Tapping the Sudanese sorghum germplasm for drought tolerance

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ABSTRACT

Two hundred and ten, seventy four, twenty four and eleven genotypes of sorghum were evaluated in 2001, 2002, 2003 and 2004, respectively, under full and partial irrigation at Gezira Research Farm, Wad Medani, Sudan. The experiment was arranged in a randomized complete block design with three replicates. The objectives of this study were to estimate the variability and genotype-environment interaction. Significant differences were detected among genotypes for the studied characters under both types of irrigation in almost all seasons. Stem borer damage was highly significantly affected by watering regimes, however, partial irrigation reduced stem borer damage. Genotypes PI 568329 and Yruasha had the least leaf senescence scores while PI 569371 and Yruasha were the least damaged by stem borer. Genotypes PI 563310 (5488 kg/ha) and PI 570851 (5452 kg/ha) outyielded the check varieties Yruasha (4596 kg/ha) and Wad Ahmed (5434 kg/ha). The current study depicted that the variability observed among the genotypes was maintained for most characters under both water regimes. Water stress reduced most of the studied characters but increased number of tillers per plant, lodging and senescence which could be used as selection indices.

INTRODUCTION

In Sudan, sorghum [*Sorghum bicolor* (L.) Moench] is leading other cereal crops in total cultivated area and total tonnage produced and consumed. It is the main staple food in the drier parts of the country and is used in different forms ranging from food to animal feed. The use of grain as an animal feed has been an important stimulus for the global use of sorghum (Dendy, 1995), and likewise human food in Sudan. Sorghum grain is used in the manufacture of items such as glue, starch and gluten feed.

In Sudan, sorghum is grown in an estimated area of 5 million ha and the production per year was 4,999 million tons (FAO, 2007). Compared to other cereals, sorghum is more tolerant to many stresses including heat, drought, salinity and flood (Ejeta and Knoll, 2007). The main problems limiting production of sorghum under rain-fed conditions are drought (Mohamed, 1998), sorghum midge, shortages of farm machinery and striga (Dawoud, *et al*., 2007). Confirmation of the drought constraint also come from the reports which indicated the high correlations between rainfall and sorghum yield (r = 0.7) in Kassala (Eastern Sudan) indicating that annual yields were mostly dependant on climate (Larsson, 1996). Similar results were found in western Sudan by Ahlcrona (1988) who reported that the decline in yield during 1961 to 1986 was due to the low amount of rainfall and the small number of days with rainfall over 10 mm per day which were highly correlated to the yield of sorghum and millet (r = 0.7).

Improving drought tolerance in sorghum would increase and stabilize grain and food production in areas with low rainfall and harsh environments. Plant breeders at the Agricultural Research Corporation (ARC) were successful in releasing many varieties like Yruasha, Bashayir, Butana and AG 8 targeting the low rainfall areas. Evaluation of large number of sorghum genotypes with different genetic background would help in identifying and selecting drought tolerant types for further improvement. This study was conducted to (1) estimate the amount of variability present in the local sorghum germplasm across four seasons; and (2) quantify the amount of variation attributable to the effects of environment, genotypes and genotype by environment interactions.

MATERIALS AND METHODS

Different sorghum genotypes were evaluated under full and partial irrigation in the Gezira Research Farm (GRF) of the Agricultural Research Corporation (ARC), Wad Medani (latitude 13^{0} 30́ - 15^{0} 15́ North, longitude 30^{0} 33́ East and 407 masl), during the rainy seasons of 2001 to 2004. The experiments were arranged in a randomized complete block design with three replications. Gezira soil is alkaline and has a high clay content, poor structure, low organic content, low permeability but with high water holding capacity (Amin, 2002).

The climate of Gezira is a typical semi-arid tropical environment, characterized by a short period of rainfall and a prolonged dry spell. Kharif season, usually starts in July and extends to October. The total rainfall received was generally low and ranged from 190 mm to 395 mm. The mean daily minimum and maximum temperatures were 23^{0}C and 37^{0}C, respectively.

Two hundred and ten accessions of sorghum were selected from the total sorghum germplasm conserved in the gene bank of the ARC of Sudan based on days to 50 % flowering (less than 70 days) and plant height (less than 2 m). The material used in 2002 consisted of 74 sorghum genotypes selected from the 210 genotypes based on yield, plant height, flowering time and leaf senescence. In addition, 4 genotypes, namely, Arfaa Gadamac, Wad Ahmed, Gadamplia and PI 563310 were introduced to the experiment for the first time. Arfaa Gadamac and Gadamplia are landraces grown in the rain fed areas, Wad Ahmed is a released variety for high rainfall areas, and PI 563310 was reported by ICRISAT to be drought tolerant. In 2003, 24 genotypes were selected from the 74 genotypes based on their superiority of grain yield. Six of them are Sudanese germplasm evaluated in USA and has been proved to have a gene of drought tolerance (Rosenow *et al.*, 1996); and the other two were used as checks (Tabat and Yruasha). Selection from the 24 genotypes continued till the genotypes were reduced to 11 accessions in 2004 season. The genotypes Wad Ahmed and Yruasha were used as resistant checks and Tabat as a susceptible check to water stress.

The land was prepared by plowing, harrowing, leveling and then ridging. Intra and inter-row spacing were 80cm and 20 cm, respectively. Plot size was 5m x 2.4m. The trials were planted during the second week of July in 2001 through 2004 and harvested in October of each season.

The experiments were watered immediately after sowing to ensure uniform germination and crop establishment. Water stress was imposed by withholding water from the partially irrigated (PI) plots when water depletion reached the specified point (70% of the available water) while the fully irrigated plots (FI) were irrigated when 50% of the available water was depleted.

Selected sorghum heads were bagged to prevent out-crossing and protect them from bird's damage and were used for grain yield determination. These plants were used for recording observations on different morph-agronomic traits. The following measurements were taken during the four seasons under full and partial irrigation: Plant height (cm), flowering time, number of leaves per plant, flag leaf area (cm^2) (measured as an average of three plants per plot at flowering stage, by using the ruler method (leaf area= length x width x 0.75) as described by Stickler *et al.* (1961)). Number of tillers per plant, lodging (visually rated using the scale where, not = no lodging, low = the stems half lodged, and high = the plants completely lodged and uprooted or broken), senescence (measured at maturity as percentage of dry leaves to the total leaves per plant for three plants per plot), grain yield (t/ha), 100-grain weight (g), number of grains per panicle and stem borer damage (%) (measured as the percentage of infected plants to the total plants in the plot).

Data collected were analyzed following the procedure of analysis of variance to examine the differences among the genotypes for all traits measured in each season separately and then combined. In the combined analysis of variance seven genotypes that were grown throughout the four seasons (2001- 2004) were used to test for the effect of environment, genotypes and their interactions. Treatment means were separated using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Significant differences were found among genotypes for the studied characters in almost all seasons and under both types of irrigation (Table 1), suggesting that the sorghum population used in this study were highly variable and, therefore, will respond to selection. Genotypes had a wide range of variability for each character as shown by range values under full and partial irrigation. The upper limits range for most of the characters were more than two times their lower limits. Comparing the range values under two watering regimes, the range values of these characters were either increased or maintained. Generally, the lower limits under water stress were less than that under irrigation, whereas, the upper limits were similar indicating that water stress increases variability in term of plant height, flowering time and number of tillers, but reduced variability of leaf senescence, grain yield and number of grains per panicle. The number of leaves, flag leaf area, lodging, 100 grain weight and stem borer damage were similar.

Generally, water stress reduced the mean for most of the characters but increased tiller production, lodging and senescence. The plant height, flowering time, flag leaf area, grain yield, 100 grain weight, number of grains per panicle and stem borer damage under partial irrigation were less by 11%, 3%, 14%, 19%, 8%, 12% and 39%, respectively, than that under full irrigation. However, number of tillers, senescence and lodging were higher by 15%, 16% and 9%, respectively, than under full irrigation, whereas number of leaves per plant was not affected by watering. The largest decreases induced by drought stress were observed for stem borer damage and yield. The plant height reduction can be attributed to occurrence of pre-flowering drought tolerance which was accompanied by reduction in dry matter production and grain yield. The flowering time was enhanced by drought stress and the difference was 6 days which was observed in the second season, suggesting that mild drought stress occurred at the early stages of growth. The present results were similar to Angus and Moncur (1977) in which mild water stress

Table 1. Phenotypic variability for 11 traits in different sorghum genotypes grown under full (FI) and partial irrigation (PI) at the Gezira Research Station, 2001, 2002, 2003 and 2004.

Trait	Season	General Mean		Range of mean		SE (±)		CV (%)		Sig. level	
		FI	PI	FI	PI	FI	PI	FI	PI	FI	PI
Plant height (cm)	2001	154	138	62-265	59-243	0.9	2.1	8	21	***	***
	2002	161	136	92-233	49-233	2.6	1.4	16	7.5	***	***
	2003	154	154	78-202	83-251	5.6	5.6	18	18	***	***
	2004	160	150	117-195	133-181	8.9	4.8	19	10	NS	*
Flowering time (days)	2001	64	64	46-78	54-78	0.3	0.2	7	6	***	***
	2002	63	57	45-68	46-68	0.4	0.3	5	5	***	***
	2003	75	74	71-83	68-78	0.7	0.6	4.7	4	**	**
	2004	72	73	61-83	62-90	1.3	2.7	6	12	***	*
Number of leaves/plant	2001	10	10	6-13	7-13	0.1	0.1	13	12	***	***
	2002	11	9	7-14	7-14	0.1	0.2	11	11	***	***
	2003	12	12	9-16	10-15	0.4	0.4	17	15	***	***
	2004	12	12	9-17	11-14	0.5	0.5	12	12	***	***
Flag leaf area (cm^2)	2001	252	240	148-378	145-401	6.1	3.1	34	19	***	***
	2002	165	165	95-305	115-305	1.1	1.1	30	27	***	***
	2003	213	180	140-299	138-286	5.2	6.3	12	17	***	***
	2004	187	123	149-218	90-156	14	3.6	25	23	***	NS
Number of tillers/plant	2001	1.6	1.7	0.7-3.3	0-3	0.03	0.04	30	33	***	***
	2002	0.8	0.6	0.7-2	0-2	0.03	0.02	34	28	***	***
	2003	1.6	1.8	0-4	0-3	0.09	0.10	27	27	***	***
	2004	0.7	1.8	0.3-2	1-3	0.07	0.09	30	17	***	***

Table 1. (Continued).

Trait	Season	General Mean		Range of mean		SE (±)		CV (%)		Sig. level	
		FI	PI	FI	PI	FI	PI	FI	PI	FI	PI
Senescence (%	2001	5.8	6.5	4.9-8.1	4.4-8.7	0.04	0.08	11	19	***	***
	2002	7.6	8.1	6.8-9.7	6.8-9.6	0.07	0.10	9	10	**	**
	2003	6.6	7.5	5.1-8.9	6.1-9.4	0.15	0.09	11	6	***	***
	2004	5.6	7.5	4.3-8	6.3-8.7	0.31	2.26	18	12	**	**
Lodging (%)	2001	3.9	4.1	1.55-10	0.5-9.6	0.9	0.70	33	30	***	***
	2002	7.0	7.1	0.5-9.1	0.5-9.1	0.16	0.27	18	29	***	***
	2003	6.4	7.2	5.5-9.2	5.5-9.2	0.14	0.20	11	14	***	***
	2004	6.6	7.6	5.5-7.5	6.6-8.6	0.3	0.32	16	14	NS	NS
Yield (kg/ha)	2001	4294	3461	1205-7854	1146-5824	85	72	29	30	***	***
	2002	3472	2214	1147-4564	1147- 4564	75	88	19	28	***	***
	2003	3504	3436	1984-5837	1416-5488	226	181	32	26	***	***
	2004	5541	4540	3405-6770	2966-5952	449	430	27	31	***	NS
Grain weight (g	2001	2.28	2.16	1.10-4.30	0. 68-4.20	0.02	0.03	18	2	***	***
	2002	2.40	2.04	1.20-3.60	1.2- 3.6	0.06	0.04	23	16	***	***
	2003	2.24	2.14	1.10-3.00	1.2-3.8	0.06	0.04	17	10	***	***
	2004	2.30	2.26	1.85-3.40	1.6-3.2	0.06	0.19	10	29	***	***
Number of grains/panicle	2001	1900	1641	632-3785	350-3384	32	27	24	24	***	***
	2002	1452	1405	602-2366	602- 2366	57	26	57	15	***	***
	2003	1325	1423	490-2513	888-2399	63	55	23	19	***	***
	2004	2316	1791	929-3027	1091-2606	137	172	20	32	***	***
Stem borer damage (%)	2001	2.4	1.5	1.5-6.3	0.7-5.2	0.04	0.04	27	34	***	***
	2002	6.2	4.4	2.6-7.8	2.6 -7.8	0.15	0.14	20	28	***	***
	2003	3.98	2.07	1.3-5.8	0.5-2.6	0.23	0.11	28	26	***	***
	2004	3.93	2	0.5-5.6	0.5-4.0	0.19	0.19	19	32	***	***

*,** and *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.
NS : Not significant.

hastened flowering by a few days while under severe water stress a delay in flowering was more common.

The reduction of flag leaf area for Yruasha and PI 569371 could be one of the mechanisms by which sorghum was able to acquire drought tolerance that helped in the reduction of water loss by transpiration. Water stress also hastened leaf senescence and the susceptible genotypes like PI 568329 and Tabat showed more rapid leaf yellowing and senescence than drought tolerant genotypes. These drought tolerant genotypes possess the stay green trait which is an important character as drought tolerant mechanism for post-drought tolerance (Rosenow *et al.*, 1983). Senescence and leaf shedding reduce leaf area and hence reduce evapotranspiration rate and grain yield.

The yield reduction presented in Table 1 was mainly a result of pre-flowering drought stress which directly affected panicle size and grain number per panicle, while grain weight reduction was possible and could reduce yield if terminal stress prevailed. The grain weight reduction was a result of post-flowering drought that occurred due to dry spells at the grain filling stage, especially for the late maturing cultivars. The reduction in the number of grains per panicle, particularly in the first and the last season could be attributed to pre-flowering drought which might have caused poor head exsertion and sterile spikelets (Mastrorilli *et al.*, 1995). The combined analysis of variance showed that seasons were a significant source of variation for all characters under study (Table 2).

The significant mean squares values obtained across seasons for all characters indicated that the conditions in the four seasons were not similar and accordingly the genotypes did not perform the same in all seasons.

The interaction of genotypes with seasons (GxS), irrigation x seasons (IxS) and genotype x irrigation (GxI) were significant for most of the characters (Table 2). However, the significant interactions of genotypes with seasons for all the characters reflected their instability across seasons.

Similar results were reported by other workers (Shivanne *et al.*, 1992; Santos *et al.*, 1995; Tadesse and Debelo, 1995). The significant genotype x season x irrigation interactions demonstrated that genotype x season interaction was different at different irrigation and, likewise, genotype x irrigation was different in the different seasons. It also indicated that the genotypes responded differently at a certain irrigation regime in different seasons.

In general, the data in Table 2 showed the importance of testing genotypes over seasons. There is a general agreement among breeders that testing genotypes over seasons increases the efficiency of selection and hence results in high yielding genotypes with a wide adaptation to different

Table 2. Mean squares of irrigation, seasons, genotypes and their interaction of 11 traits for seven sorghum genotypes grown at the Gezira Research Station during 2001–2004 seasons.

Trait	Irrigation(I)	Season(S)	Genotype(G)	IxS	IxG	SxG	SxGxI
Plant height	49 NS	2214^{**}	3184^{***}	8208^{***}	434 NS	970^{*}	214 NS
Days to flowering	590^{*}	1598^{***}	243^{*}	65 NS	120 NS	201^{*}	130 NS
No. of leaves/plant	63^{***}	61^{***}	7.3^{*}	29^{***}	1.3 NS	8^{***}	4.99^{***}
Flag leaf area	28687^{***}	63182^{***}	13475^{***}	9413^{***}	4059^{*}	3334^{**}	5166^{***}
No. of tillers	0.19NS	20^{***}	2.07^{***}	2.23^{***}	1.07^{*}	2.56^{***}	1.12^{***}
Senescence	2870^{***}	2378^{***}	975^{***}	929^{***}	728^{***}	1453^{***}	311^{**}
Lodging	2442^{***}	4458^{***}	90 NS	2344^{***}	226 NS	488^{***}	319^{*}
Yield	9198770^{*}	23666302^{***}	1694390 NS	9590362^{***}	4235581^{**}	2625271^{*}	1998923^{*}
Grain weight	1.21^{**}	2.81^{***}	5.52^{***}	0.92^{**}	0.36^{*}	0.75^{***}	0.251^{*}
No. of grains	294396 NS	3301439^{***}	1500265^{***}	2015295^{***}	362366 NS	893221^{***}	496817^{***}
Stem borer	2474^{***}	3137^{***}	319^{*}	372^{*}	150^{*}	238^{*}	256^{***}

*, ** and *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

NS : Not significant at probability ≤0.05

environments. The breeding strategy for sorghum under water limited conditions emphasized early and stable flowering as means of avoiding moisture stress in areas where unreliable rainfall is the major constraint to sorghum productivity.

Genotype PI 563310 showed the highest plant height in both seasons while Tabat was the shortest genotype under irrigation. Later on plant height was quite variable under water stress conditions. The susceptible check (Tabat) showed reduced plant height under water stress, while the tolerant check (Yruasha) also showed a reduced plant height under the same condition. In general, drought stress hastened flowering in both tolerant and susceptible checks as well as the other genotypes used in this study.

Wad Ahmed, the leafy genotype, produced 16 leaves in 2003 season compared to 14 leaves in the 2002 under full irrigation (Table 3a). Yruasha, produced the minimum number of leaves (9) in the same season and irrigation, while under partial irrigation Yruasha produced the lowest number of leaves (10) per plant and genotype PI 568308 produced the highest. Water stress had little effect on number of leaves per plant in both seasons.

Sorghum also avoids drought by reducing transpiration demand as a result of reduced leaf area. In this study, water stress reduced flag leaf area by 16% and 39% in 2003 and 2004, respectively. Water stress increased number of tillers per plant by 9% and 32% in seasons 2003 and 2004, respectively. The adjustment of tillers during mid-season stress is one of the developmental plasticity required and useful when there is a good probability of adequate rains to complete and extend cropping period. Drought stress during grain filling in sorghum usually results in rapid premature plant senescence. The results in this study showed that Tabat and PI 568377 were highly senescent genotypes under full irrigation in 2003 and 2004 seasons, while the least senescent under the same watering regime were PI 568383 and PI 563310. But under partial irrigation, genotypes PI 568329 and Yruasha were the least senescent. Water stress increased senescence by 13% and 34% in seasons 2003 and 2004, respectively. The drought tolerant check (Yruasha) showed less senescence under partial irrigation compared to that under full irrigation, suggesting that this genotype continues to fill their grains normally under water stress (Rosenow and Clarck, 1981).

Generally, water stress increased lodging by 13% and 16% in season 2003 and 2004, respectively. The susceptible check (Tabat) showed an increase in lodging under water stress, while the tolerant check (Yruasha) showed a reduction in lodging under water stress in both seasons.

Table 3a. Means and ranks of 11 characters of 11 sorghum genotypes grown at Gezira Research Station under full irrigation (FI), in 2003 and 2004.

Genotype	Plant height (cm)	Flowering (days)	Number of leaves /plant	Flag leaf area (cm^2)	Senescence (%)	Numbers of tillers /plant	Lodging (%)	Yield (kg/ha)	100 Grain weight (g)	Grain number per panicle	Stem borer damage (%)
PI 568335	180 A-C (2)	74 CDE (9)	13 B-F (3)	299 AB (2)	6.26 E-H (8)	2.33 CE (4)	5.5 B (11)	2404 DG (10)	2.29 AD (5)	822 FG (9)	5.0 AB (3)
	157 ABC (7)	77 AB (5)	10 BC (10)	225 B (2)	5.66 B-D (4)	0.0 D (11)	6.19 AB (9)	3738 C (11)	3.18 A (1)	929 C (11)	3.76 BC (6)
PI 563310	202 A (1)	74 CDE (8)	11 B-E (5)	142 I (1)	6.88 B-F (4)	2.00 DF (6)	5.5 B (10)	4687 AC (4)	1.95 DH (7)	1946 B (2)	3.41 BC (10)
	195 A (1)	68 CD (7)	12 B (4)	218 BC (3)	4.33 D (11)	1.0 BC (5)	7.57 A (1)	6129 B (3)	1.76 CD (10)	2625 AB (5)	2.8 CD (9)
PI 569371	176 A-D (3)	73 C-E (11)	11 B-E(6)	140 I (11)	5.72 E-H 10)	2.33 CE (3)	9.2 A (1)	4208 AE (7)	2.41 BE (4)	1550 BE (6)	4.36 AB (8)
	180 AB (3)	61 D (11)	17 A (1)	305 A (1)	5.33 C-D (5)	0.0 D (7)	6.19 AB (8)	8437 A (1)	2.57 B (2)	2632 AB (4)	3.77 BC (4)
Tabat	114 DE (11)	82 AB (2)	11 B-E (7)	170 H-I (7)	8.26 A (1)	1.66 E-G (7)	6.2 B (4)	3563 BF (8)	1.80 EH (10)	1887 BC (3)	4.81 AB (5)
	117 C (11)	82 A (2)	12 BC (7)	217 BC (4)	4.66 D (9)	2.0 A (2)	6.19 AB (10)	5966 BC (4)	2.09 BCD (8)	2944 A (3)	3.31 BD (7)
Yruasha	170 A-D (5)	75 C-E (9)	9 E (11)	174 H-I (6)	7.92 A-D (2)	2.66 BD (2)	9.2 A (2)	4450 AD (6)	2.86 A (2)	870 FG (8)	4.67 AB (6)
	158 ABC (6)	66 D (5)	13 B (3)	183 B-D (7)	4.66 D (10)	13 AB (4)	7.57 A (2)	5620 BC (5)	2.22 BCD (7)	3010 A (2)	2.45 D (10)
PI 568308	141 A-E (7)	83 A (6)	12 B-E (4)	255 B-E (3)	7.04 B-E (3)	1.66 EG (9)	5.5 B (9)	4697 AC (3)	1.87 EH (8)	1575 BE (5)	4.89 AB (4)
	169 ABC (4)	80 AB (3)	9 C (11)	149 B-E (8)	5.00 D (6)	0.3 CD (6)	7.50 A (3)	4358 BC (10)	2.53 B (3)	1575 BC (10)	0.50 E (11)
PI 568383	140 A-E (9)	74 C-E (1)	10 C-E (8)	237 C-F (4)	5.22 GH (11)	1.33 FH (10)	5.5 B (8)	3149 BG (9)	2.03 CG (6)	702 FG (11)	5.84 A (1)
	152 ABC (9)	72 BC (6)	16 A (2)	200 BC (5)	5.00 D (7)	0.0 D (8)	5.5 B (11)	5028 BC (8)	1.62 D (11)	3027 A (1)	3.26 BD (8)
PI 570851	172 A-D (4)	76 B-E (4)	14 A-C (2)	145 I (9)	6.79 C-F (6)	2.66 DF (1)	6.2 B (3)	5837 A (1)	3.08 A (1)	1582 BE (4)	4.61 AB (7)
	155 ABC (8)	64 CD (10)	11 BC (9)	142 C-E (9)	5.00 D (8)	0.0 D (9)	7.41 AB (4)	6216 B (2)	2.08 BCD (9)	2210 AB (7)	5.57 A (1)
PI 568329	166 A-D (6)	74 C-E (7)	10 C-E (9)	209 E-H (5)	6.84 B-F (5)	1.66 EG (8)	5.5 B (7)	1984 FG (11)	1.68 FI (11)	918 FG (7)	5.33 AB (2)
	183 AB (2)	78 AB (4)	12 B (5)	104 E (11)	7.00 ABC (3)	0.0 D (10)	6.8 AB (6)	4844 BC (9)	2.30 BC (6)	1876ABC (9)	4.17 B (2)
PI568377	134 BE (10)	73 C-E (10)	10 B-E (10)	146 I (8)	6.3 D-G (9)	0.00 I (11)	5.5 B (6)	2652 CG (5)	2.66 AC (3)	754 FG (10)	3.38 BC (11)
	166 ABC (5)	68 CD (8)	11BC (8)	121 DE (10)	8.00 A (1)	2.0 A (3)	6.88 AB (5)	5334 BC (6)	2.47 B (4)	2605 AB (6)	3.76 BC (5)
W Ahmed	140 A-E (8)	77 A-D (3)	16 A (1)	324 A (1)	6.68 C-G (7)	2.33 CE (5)	6.19 B (5)	4915 AB (2)	1.81 EH (9)	2513 A (1)	4.19 AB (9)
	132 BC (10)	83 A (1)	12 BC (6)	193 B-D (6)	7.33 AB (2)	2.0 A (1)	6.19 AB (7)	5287 BC (7)	2.40 B (5)	2051 AB (8)	3.98 BC (4)
Mean	157	75	12	204	6.71	1.87	6.36	3867	2.22	1374	4.49
	160	73	12	187	5.63	0.78	6.72	5541	2.29	2316	3.39

Values between parentheses are the rank number

Upper values are for season 2003, while the lower values are for season 2004.

Means followed by the same letter(s) within a column do not differ significantly at the probability level of 5% according to Duncans Multiple Range Test.

The highest average yield across the two seasons (2003,2004) were obtained by genotypes PI 570851 (5837kg/ha) and PI 569371 (8437kg/ha) in seasons 2003 and 2004, respectively, under full irrigation; while the lowest average yield in 2003 and 2004 seasons under full irrigation were recorded by genotypes PI 568329 (1984kg/ha) and PI 568335 (3738 kg/ha), respectively. Under partial irrigation, PI 563310 (5488 kg/ha) and Yruasha (5952 kg/ha) gave the highest grain yield in 2003 and 2004, respectively. The lowest grain yield was scored by genotypes Tabat (2146 kg/ha) and PI 568308 (2996 kg/ha) in 2003 and 2004, respectively. The genotype PI 563310 outyielded the tolerant check varieties Yruasha and Wad Ahmed by 16% and 1%, respectively, while PI 570851 outyielded the tolerant check varieties Yruasha and Wad Ahmed by 16% and 0.3%, respectively.

Sorghum crop produced lower grain yields when subjected to water stress in seasons 2003 and 2004. The reductions in yield were approximately 2% and 12.5% in seasons 2003 and 2004, respectively. The low grain yield obtained in 2003 could be attributed partly to reduction in number of grains per panicle and the compensatory effect of grain weight.

The highest weight of 100 grains under full irrigation in the last two seasons (2003-2004) were 3.08 and 3.18 g recorded by genotypes PI 570851 and PI 568335, respectively, (Table 3a). However, the lowest 100 grain weight under same watering regimes and seasons were 1.68 and 1.62 g, recorded by PI 568329 and PI 568383, respectively. The highest weight of 100 grains under partial irrigation in the last two seasons (2003-2004) were 3.8 and 3.17g recorded by PI 570851 and Wad Ahmed. Whereas, the lowest weight of 100 grains under same watering regimes and seasons were 1.81 and 1.68g recorded by Tabat and PI 569371. Susceptible control (Tabat) showed a reduction in 100 grain weight in the two seasons under water stress.

The number of grains per panicle varied from 2513 to 3027 in 2003 and from 702 to 929 in 2004 under full irrigation. While under partial irrigation, the number of grains ranged from 2339 to 2606 in 2003 and from 888 to 1091 in 2004. In 2003, Wad Ahmed produced the highest number of grains per panicle whereas genotype PI 570851 produced the lowest number of grains per panicle in 2004, under both water regimes. Whereas, the susceptible check (Tabat) showed a reduction in the number of grains per panicle under partial irrigation in 2004. Water stress reduced number of grains per panicle of the tolerant check, Yruasha, in 2004.

Stem borer damage varied from 3.38 to 5.84% in 2003 and from 0.50 to 5.57% in 2004 under full irrigation (Table 3a).

Table 3b. Means and ranks of 11 characters of 11 sorghum genotypes grown at Gezira Research Station under partial irrigation (PI), in 2003 and 2004.

Genotype	Plant height (cm)	Flowering (days)	Number of leaves /plant	Flag leaf area (cm^2)	Senescence (%)	Number of tillers /plant	Lodging (%)	Yield (kg/ha)	100 Grain weight (g)	Grain number per panicle	Stem borer damage (%)
PI 568335	171 BF (7)	74 A-E (5)	13 AF (5)	184 BG (3)	6.15 I (11)	2.33 ABC (4)	8.63 AB (2)	4485 AC (6)	2.69 BD (4)	1246 DG (9)	2.39 A (3)
	155 AC (3)	71 B (7)	13 AB (3)	150 AB (2)	6.6 CD (9)	1.0 D (8)	7.0 A (9)	4367 AB (8)	1.96 AB (7)	1860 AC (4)	3.98 A (2)
PI 563310	251 A (1)	71 D-F (11)	14 A-D (4)	164 D-G (5)	6.49 G-I (9)	0.33 EF (11)	7.41 A-C (7)	5488 A (1)	2.12 EG (7)	2234 AB (2)	1.97 A (9)
	165 AB (2)	68 B (8)	11 B (9)	125 A-C (5)	7.0 BD (6)	2.0 C (5)	7.4 A (7)	4885 AB (4)	2.27 AB (6)	1618 AC (8)	0.50 C (8)
PI 569371	211 AB (2)	73 A-F (6)	11 B-E (8)	140 I (11)	6.40 H-I 10)	2.33 BC (5)	8.63 AB (3)	4751 AB (4)	2.30 BF (5)	1863 AF (6)	1.58 AB (11)
	148 BC (6)	74 AB (5)	13 AB (4)	116 A-C (8)	8.2 AC (5)	1.0 D (1)	7.4 A (8)	4407 AB (6)	1.68 B (11)	2606 A (1)	1.07 BC (7)
Tabat	131 FJ (11)	78 A (1)	12 A-F (7)	151 F-G (8)	6.86 BF (6)	2.33 BC (6)	5.5 C (10)	2146 DE (11)	1.81 GI9 (11)	1946 AD (5)	2.38 A (4)
	149 BC (5)	77 AB (3)	11 B (8)	123 AC (6)	8.7 A (2)	3.0 A (2)	8.6 A (1)	5642 AB (2)	1.90 B (9)	2289 AB (2)	0.50 C (9)
Yruasha	199 BD (4)	72 C-F (9)	10 F (11)	140 G (10)	6.73 E-I (7)	2.66 AB (2)	8.1 AB (5)	4596 AB (5)	3.57 A (2)	888 J (11)	2.31 A (7)
	149 BC (4)	64 B (10)	11 B (10)	107 A-C (9)	6.4 D (10)	2.3 AC (4)	6.8 A (10)	5952 A (1)	2.57 AB (3)	1945 AC (3)	3.85 A (4)
PI 568308	145 EI (1)	77 A-C (2)	15 A (1)	210 B-F (2)	6.88 E-I (5)	2.0 BC (9)	8.6 AB (4)	4301 AD (8)	1.87 GI (8)	2031 ABC (3)	2.51 A (2)
	145 BC (8)	90 A (1)	14 A (1)	90 C (11)	8.3 AB (3)	1.0 D (11)	7.5 A (6)	2996 B (11)	1.77 B (10)	1429 BC (9)	1.07 BC (6)
PI 568383	172 BF (6)	72 B-F (10)	11 B-F (9)	286 C-E (1)	7.17 C-I (4)	2.33 BC (8)	7.41 AC (8)	3104 AD (10)	2.13 EG (6)	1593 BI (8)	2.21 A (8)
	148 BC (7)	71 B (6)	11 B (11)	120 AC (7)	6.6 CD (8)	1.0 D (7)	7.5 A (5)	4183 AB (9)	1.93 B (8)	1725 AC (7)	3.89 A (3)
PI 570851	203 BC (3)	73 A-F (7)	14 A-C (3)	178 CG (4)	7.71 C-I (1)	2.66 AB (3)	7.6 AC (6)	5452 A (2)	3.8 A (1)	1141 GJ (10)	2.37 A (6)
	142 BC (9)	66 B (9)	12 AB (5)	96 C (10)	6.3 D (11)	1.0 D (6)	8.1 A (3)	3344 AB (10)	2.40 AB (5)	1091 C (1)	4.0 A (1)
PI 568329	182 BF (5)	76 A-E (4)	10 D- (10)	154 E-G (7)	7.32 C-I (3)	3.33 A (1)	7.41 AC (9)	4214 AD (9)	1.73 GH (9)	1957 ABC (4)	1.74 AB (10)
	181 A (1)	77 AB (4)	12 AB (7)	156 A (1)	9.1 A (1)	1.0 D (9)	6.8 A (6)	4386 AB (7)	2.54 AB (4)	1425 BC (10)	2.13 B (5)
PI 568377	133 FJ (10)	72 B-F (8)	12 B-F (6)	163 D-G (6)	6.57 F-I (8)	1.00 DF (10)	9.2 A (1)	4426 AD (7)	3.0 B (3)	1610 BH (7)	2.61 A (1)
	136 BC (10)	62 B (11)	12 AB (6)	142 A-C (3)	6.7 BD (7)	2.7 B (3)	8.1 A (4)	4600 AB (5)	2.64 AB (2)	1854 AC (6)	0.50 C (10)
W.Ahmed	143 EI (9)	76 A-E (3)	15 AB (2)	151 FG (9)	7.36 C-H (2)	2.33 ABC (7)	5.5 C (11)	5434 A (3)	1.81 GH (10)	2399 A (1)	2.38 A (5)
	133 C (11)	89 A (2)	14 A (2)	134 A-C (4)	8.2 AC (4)	3.0 A (1)	8.1 A (2)	5181 AB (3)	3.17 A (1)	1858 AC (5)	0.50 C (11)
Mean	176	74	12	175	6.88	2.15	7.63	4399	2.42	1718	2.22
	150	74	12	123	7.46	1.73	7.57	4540	2.26	1790	1.99

Values between parentheses are the rank number

Upper values are for season 2003 while the lower values are for season 2004.

Means followed by the same letter(s) within a column do not differ significantly at the probability level of 5% according to Duncan s Multiple Range Test.

However, under partial irrigation, it ranged from 2.61 to 4% and from 0.50 to 1.6% in 2003 and 2004, respectively. Water stress reduced stem borer damage by 48% and 41% in 2003 and 2004, respectively. The highest damaged genotypes under full irrigation were PI 568383 in 2003 and PI 570851 in 2004, while the least damaged genotypes under partial irrigation for the same period were PI 569371 and Yruasha, respectively.

The current study depicted that variability was maintained for most characters under both water regimes. Water stress reduced most of the studied characters but increased number of tillers per plant, lodging and senescence. Stem borer damage was highly significantly affected by watering regimes and seasons.

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دراسة تحمل الجفاف لمداخيل ذرة رفيعة سودانية

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الخلاصة

تم تقييم مائتين وعشرة سلالة من الذرة الرفيعة موسم 2001، أربعة وسبعون سلالة موسم 2002، أربعة وعشرون سلالة موسم 2003 واحد عشرة سلالة موسم 2004 في مزرعة محطة بحوث الجزيرة بواد مدني, السودان. استخدم تصميم القطاعات العشوائية الكاملة بثلاث مكررات تحت ظروف ري كامل وجزئي وذلك لدراسة التباين و تفاعل السلالة مع البيئة. أظهرت النتائج أن هنالك تبايناً معنوياً بين السلالات في معظم الصفات المدروسة تحت الري والجفاف خلال المواسم الأربعة (2001 – 2004). تأثرت الإصابة بثاقبات الساق بمستوي الري فقد إزدادت متأثرة بالجفاف بينما زاد عدد الخلف في النبات، جفاف الأوراق والرقاد. السلالات و يرواشا بينما PI 569371 ويرواشا كانت الأقل جفافاً للأوراق و كانت السلالات الأقل إصابة بثاقبات الساق هي PI 568329 PI في الإنتاجية هي kg/ha (5434 و ود احمد (4526 kg/ha) التي تفوقت على الشواهد المتحملة للجفاف يرواشا (أوضحت الدراسة ثبات التباين تحت الري الكامل والجزئي ولكل 5452). kg/ha (PI 570851 و 54) 563310)kg/ha88 المواسم. الإجهاد المائي قلل معظم الصفات بينما زاد عدد الخلف للنبات ونسبة الرقاد وجفاف الأوراق لذا يمكن استخدامها كدلائل انتخاب.