Easily measureable morpho-physiological traits as selection criteria for terminal drought tolerance in groundnut (*Arachis hypogaea* L.)

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ABSTRACT

This study was conducted at El Obied Research Station Farm, North Kordofan State Sudan, with the objective of identifiying easily measurable morpho-physiolgical traits that could be used in drought tolerance breeding programs. Nine groundnut mutants together with three parents were evaluated under normal and terminal drought stress environments in 2003 and 2004 cropping seasons in a randomized complete block design with four replications. The genotypes did not differ significantly in the number of days to 75% emergence, with a range of 6-8 days. Most of the measured traits showed higher values under normal than under stressed environments. Under stressed environment, some mutants like Barberton-B-30-3 and Barberton-B-30-4, exceeded their parents in pod yield (PY) /plant, dry matter production (DM) and leaf relative water content (LRWC), whereas they showed lower specific leaf area (SLA), canopy temperature (CT) and leaf senescence (LSENS) than their parents. CT, LRWC, LSENS and PY showed relatively medium broad-sense heritab-ility estimates under stress environment. PY was positively, significantly and genotypically correlated with DM and LRWC while significantly and negatively correlated with SLA, CT and LSENS under stress enviro-nment. Since these traits are reasonably heritable, strongly correlated with PY under stress enviroment and easily measurable under field conditions, they could be suggested as selection criteria for droguht tolerance in groundnut. The mutant Barberton-B-30-3, which produced the highest PY, DM and LRWC, under terminal drought stress, could be suggested as the best drought tolerant mutant in this study bending further testing over years and locations.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in the Sudan. It is widely grown in both rainfed (85%) and irrigated areas (15%). The low productivity (517 kg/ha) and highly variable, unstable production are characteristic features of groundnut production in the rainfed sector of western Sudan as compared to the stable and high productivity (1930 kg/ha) in the irrigated sector (Osman, 2003).

Planting of rainfed groundnut in western Sudan is carried out during the first week of July with the onset of the rainy season. Mid season drought effect is rare as the probability of long duration drought incid-ences is very low during the rainy months of July and August. Early cessation of rains after mid-September was frequently witnessed, thus shortening the season to 70-76 days in the rainfed groundnut producing areas. Consequently, the predominantly grown Spanish cultivars with 90 days maturity duration are subjected to terminal drought stress.

Large portion of yield loss due to end-of-season drought could be recovered through genetic enhancement for drought tolerance. Such enhancement could be obtained by using easily measureable morpho-physiolgical characters as selection criteria for terminal drought toler-ance. This is because drought triggers a wide range of morphological, physiological and molecular responses in plants.

Nageswara Rao *et al.* (1993) reported high positive correlation between dry matter production (DM) and transpriation of groundnut cultivars subjected to end of season drought stress. DM produced by a crop is a product of transpiration (T) and water use efficiency (WUE). According to Arjunan *et al.*, (1992), DM production is positively and significantly correlated with pod yield in groundnut. A high negative correlation was reported between WUE and carbon isotope discrimination ratio (Craufurd *et al.*, 1999). The lack of relationship between T and WUE suggests the possibility of selecting genotypes with greater T and WUE. Hence, selection for high DM accumulation could indirectly lead to selection for high WUE.

Leaf relative water content (LRWC) has been used extensively in sorghum and wheat as a potential index for dehydration avoidance (Stout *et al.*, 1978; Clarke and Mc Caig, 1982). Low specific leaf area (SLA) cultivars were found to be drought tolerant interms of high total DM production, maintenance of high LRWC and production of high pod yield (Nautiyal *et al.*, 2002; Chuni *et al.*, 2005). In groundnut, a strong negative correlation was found between mid season canopy-air temper-ature differences and pod yield under stress (Greenberg and Ndunguru, 1989).

The objective of the present study was to identify reasonably inherited, correlated, easily measurable morpho-physiological traits that could be used as direct or indirect selection criteria for terminal drought tolerance in breeding programs of groundnut.

MATERIALS AND METHODS

This study was undertaken at El Obied Research Station Farm (13^0 10' N; 30^0 14'E ; 570 masl, with 324 mm annual rainfall and 70 days rainy season), El Obied, Sheikan locality, North Kordofan State, Sudan. Sheikan locality is the northern limit of the groundnut producing zone with dominant sandy soils characterized by low clay content, high pH, low cation exchange capacity (CEC) and low organic matter content (Osman, 2003).

Nine groundnut mutants (ICGV89104-A-10-1, Barberton-A-17-1, Barberton-B-30-4, Barberton-A-16-2, ICGV221-A-1-1, Barberton-B-12-2, Barberton-B-12-3, Barberton -B-30-1 and Barberton-B-30-3) together with their three parents (ICGV89104, ICG221 and Barberton) were evaluated under terminal droughtstress environment, in two consecutive seasons (2003 and 2004), in a randomized complete block design with four replications. Each plot consisted of two rows, five meters in length and 60 cm apart. The intra-row spacing was 20 cm. Sprinkler irrigation facility was used to release any drought stress during the first two months of crop age, while the mechanical rainout shelter was used to impose terminal drought stress of 25 days duration after 60 days of crop age.

Days to 75% emergence were calculated as the number of days from planting until 75% of the planted seeds emerged. Leaf area (LA) (cm^2) was measured from a random sample of three plants taken from each plot, early in the morning, after 70 days from planting using a leaf area meter (Model AM10/.001). Specific leaf area (SLA) (cm^2g^{-1}) was calculated as the ratio of the total leaf area/plant and the respective leaf dry weight/plant. Total plant dry matter weight (DM) was measured after oven drying at 80^0C for 72 hours. Leaf samples for determining leaf relative water content (LRWC) were taken at mid-day from three random plants, from each plot, after 20 days stress period. Three leaflets from the third most recent fully expanded leaf on the main stem were cut and weighed immediately to obtain the fresh weight (W). The samples were rehydrated using distilled water by putting the leaflets into Petri dishes at room temperature. After four hours, the leaflets were thorou-ghly surface dried with tissue paper and weighed again to obtain the turgid weight (TW). The samples were then oven dried overnight at 80^0C and weighed again to obtain the dry weight (DW). LRWC was calculated as :

$$LRWC = [(W-DW)/(TW-DW)] \times 100$$

Canopy temperature (CT) readings (^{0}C) from each plot were taken at mid-day after 20 days stress period. The infrared thermometer (Model QUICKTEMP 850-2) was directed to fully expanded leaves in the canopy to avoid other objects that may give misleading temperature readings.

For leaf senescence (LSENS) measuring, light sprinkler irrigation was applied just before harvest to moisten the leaves and avoid shedding. Pod yield (PY) (g) per plant and the number of completely dry leaves per plant, from randomly selected five plants, were recorded from each plot at harvest time (85 days from planting).

The analysis of variance procedure was used to test differences due to genotypes for each trait and in each season separately. Then, the combined trait means for the two seasons were used to calculate the broad sense heritability estimates as well as the genotypic correlation coefficients.

RESULTS AND DISCUSSION

Days to 75% seedling emergence

Differences in days to 75% seedling emergence between stressed and unstressed environments were not expected since the moisture regimes under the sprinkler system and the rainout shelter were similar up to 60 days from sowing. Genotypic differences in seedling emergence were not significant under both environments and seasons (data not shown). All genotypes reached 75% seedling emergence within 6-8 days. The mutants ability to emerge was not significantly different from their parents, though variability in seedling emergence of groundnut was reported by Mixon (1971) and Wynne and Sullivan (1978).

Specific leaf area (SLA)

Significant differences in specific leaf area among genotypes were found at 25 days after planting (DAP) and 70 DAP (Table 1). Averaged over the two environments (shelter and rainout) and seasons, the genotpes differed singificantly in SLA throughout the different sampling dates. The genotypes attained their highest SLA values at 25 DAP, and then the values decreased progressively to reach their lowest at 70 DAP, especially under stressed environment.

Groundnut mutants Barberton-B-30-3, Barberton-B-30-4 and Barberton-A-16-2 recorded the lowest mean values of SLA across sampling dates. The same mutants recorded the lowest SLA values under stressed environment in season 2003 and when averaged over environments (Table1). Nauyital *et al.*,(2002) reported that low SLA genotypes genotypes performed better than high SLA genotypes under water-deficit enviro-nment.

Dry matter prodution (DM)

Differences in DM per plant among genotypes were significant (P=0.05)at 55 DAP in 2004 and at 85 DAP in seasons 2003 and 2004 (Table 2). DM was higher in the unstressed than under stressed enviro-nment at 85 DAP. Groundnut mutants Barberton-B-30-1, Barberton-B-30-3 and Barberton-B-30-4 were consistently among the highest DM pro-ducing genotypes.

Table 1. Specific leaf area ($cm^2\ g^{-1}$) of 12 groundnut genotypes at 25 and 70 days after planting (DAP), under the sprinkler irrigation system (SP) and the rainout shelter (RN), in 2003 and 2004 cropping seasons, in El Obeid, Sudan.

Genotype	25 DAP					70 DAP					
	2003		2004		Mean	SP (unstressed)			RN (stressed 10 days)		
	SP	RN	SP	RN		2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	330	290	302	291	303	245	220	232	185	203	194
Barberton-A-17-1	308	297	279	296	295	275	212	242	239	188	213
Barberton-B-30-4	284	237	244	279	261	184	206	195	126	198	162
Barberton-A-16-2	300	257	281	290	282	204	204	204	159	183	171
ICG221-A-1-1	310	286	270	302	292	241	216	228	237	205	221
Barberton-B-12-2	358	294	279	260	298	222	210	216	174	219	197
Barberton-B-12-3	320	293	272	251	284	225	241	233	200	186	193
Barberton-B-30-1	282	242	263	266	263	205	193	199	157	185	171
Barberton-B-30-3	276	226	263	269	259	221	201	211	157	157	157
ICGV89104	338	317	298	285	310	252	217	235	229	181	205
ICG221	369	342	298	305	328	236	208	222	207	200	204
Barberton	326	336	325	299	328	218	201	210	238	186	212
SE (±)	18*	14**	15*	41	8**	20	10	11*	21**	12	12**
CV (%)	11	10	11	28	11	18	9	14	21	13	18

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 2. Dry matter production (g/plant) of 12 groundnut genotypes at 55 and 85 days after planting (DAP) under the sprinkler irrigation system (SP) and the rainout shelter (RN), in 2003 and 2004 cropping seasons, in El Obeid.

Genotype	55 DAP					85 DAP					
	2003		2004			SP			RN (streseesed)		
	SP	RN	SP	RN	Mean	2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	19	24	31	30	26	77	51	64	51	41	46
Barberton-A-17-1	14	26	24	26	23	58	55	57	38	31	35
Barberton-B-30-4	21	21	28	27	24	67	56	62	53	41	47
Barberton-A-16-2	19	27	34	28	27	68	60	64	38	39	38
ICG221-A-1-1	17	26	30	27	25	56	48	52	53	34	43
Barberton-B-12-2	19	27	25	30	25	50	49	49	55	37	46
Barberton-B-12-3	15	22	23	28	22	54	50	52	54	33	43
Barberton-B-30-1	24	23	27	26	25	71	50	60	57	38	48
Barberton-B-30-3	20	24	27	29	25	62	60	61	46	49	48
ICGV89104	20	23	26	27	24	60	56	58	55	36	46
ICG221	17	35	27	32	28	62	52	57	44	30	37
Barberton	17	24	23	23	22	67	43	55	48	36	42
SE (±)	3	3	2*	3	1	5*	5	3*	6	3**	3
CV (%)	31	27	15	23	24	17	18	17	26	15	23

RN (stressed): Stressed under the rainout shelter for 25 days.
, * Significant at 0.05 and 0.01 probability levels, respectively.

Cumulative dry matter, recorded at 25,40,55 and 85 DAP, revelaed that Barberton-B-30-3 accumulated the highest DM within the first 70 days of crop growth, while its parent, Barberton, accumulated the lowest DM (Fig.1). The three mutants, Barberton-B-30-1, Barberton-B-30-3 and Barberton-B-30-4, produced high DM during both stressed and unstressed periods. (Fig.1) indicating that these mutants were least affected by the imposed drought stress. This showed that these mutants had rapid early growth and canopy development necessary to reduce surface soil evaporation and increase moisture availability for transpiration. Early growth vigor was reported in several grain legumes (Onim, 1983; Silim *et al.*, 1993).

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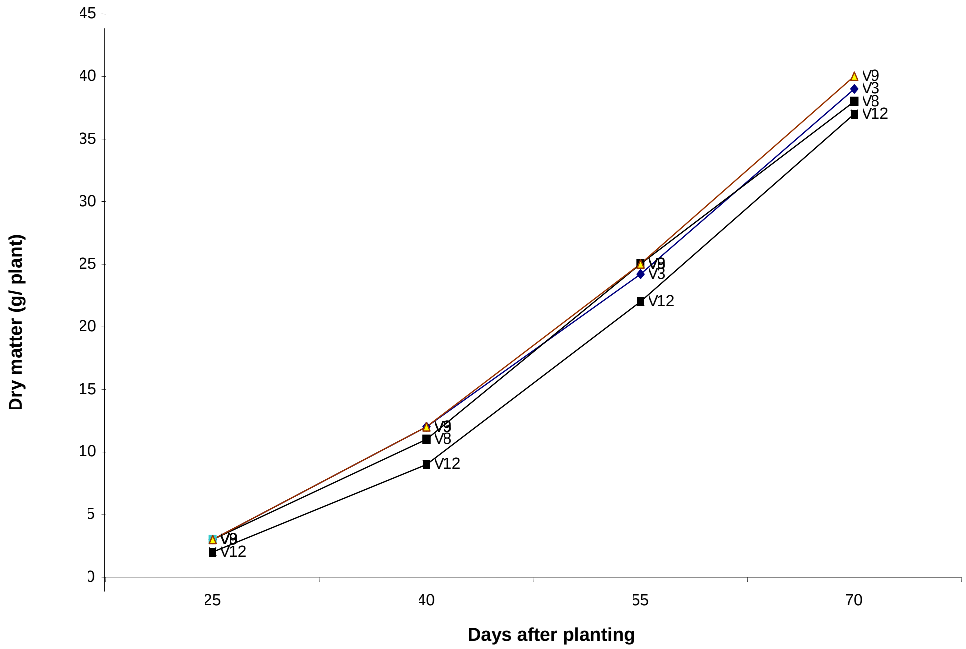

Fig. 1. Dry matter production (g/plant) of four groundnut genotypes (V9: Barberton-B-30-3; V8: Barberton-B-30-1; V7: Barberton-B-30-4; V12: Barberton) averaged over seasons and environments at 25, 40,55 and 70 days after planting.

Canopy temperature (CT)

Differences in CT between the genotypes were significant only in the stressed environment of season 2003 and in the overall means of both seasons (Table 3). Generally, the CT was low in unstressed environment (in the mid thirties) compared to that of the stressed environment (above forty). CT was greatly affected by hot weather and relative humidity. CT readings during pod filling were best assoicated with pod yield ,and pod yield increased with decreased CT (Fig. 2).

Table 3. Canopy temperature (^{0}C) of 12 groundnut genotypes under unstressed (SP) and stressed (RN) environments, at 85 days from planting, in 2003 and 2004 cropping seasons, in El Obeid, Sudan.

	SP-unstressed			RN-stressed (20 days)		
Genotype	2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	34	34	34	40	44	42
Barberton-A-17-1	37	34	35	41	43	42
Barberton-B-30-4	35	37	36	40	44	42
Barberton-A-16-2	35	34	34	42	44	43
ICG221-A-1-1	38	34	36	39	42	40
Barberton-B-12-2	35	36	35	41	42	41
Barberton-B-12-3	36	34	35	39	42	40
Barberton-B-30-1	37	35	36	40	43	42
Barberton-B-30-3	36	34	35	40	43	42
ICGV89104	36	34	35	39	43	41
ICG221	37	34	35	41	45	43
Barberton	36	36	36	41	44	43
SE (±)	1	1	1	1*	1	1**
CV (%)	6	6	6	4	4	4

, * Significant at 0.05 and 0.01 probability levels, respectively.

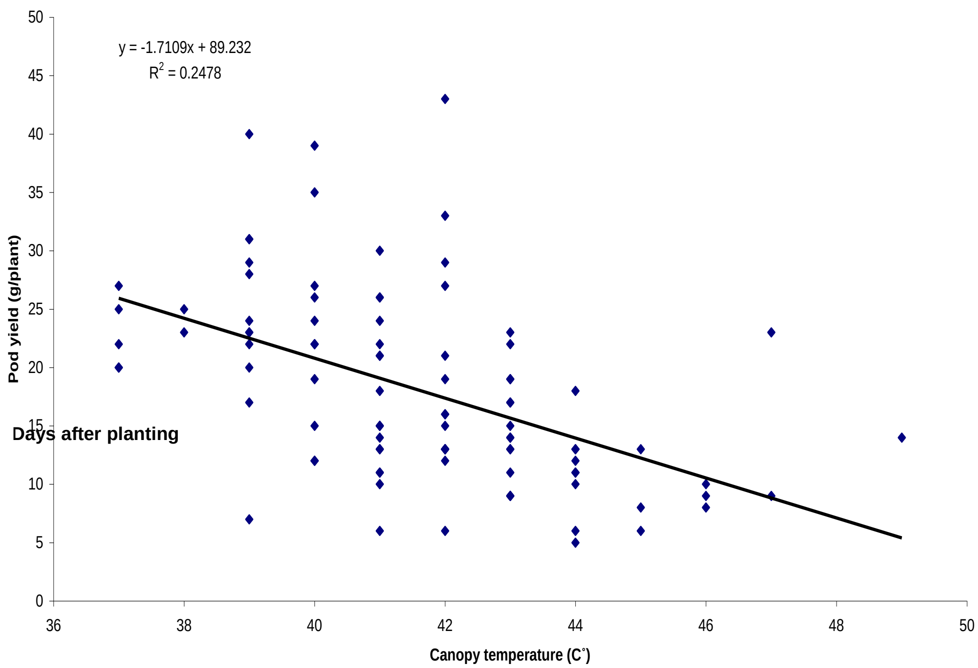

Fig. 2. Relationship between canopy temperature and pod yield averaged over seasons and environments.

Leaf relative water content (LRWC)

Genotypes differed significantly in LRWC under stressed environment in both seasons and the overall mean (Table 4). LRWC measured under stressed environment was lower than that measured under unstressed enviroment. Barberton-B-30-3 and ICGV221-A-1-1 showed the highest mean values of

LRWC under stress conditions. Drought tolerance in groundnut cultivars has been characterized by maintenance of high LRWC under water-deficit conditions (Nautiyal *et al.*, 1995). LRWC is easy to measure and could be used to screen large breeding populations of groundnut for drought tolerance.

Leaf senescence (LSENS)

The number of dry leaves per 5 plants counted at harvest time under stressed and unstressed environments, in seasons 2003 and 2004, are shown in Table 5. The number of dry leaves under unstressed enviro-nment was much lower than under stressed environment. Barberton showed the highest number of senescent leaves (12) under unstressed environment, while Barberton-B-A-17-1 and ICGV221-A-1-1 showed the highest number of senescent leaves (39) under stressed environment. Significant differences, in LSENS, among genotypes were observed in 2004 under both environments.

Table 4. Leaf relative water content of 12 groundnut genotypes under unstressed (SP) and stressed (RN) environments, at 85 days from planting, in 2003 and 2004 cropping seasons, in El Obeid, Sudan.

Genotype	SP-unstressed			RN-stressed (20 days)		
	2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	70	81	76	36	24	30
Barberton-A-17-1	60	75	68	53	29	41
Barberton-B-30-4	64	71	67	50	34	42
Barberton-A-16-2	73	74	74	33	37	35
ICG221-A-1-1	53	75	64	50	38	44
Barberton-B-12-2	68	69	69	56	29	42
Barberton-B-12-3	60	71	65	33	29	31
Barberton-B-30-1	68	65	66	48	31	39
Barberton-B-30-3	65	74	69	56	31	44
ICGV89104	66	74	70	51	33	42
ICG221	60	74	67	48	27	38
Barberton	59	82	70	31	31	31
SE (±)	1	7	2	3**	3*	2**
CV (%)	10	10	10	15	18	16

, * Significant at 0.05 and 0.01 probability levels, respectively.

Leaf senescence under the unstressed enviroment reflected the gradual natural leaf senescence due to crop maturity (Boyers, 1983). The ability to retain leaf area is an integrative function of many lower level traits leading to dehydration tolerance (Blum, 2002). Large genotypic differ-rences in leaf area retention under drought stress conditions were observed in groundnut (Nageswara Rao and Wright, 1994). The relative easiness of visually assessing this trait could highly be utilized to screen large test lines.

Pod yield (PY) (g/plant)

Pod yield per plant of the genotypes differed significantly in both environments and genotypes (Table 6). The performance of the genotypes in 2003 was higher than in that of 2004, under both environments. The mutant Barberton-B-30-3 produced the highest PY/plant under both environments and seasons, followed by mutant Barberton-B-30-4. They exceeded the PY/plant of their parent (Barberton). The performance of the genotypes under stressed conditions was lower than under normal conditions.

Table 5. Number of senescent leaves per 5 plants of 12 groundnut genotypes under unstressed (SP) and stressed (RN) environments at 85 days from sowing in 2003 and 2004 cropping seasons, in El Obeid, Sudan.

Genotype	SP-unstressed			RN-stressed (25 days)		
	2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	8	5	7	49	41	42
Barberton-A-17-1	10	5	8	37	42	39
Barberton-B-30-4	9	5	7	30	22	18
Barberton-A-16-2	12	5	9	45	34	36
ICG221-A-1-1	13	4	8	54	41	39
Barberton-B-12-2	14	9	11	23	36	29
Barberton-B-12-3	15	7	11	32	44	38
Barberton-B-30-1	9	6	7	22	23	22
Barberton-B-30-3	13	6	9	27	22	25
ICGV89104	6	5	5	22	36	29
ICG221	7	6	6	36	38	35
Barberton	19	6	12	53	53	51
SE (±)	3	1*	2	9	5**	4**
CV (%)	62	29	59	52	29	37

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Under the predetermined harvesting date of 85 days from planting, the current study suggested that the mutant Barberton-B-30-3 could be subjected to further field testing to replace its parent Barberton. In cojunction with its highest PY/plant, this line also showed the highest mean values of LRWC under stress conditions and among the highest DM producers. It was also among the mutants that showed the lowest SLA, CT and LSENS. This line also combined high PY/plant with relative drought tolerance.

Table 6. Pod yield (PY) (g/plant) under unstressed and stressed enviro-nments, seasons 2003 and 2004, in El Obeid, Sudan.

Genotype	Unstressed			Stressed		
	2003	2004	Mean	2003	2004	Mean
ICGV89104-A-10-1	30	21	25	21	12	16
Barberton-A-17-1	24	21	23	18	10	14
Barberton-B-30-4	34	25	29	30	14	22
Barberton-A-16-2	32	27	30	20	11	15
ICG221-A-1-1	27	20	24	27	11	19
Barberton-B-12-2	22	22	22	25	12	19
Barberton-B-12-3	25	21	23	28	12	20
Barberton-B-30-1	33	20	26	29	12	21
Barberton-B-30-3	36	30	33	35	20	28
ICGV89104	25	25	25	23	12	17
ICG221	24	19	22	23	8	16
Barberton	30	17	23	29	12	20
SE (±)	3**	2**	2**	3*	1**	2**
CV (%)	19	20	19	25	22	26

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Heritability and genotypic correlations

The broad sense heritability estimates (H) of canopy temperature, leaf relative water content, leaf senescence and pod yield/plant were medium (0.18-0.46) under both irrigation systems (Table 7). Such estimates were higher under rainout shelter indicating that selection for the traits is more reliable under stressed environment, e.g., leaf relative water content was used in sorghum and wheat as a potenital index for dehydration avoidance (Stout *et al.*, 1978; Clarke and Mc Caig, 1982).

Pod yield/plant was positively, significantly and genotypically correlat-ed with 75% emergence, dry matter/plant and leaf relative water content (LRWC), under both environments (Table 7). It was negatively, signi-ficantly and genotypically correlated with specific leaf area, canopy temperature and leaf senescence. According to Arjunan *et al.* (1992), pod yield is positively and significantly correlated with dry matter production in groundnut under drought stress. Drought tolerance in groundnut cultivars has been characterized by the maintenance of high LRWC under water deficits conditions (Nautiyal *et al.*, 1995).

Chuni *et al.* (2005) reported negative correlation between SLA and pod yield. Low SLA genotypes were found to perform better than high SLA genotypes under water-deficit environment (Nautiyal *et al.*, 2002). SLA was suggested as an indirect selection criterion for both water use efficiency (WUE) and leaf carbon discrimination ratio in groundnut under terminal drought stress (Craufurd *et al.*, 1999), because SLA was negatively correlated with WUE.

Table 7. Heritability in broad sense (H) and genotypic correlation coefficients (rg) between groundnut pod yield per plant and putative drought tolerant traits under the sprinkler irrigation system (SP) and the rainout shelter (RN) combined over two seasons (2003 and 2004).

Trait	Heritability (H)		Genotypic correlation coefficient (rg)	
	SP	RN	SP	RN
75% emergence	0.12	0.10	0.24*	0.25*
Specific leaf area	0.11	0.27	-0.86**	-0.80**
Dry matter/plant	0.09	0.07	0.79**	0.93**
Canopy temperature	0.18	0.22	-0.15	-0.27*
Leaf relative water content	0.24	0.37	0.75**	0.35**
Leaf senescence	0.27	0.46	-0.34**	-0.63**
Pod yield /plant	0.21	0.32		

*,** Significant at 0.05 and 0.01 probability levels, respectively.

CT as a selection criterion for dehydration avoidance has been recognized (Blum *et al.*, 1982). Low CT reflected high transpiration rate which leads to canopy cooling. Transpiration was found to be independent of WUE which could pave the way to select genotypes that combine high transpiration and high WUE (Nageswara Rao *et al.*, 1993). Thus, selection for low CT is an indirect selection for terminal drought tolerance.

The high, direct, negetative and significant contribution of LSENS to pod yield/plant indicated that the ability to retain leaf area is an integrative function of many lower level traits leading to dehydration tolerance (Blum, 2002). Genotypic improvement of crop performance under drought conditions may be based on genotypes that retain leaf area during drought but undergo the normal senescence at maturity. Hence, LSENS could be used as a reliable indirect selection trait for terminal drought tolerance in groundnut with less number of senescent leaves indicating more drought tolerance. The relative easiness of visually assessing this trait could highly be utilized to screen large test lines.

In conclusion, groundnut genotypes with low values of SLA, CT and LSENS and high values of LRWC produced relatively high pod yield under terminal drought stress. Incorporation of these tratis into cultivars by breeding could improve tolerance to terminal drought stress.

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إستعمال الصفات المورفوفسيولوجية سهلة القياس كمؤشرات إنتخاب لمقاومة جفاف آخر الموسم في الفول السوداني

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الخلاصة

أجريت هذه التجارب بمزرعة محطة بحوث الأبيض في ولاية شمال كردفان ، السودان، بغرض تحديد صفات مورفوفسيولوجية ، سهلة القياس، كمؤشرات إنتخاب لمقاومة جفاف آخر الموسم في الفول السوداني. زرعت تسع سلالات فول سوداني مطفرة وآبائها الثلاثة تحت ظروف ري عادية وكذا تحت المحمية المطرية لفرض 25 يوماً جفاف في موسمي 2003 و 2004. لم تظهر السلالات والآباء إختلافاً معنوياً لصفة عدد الأيام حتى بزوغ 75% من البادرات وكان مداها 6-8 أيام. أعطت الصفات المقاسة أعلى قيم تحت ظروف الري العادية مقارنة بتحت ظروف جفاف نهاية الموسم. تفوقت معظم الطفرات مثل Barberton-B-30-3 و Barberton-B-30-4 على الآباء تحت ظروف الإجهاد المائي في الإنتاجية من القرون وإنتاج المادة الجافة والمحتوى من الرطوبة النسبية في الأوراق، وأعطت قيم أقل من الآباء لصفات مثل المساحة النوعية للأوراق وحرارة التاج الخضري وعدد الأوراق المتساقطة. صفات حرارة التاج الخضري والمحتوى من الرطوبة النسبية في الأوراق والعدد المتساقط من الأوراق والإنتاج من القرون أعطت نسبياً قيم متوسطة لدرجة التوريث على النطاق العريض تحت ظروف الإجهاد المائي. أوضحت الدراسة وجود إرتباط وراثي موجب ومعنوي بين الإنتاج من القرون وإنتاج المادة الجافة ومعدل الرطوبة النسبية في الأوراق ، بينما كان إرتباطه سلبياً مع المساحة النوعية للأوراق ودرجة حرارة التاج الخضري والعدد المتساقط من الأوراق تحت ظروف الإجهاد المائي. بما أن هذه الصفات سهلة القياس وذات درجة توريث عالية نسبياً ومرتبطة بالإنتاجية فيمكن إستخدامها كمؤشرات إنتخاب لتحمل الإجهاد المائي. السلالة Barberton-B-30-3، والتي أعطت أعلى إنتاجية للقرون والمادة الجافة ومعدل الرطوبة نسبية للأوراق تحت ظروف الجهد المائي، يمكن إعتبارها أفضل السلالات المقاومة لجفاف نهاية الموسم على أن تجري عليها إختبارات أخرى في عدة مواسم ومواقع للتأكد من هذه الحقائق.