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The Effects of Midseason and Terminal Drought Stress on Morphological, Physiological and Seed Yield Attributes in Groundnut (*Arachis hypogaea L.*) for Malawian Genotypes

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***Abstract*: Groundnuts (Arachis hypogaea L.), is the world's 13th most important food crop, 4th most important source of edible oil and 3rd most important source of vegetable protein. Although, groundnut considered as a profitable venture, its production in African countries such as Malawi where it is grown at small-scale level with less application of modern technologies, still farmers are experiencing a sharp decline in yield. The decline in productivity is caused by several factors where drought due to inadequate and highly variable rainfall has been reported as the major causing factors of low groundnuts productivity. Therefore, developing groundnuts enhanced with drought stress is an inevitable strategy to serve the livelihood of the farmers. Current study aimed to determine the level of drought tolerance among segregating population using agronomical and physiological traits and to identify the effects of drought stress on water use efficiency (WUE) traits. Twenty-five genotypes from the International Crop Research for Semi-Arid Tropics (ICRISAT) were evaluated under glasshouse and field condition at three different levels of drought regimes in a glasshouse and one level at field condition making four drought treatments. The data collected after stress imposition were grain yield (GY), hundred seed weight (HSW), shelling percentage (SHP), SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA) and relative water content (RWC). Drought tolerance index (DTI) and percentage yield reduction (PYR) were calculated to determine the effects of drought on water use efficiency (WUE) traits and performance of the genotypes. Drought treatments affected all traits studied and the magnitude varied significantly where the effects was more severe on 60 days after planting (DAP) followed by 90 DAP and later RD and watered condition. Genotypes also showed different degrees of tolerance where 8 genotypes with high yield and favourable adaptive traits for breeding were selected.**

***Keywords*: drought tolerance, groundnut, moisture stress, morphological traits, physiological traits, yield, water use efficiency.**

1. Introduction

Groundnuts (Arachis hypogaea L.), is known by many local names, including peanut, earthnut, monkey-nut and goobers (MUHAMMAD, 2022). It is the world's 13th most important food crop, 4th most important source of edible oil and 3rd most important source of vegetable protein (Syed et al., 2021). It is cultivated in more than 100 countries in tropical and warm temperate regions of the world (Yenagi and Sugandhi, 2024). Although, groundnut production considered as a profitable venture, the total world production with not increased much (Das et al., 2023). Groundnut in African countries such as Malawi where about 93% it's grown at small-scale level with less application of modern technologies, still farmers are experiencing a sharp decline in yield (Simtowe et al., 2012; Owusu and Bravo-Ureta, 2022).

Although the trend shows that, there has been increase in area planted, however the yields for groundnuts per hectare are still low averaging from 250 – 800kg/ha compared to the yield of about 4 tons/ha obtained at research stations (Kpienbaareh et al., 2022; Bekele et al., 2023). The decline in productivity of groundnuts is due to several abiotic and biotic factors constraints that smallholder farmers encounter. Among the abiotic factors, drought due to inadequate and highly variable rainfall has been reported as the major causing factors of low groundnuts productivity in the country (Minde et al., 2008 and Simtowe, 2009). Irrigation can be a considerable gain to increase groundnut productivity and stabilize the yield in areas prone to drought. However, in Malawi the irrigated land comprises only 0.6% of the total arable land, which is too small to make significant increase in production (Minde et al., 2008). Therefore, developing groundnuts enhanced with drought stress is an inevitable strategy to serve the livelihood of the farmers. The information on response of different genotypes to various patterns of drought stress and the explanation of these variabilities is of an important requirement in breeding programme for drought tolerance groundnut. Previous studied have reported the effects of drought on performance of groundnut at different growth stages (Nautiyal et al., 2002; Sanchez, 2010; Koolachart et al., 2013; Nigam, 2014). However, there is scanty information on genotypic diversity of groundnut under different drought regimes.

Selection of segregating populations under stress condition

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has been a standard approach for developing varieties enhanced with drought stress tolerance (Songsri et al., 2008). However, breeding progress for drought tolerance groundnut based on yield alone as selection criterion has been slow due to large and uncontrollable genotypes x environment interactions (Girdthai et al., 2012; Nigam, 2014). Physiological traits like relative water content (RWC), SPAD chlorophyll meter reading (SCMR) and specific leaf area (SLA) have reported to be rapid and reliable measure to identify genotypes enhanced with high water efficiency in groundnut (Nageswara Rao et al., 2001; Songsri et al., 2008; Painawadee et al., 2009; Nigam, 2014). Wright et al. (1996), Nageswara Rao et al., (2001) and Nigam et al., (2005) reported low genetic x environment (G x E) interactions for SCMR traits suggesting high stability across the environment. In addition, study by Songsri et al. (2008) found that the measurement for SCMR was easier than that of pod yield. This suggest that SPAD chlorophyll meter reading could be used as a rapid, cost effective and simple technique for screening large breeding populations for drought tolerance in groundnut. Therefore, selection approach based on physiological traits would improve the selection efficiency for superior drought tolerance genotypes and supplement the yield-based selection approach. The objectives of the study were to determine the genotypic response for drought tolerance among 25 genotypes of segregating population based on agronomical and physiological traits, and to identify promising genotypes to be used in breeding programs for drought tolerance in groundnut.

2. Material and Method

The study consisted of 25 genotypes of F3 segregating population of groundnut obtained at the international Crop Research Institute for Semi – Arid Tropics (ICRISAT) Center at Chitedze in Lilongwe – Malawi. The selection of the planting materials was based on the differential pedigrees and background of their parents. The genotypes were evaluated under glasshouse and field conditions at three different moisture regimes in a glasshouse (watered, 60 DAP and 90 DAP) and one field condition making four testing drought treatments as described below; -

A. Glasshouse Experiment

The pot experiment was conducted in a glasshouse at the International Crop Research Institute for Semi – Arid Tropics (ICRISAT) Center at Chitedze in Lilongwe – Malawi during 2016/2017 season. The soil type used for pot experiment were sandy–loamy rich in organic matter collected from Chilende forest, 5 km from ICRISAT Center (Latitude: S $13^0$58'46", Longitude: E 33^0 39'24", Altitude of 1103.07 m above sea level). Pots with 32cm in diameter and 25 cm in height were filled with 20 kg of dry soil from bottom to 5 cm below the top to create uniform bulk density. Since soil was collected in the forest with high organic matter, no application of fertilizers was done. Twenty – five progenies with ten parents were planted in a glasshouse pot experiment under randomized complete block design (RCBD) with four replications. Four seeds were planted per pot and the seedlings were thinned to two plants per hill at 14 days after planting (DAP). Pests and diseases were controlled by Nova Tellic Supper 500EC [Pirimophos – methyl, Organophosphate 400g/l, Permethrin (pyrethroid) 100 g/l] emulsifiable concentrate at 2.5 Lha^{-1}.

B. Field Experiment

Field experiment was carried out at Ngabu Agricultural Research Station – Chikwawa region in southern part of Malawi located (34^0 53'43.04" E, 16^0 27'28.89" S), 425 km south of Chitedze ICRISAT Centre. The site laid at an altitude of 110m.a.s.l. It is characterized with warm and dry condition in the lower shire of southern Malawi. The experiment was carried out from December 2016 to June 2017 in a drought-testing site under a natural rainfed condition. The site was dominated by a clay loam–vertisol soil type with pH ($CaCl_2$) of 7.12, Organic carbon (OC) 1.01%, Organic matter (OM) 2.05%, Total N 0.30%, Phosphorus (P) 8.27 ppm, Potassium (K) 1.00 meq/100g, Calcium (Ca) 25.55 meq/100g, Magnesium (Mg) 5.45 meq/100g and Sodium (Na) 0.48 meq/100g. The experiment was laid up in a complete randomized block design with 4 replications. Seeds were sown in plots with four rows of 5 m length, spaced in 70 cm × 15 cm. Two seeds were planted per hill and then seedlings were thinned to one plant per hill at 14 days after emergence. JL 24 groundnut variety was grown around the trial as a guard row to avoid damage and boarder effects. Weather parameters data were collected at meteorological station at Ngabu research station located about 120 m from the experimental site. Recommended agronomic and plant protection measures were performed as suggested by Santos et al. (2006).

C. Soil Moisture regimes

In the glasshouse experiment, three moisture regimes were used including well-watered conditions throughout the season, midseason season drought stress imposed at flowering stage and late season drought stress imposed during seed filling. Initially, water was maintained at field capacity from planting to 30 days after planting (DAP). Stress was induced by withholding water at 30 DAP for midseason drought treatment and was maintained at 1/3 of available water (AW) to 60 DAP, then was water was resumed at FC until harvest. For terminal drought stress treatment, stress was induced at 60 DAP and was maintained at 1/3 AW to 90 DAP then resumed at field capacity (FC) up to harvest as described by Painawadee et al., (2009). In the control treatment, water was kept at field capacity (FC) throughout the season until harvest. Soil moisture content in the soil were determined through the volumetric water content method. Watch Dog 2000 series, (Soil moisture and temperature data loggers), Spectrum technologies, USA, was installed and used to recorded soil moisture content and soil temperature. Probes were installed randomly in the pots for soil moisture and soil temperature and were exchanged into different pots at the interval of each 7 days. Data were uploaded into a computer through data logger weekly. Soil moisture in the pots were maintained based on readings from the soil moisture meter TDR (Time Domain Reflectometry), Field Spectrum Scout, Technology Spectrum, Inc. TDR neutron probes with length of 15cm and 25cm were inserted randomly in different pots and volumetric moisture content measurements were recorded and averaged. Air temperature and relative humidity in the glasshouse were collected using Thermohygrometer, HI 93640N (HANNA Instrument Inc. USA).

D. Data collection

1) Weather parameters data for field and glasshouse experiment

Weather data for field trial were obtained from Ngabu meteorological station about 105 m away from the experimental site and are presented in Table 1 and Figure 1.

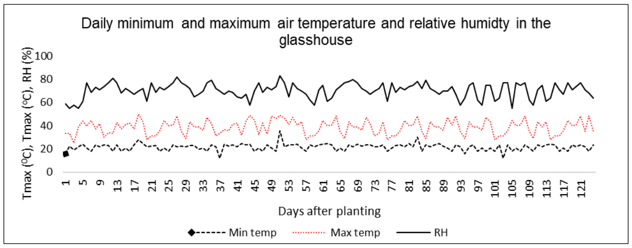

Fig. 1. Daily maximum and minimum air temperature and relative humidity in the glasshouse at ICRISAT – Malawi, during crop season 2016/17

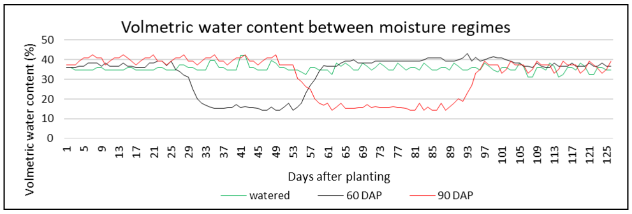

Fig. 2. Volumetric water content under watered, 60 DAP and 90 DAP in the glasshouse experiment during crop season 2016/17 at ICRISAT- Malawi center

There was a maximum rainfall of (25.0 mm) in November, (149.8 mm) in December, (86.3 mm) in January, (119.5 mm) in February, (230.0 mm) in March, (27.8 mm) in April and (10.5 mm) in May. The seasonal mean maximum and minimum air temperature ranged between 36 ^{O}C and 20 ^{O}C in 2016/17. Daily pan evaporation ranged from 6.4 to 97 mm and the seasonal monthly mean solar radiation was ranged 7.5 to 59.6 Mj m-2 d-1 during the crop season. Monthly relative humidity and mean wind speed were 57.9% to 72.97% and 4.33 to 13.3 km/h respectively.

Glasshouse weather parameters for soil moisture content, soil temperature, relative humidity, and air temperature are presented in Figure 1. Average daily minimum and maximum temperature ranged from 21.6 ^{0}C to 36 ^{0}C and 25.5 ^{0}C to 48.9 ^{0}C. Average daily relative humidity in the glasshouse for crop season also ranged between 55 % and 83 %. Volumetric water content of the soil and soil temperature are presented in Figure 1 and Figure 2 respectively.

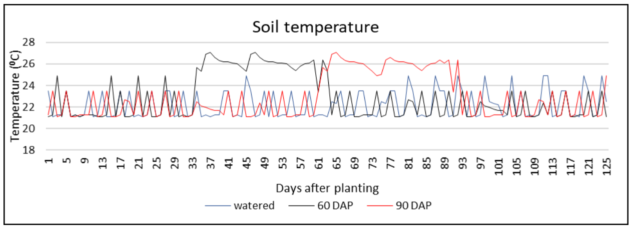

Fig. 3. Glasshouse soil temperature under watered, 60 DAP and 90 DAP drought regimes

2) Agronomical and physiological data

Relative water content **(**RWC) was recorded from four leaflets of the third fully developed groundnut leaf from the top of the main stem. Leaves were harvested and transported to the ARET laboratory, fresh weigh (FW) of the leaf was recorded. The leaf samples then were soaked in distilled water for 8 hours and blotted for surface drying and leaf turgidity weight (TW) was determined. The samples were oven – dried at 80^{0}C until reaching constant weight and leaf dry weight (DW) was determined. Relative water content was determined based on formula suggested by Bajji *et al.,* (2001) as follows.

$$\text{RWC (\%)} = \frac{(\text{FW}-\text{DW})}{(\text{TW}-\text{DW})} \text{ X } 100 \qquad (1)$$

SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA) were recorded at 60 DAP after imposition of stress at a mid – way through stress as suggested by Nigam, (2014). The third leaf from the terminal bud of the main stem was detached and kept in a plastic cooler box. The leaf samples were transferred to a laboratory for further analysis. SCMR was measured by handheld portable SCMR meter (SPAD – 502 Plus, Spectrum Technology, USA) at four leaflets per plant. The leaf samples were then oven – dried at 80^{0}C until reaching constant weight and leaf dry weight was measured for determination of specific leaf area (SLA) which was further calculated based on the equation suggested by Wilson *et al.* (1999).

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

After harvest, selected plants were washed to remove the soil particles followed by separating the sample into roots, stem and

Table 1
Monthly weather data during the field trial at Ngabu, Chikwawa – Malawi in a season of 2016/2017

Year	**Month**	**T max (°c)**	**T min (°c)**	**Wind (km/)h**	**RH (%)**	**SR (Mjm^{-2})**	**Rain (mm)**	**ETo (mm)**
2016	Nov	36.50	24.60	13.3	57.90	E	25.0	E
2016	Dec	35.80	25.37	9.33	64.50	7.50	149.8	28.17
2017	Jan	34.31	24.39	6.67	75.52	59.07	119.5	62.65
2017	Feb	35.21	24.90	5.73	69.625	44.56	86.3	E
2017	March	32.28	23.11	4.33	72.97	37.56	230.0	55.60
2017	April	31.62	21.79	4.60	72.73	59.60	27.8	E
2017	May	31.74	20.18	5.47	68.74	E	10.5	E

Monthly total rainfall, average wind speed, ETo = average evapo - transpiration, RH = average total relative humidity, SR = average total solar radiation, T min = average minimum temperature, T max = average maximum temperature.

reproductive structures for measurement. Reproductive parts were separated into mature and immature pods for counting and weights determination after oven drying. The pod yields were shelled, the grain yield, hundred seed weight and shelling percent were measured. Shelling percentage was calculated based on the following formula as suggested by Painawadee et al., (2009).

$$\text{Shelling percentage} = \frac{\text{Grain yield (g)}}{\text{Total pod yield (g)}} \times 100 \qquad (3)$$

E. Data analysis

Agronomical and physiological data were analyzed separately using the GenStat Version 22 software, VSN, International Ltd (2022). Combined analysis of variance was performed following a test of homogeneity of variances. Pairwise multiple comparisons and separation of means was based on Turkey's procedures (Honestly significant difference test) in GenStat version 22 software. To deduce the impact of drought among genotypes, drought tolerance index (DTI) was calculated based on the following equation used by Painawadee et al., (2009). Percentage yield reduction (PYR) was calculated based on the equation described here below;

DTI = (Yield under stressed condition)/(Yield under non-stressed condition) (4)

PYR = (Yield under normal-Yield under stress)/(Yield under normal condition) x 100 (5)

3. Results

The analysis of variance for agronomical and physiological traits is presented in Table 2. High significant differences for drought treatments were observed for all studied traits. The genotypes also were differed significant differently in all traits. In addition, the genotype by drought treatment interaction were significant differences in all studied traits.

A. Grain Yield Per Plant (GY)

The means for grain yield per plant under different drought regimes are presented in Table 3. The results showed that the means for grain yield per plant were significantly lower in both 60 DAP (11.51) and 90 DAP (11.37) compared to watered (12.39) and RD (12.41). Under watered condition, genotype ICGV – SM 14078 reordered the highest GY (19.48), followed by ICGV – SM 14081 (18.61), ICGV – SM 14098 (17.85) and ICGV – SM 14101 (17.69). While low GY for this regime was observed for genotypes ICGV – SM 14050 (9.1), ICGV – SM 14052 (9.33) and ICGV – SM 14088 (9.33). Under 60 DAP drought regimes, genotypes ICGV – SM 14098 (17.96), ICGV – SM 14073 (17.66), ICGV – SM 14101 (17.34), ICGV – SM 14081 (16.56) and ICGV – SM 14078 (16.47) scored the highest significantly for grain yield (GY). The less significant mean GY under this moisture regime was noted for genotypes ICGV – SM 14091 (7.71) and ICGV – SM 14047 (7.84). Significant high GY under 90 DAP was observed for genotypes ICGV – SM 14101 (18.49) and ICGV – SM 14060 (18.73) whereas significant low GY under this moisture regime showed by genotype ICGV – SM 14047 (5.67) and ICGV – SM 14050 (7.73). Except for the high and less performing genotypes, the rest were exhibited significant moderate mean GY in all drought moisture regimes.

B. Hundred Seed Weight (HSW)

Hundred seed weight (HSW) was lower in both 60 DAP (44.47) and 90 DAP (44.26), however the mean HSW for RD (48.72) was high compared with watered (47.33) moisture regime (Table 3). Genotype ICGV – SM 14081, ICGV – SM 14101 and ICGV – SM 14098 were recorded high HSW 61.88, 59.13 and 58.61 respectively under watered regime. Genotypes namely ICGV – SM 14046 (36.6), ICGV – SM 14052 (28.38) and ICGV – SM 14083 (34.68) recorded significantly lower HSW than other genotypes under this regime. Under 60 DAP drought regime, significantly high HSW was showed by ICGV – SM 14075 (61.77) and ICGV – SM 14101 (55.13) whereas ICGV – SM 14052 (28.2) and ICGV – SM 14046 (36.82) scored significantly lower HSW compared with other genotypes. At 90 DAP; ICGV – SM 14055 and ICGV – SM 14081 intercepted a maximum HSW of 57.65 and 57.57 respectively. Genotype ICGV – SM 14052 (30.3) and ICGV – SM 14046 (32.75) were the least performing genotypes under this regime. The high significant mean performance for HSW under random drought (RD) was exhibited by genotype ICGV – SM 14075 (60.46) and ICGV – SM 14101 (60.4) whereas ICGV – SM 140452 (27.67), ICGV – SM 14050 (36.05) and ICGV – SM 14053 (37.6) scored a least HSW for this drought regime.

C. SPAD Chlorophyll Meter Reading (SCMR)

The means for SPAD chlorophyll under 60 DAP was significant lower (38.68) than that of either drought regime (Table 4). The highest significant mean for SCMR was observed under watered condition (50.77) whereas 90 DAP (44.74) and RD (44.86) were moderate and did not differ significantly from each other. The least significant mean for SPAD chlorophyll meter reading (SCMR) was recorded under 60 DAP (38.68). Genotypes ICGX-SM 14101 and ICGX-SM 14100 recorded high significant SCMR under watered

Table 2
Combined analysis of variances for water use efficiency traits under different drought regimes

SOV	DF	GY	SHP	HSW	SCMR	SLA	RWC
REP	3	1.26	7.55	3.285	0.243	64.87	3.932
GENOTYPE	24	177.925***	139.54***	787.954***	312.63***	2538.32***	376.247***
TREATM	3	20.533***	182.7***	302.88***	2460.58***	16317.52***	5258.975***
GEN.TREAT	72	9.944***	90.88***	54.55***	45.821***	588.3***	141.237***
ERROR	297	1.76	31.45	1.499	1.356	35.75	4.906

*, **, *** significant at 0.05, 0.01 and 0.001 level respectively

DF = Degree of freedom, SOV = Source of variation, GY = Grain yield, SHP = Shelling percentage, HSW = Hundred seed weight, SCMR = SPAD chlorophyll meter reading, SLA = Specific leaf area, RWC = Relative water content, REP = Replication, GEN = Genotype and TREAT = Treatment.

Table 3
Means of grain yield and hundred seed weight for 25 groundnut genotypes measured under 4 drought moisture regimes

Genotype	**Grain yield per plant (g)**				**Hundred seed weight (g)**			
	Watered	**60 DAP**	**90 DAP**	**RD**	**Watered**	**60 DAP**	**90 DAP**	**RD**
ICGX-SM 14046	10.71 ab	7.84 a	7.99 abc	4.91 a	36.6 b	36.82 b	32.75 ab	38.3 abcd
ICGX-SM 14047	10.06 ab	8.93 ab	5.67 a	8.34 ab	47.55 gh	44.77 efg	42.65 fg	38.33 abcd
ICGX-SM 14050	9.1 a	9.38 ab	7.73 ab	8.86 ab	40.89 cd	37.65 bc	40.47 def	36.05 ab
ICGX-SM 14052	9.33 a	8.36 ab	10.4 bcde	10.29 ab	28.38 a	28.4 a	30.3 a	27.67 a
ICGX-SM 14053	9.4 ab	9.12 ab	9.95 bcde	8.65 ab	47.63 gh	41.18 cde	40.95 ef	37.6 abc
ICGX-SM 14054	9.73 ab	10.67 abc	10.25 bcde	8.02 ab	47.98 gh	44 defg	41.8 fg	45.95 bcdef
ICGX-SM 14055	11.35 abc	10.36 ab	9.71 bcde	10.39 ab	52.83 ij	47.63 gh	57.65 m	56.67 ef
ICGX-SM 14057	15.68 cde	14.18 cd	10.97 bcde	8.9 ab	42.6 de	40.9 bcde	46.65 hi	49.34 bcdef
ICGX-SM 14059	11.1 ab	10.07 ab	8.37 abcd	9.36 ab	44.13 ef	41.86 cdef	34.97 bc	52 cdef
ICGX-SM 14060	17.58 de	11.01 abc	18.73 h	13 bc	51.33 i	41.18 cde	37.42 cd	52.38 def
ICGX-SM 14073	13.71 bcd	17.66 de	11.56 def	21.2 d	50.63 i	47.65 gh	54.25 l	53.67 ef
ICGX-SM 14075	12.9 abc	15.47 de	12.55 ef	18.59 cd	51.43 i	61.77 j	55.12 lm	60.46 f
ICGX-SM 14078	19.48 e	16.47 de	17.26 gh	18.57 cd	55.35 k	53.15 i	54.49 lm	51.48 cdef
ICGX-SM 14080	10.72 ab	9.73 ab	9.5 bcde	9.27 ab	44.65 ef	42.25 def	49.45 ij	53.95 ef
ICGX-SM 14081	18.61 e	16.56 de	16.82 gh	23.71 d	61.88 m	53.98 i	57.57 m	57.85 ef
ICGX-SM 14083	9.69 ab	11.49 bc	8.61 abcd	8.72 ab	34.68 b	37.88 bc	33.92 b	47.4 bcdef
ICGX-SM 14085	10.13 ab	8.66 ab	8.92 abcd	18.76 cd	40.33 c	39.82 bcd	44.48 gh	47.05 bcdef
ICGX-SM 14088	9.33 a	9.76 ab	11.33 cde	9.97 ab	41.6 cd	40.87 bcde	40.32 def	54.6 ef
ICGX-SM 14090	9.56 ab	9.01 ab	8.45 abcd	9.39 ab	45.75 fg	42.38 def	38.05 cde	44.94 bcde
ICGX-SM 14091	11.11 ab	7.71 a	9.6 bcde	8.43 ab	50.75 i	45.55 fg	42.92 fg	50 bcdef
ICGX-SM 14093	11.2 ab	10.45 ab	10.1 bcde	8.31 ab	48.33 h	44.08 defg	33.58 b	47.45 bcdef
ICGX-SM 14095	13.16 abc	10.78 abc	14.91 fg	12.32 bc	54.43 jk	47.79 gh	53.15 kl	52.45 def
ICGX-SM 14098	17.85 de	17.96 e	17.03 gh	18.69 cd	58.6 l	51.12 hi	48.6 ij	53.15 ef
ICGX-SM 14100	10.61 ab	8.76 ab	9.19 bcde	11.42 ab	45.83 fg	43.95 defg	44.85 gh	48.8 bcdef
ICGX-SM 14101	17.69 de	17.34 de	18.49 h	22.32 d	59.13 l	55.13 i	50.1 jk	60.4 f
MEAN	**12.39**	**11.51**	**11.37**	**12.41**	**47.329**	**44.47**	**44.26**	**48.72**
CV	**130**	**11.70**	**11.10**	**20.90**	**1.80**	**3.60**	**2.70**	**11.10**
se	**1.143**	**0.955**	**0.892**	**1.832**	**0.595**	**1.136**	**0.838**	**3.817**
LSD	**2.278**	**1.903**	**1.779**	**3.652**	**1.186**	**2.264**	**1.67**	**7.609**

condition of 64.33 and 60 respectively whereas genotypes ICGX-SM 14085 (41.2), ICGX-SM 14083 (41.4) and ICGX-SM 14046 (42.58) scored significant lower SCMR under watered condition. Under 60 DAP drought regime, high significant mean for SCMR were exhibited by genotype ICGX-SM 14100 (52.6) and ICGX-SM 14098 (50.7) whereas ICGX-SM 14046 (29.82) and ICGX-SM 14047 (30.22) were the least performing genotypes under this regime. High mean under 90 DAP regime was showed by ICGX-SM 14101 (51.3) and ICGX-SM 14095 (51.78) while the lowest SCMR was intercepted by genotypes ICGX-SM 14046 (37.48), ICGX-SM 14047 (38.7) and ICGX-SM 14050 (39.28). Genotype ICGX-SM 14101 recorded the maximum SCMR (59.65) under RD regime though the least significant mean was observed for genotype ICGX-SM 14047 (36.48). Other genotypes were significantly different however were moderate through all drought regimes.

D. Shelling Percentage (SHP)

Mean shelling percentage (SHP) under watered condition was significantly high (71.02) followed by Random drought (69.00) and 68.49 for 90 DAP. Shelling percentage was significantly lower (67.94) under 60 DAP compared with any drought regime. The highest performing genotypes for shelling percentage (SHP) under watered regime were ICGX-SM 14046 (80.18) and ICGX-SM 14060 (81.22) whereas ICGX-SM 14083 (62.46) was the only least performing genotype under this regime. Among 25 genotypes evaluated under 60 DAP regime, only ICGX-SM 14101 (76.98) was the highest performing genotype while ICGX-SM 14053 (59.7) recorded significant lower value for SHP. Except for ICGX-SM 14060 (78.08), genotype ICGX-SM 14100 (59.8), ICGX-SM 14046 (60.54) and ICGX-SM 14053 (60.9) were the least performing genotype under 90 DAP drought regime. High statistical difference for shelling percentage under random drought (RD) was shown by ICGX-SM 14101 (78.97), ICGX-SM 14073 (78.98), ICGX-SM 14081 (78.57) and ICGX-SM 14098 (76.86) whereas ICGX-SM 14057 (57.47), ICGX-SM 14080 (59.49) and ICGX-SM 14088 (59.88) were the least performing genotypes under this moisture regime. Apart from the mentioned genotypes, other genotypes were performed moderately and did not differ significantly from each other.

E. Specific Leaf Area (SLA)

The means for specific leaf area (SLA) under watered drought regime were significant high (50.77) than that of either drought regime (Table 5). Mean SLA under 60 DAP was significant lower (38.68) compared with that of any regime. SLA for both 90 DAP and RD regime were 44.74 and 44.86 respectively and did not differ significantly from each other. Significantly, ICGX-SM 14101 (64.33) and ICGX-SM 14100 (60.0) intercepted high SLA under watered regime whereas genotype ICGX-SM 14085 (41.2), ICGX-SM 14083 (41.4) and ICGX-SM 14046 (42.58) were the least performing genotypes. ICGX-SM 14100 (52.6) and ICGX-SM 14098 (50.7) were the high performing genotypes under 60 DAP drought regime while the least performing genotypes under this regime were ICGX-SM 14046 (29.82) and ICGX-SM 14047 (30.22). Genotypes ICGX-SM 14095 and ICGX-SM 14101 showed consistently high SLA under both 90 DAP and RD drought regimes. On the other hand, ICGX-SM 14046 (37.48), ICGX-SM 14047 (38.7), ICGX-SM 14050 (39.28) under 90 DAP and ICGX-SM 14047 (36.48) under random drought (RD) drought regime recorded significant lower SLA. Further genotypes were

Table 4
Means of SPAD chlorophyll content and shelling percentage for 25 genotypes at under 4 drought regimes

Genotype	SCMR				SHP (%)			
	watered	**60 DAP**	**90 DAP**	**RD**	**watered**	**60DAP**	**90 DAP**	**RD**
ICGX-SM 14046	42.58 ab	29.82 a	37.48 a	39.75 ab	80.18 b	60.88 ab	60.54 a	62.89 abcd
ICGX-SM 14047	43.7 bc	30.22 ab	38.7 ab	36.48 a	70.44 ab	72.88 ab	65.1 ab	73.19 abcd
ICGX-SM 14050	50.1 fg	30.62 abc	39.28 ab	38.55 ab	68.45 ab	61.49 ab	69.65 ab	72.13 abcd
ICGX-SM 14052	43.6 abc	30.32 abc	40.53 bc	42.78 ab	66.51 ab	71.53 ab	71.51 ab	70.79 abcd
ICGX-SM 14053	51.98 ghi	39.2 ghij	42.98 cdef	43.58 ab	74.5 ab	59.7 a	60.9 a	69.71 abcd
ICGX-SM 14054	48.65 ef	31.9 abcd	41.23 bcd	39.7 ab	70.66 ab	68.73 ab	63.39 ab	71.19 abcd
ICGX-SM 14055	54.3 ijk	34.02 bcde	41.23 bcd	38.58 ab	76.87 ab	65.12 ab	73.69 ab	63.59 abcd
ICGX-SM 14057	54.1 ijk	34.07 bcdef	42 cde	45.3 ab	71.94 ab	70.3 ab	66.31 ab	57.47 a
ICGX-SM 14059	55.1 jk	34.32 cdef	42.5 cde	38.38 ab	68.64 ab	60.38 ab	69.22 ab	65.35 abcd
ICGX-SM 14060	57.63 lm	40.12 hij	46.98 ij	44.9 ab	81.22 b	63.86 ab	78.08 b	71.57 abcd
ICGX-SM 14073	53 hij	35.4 defg	42.98 cdef	44.8 ab	65.2 ab	75.15 ab	65.24 ab	78.98 d
ICGX-SM 14075	45.78 cd	36.77 efghi	43.55 defg	44.55 ab	64.88 ab	73.32 ab	68.36 ab	74.25 bcd
ICGX-SM 14078	55.48 kl	38.1 fghij	43.88 defg	42.7 ab	75 ab	69.31 ab	70.9 ab	75.08 bcd
ICGX-SM 14080	46.4 de	38.52 ghij	44.25 efgh	43.88 ab	72.1 ab	70.13 ab	70.44 ab	59.46 ab
ICGX-SM 14081	55.73 kl	41.6 jk	46.75 hij	47.6 abc	73.81 ab	68.84 ab	71.06 ab	78.57 cd
ICGX-SM 14083	41.4 ab	40.32 hij	45.68 fghi	42.85 ab	62.46 a	69.1 ab	67.7 ab	61.81 abc
ICGX-SM 14085	41.2 a	40.65 ij	45.7 ghi	46.1 ab	65.44 ab	65.11 ab	64.2 ab	64.52 abcd
ICGX-SM 14088	43.33 abc	40.65 ij	45.83 ghi	46.13 ab	64.49 ab	62.44 ab	69.45 ab	59.58 ab
ICGX-SM 14090	50.7 fgh	41.37 j	46.15 ghij	46.1 ab	74.97 ab	69.31 ab	71.82 ab	64.33 abcd
ICGX-SM 14091	49.63 fg	46.12 l	48 ijk	50.75 bc	68.64 ab	66.93 ab	63.91 ab	67.62 abcd
ICGX-SM 14093	54.55 jk	45.62 kl	48.58 jkl	47.25 abc	68.53 ab	70.19 ab	70.44 ab	72.25 abcd
ICGX-SM 14095	54.05 ijk	47.55 lm	51.78 m	51.63 bc	67.42 ab	64.22 ab	74.74 ab	66.47 abcd
ICGX-SM 14098	52 ghi	50.7 mn	50.85 lm	50.63 bc	72.57 ab	76.1 ab	71.61 ab	76.86 cd
ICGX-SM 14100	60 m	52.6 n	50.25 klm	48.95 abc	71.16 ab	66.48 ab	59.8 a	68.29 abcd
ICGX-SM 14101	64.33 n	36.45 efgh	51.3 m	59.65 c	79.46 ab	76.98 b	74.32 ab	78.97 d
MEAN	**50.77**	**38.68**	**44.74**	**44.86**	**71.02**	**67.94**	**68.49**	**69.00**
CV	**1.80**	**3.90**	**2.30**	**11.00**	**9.10**	**9.40**	**8.50**	**9.00**
se	**0.649**	**1.067**	**0.714**	**3.513**	**4.571**	**4.54**	**4.112**	**4.408**
LSD	**1.294**	**2.128**	**1.424**	**7.002**	**9.111**	**9.05**	**8.198**	**8.787**

recorded moderate SLA across the four drought treatments.

F. Relative Water Content (RWC)

All the four drought treatments differed significantly from each other and the mean RWC were significant high under watered condition (85.3) followed by RD (81.58) and 90 DAP (74.71). Mean RWC under 60 DAP drought regime was significantly lesser (68.93) as compared to other regimes. Overall, ICGX-SM 14098, ICGX-SM 14088 and ICGX-SM 14060 exhibited significant high RWC under watered condition. Significant high relative water content (RWC) under 60 DAP drought regime showed up by ICGX-SM 14081 (81.12) and ICGX-SM 14078 (80.91). Genotypes ICGX-SM 14098 and ICGX-SM 14081 under both 90 DAP and RD drought regimes maintained high RWC (86.83 and 87.1) and (82.79 and 87.37) respectively. The least significant RWC was shown by ICGX-SM 14073 (52.56), ICGX-SM 14090 (52.71), ICGX-SM 14080 (55.59) and ICGX-SM 14091 (55.86) for 60 DAP and ICGX-SM 14053 (46.46) and ICGX-SM 14090 (57.16) for 90 DAP drought regime. Additionally, genotypes ICGX-SM 14046 and ICGX-SM 14080 were the less performing genotypes under random drought (RD) as evidence from its significant lower RWC recorded. The former genotypes displayed significant relative water content (RWC) however, the performance was within the range between the high and the least performing genotypes.

G. Drought Tolerance Index (DTI) for Yield

The drought tolerance index (DTI) for yield is presented only under 60 DAP and 90 DAP drought regimes (Table 6). Drought tolerance index was varied significantly among genotypes and drought regimes. Drought tolerance index ranged from 0.63 to 1.29 under 60 DAP and 0.53 to 1.21 under 90 DAP drought regime. Under 60 DAP regime, high drought tolerance index was observed for genotype ICGX-SM 14073 (1.29), ICGX-SM 14075 (1.20), ICGX-SM 14083 (1.19), ICGX-SM 14054 (1.10), ICGX-SM 14088 (1.05), ICGX-SM 14050 (1.03) and ICGX-SM 14098 (1.01). Under 90 DAP drought regime, high drought tolerance index exhibited by genotypes ICGX-SM 14088 (1.21), ICGX-SM 14095 (1.13), ICGX-SM 14052 (1.11), ICGX-SM 14090 (1.07), ICGX-SM 14053 (1.06), ICGX-SM 14054 (1.05), ICGX-SM 140101 (1.05) and ICGX-SM 14075 (0.97). For 60 DAP drought regime, low drought tolerant index was shown by ICGX-SM 14060 (0.63), ICGX-SM 14091 (0.69) and ICGX-SM 14046 (0.73) whereas under 90 DAP regime, genotypes ICGX-SM 14047 (0.56), ICGX-SM 14057 (0.70), ICGX-SM 14059 (0.75) and ICGX-SM 14046 (0.75). Apart from high and low DTI exhibited by the presented genotypes above, the rest showed a moderate drought tolerance index.

H. Percentage Reduction in Yield

The percentage yield reduction among 25 genotypes evaluated under different drought regimes are presented in Table 6. The results indicated that genotypes were performed differently within and between drought regimes. The overall average mean for percentage yield reduction showed that drought stress had more severe impact under 60 DAP regime and at 90 DAP drought regime. High significant average percentage yield reduction of 6.47 was observed under 60 DAP as compared to 8.47 noted under 90 DAP drought regime. Under 60 DAP regime, genotypes with less percent yield reduction and high yield potential were ICGX-SM 14073 (-28.81), ICGX-SM 14075 (-19.92), ICGX-SM 14083 (-18.58),

Table 5
Means of specific leaf area and relative water content for 25 genotypes under 4 drought moisture regimes

Genotype	Specific leaf area (cm^2/g)				Relative water content (%)			
	Watered	**60D AP**	**90 DAP**	**RD**	**Watered**	**60 DAP**	**90 DAP**	**RD**
ICGX-SM 14046	178.5 ghijk	148.1 bcdef	120.3 ab	140.1 bcdef	84.14 abcde	72.91 def	73.5 cde	75.64 a
ICGX-SM 14047	167.1 defg	157.4 defghi	150.1 fghij	142.5 bcdefg	81.49 ab	57.6 ab	77.3 defghi	82.86 abcd
ICGX-SM 14050	162.5 cdef	137.3 ab	144.2 defgh	153.7 cdefgh	82.75 abcd	63.94 c	76.96 defghi	85.83 cd
ICGX-SM 14052	170 defgh	137.3 ab	151 fghij	139.9 bcdef	82.31 abc	58.12 ab	77.85 efghi	80.38 abcd
ICGX-SM 14053	166.6 defg	166.1 ghi	152.3 ghijk	130.6 abc	86.06 bcdef	74.37 efg	46.46 a	78.76 abc
ICGX-SM 14054	177.2 ghij	137.8 ab	132.9 bcde	139.5 bcde	84.71 abcde	63.13 bc	69.69 c	79.54 abcd
ICGX-SM 14055	148 ab	137.6 ab	147.3 efghij	139.3 abcde	80.31 a	72.06 de	74.45 cde	78.98 abcd
ICGX-SM 14057	157.8 abcd	144.8 bcde	135.5 bcdef	171.1 fgh	86.31 bcdef	63.23 bc	78.2 efghi	81.39 abcd
ICGX-SM 14059	188.6 jklm	164.9 fghi	168.2 klmno	158.9 cdefgh	83.02 abcd	73.15 def	76.42 defg	81.14 abcd
ICGX-SM 14060	191.9 lm	169.3 hi	174.1 mno	162.8 defgh	90.42 fg	76.75 efgh	81.41 ghij	85.44 bcd
ICGX-SM 14073	145.5 a	148.2 bcdef	124.9 abc	136.2 abcde	81.22 ab	52.56 a	74.85 cdef	81.12 abcd
ICGX-SM 14075	197.3 m	161.2 defghi	176.6 no	133.9 abcd	86.86 cdef	75.6 efgh	80.63 fghi	85.29 bcd
ICGX-SM 14078	158.4 bcde	134.1 ab	131.1 bcd	151.7 cdefgh	88.56 efg	80.91 h	82.72 hij	86.03 cd
ICGX-SM 14080	169.5 defgh	158.7 defghi	135.9 bcdef	119.7 ab	86.13 bcdef	55.59 a	76.25 defg	77.13 ab
ICGX-SM 14081	176.4 ghij	155.3 cdefgh	139.3 cdefg	108.1 a	85.49 bcdef	81.12 h	82.79 ij	87.37 d
ICGX-SM 14083	153.4 abc	149.4 bcdefg	111.3 a	143.4 bcdefg	84.19 abcde	73.82 efg	76.17 defg	80.25 abcd
ICGX-SM 14085	181.8 hijkl	146.2 bcde	126.7 abc	137.3 abcde	82.92 abcd	71.29 de	51.86 ab	78.82 abc
ICGX-SM 14088	172.4 fghi	127 a	155.4 ghijkl	147.9 bcdefg	93.61 gh	74.21 efg	77.36 defghi	79.33 abcd
ICGX-SM 14090	184.2 ijkl	139.8 abc	161.5 jklmn	165.8 efgh	81.25 ab	52.71 a	57.16 b	82.42 abcd
ICGX-SM 14091	162.6 cdef	149.1 bcdef	152.6 ghijkl	156.2 cdefgh	82.26 abc	55.86 a	77.17 defghi	78.76 abc
ICGX-SM 14093	170.4 efgh	144.6 bcd	144.3 defghi	158.4 cdefgh	82.88 abcd	73.43 defg	76.9 defgh	78.71 abc
ICGX-SM 14095	191.4 lm	166.5 hi	160.4 ijklm	173.6 gh	87.19 cdef	76.06 efgh	81.41 ghij	80.87 abcd
ICGX-SM 14098	190 klm	161.5 efghi	157.3 hijkl	163.5 defgh	95.99 h	77.92 fgh	86.83 j	87.1 cd
ICGX-SM 14100	191.1 lm	173.3 i	168.8 lmno	179.5 h	84.95 abcde	67.76 cd	71.54 cd	80.95 abcd
ICGX-SM 14101	183.8 ijkl	158.9 defghi	178.9 o	163.8 defgh	87.47 def	79.06 gh	81.94 ghij	85.48 bcd
MEAN	**173.46**	**150.97**	**148.04**	**148.69**	**85.3**	**68.93**	**74.71**	**81.58**
CV	**2.70**	**4.20**	**4.00**	**7.80**	**2.20**	**3.10**	**2.90**	**3.90**
se	**3.298**	**4.451**	**8.451**	**8.226**	**1.339**	**1.511**	**1.542**	**2.228**
LSD	**6.575**	**8.873**	**8.451**	**16.398**	**2.67**	**3.012**	**3.074**	**4.441**

Table 6
Drought tolerance index and percentage yield reduction for 25 genotypes measured under 4 drought regimes

Genotype	Mean yield (g/plant)			Drought tolerance index		Percentage yield reduction (%)	
	Watered	**60 DAP**	**90 DAP**	**60 DAP**	**90 DAP**	**60 DAP**	**90 DAP**
ICGX-SM 14046	10.71	7.84	7.99	0.73	0.75	26.80	25.40
ICGX-SM 14047	10.06	8.93	5.67	0.89	0.56	11.23	43.64
ICGX-SM 14050	9.10	9.38	7.73	1.03	0.85	-3.08	15.05
ICGX-SM 14052	9.33	8.36	10.40	0.90	1.11	10.40	-11.47
ICGX-SM 14053	9.40	9.12	9.95	0.97	1.06	2.98	-5.85
ICGX-SM 14054	9.73	10.67	10.25	1.10	1.05	-9.66	-5.34
ICGX-SM 14055	11.35	10.36	9.71	0.91	0.86	8.72	14.45
ICGX-SM 14057	15.68	14.18	10.97	0.90	0.70	9.57	30.04
ICGX-SM 14059	11.10	10.07	8.37	0.91	0.75	9.28	24.59
ICGX-SM 14060	17.58	11.01	18.73	0.63	1.07	37.37	-6.54
ICGX-SM 14073	13.71	17.66	11.56	1.29	0.84	-28.81	15.68
ICGX-SM 14075	12.9	15.47	12.55	1.20	0.97	-19.92	2.71
ICGX-SM 14078	19.48	16.47	17.26	0.85	0.89	15.45	11.40
ICGX-SM 14080	10.72	9.73	9.50	0.91	0.89	9.24	11.38
ICGX-SM 14081	18.61	16.56	16.82	0.89	0.90	11.02	9.62
ICGX-SM 14083	9.69	11.49	8.61	1.19	0.89	-18.58	11.15
ICGX-SM 14085	10.13	8.66	8.92	0.85	0.88	14.51	11.94
ICGX-SM 14088	9.33	9.76	11.33	1.05	1.21	-4.61	-21.44
ICGX-SM 14090	9.56	9.01	8.45	0.94	0.88	5.75	11.61
ICGX-SM 14091	11.11	7.71	9.60	0.69	0.86	30.60	13.59
ICGX-SM 14093	11.20	10.45	10.10	0.93	0.90	6.70	9.82
ICGX-SM 14095	13.16	10.78	14.91	0.82	1.13	18.09	-13.30
ICGX-SM 14098	17.85	17.96	17.03	1.01	0.95	-0.62	4.59
ICGX-SM 14100	10.61	8.76	9.19	0.83	0.87	17.44	13.38
ICGX-SM 14101	17.69	17.34	18.49	0.98	1.05	1.98	-4.52
Mean	**12.39**	**11.51**	**11.37**	**0.94**	**0.92**	**6.47**	**8.47**

ICGX-SM 14054 (-9.66), ICGX-SM 14098 (-0.62), ICGX-SM 14088 (-4.61), ICGX-SM 14050 (-3.08) and ICGX-SM 14101 (1.98). Genotypes ICGX-SM 14060 (37.37), ICGX-SM 14091 (30.60) and ICGX-SM 14046 (26.80) showed highly significant percentage yield reduction under this drought regime. Under 90 DAP drought regime, potential genotypes that recorded less percent yield reduction were ICGX-SM 14088 (-21.44), ICGX-SM 14095 (-13.30), ICGX-SM 14052 (-11.47), ICGX-SM 14060 (-6.54), ICGX-SM 14053 (-5.85), ICGX-SM 14054 (-5.34) and ICGX-SM 14101 (-4.52) and ICGX-SM 14075 (2.71). High percentage yield reduction under 90 DAP drought regime was showed by genotypes ICGX-SM 14047 (43.64), ICGX-SM 14057 (30.04), ICGX-SM 14046 (25.40), ICGX-SM 14059 (24.59), ICGX-SM 14073 (15.68), ICGX-SM 14050

(15.05) and ICGX-SM 14055 (14.45).

4. Discussion

A. Analysis of Variance for Agronomical and Physiological Traits

Drought is the most significant constraint that affect groundnut productivity in rainfed agriculture. Breeding for drought tolerant in most crops is based on experimental approach, which has gained little success up to dates. Currently, various agronomical and physiological traits such as specific leaf area (SLA), SPAD chlorophyll meter reading (SCMR) and relative water content (RWC) have been reported to be associated with water use efficiency in groundnut (Songsri et al., 2008; Nigam and Aruna, 2007 and Painawadee et al., 2009; Shinde et al., 2010; Kachout et al., 2011; Pereira et al., 2015). Therefore, if selection for drought tolerance in groundnut is a trait based, rapid improvement in developing drought tolerant cultivars would be granted in breeding programs rather than using empirical approach.

The analysis of variance observed high significant variations among genotypes evaluated for all traits studied. Presence of significant genotypic difference offers an opportunity for breeder to select appropriate diverse material to utilize in breeding programme. Previous studies also reported genotypic significant variations for traits like SLA (Jayalakshmi et al., 1999; Nageswara Rao et al., 2001; Painawadee et al., 2009 and Girdthai et al., 2012), RWC (Ketring, 1986; Songsri et al., 2008 and Girdthai et al., 2012) and SPAD chlorophyll meter reading (Songsri et al., 2008; Girdthai et al., 2012; Zhen et al., 2022). Drought treatments also showed highly significant differences among all straits studied. Vanangamudi (1987) reported similar results for hundred seed weight under six moisture stress treatments. Suvarna (2000) also reported significant differences for RWC, SHP, HSW, SCMR and GY under three drought stress treatments. Highly significant differences for genotypes x treatment interactions were observed for all studied traits. This suggested that genotypes were responded contrarily under different drought regimes. Therefore, a comprehensive analysis of genotypes performance across the drought treatments under measured traits will help to understand their responses and finally help in selection for superior genotypes. Suvarna (2000) reported similar high significant differences genotypes x drought stress treatments for studied traits.

B. The Effects of Drought Moisture Regimes on Drought Tolerance Traits

The drought stress had shown significant differences for most all studied agronomical and physiological water use efficiency traits (Table 7) and (Figure 4) Agronomical traits and physiological traits, grain yield (GY), shelling percentage (SHP) and hundred seed weight (HSW), SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA) and relative water content (RWC) were significantly reduced under drought stress conditions. For agronomical traits, GY, SHP and HSW showed differential responses under different drought moisture regimes suggesting that these traits are sensitive to drought moisture stress. The sensitiveness of these traits to drought moisture stress have been reported by previous studies (Boontang et al., 2010; Koolachart et al., 2013; Pereira et al., 2015).

Under 60 DAP and 90 DAP regimes, SHP and HSW were reduced significantly as compared to both watered and RD conditions although drought had more severe impact under 60 DAP than in 90 DAP drought regime for SHP. High reduction for GY also was observed under 60 DAP and 90 DAP regimes than under both watered and RD regimes indicating that GY also was sensitive to moisture stress. Similar results were reported (Yao et al., 1982; Janamatti et al., 1986; Boote and Ketring, 1990 and Karimian et al., 2015) for HSW, (Reddy, 1978; Pallas et al., 1977; Rasve et al., 1983; Golakiya and Patel, 1992) for SHP and (Patel and Golakiya, 1988; Ravindra et al., 1990 and Boontang et al., 2010) for GY.

For physiological traits, RWC and SLA were affected by drought stress conditions indicating that these traits are sensitive to moisture stress. Nageswara Rao et al., (2001), Sanchez et al., (2010) and Karimian et al. (2015) found that drought stress effected the performance of these traits. The current study observed that these traits were significantly reduced under 60 DAP followed by 90 DAP and later RD and watered drought conditions. SCMR was moderate affected with drought treatment and could be probably used as a stable measure of yield and other drought related traits. Nageswara Rao et al., (2001) and Reddy et al., (2003) reported similar results on these physiological traits. However, the results are in contradiction with Jongrungklang et al. (2008) reported increase in SCMR under drought stress and Painawadee et al., (2009) reported no significant in SCMR between drought stress treatments. The discrepancy of the results might be due to the material used and differences in experimental conditions between glasshouse and field condition. Generally, the drought stress under 60 DAP had more severe impacts on these traits followed by 90 DAP which later affected the performance of individual genotypes. Shinde et al. (2010), Koolachart et al. (2013) and Aninbon et al. (2015) reported that the impacts of drought is higher with stress imposed at a time between pegging and pod development and lowest with drought stress imposed

Table 7

The effects of watered, 60 DAP and 90 DAP drought moisture regimes on different agronomical and physiological drought tolerance traits of groundnut

TRAIT	WATER-ED	60 DAP	REDUCT (%)	90 DAP	REDUCT (%)
Grain Y	12.39	11.51	7.10	11.37	8.23
SCMR	50.77	38.68	23.81	44.74	11.88
W	47.33	44.47	6.04	44.26	6.48
SHP	71.02	67.94	4.34	68.49	3.56
SLA	173.46	150.97	12.97	148.04	14.65
RWC	85.30	68.93	19.19	74.71	12.42

RWC = Relative water content, SCMR = SPAD chlorophyll meter content, HSW = hundred seed weight, SHP = Shelling percentage, SLA = Specific leaf area and GY = Grain yield, REDUCT (%) = Percentage reduction.

between pod developments to maturation.

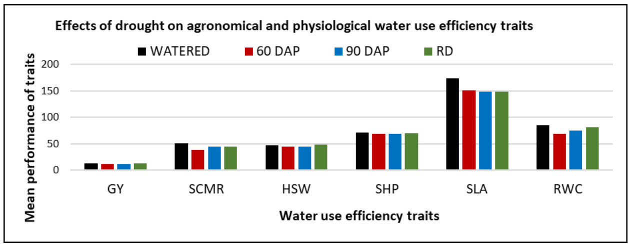

Fig. 4. Effects of drought on agronomical and physiological water use efficiency traits under four different drought stress conditions

C. The Effects of Drought on Genotypes Performances

The detail understanding of the performance of genotypes under different drought regimes is of basic importance in selection of superior genotypes to be incorporated in breeding programs for drought tolerance groundnut. The results on the genotypes performance under this study are presented for selected six important agronomical and physiological traits.

Earlier studies have indicated the importance of yield under selection of groundnut for drought tolerance (Duarte et al., 2013; Santos et al., 2010; Mijinyawa et al., 2022). Under watered regime, the high yielding genotypes were ICGX-SM 14081, ICGX-SM 14078, ICGX-SM 14098 and ICGX-SM 14101. This is may be due to high potential of these genotypes for yielding high as compared to the rest of genotypes. Genotypes ICGX-SM 14101 maintained its high yield potential under 60 DAP, 90 DAP and RD drought regimes, ICGX-SM 14081 at 60 DAP and RD regimes and ICGX-SM 14098, ICGX-SM 14081 and ICGX-SM 14078 under 60 DAP drought regime. Genotypes ICGX-SM 14098 was sensitive at both 90 DAP and RD regimes whereas ICGX-SM 14081 was sensitive under 90 DAP regime. The results indicated that, yield was reduced both under 60 DAP and 90 DAP drought regimes as compared with watered and RD drought regimes. Although 60 DAP and 90 DAP were not statistically differences but more yield reduction was observed under 90 DAP regime. The lower yield reduction observed under random drought (RD) than any other drought regime was due to differences in experimental conditions between glasshouse and field condition. Boontang et al., (2010), Koolachart et al., (2013) and Pereira et al., (2015), also reported a decrease in yield when groundnut was subjected to terminal drought stress. Patel and Golakiya, (1988) agreed that yield reductions is higher with stress imposed at a time between pegging and pod development and lowest with drought stress imposed between pod developments to maturation. This is simply that stressed groundnut loses moisture from pods and leads to reduction to physiological activities of the seeds and finally affects the yield. Therefore, these genotypes have performed well in different drought regimes probably due to their genotypic differences that enhanced with drought tolerance; selection based on these genotypes would have more impact toward breeding for drought tolerance groundnut.

Previous studies have shown that the weight of 100 seeds in groundnut is reduced due to drought stress (Janamatti et al., 1986). Therefore, genotypes with high hundred seed weight are considered as drought tolerant. For hundred seed weight, genotype ICGX-SM 14101 showed high significant under watered, 60 DAP and RD drought regime. ICGX-SM 14081 maintained its potential for this trait both under watered and 90 DAP regimes. Other genotypes that did well were ICGX-SM 14098 under watered, ICGX-SM 14055 under 90 DAP and ICGX-SM 14075 for both 60 DAP and RD drought regimes. These genotypes performed high probably due to their ability to utilize the limited water resource effectively during seed development. Other genotypes did not perform well due to water deficit probably in the root zone during pod filling which affected the development of seeds and resulted on reduction of seed weight of these genotypes. Boote and Ketring, (1990) reported that pod and kernel development are progressively affected by drought stress due to insufficiency plant turgor and lack of assimilates. In addition to this, water deficit in the root zone during pegging was reported to decrease pod and seed growth during drought stress by approximately 30% and decrease weight per seed from 563mg to 428 mg (Sexton et al., 1997). Therefore, these situations have an impact on the final weight of the seeds and the result is reduction of the 100 seed weight.

Shelling percentage is among of the traits being affected when groundnut encounter drought stress condition. Genotypes with relative high shelling percentage under drought condition are considered as drought tolerant (Pallas et al., 1977 and Reddy, 1978). Genotypes and ICGX-SM 14060 maintained high potential for shelling percentage in both watered and 90 DAP regimes. These genotypes have shown their potential to withstand drought stress for these drought conditions, hence can be considered during selection. Genotypes ICGX-SM 14064 performed well under both watered and RD drought regimes whereas ICGX-SM 14101 scored high under 60 DAP drought regime. Since shelling percentage is usually lesser under moisture-stress condition than that under the normal condition, genotypes with relative high shelling percentage under drought condition will be considered as drought tolerant. Therefore, selection of these genotypes would add some improvement in groundnut breeding programs for drought tolerance.

A SPAD chlorophyll meter reading provides a useful tool to screen for genotypic variation in potential photosynthetic capacity under drought condition (Nageswara Rao et al., 2001; Songsri et al., 2008). It is among the surrogate traits that can be used to achieve more effective and rapid progress in selection for drought tolerance (Nigam et al., 2005). High performing genotypes for SPAD chlorophyll meter reading were ICGX-SM 14101 under both watered, 90 DAP, RD drought regimes, ICGX-SM 14100 under watered and 60 DAP drought regimes. Other high performing genotypes for this trait were ICGX-SM 14098 under 60 DAP regime and ICGX-SM 14095 under 90 DAP regime. Therefore, these genotypes performed well due to its high potential photosynthetic capacity under drought condition; hence, selection for these genotypes in breeding programme would help to develop varieties with improved drought tolerance.

The low specific leaf area (SLA) value is preferable as it indicates drought tolerance (Nageswara et al., 2001; Songsri et al., 2008; Painawadee et al., 2009 and Nigam, 2014, Gao et al., 2023). Genotypes ICGX-SM 14073 maintained low SLA at both watered and 90 DAP drought regimes whereas ICGX-SM 14055 had significant low SLA at watered and 60 DAP regimes. Significant low SLA exhibited by genotypes ICGX-SM 14050, ICGX-SM 14052, ICGX-SM 14054, ICGX-SM 14078 and ICGX-SM 14088 under 60 DAP regimes. Under 90 DAP, ICGX-SM 14046, ICGX-SM 14083, ICGX-SM 14085 under 90 DAP and ICGX-SM 14053, ICGX-SM 14080 and ICGX-SM 14081 under RD drought regimes exhibited low SLA for these regimes. It has reported that genotypes with low SLA have thicker leaves which usually indicates greater photosynthetic capacity compared with thinner leaves (Nageswara Rao et al., 2001; Upadyaya, 2005; Songsri et al., 2008 and Painawadee et al., 2009; Girdthai et al., 2012, Mijinyawa et al., 2022; Zhen et al., 2022). Therefore, these genotypes have more photosynthetic machinery per unit leaf area and greater assimilation under drought conditions, hence are potential to be selected and incorporated in the groundnut-breeding pipeline for drought tolerance.

Groundnut is a relatively drought tolerant crop having improved water-use efficiency mechanisms that allow it to withstand water stress for certain period (Kundy et al., 2023). However, in drought years it suffers consequently and leads to reduction in yield significantly. One of the early responses of drought stress in groundnut is the decrease of relative water content (RWC), which is considered as the best physiological measure of plant water status (Madhusudhan and Sudhakar, 2023). Dang et al. (2024) argued that RWC is a more useful integrator of plant water balance than leaf water potential and should provide universal relationship between physiological traits and level of drought stress. Obviously, stressed plants have lower RWC than non-stressed plants. From the results, genotypes were varied significantly within and between drought moisture regimes. Genotypes ICGX-SM 14098, ICGX-SM 14081 and ICGX-SM 14078 maintained its ability to withstand water stress relatively across drought regimes. Genotypes ICGX-SM 14088 and ICGX-SM 14050 were very sensitive to water stress however, they performed well under watered and RD drought regimes respectively. Therefore, these genotypes are potential to be selected and need to be incorporated in drought breeding programs for drought tolerance groundnut.

5. Conclusion

Drought stress affected both evaluated genotypes and water use traits; RWC, SLA, SHP, HSW, SCMR and GY. Groundnut genotypes were significantly differently for all studied traits indicating that drought stress increased variations among water use efficiency traits. These genotypes displayed different responses for these traits associated with drought tolerance and the genotypes with good degree of drought tolerance were identified. Genotypes ICGX-SM 14075, ICGX-SM 14078, ICGX-SM 14060, ICGX-SM 14098, ICGX-SM 14081, ICGX-SM 14101, ICGX-SM 14100 and ICGX-SM 14095 had showed high degree of drought tolerance for various water use efficiency traits in different moisture regimes indicating that they are superior and need to be incorporated in breeding programs for drought tolerance in groundnut. Most of the traits were significantly affected by drought stress. When the magnitude of reduction was considered in percentage among traits RWC, HSW, SLA and SHP showed more sensitivity to drought stress conditions. Grain yield (GY) and SCMR showed a fair stability among all drought moisture regimes indicating that these traits could probably be used as stable measure of yield and other drought related traits. In addition, the differential responses of groundnut genotypes under these traits suggested that several drought tolerance mechanisms might be exists which contributed to superiority of these genotypes. Therefore, combining of these traits into breeding programs would help to develop groundnut genotypes enhanced with drought tolerance.

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