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ORIGINAL ARTICLE

Effect of Water Stress on Vegetative Growth, Yield and Yield Components of Sweet Sorghum (*Sorghum bicolor* L.) Genotypes

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Abstract

A field experiment was conducted during autumn season 2015 in semi arid zone of Sudan, at two different sites namely; Demonstration Farm of the College of Agriculture and Natural Resources, Bakhat AlRuda University, El-Dueim, White Nile State, and the Salinity Research Station, Agricultural Research Cooperation, Soba, Khartoum State. The objectives were to estimate the genetic variability of sweet sorghum lines under drought stress conditions, and to identify the most tolerant lines under such conditions. Six lines of sweet sorghum selected from forty genotypes, based on high yielding ability and high juice and drought stress resistance, were evaluated using a split- plot design with three replications. Three watering regimes were applied, namely, water stress during vegetative and grain filling stages and well-watering as a control. Genotypic coefficient of variation, heritability and drought tolerance parameters were determined. Results obtained showed that, non-significant differences were detected between the genotypes for most of the studied characters except plant height, grain yield/plant and number of seeds/head. Water stress at vegetative stage significantly reduced number of grains/head of all genotypes, and so, it caused a greater grain yield (ton/ha) reduction than water stress at other stages. Water deficit during vegetative and grain filling stages reduced grain yields by 10% and 2.8% on average in comparison to control, respectively. High genotypic coefficient of variation and heritability were exhibited by juice yield/plant. A wide range of genetic variability was detected by genotypes for drought tolerance. According to their high yield and tolerance under drought conditions, the genotypes G6 and G8 could be used for further breeding program to improve drought tolerance in sweet sorghum.

Keywords: Cereal, genetic variability, lines, drought tolerance

Introduction

Sorghum (S*orghum bicolor* L. Monech) is the fifth most important cereal crop in the world. It yields multiple products depends on variety. Grain sorghums are used for human food, while forage sorghums are used for animal feed, and sweet sorghums for edible syrup. The latter varieties accumulate high amount of sugars in the stem during maturation. Sorghum has a highly efficient photosynthetic pathway and is very efficient in the utilization of soil nutrients. It requires less water than sugarcane and is tolerant to drought and flooding. It has a short production cycle and is capable of re-growth as a ratoon crop. Recent studies comparing various crops found that, sugarcane in Brazil and sweet sorghum in China are the most sustainable ecosystems for renewable fuel production. They provide the most efficient use of land, water, nitrogen and energy resources (De Vries *et al*., 2010).

In Sudan, sweet sorghum, locally known as “Ankolib”, is grown in small areas under traditional farming systems in Kordofan, Darfur, Sennar and White Nile states. Drought is a multidimensional stress, often coupled with heat stress affecting plants at various levels of their metabolic mechanisms (Blum, 1996). It is generally accepted as the most widespread abiotic stress experienced by crop plants (Quarrie *et al*., 1999). If plants are to survive this abiotic stresses they must have a range of morphological, biochemical and physiological mechanisms that enable them to grow and reproduce despite water limitations (Turner, 1997).

Drought tolerance is defined as the relative ability to sustain plant function under dehydrated state and achieving an economic yield potential (Blum, 2004). Many studies were conducted to investigate sweet sorghum as a drought-tolerant crop. Sweet sorghum is an annual warm season crop similar to grain sorghum in grain production, and almost like sugarcane for sugar-rich stalk and high sugar accumulation (Ratanavathi *et al*., 2003). As a C4 crop, sweet sorghum features have rapid growth, low water requirement, high biomass production and wide adaptation. However, the objectives of this study were to estimate the genetic variability among different sweet sorghum genotypes under drought stress conditions, and to identify the most tolerant genotypes under such conditions.

Materials and Methods

Experiment sites

In order to achieve the objectives of this study, two field experiments were carried out simultaneously, during the autumn season (2015), at two locations in semiarid zone of Sudan. These locations were: the Demonstration Farm of the Faculty of Agriculture, University of Bakhat Al-Ruda, El-Dueim, White Nile State; and the Salinity Research Station, Soba, Agricultural Research Cooperation, Khartoum State, Sudan. The annual rainfall of the semiarid zone ranges between 100 and 300mm (Elhadary, 2007).

Plant materials

Six sweet sorghum lines were selected from forty genotypes (tested in Bakhat Al-Ruda, University at El-Dueim, White Nile State, Sudan), based on high yielding ability, high juice contents and good resistance to drought. The genotype code number and name of such lines used in the study were: 1 (G6), 2 (G7), 3 (G8), 4 (G9), 5 (S8) and 6 (S1).

The experiment

Regarding treatments, drought stress was induced by applying three watering regimes during both vegetative and reproductive stages included; 1) control (D_0) which represented watering every 7 days throughout the growing season, 2) water stress (D_1) which represented watering every 21 days till end of flowering, pursued by watering every 7 days till physiological maturity, and 3) water stress (D_2) which represented watering every 7 days till end of the flowering, then watering every 21 days till maturity. The two experiments were conducted in a split-plot design with three replications, where the water regimes were assigned randomly as main plots, and the genotypes were grown randomly as subplots. Each genotype was sown in five ridges, each of 4 meters length. All cultural practices were done according to the recommendations. Five randomly selected plants per sub plot were used for data collection at each location. Different growth and yield characters were measured included: plant height (cm), stem diameter (mm), leaf area (cm^2), fresh weight/plant (t/ha), dry weight/ m^2 (t/ha), grain yield (g) and volume of juice (L\ha), number of grains/head and grain yield (ton/ha). The Drought tolerance parameters measured included: ratio between yields of the genotypes evaluated under non-stressed condition to yields of genotypes evaluated under stressed condition (YD_0/YD_1), stress susceptibility index (SSI) and geometric mean productivity (GMP). The statistical analysis of variance was carried out according to Gomez and Gomez (1984) for split-plot arrangements. Based on the analysis of variance the genotypic coefficient of variation (GCV%) was calculated according to the method of Burton (1952), and heritability percentage in broad sense (h^2) was estimated according to the method suggested by Johnson *et al*. (1955).

Results and Discussion

The combined analysis of variance revealed that, highly significant differences ($P \leq 0.01$) were detected between the different environments for most characters under study (Table 1). The general means of genotypes for grain yield were 3.01 and 6.37 ton/ha at Soba and El-Dueim locations, respectively. The location of El-Dueim was more productive than that of Soba (Table 2). On the other hand, highly significant difference was detected between locations for most characters studied except stem diameters, leaf area and juice yield/ plant.

Table 1. Mean squares of the combined analysis for different traits of six sweet sorghum genotypes, under three levels of water stress at Soba and El-Dueim areas, autumn (2015).

	Locations	Stress	stress x locations	Genotype	genotype x locations	genotype x stress	location x genotype x stress
Traits	**1**	**2**	**2**	**5**	**5**	**10**	**10**
Plant height	293304^{**}	44.00^{ns}	2114.7^{*}	1891.0*	725.9	919.6	445.6
Stem diameter	8.74^{ns}	16.48^{ns}	1.63	9.19	17.15^{**}	5.48	2.99
Leaf area	23078^{ns}	33348^{ns}	10776^{*}	21947^{ns}	41332^{**}	8786^{ns}	63123.0^{ns}
Fresh weight/plant	1400.3**	2.65^{ns}	155.8^{ns}	310.0^{ns}	106.6^{ns}	109.0^{ns}	107.5^{ns}
Dry weight from $1M^2$	5569.9^{**}	17.92^{ns}	24.12^{ns}	54.73^{ns}	54.73^{ns}	13.20^{ns}	21.84^{ns}
Grain yield/plant	6510.06^{**}	144.1^{ns}	239.0^{ns}	266.0^{*}	112.4^{ns}	216.0^{ns}	154.4^{ns}
Juice yield/plant	5580ns	34.90^{ns}	66.21^{*}	12.30^{ns}	22.86^{ns}	10.01^{ns}	17.72^{ns}
Number of seed/head	899953*	569555*	622888*	285684*	63039.0^{ns}	151897.0^{ns}	121785^{ns}
Grain yield (Ton/ha)	305.96**	2.65^{ns}	1.18^{ns}	3.90^{*}	2.35^{ns}	1.75^{*}	1.34^{ns}

*,**: significant at the 0.01 level of probability,* : significant at the 0.05 level of probability, and ns : none significant at the 0.05 level of probability.

Table 2. Environmental effects of two locations on some characters of six sweet sorghum genotypes evaluated under three water treatments (D_0 , D_1 and D_2), during autumn 2015.

Traits	Locations			LSD	CV (%)
	Soba	**El-Dueim**	**Means**		
Plant height (cm)	161.60	194.50	178.10	15.60	14.6
Stem diameter (mm)	19.46	18.89	19.17	2.00	13.8
Leaf area (cm^2)	403.80	433.10	418.50	42.52	23.7
Fresh weight/plant (g)	33.00	55.80	44.40	6.67	26.6
Dry weight from $1m^2$ (g)	5.11	19.47	12.29	2.66	9.6
Grain yield/plant (g)	37.60	53.10	45.30	2.49	25.2
Juice yield/plant (ml)	4.07	18.44	11.25	7.15	28.0
Number of seed/head	1064	1246	1155	153.80	30.7
Grain yield (ton/ha)	3.01	6.37	178.10	0.21	24.7

Variation due to genotypes × locations interaction was non-significant for all investigated traits, except stem diameter (Table 1). In addition, significant differences were observed among the genotypes for plant height, number of seeds/head and grain yield (ton/ha). Water stress treatments were non-significantly different in all morphological traits except number of seeds/head. The interactions between genotype and treatment were also non-significant for all morphological traits except grain yield (ton/ha) (Table 1). Similar findings of the decreased shoot growth during water stress have been reported in sweet sorghum (Khanzada *et al*., 2001) and in other plants (Srinivasan and Arjunan, 1987). These results indicated that, water stress in sweet sorghum can cause significant reduction in biomass production including grain yield. Stage sensitivity studies for understanding the effect of water stress on sweet sorghum revealed that the water stress had severe impact in the water use efficiency at early stage of sweet sorghum (Mastrorilli *et al*., 1999). However, a perennial stress had a significant impact at the late stage (Tingting *et al*., 2010). In this study, water stress at vegetative (D1) stage in sweet sorghum had significant effect on growth and yield traits. The highest GCV was exhibited for juice yield/plant, and the lowest was for number of seeds/head. Moreover, the highest value of heritability was estimated for plant height and the leaf area, and lowest value was recorded for juice yield/plant (L), dry weight/ m^2, stem diameter and grain yield (Table 3). Similar results were observed by Bello *et al*. (2001) and Bello *et al.* (2007), who revealed that the low heritability estimate of grain yield is due to the direct and indirect multiplicative effects of yield components on grain yield.

A wide range of genetic variability was detected among genotypes under drought conditions (Table 4). The highest (5.75

Table 3. Morphological traits of sweet sorghum genotypes evaluated under three water stress conditions (D_0, D_1 and D_2), and estimates of genotypic coefficient of variation (GCV) and heritability (h^2) at two locations (Soba and El-Dueim), during autumn 2015.

Traits	Drought treatments			Mean	LSD	GCV (%)	h^2
	D_0	D_1	D_2				
Plant height (cm)	178.8	178.6	176.8	178.1	12.31	1.64	37.56
Stem diameter (mm)	19.57	19.90	19.05	19.17	1.25	1.10	22.73
Leaf area (cm^2)	393.8	428.1	433.5	418.5	46.62	1.36	37.56
Fresh weight/plant (g)	42.1	44.9	46.2	44.4	5.56	1.35	28.89
Dry weight from $1m^2$(g)	12.94	11.54	12.39	12.29	3.03	0.69	9.67
Grain yield/plant (g)	47.0	43.4	46.0	45.3	5.37	1.25	25.80
Juice yield/plant (ml)	10.19	11.43	12.14	11.25	2.42	5.45	6.61
Number of seed/head	1294	1048	1123	1155	166.7	0.02	25.25
Grain yield (ton/ha)	4.90	4.41	4.76	4.69	0.54	1.22	24.55

Table 4. Effects of water stress and sorghum genotypes on mean of drought tolerance parameters at two locations (Soba and El-Dueim), during autumn 2015.

Genotypes	Yield (ton/ha)			Drought tolerance parameters					
				Yd/Yw		SSI		GMP	
	D_0	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
G6	4.51	4.37	4.24	0.97	0.94	0.18	0.75	4.44	4.37
G7	5.27	3.51	5.21	0.67	0.99	1.91	0.14	4.30	5.24
G8	4.36	3.99	4.26	0.92	0.98	0.49	0.29	4.17	4.31
G9	5.6	4.53	5.52	0.81	0.99	1.09	0.18	5.04	5.56
S8	5.75	4.95	4.48	0.86	0.78	0.80	2.76	5.34	5.08
S1	5.11	3.9	4.44	0.76	0.87	1.35	1.64	4.46	4.76
Means	5.10	4.21	4.69	0.83	0.92	0.97	0.96	4.62	4.89

Yd/Yw= grain yield under drought conditions/grain yield under normal conditions; SSI= stress susceptibility index; GMP= geometric mean productivity.

ton/ha) grain yield under non-stress (D_0) conditions was obtained by genotype S8, while the lowest (4.36 ton/ha) was produced by genotype G8. On the other hand, under drought stress conditions D_1, the highest grain yield (4.95ton/ha) was recorded for genotype S8 and the lowest (3.71 ton/ha) for the genotype G7 (Table 4). In additions, the highest (5.52 ton/ha) grain yield under drought stress D_2 conditions was obtained by genotype G9, while the lowest (4.24 ton/ha) was produced by genotype G6 (Table 4). However, the genetic variability of the genotypes under drought stress conditions was referred to different inheritance of genotypes to drought resistance which encouraged breeders to adopt alternative strategies to improve stress resistance (Borrell, *et al*., 2006). The analysis for drought tolerance recorded that, the ratio of grain yield under drought conditions/grain yield under normal conditions (Yd/Yw) expresses drought tolerance as shown in Table 4. The highest value of Yd/Yw (97.0%) under D_1 was exhibited by G6, whereas the lowest value (67%) was exhibited by G7. However, under D_2 the highest value of Yd/Yw (99%) was given by G7, while the lowest one (78%) was obtained by S8 (Table 4). Under D_1 the highest value of SSI (1.91) was given by G7, whereas the lowest value of SSI (0.18) was obtained by G6. When drought was induced during D_2, the highest value of SSI (2.76) was given by S8, while the lowest value of SSI (0.18) was exhibited by G9. The highest geometric mean of productivity (GMP) was produced by genotype S8 under D_1 and G7 under D_2. The values were 5.34 and 5.24, respectively. Whereas, the lowest GMP was obtained by genotype G8 under both D_1 and D2, and the values were 4.17 and 4.31, respectively. A larger value of SSI and GMP show relatively more sensitivity to stress (Gobaladi *et al*., 2006).

Conclusion and Recommendation

It could be concluded that there is a differential response of sorghum genotypes to drought stress. Grain yield and its components were more sensitive to water stress than other morphological characters. A wide range of genetic variability was detected among the studied genotypes for drought tolerance. This variability can be exploited in the improvement for drought tolerance in this crop. The genotypes G6 and G8 could be recommended under unfavorable conditions. These genotypes could be used for further breeding program to improve drought tolerance in sweet sorghum.

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