water was applied at FC from plants to harvest. Water treatments were controlled according to the crop water requirement described by Doorenbos and Pruitt (Doorenbos and Pruitt, 1992) and surface evaporation (Singh and Russell, 1980). The crop water requirement was calculated as follows;

$$ETcrop = ETo \times Kc$$

Where ETcrop is crop water use of peanut. ETo is evapo-transpiration of reference plant, and Kc is a coefficient of water requirement of peanut at different growth stages (Doorenbos and Pruitt, 1992). Surface evaporation; (SE) was calculated as follows;

$$SE = ß \times (Eo/t),$$

Where, SE is evaporation. ß is a coefficient of light penetration, Eo is evaporation of A pan, and t is the number of days from the last watering.

Data Collection

Meteorological Data and Soil Physical and Chemical Properties

Meteorological data were recorded daily from planting until harvest for rainfall (mm), maximum and minimum temperature (°C), relative humidity (RH %), evapotranspiration (mm), and solar radiation by the nearest weather station.

Soil samples were analyzed for physical and chemical properties before filling the pots. The bulk of all soil samples was analyzed for physical properties such as sand, silt, clay (%) and bulk density (g/cm^3) with hydrometer method (Kilmer and Mullins, 1954), chemical properties such as total N analysis with Micro Kjeldahl method (Land Development Department, 2004), organic matter by Wet oxidation (Walkley and Black, 1934), available P with Bray ll method (Bray and Kurtz, 1945), exchangeable K and Ca extraction by 1N NH_4OAC pH 7.0 method, analysis absorption by a flame photometer (Cope and Evans, 1985; Pansu and Gautheyro, 2006), cation exchange capacity (CEC) by 1N NH_4OAC pH 7.0 method (Tisdale et al., 1993; Havlin et al., 2005), pH by pH meter (potention metric method) with the ratio of soil and water 1:1 (Peech, 1965), and electrical conductivity (EC) by EC meter method rate ratio soil and water 1:5 (Land Development Department, 2004).

Soil Moisture Content

Soil moisture content was recorded in 60, 75, and 90 DAP and final harvest by using micro auger stored at a depth of 0 – 30 cm. The samples were further oven-dried at 105 °C for 72 hours or until the weights were constant. The soil moisture content was calculated by using the formula below;

$$\text{Soil moisture} = ((\text{fresh weight-dry weight}) / (\text{dry weight})) \times 100$$

Relative Water Content (RWC)

RWC was used to evaluate the plant water status. It was measured at 09:00 -11:00 am. The second or third fully expanded leaf from the top of the main stem from a plant of each pot was taken in 60, 75 and 90 DAP. The samples were put into sealable plastic bags and immediately stored in an icebox to prevent moisture loss. Fresh weight (FW) was measured as soon as possible once the samples were transported to the laboratory and then the leaflets were immersed in distilled water for 8 h to determine the turgid weight and weighted (TW). The leaflets were transferred into paper bags and oven-dried at 70 °C for 48 h or until the leaf weights were constant and weighted (DW). Finally, RWC was determined using the formula suggested by Turner (Turner, 1986);

$$RWC = (FW\ (g) - DW\ (g) / TW\ (g) - DW\ (g)) \times 100$$

Biomass (BM), Shoot and Pod dry weight and Harvest Index (HI)

At the final harvest, data for total biomass, pods yield dry weight, and HI were recorded from the plant in three pots of each experimental unit. The plants were cut at ground level and separated into different plant parts, leaves, stems, pods, and pegs. The samples were further oven-dried at 70 °C for 48 hours or until the weights were constant. Then, the data were determined for stem dry weight, leaf dry weight, pod dry weight, and peg dry weight. Total biomass was calculated by the sum of stems, leaves, pods, and pegs dry weight. HI was determined as a ratio of pod dry weight and total biomass.

Percentages of reduction in growth and yield of TD were used to evaluate the responses of the genotypes to TD (Pimratch et al., 2008). Percentages of reduction in growth and pod yield were calculated for each genotype as:

Percentage of reduction of pods dry weight = [1- (weight TD/ weight under FC)] × 100

Data Analysis

Each year's data sets were analyzed for all traits according to the factorial experiment in an RCBD. The traits have the difference of error variance not larger than three folds (Hoshmand, 2006), therefore the combined analysis of variance was performed. Means of main effects were separated by Duncan's multiple range tests at the 0.05 probability level. For the year 2019, the harvest index data violated of assumption of analysis of variance because the variance and means were functionally related therefore the log base 10 was used to transform values before subjecting to the analysis of the data.

Multiple-linear regression was used to determine the relative contribution of PP and the percentage of RP under TD to dry weight or pod yield under TD condition. The analysis was based on the following statistical model (Gomez and Gomez, 1984):

Where Yi is pod yield under TD of genotype i, α is the Y-intercept, X1i and X2i are PP and percentages of RP under TD of genotypes i, respectively, β1 and β2 are regression coefficients for the independent variables X1 and X2, and δi is the associated deviation from the regression

$$Y_i = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \delta_i$$

The fitting of the full model was carried out first and then the relative importance of the individual independent variables was determined. A sequential fit was then carried out. The most important variable was fitted first then the second was fitted and so on. The importance of individual variables contributing to pod yield in terminal drought conditions was investigated by using the percentages in the regression sum of squares due to the respective independent variables to the total sum of squares in the sequential fitted analysis.

Relationship of pod yield under field capacity in 2018 and 2019, relationship for the percentage of reduction of pod yield in 2018 and 2019, and the relationship of pod yield under field capacity and percentage reduction of pod yield in two years (2018 and 2019) were plotted graph between the two factors.

Results

Meteorological Conditions

Meteorological data during the trial for the years 2018 and 2019 were presented in **Figure 1.** In the year 2018, the means of minimum and maximum temperatures in this experiment ranged from 9.0 - 27.0 °C and 24.0 - 40.0 °C, respectively whereas relative humidity values ranged from

61.0 to 96.0%. The total of rainfall was 323.4 mm, daily pan evaporation ranged from 2.0 - 8.4 mm and solar radiation ranged from 1.0 – 11.0 MJ/m^{2}day and total 754.3 MJ/m^{2}season. In the year 2019, the means of minimum and maximum temperatures in this experiment ranged from 18.5 - 29.0 °C and 31.0 - 45.8 °C, respectively whereas relative humidity values ranged from 64.0 to 96.0%. The total of rainfall was 118.1 mm, daily pan evaporation ranged from 2.7 - 10.1 mm and the solar radiation ranged from 2.4 – 11.4 MJ/m^{2}day and total 887.9 MJ/m^{2}season.

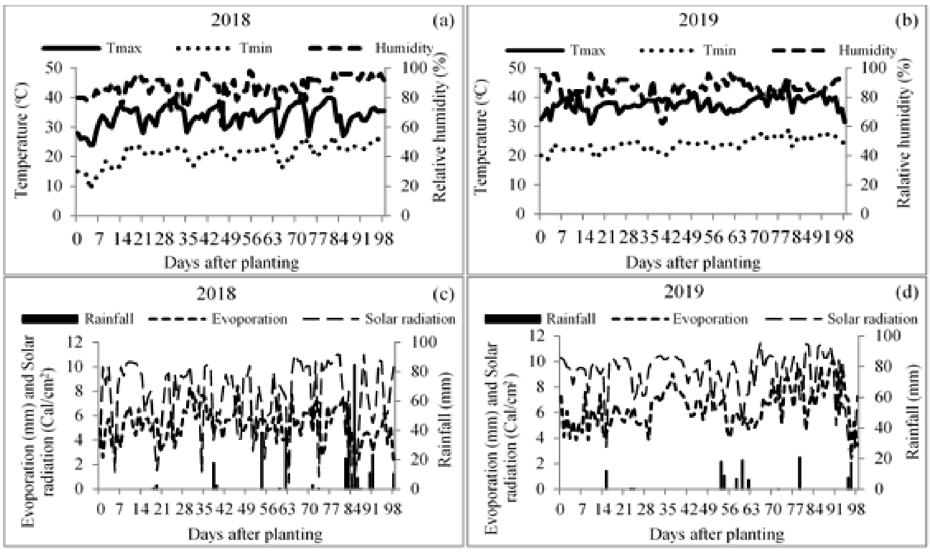

Figure 1 Maximum and minimum air temperatures (°C) (a and b), relative humidity (RH %) (a and b) and rainfall (mm) (c and d) evaporation (mm) (c and d) and solar radiation (c and d) during the crop growth period stage of 10 peanut genotypes grown under full irrigated and 1/3 available water in 2018 (a and c) and in 2019 (b and d)

Soil Moisture Content

At 60 DAP for FC and 1/3 AW, soil moisture content was not a significant difference, whereas, at 75, 90 DAP and final harvest, the soil moisture content in the 1/3 AW at 75 DAP (5.51% in 2018 and 4.83% in 2019) were lower than at FC (9.4% in 2018 and 9.7% in 2019) (**Figure 2**). After 75 DAP, soil moisture content of both treatments was held fairly content until harvest.

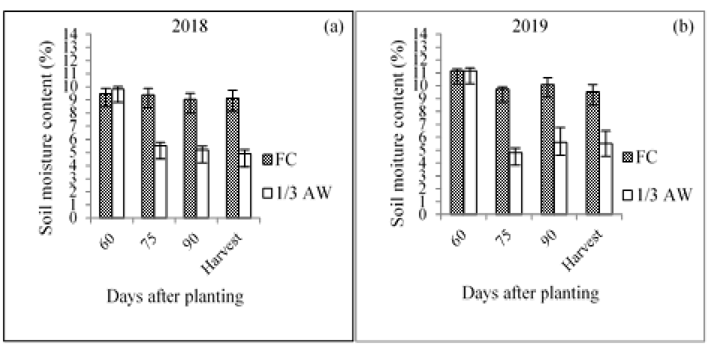

Figure 2 Soil moisture content at the 60, 75, 90 DAP, and harvest under field capacity (FC) and 1/3 available water (1/3 AW) of the year 2018 (a) and 2019 (b)

Relative Water Content (RWC)

At FC and 1/3 AW, RWC was no significant difference at 60 DAP whereas the RWC was different at 75 and 90 DAP. The RWC at 75 DAP was greatly reduced in 1/3 AW (87.44%) plants compare to FC plants (92.95%) in 2018 and 1/3 AW (79.68%) plants compare to FC plants (91.99%) in 2019 (**Figure 3**). The degree of TD was reasonably controlled at the predetermined levels.

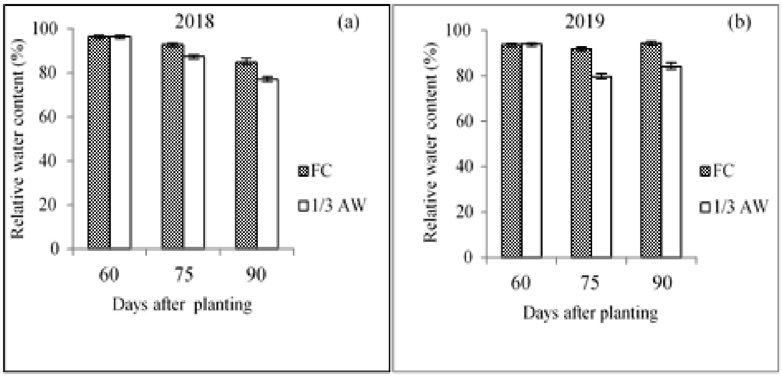

Figure 3 Relative water content at the 60, 75, and 90 DAP of crops grown under field capacity (FC) and 1/3 available water (1/3 AW) of the year 2018 (a) and 2019 (b)

Soil Physical and Chemical Properties

The soil used in this experiment for both years was characterized as a loamy sand soil with a pH of 6.04, Ec of 0.04 dS/m, low organic matter, low nitrogen, low phosphorus, low potassium, and low calcium (**Table 1**)

Table 1 Chemical and physical properties of the soil in pot experiment before application of fertilizer at Field Crop Research Station of Khon Kaen University

Chemical properties							
pH (1:1 H_2O)	EC 1:5 H_2O (dS/m at 25 °C)	Organic Matter (%)	Total N (%)	Available P (mg/kg)	Exchangeable K (mg/kg)	Exchangeable Ca (mg/kg)	CEC [c mol (+)/kg]
6.04	0.04	0.235	0.0227	3.54	22.18	195	3.943

Physical properties					
Particle size			Texture	Soil water holding capacity	
% Sand	% Silt	% Clay	Loamy sand	Permanent wilting point	Field capacity
83.81	10.05	6.15		2.32%	13.00%

Combined Analysis of Variance

The effect of the year (Y), water (W) and genotype (G) were significant for all traits (**Table 2**), whereas the interactions between water and genotype (W×G) were significant for total biomass and shoot dry weight except pod dry weight and HI (**Table 2**). However, the interaction between year and water (Y×W) were significant for all traits except HI. The interaction between year and genotype (Y×G) and the secondary level interaction (Y×W×G) were significant for all traits. Therefore, the data for each year were presented.

Table 2 Mean squares from the combined analyses of variance of total biomass, shoot dry weight, pods dry weight and harvest index of 10 peanut genotypes under field capacity (FC) and 1/3 available water (1/3 AW) at harvest in the year 2018 and 2019

Source of variance	df	Biomass (g/plant)	Shoot dry weight (g/plant)	Pods dry weight (g/plant)	Harvest index
Year (Y)	1	36752.4**	14406.8**	5133.7**	0.02450*
Rep. within Y	6	580.7	243.2	180.4	0.01446
Water regimes (W)	1	30025.2**	6016.4**	9162.9**	0.05184**
Genotypes (G)	9	6220.7**	4691.9**	1026.9**	0.10889**
W*G	9	933.4**	605.1**	384.0^{ns}	0.01757^{ns}
Y*W	1	5598.8**	1920.2**	961.9**	0.00169^{ns}
Y*G	9	1749.7**	1289.3**	1072.1**	0.08333**
Y*W*G	9	1150.4**	412.0**	833.6**	0.04645**
Pooled error	114	4286.8	938.7	3387.0	0.18374

^{ns,*,**} = non-significant and significant difference at P<0.05 and P<0.01, respectively.

Analysis of Variance for Total Biomass, Shoot and Pod Dry Weight and Harvest Index

The year 2018, peanut genotypes and water regimes were significantly different (P<0.01) for total biomass, shoot dry weight, pods dry weight, and HI in the year 2018 (**Table 3**). No significance for the interaction of genotypes by water regimes for all traits except for shoot dry weight was observed. Genotypes by water regimes interaction had less contribution to shoot dry weight in comparison to main effects (**Table 3**), genotypes, and water regimes, therefore the data of main effects of all traits were presented in **Table 4**.

In the year 2019, peanut genotypes and water regimes were significantly different (P<0.01) for total biomass, shoot dry weight, pods dry weight, and HI in the year 2019 (**Table 5**). The interaction of genotypes by water regimes was a significant difference (P<0.01) for total biomass, shoot dry weight, pods dry weight and HI, therefore two ways table was used to present the performance of each genotype in two water regimes (**Table 6**).

Table 3 Mean squares for total biomass, shoot dry weight, pods dry weight and harvest index of 10 peanut genotypes under field capacity (FC) and 1/3 available water (AW) at harvest in 2018

Source of variance	df	Biomass (g/plant)	Shoot dry weight (g/plant)	Pods dry weight (g/plant)	Harvest index
Replication	3	319.99 (3.65)$^{1/}$	130.18 (8.10)	142.56 (3.12)	0.01 (5.78)
Genotype (A)	9	1714.35(19.54)**	629.07 (39.14)**	769.59 (16.84)**	0.05 (23.79)**
Water regimes (B)	1	4846.47 (55.23)**	569.35 (35.43)**	2093.57 (45.80)**	0.04 (16.88)**
A x B	9	347.95 (3.97)^{ns}	71.55 (4.45)*	267.77 (5.86)^{ns}	0.02 (8.26)^{ns}
Error	57	154.96 (17.62)	206.91 (12.87)	1297.49 (28.39)	0.10(45.29)
CV (%)		7.01	4.80	13.78	8.94

^{ns,*,**} = non-significant and significant difference at P<0.05 and P<0.01, respectively.

$^{1/}$ = percentage of a sum of square for a source of variance in parenthesis.

Means of Total Biomass, Shoot and Pod Yield Dry Weight and Harvest Index

In the year 2018, TD decreased all traits, 8.33-25.74% (**Table 4**). ICG10890 and IGGV98324 had the highest total biomass dry weight (80.21 and 79.39 g/plant, respectively) among the highest group, whereas ICG14106 has the lowest total biomass dry weight (66.54 g/plant) (**Table 4**). PI536121, PI365564, and ICGV98324 were among the highest shoot dry weight group (43.58, 42.47, and 42.73 g/plant, respectively), whereas ICG14106 was the lowest shoot dry weight (34.54 g/plant).

For pods dry weight, ICG10890 and KS2 had the highest pod yield (38.38 and 38.76 g/plant, respectively) and ICG6888 had the lowest pods dry weight (29.70 g/plant). ICG10092, ICG14127, and KS2 showed the highest HI (0.491, 0.495, and 0.489, respectively), whereas PI 536121 had the lowest HI (0.425).

The year 2019, ICGV98324 had the highest total biomass dry weight (149.68 g/plant) (**Table 6**), whereas ICG 14106 has the lowest total biomass dry weight (109.05 g/plant) under FC, and ICG10890 had the highest total biomass dry weight (95.89 g/plant), whereas ICG14127, ICG 6888 and ICG14106 had the lowest total biomass dry weight (75.03, 77.28 and 73.06 g/plant, respectively) of among lowest group under TD condition. Under TD, ICGV98324, KS2, ICG6888, and ICG14127 were the highest reduction in biomass (33.61-41.19%) whereas ICG10092 was the lowest reduction of biomass (22.20%).

Table 4 Means of total biomass, shoot dry weight, pods dry weight and harvest index of 10 peanut genotypes under field capacity (FC) and 1/3 available water (1/3 AW) at harvest in the year 2018

Water/Genotypes	Biomass (g/plant)	Shoot dry weight (g/plant)	Pods dry weight (g/plant)	Harvest index
Water regime (B)				
FC	82.07 a	42.33 a	39.74 a	0.48 a
1/3 AW	66.50 b (18.97)[1/]	36.99 b (12.62)	29.51 b (25.74)	0.44 b (8.33)
Genotypes (A)				
ICG10092	73.18 bc	36.89 d	36.29 a-d	0.491 a
ICG10890	80.21 a	41.83 ab	38.38 a	0.470 abc
ICG14127	75.27 ab	37.74 d	37.53 ab	0.495 a
ICG6888	68.07 cd	38.37 cd	29.70 e	0.430 bc
PI536121	76.52 ab	43.58 a	32.94 b-e	0.425 c
ICG8517	69.31 cd	38.33 cd	30.99 de	0.443 bc
ICG14106	66.54 d	34.54 e	32.00 cde	0.474 ab
PI365564	75.52 ab	42.47 a	33.06 b-e	0.435 bc
ICGV98324	79.39 a	42.73 a	36.65 abc	0.464 abc
KS2	78.87 ab	40.11 bc	38.76 a	0.489 a
Mean	74.29	39.66	34.63	0.462
F-test				
A	**	**	**	**
B	**	**	**	**
AxB	ns	*	ns	ns
CV %	7.01	4.80	13.78	8.94

[1/] number in parenthesis = % Reduction = ([1- (weight under terminal drought/ weight under field capacity)] × 100).

[ns,*,**] = non-significant and significant difference at P<0.05 and P<0.01, respective.

PI536121 and ICGV98324 were among the highest shoot dry weight group (84.39 and 88.71 g/plant, respectively), whereas ICG10092, ICG14127, ICG6888, ICG8517, and ICG14106 were among the lowest shoot dry weight group (55.43, 59.02, 60.98, 60.30 and 57.42 g/plant, respectively) under FC. Under TD condition, ICGV98324 has the highest for this trait (59.12 g/plant), whereas ICG 14106 has the lowest for this trait (40.12 g/plant). Under TD,

PI536121, PI365564, and ICGV98324 were the highest reduction in shoot dry weight (33.07-37.00%) whereas ICG8517 was the lowest reduction of shoot dry weight (15.37%).

For pod dry weight, ICG10890 had the highest pod yield (65.01 g/plant), whereas PI536121 had the lowest pod yield (47.17 g/plant) under FC. Yet under TD, ICG10092 had the highest pod yield (43.91 g/plant), and ICG14127, ICGV98324 and KS2 the lowest pod yields (29.12, 28.03 and 29.25 g/plant, respectively). Under TD, ICG14127, ICGV98324, and KS2 had the highest RP (45.67-50.40%) whereas ICG10092, PI531621, and PI365564 had the lowest RP (17.81-24.46%).

ICG10092 and ICG8517 had the highest HI (0.503 and 0.505, respectively) among the highest group and PI536121 the lowest HI (0.358) under FC. Under TD condition, ICG10092 had the highest HI (0.508) and ICGV98324 has the lowest HI (0.323). Under TD, ICG14127, ICGV98324, and KS2 were the highest reduction of HI (17.16-19.62%) whereas ICG6888 and ICG14106 were the lowest reductions of HI (4.23-5.42%). However, some genotypes, ICG10092, PI536121, and PI365564 increased slightly.

Table 5 Mean squares of dry weights of total biomass, shoot, pods, and harvest index of 10 peanut genotypes under field capacity (FC) and 1/3 available water (AW) at harvest in 2019

Source of variance	df	Biomass (g/plant)	Shoot dry weight (g/plant)	Pods dry weight (g/plant)	Harvest index
Replication	3	260.64 (0.62)	113.12 (0.78)	37.89 (0.30)	0.00 (0.00)
Genotype (A)	9	6256.00 (14.98)**	5352.01 (36.89)**	1329.39 (10.69)**	0.14 (46.67)**
Water regimes (B)	1	30778.22 (73.68)**	7366.31 (50.77)**	8031.50 (64.57)**	0.02 (6.67)**
A x B	9	1735.69 (4.16)**	945.44 (6.52)**	949.79 (7.64)**	0.05 (16.67)**
Error	57	2740.50 (6.56)	731.66 (5.04)	2089.42 (16.80)	0.09 (30.00)
CV (%)		6.63	6.11	13.17	8.96

^{ns,*,**} = non-significant and significant difference at P<0.05 and P<0.01, respective.

Table 6 Means of biomass, shoot dry weight, pods dry weights, and harvest index of 10 peanut genotypes under field capacity (FC) and 1/3 available water (1/3 AW) at harvest in the year 2019

Genotypes	Biomass (g/plant)			Shoot dry weight (g/plant)			Pods dry weight (g/plant)			Harvest index		
	FC	1/3 AW	% Red.	FC	1/3 AW	% Red.	FC	1/3 AW	% Red.	FC	1/3 AW	% Red.
ICG10092	112.03 ef	86.75 bc	22.20 d	55.43 d	42.83 de	22.61 cd	56.59 abc	43.91 a	21.45 b	0.503 a	0.508 a	-0.60 ab†‡
ICG10890	137.21 b	95.89 a	29.90 bcd	72.25 bc	54.56 ab	24.45 bcd	65.01 a	41.33 ab	35.72 ab	0.473 ab	0.430 bcd	8.39 a
ICG14127	113.55 ef	75.03 d	33.90 ab	59.02 d	45.91 cd	21.90 cd	54.53 abc	29.12 d	45.67 a	0.478 ab	0.383 cde	19.62 a
ICG6888	117.49 def	77.28 d	33.61 ab	60.98 d	41.87 de	30.91 abc	56.43 abc	35.41 bcd	35.65 ab	0.480 ab	0.458 ab	4.23 a
PI536121	131.56 bc	91.73 ab	30.27 bcd	84.39 a	53.14 b	37.00 a	47.17 c	38.59 abc	17.81 b	0.358 d	0.423 bcd	-18.04 b
ICG8517	121.87 cde	92.94 ab	23.47 cd	60.30 d	50.66 bc	15.37 d	61.57 ab	42.29 ab	31.21 ab	0.505 a	0.455 ab	10.03 a
ICG14106	109.05 f	73.06 d	32.82 abc	57.42 d	40.12 e	29.93 abc	51.63 bc	32.93 cd	36.43 ab	0.473 ab	0.448 abc	5.42 a
PI365564	127.21 bcd	89.23 ab	29.73 bcd	75.80 b	50.70 bc	33.07 ab	51.41 bc	38.52 abc	24.46 b	0.403 cd	0.430 bcd	-7.02 ab
ICGV98324	149.68 a	87.15 bc	41.19 a	88.71 a	59.12 a	33.31 ab	60.96 ab	28.03 d	50.40 a	0.400 cd	0.323 e	17.46 a
KS2	122.50 cde	80.78 cd	33.99 ab	68.04 c	51.48 b	24.24 bcd	54.46 abc	29.25 d	46.01 a	0.445 bc	0.365 de	18.40 a
Mean	124.21	84.98	31.11	68.23	49.04	27.28	55.98	35.94	34.48	0.452	0.422	5.79
CV %	6.31	6.13	19.10	5.46	7.06	23.38	12.29	13.40	37.34	7.56	10.41	14.58

†Means with the same letter in each column of each factor are not significant differences by DMRT at P<0.05.

% Red. = % Reduction = ([1- (weight under terminal drought/ weight under field capacity)] × 100).

‡Mean of each genotype in this column is the original mean and the means separation test was performed on the Log_{10} transformed data.

Factors Contributing to Pod Yield under Drought Condition (1/3 AW)

In the year 2018, regression analysis explained 99.68 of the pod yield under TD (**Table 7**). At 1/3 AW, RP contributed a larger portion of total variation (76.18%), whereas the PP (at FC) contributed a smaller portion of total variation (23.49%).

In the year 2019, the regression analysis explained 99.20% of the total variation of pod yield TD (**Table 7**). At 1/3 AW, the RP contributed a larger portion of the variation of pod yield (96.42%), whereas the PP (at FC) contributed a smaller portion of the variation of pod yield (2.78%).

The overall results of this study indicated that RP under TD was more important than the PP in both years.

Table 7 Contributions of pod yield potential (pod yield at FC) and reduction of pod yield to pod yield at 1/3 AW

Potential of pod yield under FC or Reduction of pod yield under 1/3 AW	Explained by regression (%)	
	2018	2019
Regression	99.68**	99.20**
Potential of pod yield under FC	23.49^{ns}	2.78^{ns}
Reduction of pod yield under 1/3 AW	76.18**	96.42**

FC = Field capacity, AW = available soil water.

^{ns,*,**} = non-significant and significant difference at $P<0.05$ and $P<0.01$, respectively.

Table 8 Mean of total biomass dry weight, shoot dry weight, pods dry weight and harvest index of 10 peanut genotypes under FC and 1/3 AW at harvest in 2018 and 2019

Year	Biomass (g/plant)	Shoot dry weight (g/plant)	Pods dry weight (g/plant)	Harvest index
2018	74.29 b	39.66 b	34.63 b	0.48 a
2019	104.60 a	58.64 a	45.96 a	0.44 b

Means with the same letter in each column of each factor are not significant difference by DMRT at P<0.05

Relationship between pod yield under field capacity in 2018 and 2019 and percentage reduction for pod yield in 2018 and 2019

The relationship between pod yield in 2018 and 2019 under field capacity was presented in **Figure 4**. In 2018, the high potential of pod yield (PP) genotypes was ICG10890, ICG10092, ICG14127, KS2, and PI536121, whereas ICGV98324, ICG8517, ICG6888, ICG14106, and PI365564 had low PP. In 2019, the high PP genotypes were ICG10890, ICG8517, ICGV98324, ICG6888, and ICG10092, whereas ICG14127, KS2, ICG14106, PI365564, and PI536121 had low PP. In both years, ICG10890 and ICG10092 showed the highest PP.whereas ICG14106 and PI365564 had a low PP.

Relationship between percentage for reduction of pod yield in 2018 and 2019

In 2018, the high reduction of pod yield (RP) genotypes was ICG10890, ICG14106, ICG14127, ICG6888, ICG10092, and PI536121 (**Figure 5**), whereas ICGV98324, ICG8517, KS2, and PI365564 had low RP. In 2019, the high RP genotypes were ICG10890, ICG6888, ICGV98324, ICG14127, KS2, and ICG14106, whereas ICG8517, ICG10092, PI365564, and PI536121 had low RP.

In two years, the high RP consistent genotypes were ICG14127, ICG6888, ICG10890, and ICG14106, whereas ICG8517 and PI365564 had low RP (**Figure 5**).

Relationship between pod yield under field capacity and percentage reduction for pod yield

The relationship between pod yield under field capacity and reduction percentage for pod yield could be classified into four groups (**Figure 6**). In 2018, KS2 was classified into the group with high PP and low RP, whereas ICG14127, ICG10890, ICG10092, and PI536121 were classified into the group with high PP and high RP, whereas ICGV98324, KS2, PI365564, and ICG8517 were classified into the group with low PP and low RP, whereas ICG14106 and ICG6888 were classified into the group with low PP and high RP. In 2019, ICG8517 and ICG10092 were classified into the group with high PP and low RP, whereas ICG6888, ICG10890, and ICGV98324 were classified into the group with high PP and high RP. PI536121 and PI365564 were classified into the group with low PP and low RP, whereas ICG14127, ICG14126, and KS2 were classified into the group with low PP and high RP.

In 2018, the high PP and low RP genotypes were KS2, whereas, in 2019, the high PP and low RP consistent genotypes were ICG10092 and ICG8517.

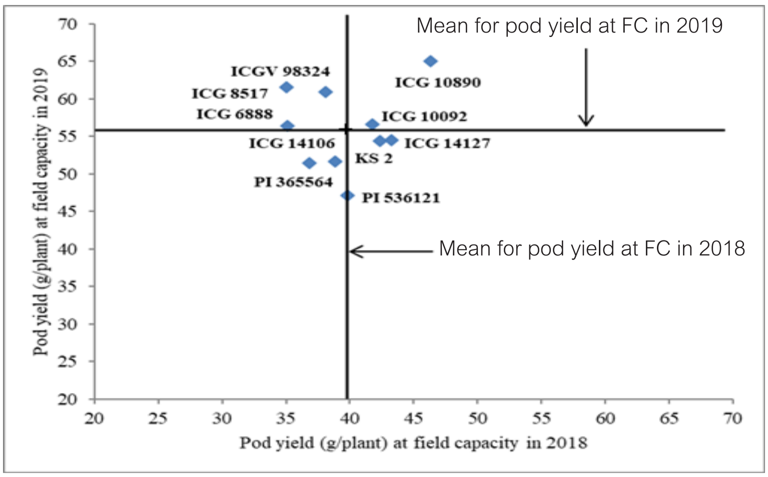

Figure 4 Relation between pod yield under field capacity (FC) of the 10 peanut genotypes in 2018 and 2019

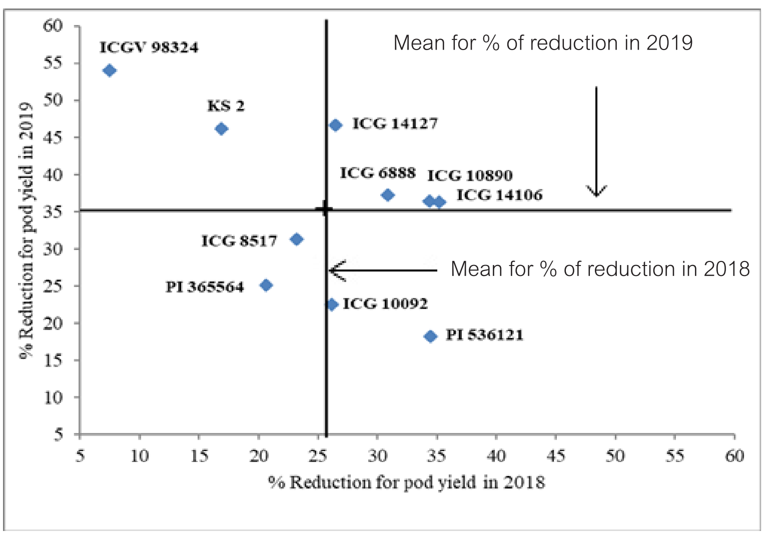

Figure 5 Relation between percentage reduction for pod yield of the 10 peanut genotypes in 2018 and 2019

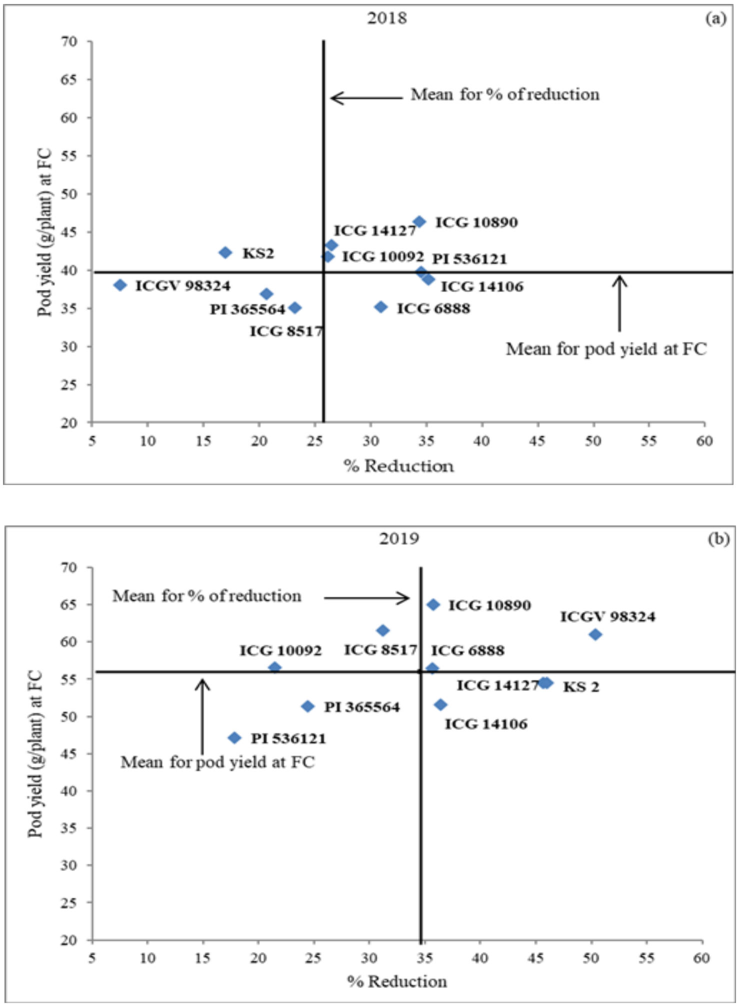

Figure 6 Relation between pod yield under field capacity (FC) and reduction for pod yield of the 10 peanut genotypes 2018 (a) and 2019 (b)

Discussion

The effect of year was significant for total biomass, shoot dry weight, pods dry weight, and harvest index. In general growth and yield in the year, 2019 were higher than obtained growth and yield in the year 2018 excepted HI (**Table 8**). Two weeks after planting the year 2018 the minimum temperature was quite low (9-18 °C). The optimum temperature for vegetative and reproductive growth of peanut was 25-30 °C and 20-25 °C, respectively (Ketring, 1984).

TD is a major factor contributing to biomass production, HI, and yield (16.88-55.23% of total variation) in 2018 (**Table 3**). In the year 2019, in general, the water regimes had a greater contribution to biomass production, HI, and yield (6.67-73.68%) than the year 2018 (**Table 5**). The results supported the previous finding that water restrictive regimes reduced growth, and yield under TD in Virginia and Spanish peanut (Boontang et al., 2010; Junjittakarn et al., 2014) and Valencia peanut (Carvalho et al., 2017; Roy et al., 1988). In contrast to water regimes, in 2018, genotypes had the greatest contribution to growth and yield than those traits in the year 2019. In this study, there were two ways of interaction of genotype x year and water regimes x year. Data of analysis of variance indicated that no significant difference in water regime x genotype interaction was found for the year 2018 however the result of the year 2019, the water regime x genotype interaction was observed. The differences between the results for the two years may be the lower of experimental error in the year 2019. In general, the variation of the interaction of water regime x genotype in both years was quite low in comparison to the variation of the main effect, water regimes, and genotypes.

The year 2018, TD reduced total biomass, shoot dry weight, and pods dry weight (18.9, 12.6, and 25.8%, respectively) (**Table 4**). Year 2019, TD also reduced total biomass (22.2-41.2%), shoot dry weight (15.4-37.0%) and pod dry weight (17.8-50.4%) (**Table 6**). TD reduced growth and yield in the year 2019 more than those obtained in the year 2018 because in the year 2019 had a higher temperature (39-40 °C) during 75-95 DAP, greater evaporation and plants showed the lower relative water content than those plants in the year of 2018. Severe drought and the high temperature was especially considered as key stress factors with higher reduction of peanut yield (Barabás et al., 2008). Previously reported that high temperatures ranged from 35-40 °C for many days causes severe crop losses in peanut (Ketring, 1984).

In a previous TD study, water stress reduced yield by 33.2 to 40.5% in the Valencia peanut genotype (Roy et al., 1988). In another report, TD reduced total biomass, pod yield, and number of mature pod per plant (13.0, 33.2, and 36.5%, respectively) of Valencia peanut genotypes, however the previous report only on the data of one season (Carvalho et al., 2013). For this study, ICGV 98324, a Spanish resistance check, drought reduced total biomass (13.2 and 41.2%, for the year 2018 and 2019, respectively), shoot dry weight (18.7 and 33.3% in the year 2018 and 2019, respectively) and pod yield (7.5 and 50.4% in the year 2018 and 2019, respectively). In yet another study, ICGV 98324 had reduced total biomass (8.10-9.09%) and pod yield (22.34-34.50%) when the crops subjected to water-stressed (Girdthai et al., 2010). The different magnitude of reduction of this study and a previous study (Girdthai et al., 2010) was likely a result of experimental conditions, the pot experiment had more severe stress when compared to the field experiment (Girdthai et al., 2010).

TD decreased biomass production and yield in both years. In previous studies, the period of late flowering, pod formation, and pod filling was more sensitive to moisture and the traits under moisture stress at this period reduced more than stress during periods at early flowering (Roy et al., 1988). These results supported previous findings that pod yield was reduced when peanut was subjected to TD (Junjittakarn et al., 2014; Girdthai et al., 2010).

From the two year results showed that the genotypes with high PP were ICG10890 and ICG10092 (Figure 4) and the low RP genotypes were ICG8517 and PI365564 (Figure 5). In 2018, ICG10890, ICG14127, ICG10092, and KS2 had a high PP (Figure 6). Whereas ICGV98324, KS2, PI365564, and ICG8517 had a low RP. In 2019, ICG10890, ICG8517, ICGV98324, ICG10092, and ICG6888 had high PP, whereas PI536121, ICG10092, PI365564, and ICG8517 had a low RP. Based on, PP and RP performance under drought in both years, Valencia peanut genotypes could be classified into three groups. ICG10890 was classified into the group with high PP and high RP, and PI365564 was classified into the group with low PP and low RP, and ICG14106 was classified into the group with low PP and high RP. From the two year results, the low RP genotypes were PI365564, and ICG8517 whereas the high PP genotypes were ICG10092, and ICG10890.

The year 2018 regression analysis explained 99.68% of the pods yield under TD condition (**Table 7**). At TD, RP contributed a larger portion of total variation (76.18%), whereas the PP (at FC) contributed a smaller portion of total variation (23.49%). Similar results were found in 2019 where the regression analysis explained 99.20% of the total variation of pod yield under TD (**Table 7**). At TD, the RP contributed a larger portion of the variation of pod yield (96.42%), whereas the PP (at FC) contributed a smaller portion for the variation of pod yield (2.78%). The overall results of this study indicated that RP under TD was more important than the PP in both years.

From the previous results of this study, the high PP genotypes should be crossed with the low RP genotypes to generate segregated progenies for a further selection of progenies with high PP and low RP Valencia peanut genotypes for TD environments.

Conclusions

Under TD conditions, total biomass, shoot dry weight, pods dry weight, and HI were reduced. The pod yield under TD was contributed by larger portion RP whereas the PP contributed a smaller portion. From the two year results, the RP genotypes were PI365564, and ICG8517, whereas the high PP genotypes were ICG10092, and ICG10890.

The distinct groups with high PP and low RP could be selected as parental lines and generated progenies in breeding programs aiming to develop peanut genotypes with high PP and low RP under TD.

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