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Research Article

Evaluation of Groundnut Mini Core to Identify Sources of Tolerance to End of Season Drought in the Sahel, Niger

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Abstract

Background: Groundnut (*Arachis hypogaea* L.) productivity is very low in the Sahel mainly because of drought caused by low and erratic rainfall. End-of-season drought is the most important factor limiting groundnut production in the Sahel. Identification of genotypes that have a greater ability to use limited available water is important to enhance productivity of the crop. **Objective:** The study was conducted to identify tolerant groundnut genotypes to end of season drought. **Methodology:** About 100 mini core entries were evaluated for chlorophyll content and pod yield under well-watered and drought stress conditions. Soil plant analysis development chlorophyll meter readings have been suggested as a surrogate way to select for drought tolerance in groundnut. Drought tolerance indices were calculated for chlorophyll content at 45, 60 and 90 days after sowing. The experimental design was balanced α -lattice design replicated two times. Data collected were analyzed with GENSTAT software version 12.0. and LSD at 5% was used. **Results:** Highly significant differences were observed among the genotypes for all the traits. The effect of the two water regimes were significant for all traits measured. All the entries showed significant ($p < 0.01$) differences for chlorophyll content at 45, 60 and 90 days after sowing, in both water regimes. The overall means under drought stress conditions were 41.16, 47.78 and 45.9, respectively at 45, 60 and 90 days after sowing. These ratings were higher than the overall means under irrigated condition (39.66, 47.77 and 41.75, respectively). Drought tolerance indices ranged from 0.51-1.76 for pod yield and from 0.91-1.13 for chlorophyll content at 60 days after sowing. ICG6703, ICGV-SM99511, Tainan-9, ICG11249 and ICGV-IS01820 were the best drought tolerant genotypes identified in this study. **Conclusion:** The varieties Tainan-9, ICG11249 and ICGV-IS 01820 performed well under both conditions. The varieties Tainan-9, ICG11249 and ICGV-IS01820 showed least pod yield difference between both water regimes can be used by farmers in the short term as drought tolerant varieties or be used as parental lines to develop new groundnut drought tolerant varieties.

Key words: Evaluation, groundnut mini core, drought, chlorophyll content, drought tolerance index

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Groundnut is the second most widely grown legume in Niger after cowpea (*Vigna unguiculata* L.) Walp. It is cultivated mainly during the rainy season from June-September. Groundnut farming experienced a remarkable development between 1950 and 1970, with a period of increased production in the 1960s due to a rapid increase in land areas and yield. This was followed in the 70s and 80s by a significant slump in production and exports due to drought spells and lack of improved varieties. Groundnut yields have declined from 0.894 t ha⁻¹ in the 1960s to 0.42 t ha⁻¹ in 2011¹. Since the 1970s, Niger has suffered from severe droughts which have triggered important food crises particularly in 1973, 1984 and 1991 and more recently in 2005, 2009 and 2010². Drought is a major constraint to productivity that significantly reduces pod yield, particularly during the pod and seed forming stages. The most prevalent drought pattern in Niger occurs at the end-of-season. Drought is known to affect chlorophyll content and inhibit the photosynthetic capacity. The ability to maintain chlorophyll density under water deficit conditions has been suggested as a drought tolerance mechanism in groundnut³. The Soil Plant Analysis Development (SPAD) chlorophyll meter readings (SCMR) could be used for indirect selection of drought tolerance as a rapid and cost effective tool for assessment of relative chlorophyll status in groundnut leaves^{4,5}. In the context of climatic variation with rainfall reduction in terms of duration, distribution and amount, recurrent drought affects groundnut performance in Niger. There is a lack of information on genetic parameters that required groundnut breeding program for drought tolerance related traits. This study aimed to exploit an existing germplasm pool to identify and select the best drought tolerant groundnut genotypes that can be used later for the development of new drought tolerant varieties.

MATERIALS AND METHODS

The study was conducted at Maradi Research Station (Tarna) located at 13°28' N latitude and 7°10' E longitude. The soil has a pH of 6.5, 90% sand, 8% clay and 2% organic matter. The annual rainfall ranges from 230-630 mm, a typical Sahelian climate. The average daily maximum temperature was 40°C and the average daily minimum temperature was 14°C during the experimentation period. The experimental materials for this study consisted of 100 mini core entries selected from a reference set of 300 accessions evaluated under water stress conditions during 2008 and 2009 by the International Crops

Research Institute for the Semi-arid Tropics (ICRISAT) (Sadore) in Niger and 65 genotypes collected from the National Agricultural Research Institutes in West Africa (Ghana, Nigeria, Mali, Burkina Faso and Niger)⁶. The 100 entries were evaluated in an α -lattice design with two replications (10 blocks each of 10 entries) in 2011 during the off season (February-April). The experiment received diammonium phosphate (DAP) (NH₄)₂HPO₄] 150 kg ha⁻¹ and farm yard manure 2000 kg ha⁻¹ and protection against aphids (*Aphis craccivora*) attack and weeds^{6,7}. The crop was grown in two-row plots on ridges, 2 m long, with spacing of 0.5 m between rows and of 0.20 m between plants within rows⁸. The plot size was 1 m² (0.5×2 m²). The two experimental plots drought stressed and well-watered were separated by 5 m. To prevent seed borne diseases, seeds were treated before planting with a combination of fungicide/insecticide: Thiram 10% (C₆H₁₂N₂S₄) and imidacloprid 25% (C₉H₁₀ClN₅O₂) 25 g for 10 kg of seeds. The field was irrigated at 1st day interval before sowing. The sowing depth was 2.5-3 cm as recommended⁹. Seeds were hand planted in two experimental plots drought stressed and well-watered. The trial is surrounded by two buffer rows. Surface irrigation was used to apply water during the experiment.

After sowing, the crop was irrigated twice a week up to 50% plants flowering time 30 Days after Sowing (DAS). After that, the crop was maintained fully irrigated until pod filling time by irrigating up to saturation weekly. The plants were exposed gradually to end of season drought from the time to pod filling (50 DAS) until maturity. At 50 DAS, which corresponded with pod filling, water stress was imposed for 14 days and irrigation was resumed just after wilting point at the 15th day to bring the soil up to saturation. Then, drought stress was imposed for 10 days, followed by irrigation just after wilting point up to saturation. After that, water stress was imposed for 7 days followed by irrigation up to harvest (Fig. 1). The well-watered plots were irrigated fully weekly until harvest stage.

In each plot, five representative plants were selected randomly to record SPAD readings¹⁰. The SPAD chlorophyll meter (SPAD-502, Minolta Corp, Tokyo, Japan) readings (SCMR) were made on 45 DAS at field capacity, before water stress was imposed and on 60 and 90 days at wilting point after drought stress. An average SCMR for each plot was derived from 20 single observations (four leaflets x 5 plants per plot). While recording the SCMR, care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina to avoid interference from veins and midribs^{10,11}. The pod yield was determined from 10 plants selected randomly from each plot in all treatments. Drought Tolerance Index (DTI) was

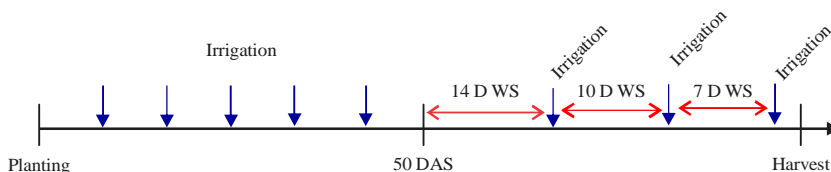


Fig. 1: Water stress imposition and irrigation frequencies

D: Days, WS: Well stress, DAS: Days after sowing

calculated for each trait as the ratio of the trait under Water Stress (WS) treatment to that under Well-Watered (WW) condition as suggested in Eq. 1¹².

$$DTI (SCMR) = \frac{SCMR (WS)}{SCMR (WW)} \quad (1)$$

Combined analysis of variance was computed for the 100 entries across water regimes for pod yield and SCMR (45, 60 and 90 DAS) following Residual Maximum Likelihood (REML) analysis using GENSTAT 12.0. with water regimes, replications and blocks treated as random effects while entries were considered as fixed effects.

RESULTS

Combined analysis of variance for pod yield and SCMRs are presented in Table 1. The genotypes showed similar ranking from one water regime to another for all tested traits. Nevertheless, highly significant differences were observed among the genotypes for all the traits in each environment. The effect of the two water regimes were significant for all traits measured.

Drought effect on pod yield: The genotype ICGV- SM 99511 had the highest yield under well-watered conditions (Table 2). However, under end of-season drought conditions, the genotype ICG6307 was the best yielding. Genotypes such as ICGV-IS01836, ICG4728, ICG5475, T13-89, ICGV-SM 99505 and ICGV-SM99511 performed well under both water regimes. Genotypes with least yield difference between water regimes include Tainan-9, ICGV-IS01820 and ICG11249. Based on the selection criteria defined previously, the top five drought tolerant genotypes were ICG6703, ICGV-SM99551, Tainan-9, ICG11249 and ICGV-IS01820. Based on the drought tolerance indexes, ICG6703 was the most drought tolerant genotype followed by ICG11249, Tainan-9; ICGV-IS01820 and ICGV-SM 99511.

Drought effect on SPAD chlorophyll meter readings: All entries showed significant ($p < 0.01$) differences in chlorophyll

content at 45, 60 and 90 DAS in both water regimes (Table 1). The overall means under drought stress conditions were higher than the overall means under irrigated condition. There was no genotype by irrigation ($G \times I$) interaction observed. Under drought conditions, ICGV-IS01820 showed the highest SCMR readings at 45 DAS, followed by ICG11249. The genotypes ICGVIS01852 and T13-89 showed the highest SCMR reading at 60 and 90 DAS under drought stress conditions. Tainan-9 had a better SCMR and ranked 2nd at 90 DAS. The magnitude of SCMRs was higher at 90 DAS compared to 45 and 60 DAS (Fig. 2-4). Tainan-9 displayed the highest DTI, followed by ICGV-SM99511 and ICG11249 at 60 DAS (Table 3).

DISCUSSION

In this study, some promising groundnut varieties with good performance for pod yield under drought stress (ICG6703) and well-watered conditions (ICGV-SM99511) were identified. The varieties Tainan-9, ICG11249 and ICGV-IS01820 performed well under both conditions. These varieties also showed good performance for SCMRs and showed higher drought tolerance indices for pod yield and chlorophyll content. Genotypes with high DTI values were considered drought tolerant while those with lower DTI values were considered drought susceptible¹³.

In this study, the responses to drought among the groundnut genotypes for SCMR at 45 and 60 DAS were similar but they were different at 90 DAS, therefore selection of drought tolerant genotypes could be done earlier at 45 or 60 DAS.

There were no significant differences among the genotypes for chlorophyll content. An increase in water stress period would likely show chlorophyll content differences among the genotypes. Although, it is not significantly different between water regimes, end of season drought seemed to increase SCMR. Similar to these results, researchers found that drought significantly increased SCMR¹⁴. However, an increase of chlorophyll content under water stress conditions, based on the increase of SCMR values was observed. Similarly researchers reported that drought stress significantly increased SCMR but it reduced stomatal

Table 1: Mean squares from the combined analysis of variance for pod yield and SCMRs under both water regimes

Source of variation	Mean square				
	DF	PY	SCMR (45 DAS)	SCMR (60 DAS)	SCMR (90 DAS)
Replications	1	129278	188.067	52.95	381.535
Genotypes	98	17134**	17.744**	26.14**	17.669**
Water regimes (Env. 1 and 2)	2	328815**	220.207**	892.2**	1760.247**
Genotypes × water regimes	98	7142	7.919	11.89	7.2
Residual	197	7423	8.071	15.78	7.067
Total	395	10885	11.426	19.7	15.116
Means		165 ^a /222.6 ^b	41.16 ^a /39.66 ^b	47.78 ^a /47.77 ^b	45.97 ^a /41.75 ^b
CV (%)		46.11	7.03	8.59	6.06
LSD at 5%		169.9	5.603	7.835	5.242

**Significant at $p \leq 0.01$, a: Under drought stress, b: Under well water condition, Env: Environment, DF: Degree of freedom, PY: Pod yield, DAS: Days after sowing, SCMR: SPAD chlorophyll meter readings, CV: Coefficient of variation, LSD: Least significant difference

Table 2: Pod yield (g m^{-2}) of the top 35 entries under drought stress and their performance under well-watered conditions and their respective drought tolerance indices

Rank	Entry	Pod yield under WS	Pod yield under WW	Least pod yield difference	DTI
1	ICG 6703 ^a	342	194	148	1.76
2	ICG 2738	326.5	191	135.5	1.71
3	ICGV 02266	310	203.5	106.5	1.52
4	ICGV-SM 99511 ^b	309	524	215	0.59
5	ICGV-87123	302.5	192.5	110	1.57
6	ICG 6022	300	218.5	81.5	1.37
7	ICGV-IS 01852	282.5	221	61.5	1.28
8	ICG 297	279	286.5	7.5	0.97
9	T13-89	274.5	315.5	41	0.87
10	ICGV-IS01836	270.5	343	72.5	0.79
11	ICG 5475	261	335.5	74.5	0.78
12	ICG 3421	253.5	309.5	56	0.82
13	ICG 3386	240.5	208	32.5	1.16
14	ICG-3301	236.5	188.5	48	1.25
15	ICG 3027	234	146.5	87.5	1.6
16	ICG 4728	224.5	337.5	113	0.67
17	ICG 1534	224	264.5	40.5	0.85
18	ICG 1834	223	229.5	6.5	0.97
19	ICGV-IS 01820 ^c	220	222.5	2.5	0.99
20	ICG 3343	213	280	67	0.76
21	ICG-6222	210	410	200	0.51
22	ICG-12991	207.5	196	11.5	1.06
23	ICGV-87281	207	213.5	6.5	0.97
24	ICG 9666	206	94.5	111.5	2.18
25	ICG 3746	206	265.5	59.5	0.78
26	ICGV-IS01859	205.5	299	93.5	0.69
27	Dayo	205.5	191	14.5	1.08
28	ICG 397	204.5	291	86.5	0.7
29	ICG 11249 ^c	204	204	0	1
30	ICG 8751	197.5	240.3	42.8	0.82
31	ICGV-SM 99507	162	319	157	0.51
32	ICGV-SM 99505	161.5	302	140.5	0.53
33	ICG 1823	160.5	253	92.5	0.63
34	T119-83	158	190.5	32.5	0.83
35	Tainan-9 ^c	157	159	2	0.99
	LSD 5%	155.17	195.71	-	-
	CV %	47.4	44.3	-	-

a: Best high yielding genotype under WS, b: Best high yielding genotype under WW, c: Entries selected based the least yield difference between WW and WS, WW: Well water, WS: Water stress, LSD: Least significant difference, CV: Coefficient of variation, DTI: Drought tolerance index

conductance¹⁵. They also found significant differences among peanut genotypes for SCMR at both stages under both conditions. Genotypes that showed high values of SCMRs and

maintained high biomass production under water stress may be drought tolerant. Similarly it has been showed that bambara groundnut plants maintain high amounts of

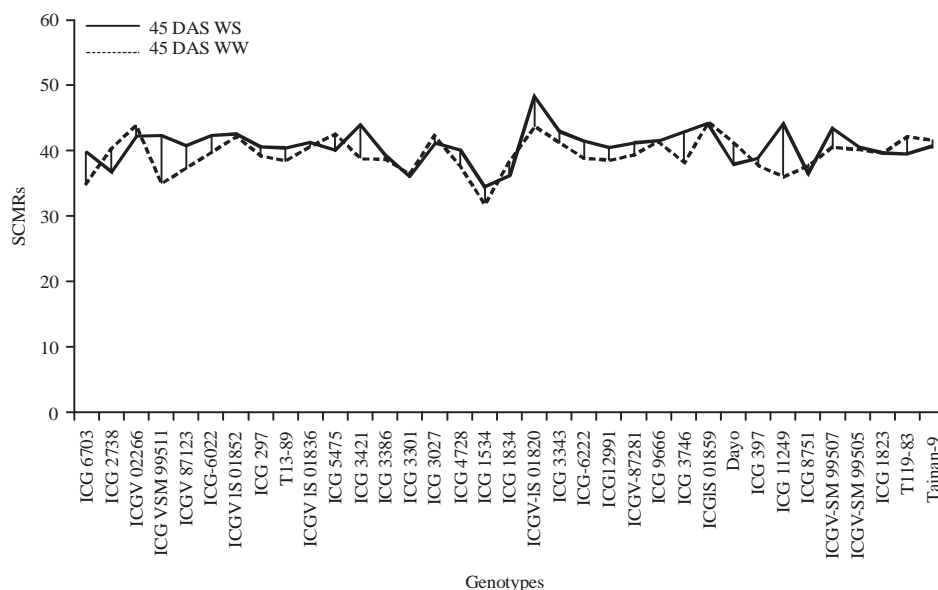


Fig. 2: Chlorophyll content 45 DAS under WS and WW conditions

DAS: Days after sowing, WW: Well water, WS: Water stress

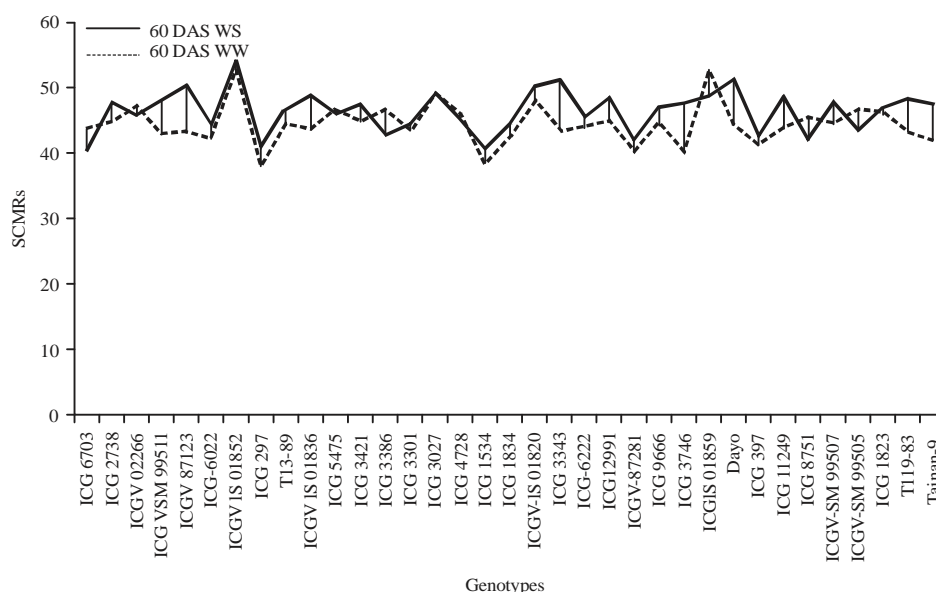


Fig. 3: Chlorophyll content pattern 60 DAS under WS and WW conditions

DAS: Days after sowing, WW: Well water, WS: Water stress

chlorophyll content despite the development of moisture deficit stress and this trait can be considered to be a line of defense against drought which can result in drought resistance¹⁶. Groundnut genotypes showing consistently high SCMRs values across water regimes and sampling dates were ICG-VSM 99511, ICGV87123, ICG6703, ICG 11249, ICGV-IS01820, Tainan-9, ICGV-IS01852, ICG12991, ICG3386, ICGV-IS01859, ICG9666, T13- 89, ICG3746 and ICG 297.

Water deficit usually causes an increase in the activity of chlorophyllase (5-aminolevulinic acid synthetase) an enzyme responsible for the breakdown of chlorophyll, resulting in a decrease in the amount of chlorophyll^{17,18}. Tolerant genotypes maintain their leaf water level and increase thickness of the leaves and chlorophyll density at early stage drought condition. The ability to maintain chlorophyll density under drought stress has been suggested as a drought tolerance

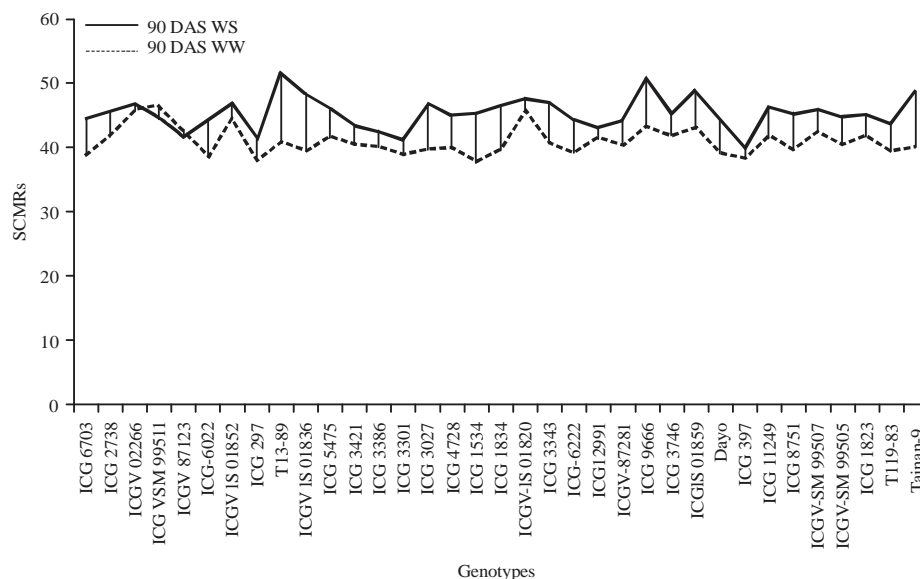


Fig. 4: Chlorophyll content pattern 90 DAS under WS and WW conditions

DAS: Days after sowing, WW: Well water, WS: Water stress

Table 3: Drought tolerance indices of the top 35 entries at 45, 60 and 90 DAS

Genotypes	DTI SCMR (45 DAS)	DTI SCMR (60 DAS)	DTI SCMR (90 DAS)
ICG6703	1.14	0.93	1.15
ICG 2738	0.91	1.06	1.09
ICGV 02266	0.96	0.96	1.02
ICG VSM 99511	1.20	1.12	0.96
ICGV 87123	1.10	1.06	0.97
ICG-6022	1.07	1.05	1.06
ICGV IS 01852	1.00	1.03	1.05
ICG 297	1.03	1.07	1.10
T13-89	1.05	1.05	1.11
ICG V IS 01836	1.02	1.11	1.02
ICG 5475	0.94	0.99	1.11
ICG 3421	1.13	1.05	1.07
ICG 3386	1.02	0.91	1.06
ICG 3301	0.98	1.03	1.06
ICG 3027	0.97	1.00	1.08
ICG 4728	1.07	0.98	1.12
ICG1534	1.08	1.06	1.02
ICG1834	0.94	1.05	1.17
ICGV-IS 01820	1.10	1.05	1.04
ICG 3343	1.04	1.08	1.05
ICG-6222	1.07	1.03	1.13
ICG12991	1.05	1.08	1.04
ICGV-87281	1.05	1.03	1.09
ICG 9666	1.00	1.05	1.17
ICG 3746	1.11	1.08	1.08
ICGIS 01859	0.99	0.93	1.13
DAYO	0.92	1.06	1.13
ICG 397	1.03	1.03	1.04
ICG 11249	1.22	1.11	1.11
ICG 8751	0.97	0.92	1.14
ICGV-SM 99507	1.07	1.07	1.08
ICGV-SM 99505	1.01	0.93	1.11
ICG 1823	0.99	1.02	1.08
T119-83	0.94	1.03	1.10
Tainan-9	0.98	1.13	1.21

DTI: Drought tolerance index, SCMR: SPAD chlorophyll meter reading, DAS: Days after sowing

mechanism in groundnut¹⁹⁻²¹. The increase of SCMR of groundnut under water limiting conditions and as this trait is related to photosynthetic capacity, they concluded that the increase of SCMR could be attributed to drought tolerance³. It could be hypothesized that groundnut genotypes with high SCMR have more photosynthetic machinery per unit leaf area and hence greater potential for assimilation under drought stress²². Drought stress has been the major environmental factor contributing to the reduced agricultural productivity and food safety worldwide. The resistance to drought is a very desired trait in breeding programs but it is also a complex process because drought triggers various molecular events in plants, leading to different responses in sensitive and resistant genotypes. Drought stress perceived by the plant from its surrounding environment varies spatially and temporally at several different scales, affecting membrane lipids and photosynthetic responses, such as thylakoid electron transport, phosphorylation and carboxylation²³. The consequences of these changes are reflected in the performance of crops, because as they have different genetic adjustments, they respond phenotypically to stress facilitating the selection. In this study, end-of-season drought caused pod yield reduction that varied among genotypes. However, certain genotypes showed less pod yield difference between both water regimes. The varieties Tainan-9, ICG11249 and ICGV-IS01820 showed least pod yield difference and continue to produce well under drought stress can be used by farmers in the short term as drought tolerant varieties prior to improvement of their popular varieties. High yielding cultivar that continues to produce well under drought stress is a priority to enable stability of production²⁴. In a participatory varietal selection conducted by INRAN in three locations in Niger in 2012, farmers in all the locations selected the variety Tainan-9 as the best drought tolerant variety that was high yielding with good biomass production.

CONCLUSION

An increase in SPAD chlorophyll in groundnut in response to imposed water deficit and effect of end of season drought on groundnut genotypes pod yields. The genotypes ICG6703, ICGV-SM 99511, Tainan-9, ICG11249 and ICGV-IS01820 were found to be best performing genotypes under normal and stress conditions and therefore, considered and selected as the drought tolerant based on their pod yield and chlorophyll content. So, these materials can be used as parental lines to establish a breeding programs for developing groundnut drought tolerant varieties.

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SIGNIFICANT STATEMENTS

- A challenge of the smallholder farmers in Niger is how to harness limited resources to mitigate harsh environment conditions for the improvement of groundnut production to enhance incomes and reduce malnutrition and poverty
- Consequently varieties that can escape drought should be developed. In the context of climatic variation with rainfall reduction in terms of duration and amount, recurrent drought affects groundnut performance in Niger
- There is a lack of information on genetic parameters required for breeding groundnut for drought tolerance related traits. Priorities in groundnut improvement should include tolerance to drought
- The findings can be used by the farmers in the Sahel as drought tolerant varieties or used by breeding programs to develop new groundnut varieties

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