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Evaluation of Some Sorghum Genotypes under Normal and Moisture-stress Conditions

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Abstract: This study was undertaken to identify the morphological and physiological attributes related to drought tolerance in sorghum [*Sorghum bicolor* (L.) Moench**]**. Eight genotypes were tested in a pot experiment carried out at Giessen, Germany. Drought conditions were imposed by withholding watering of the plants when field water-holding capacity was at 40% and 70%. The tested genotypes differed significantly in most of the measured traits. Grain yield under drought stress ranged from 28 to 61 g/ plant, and relative yield ranged from 30% to 56% with an average of 47%. Based on yield/plant, the genotypes Wad Ahmed (61g), SAR 41(55g) and ICSR 91030 (54g) were the best under drought stress conditions; and based on relative yield, the best genotypes were SAR 41 (56%), Wad Ahmed (55%), and Red Mugud (53%). The mean potassium content was 18 mg/g, with a range of 14 mg/g (Red Mugud) to 22 mg/g (Arfa Gadamak). Significant differences were obtained for protein percentage of the dry matter under conditions of drought stress. The values ranged from 14.1% (Red Mugud) to 16.7% (Tabat) with a mean of 15.3%. Grain yield under drought stress was positively correlated with relative yield (r = 0.89), total biomass (r = 0.56), number of seeds per panicle (r = 0.66) and harvest index (r = 0.81), but negatively correlated with 1000-grain weight (r = - 0.37).

Key words: Sorghum genotypes; moisture-stress

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench], the fifth in hectarages among the world's cereals (Doggett 1988), is a principal cereal in the staple diet throughout the semi-arid Asian and African regions, where various types of abiotic stress exist, especially drought and elevated temperatures (Ahmed *et al*. 2000). Drought is the major limiting factor to agriculture and is considered the most important factor in yield reduction of crop plants (Osaki *et al*. 1992). Numerous studies have indicated that drought can have substantial negative impacts on plant growth and development (Carrow 1996).

Breeding of drought tolerant sorghum varieties is an urgent issue, since this crop is widely grown under conditions of drought stress (Blum *et al.* 1989). Genetic variation for drought tolerance in sorghum is wide and frequent, depending on the mechanism involved, e.g., earliness and root depth (Jordan and Miller 1980). Identification of morphological and physiological mechanisms involved in plant responses to drought stress will provide the basis for breeding plants with improved drought tolerance (Sanchez *et al*. 2002). Therefore, the objectives of this study were to evaluate the performance of eight sorghum genotypes in pot experiments under two water regimes and to identify morphological and physiological traits that are related to drought tolerance.

MATERIALS AND METHODS

Eight genotypes (Red Mugud, Wad Ahmed, Tabat, Gadamballia, Arfa Gadamak, SAR 41, PI 569695 and ICSR 91030) from different morphological groups and geographical regions were chosen from a set of 96 genotypes, based on genetic diversity estimated by Simple Sequence Repeats (SSR) analysis (Abu Assar *et al*. 2005). A pot experiment was carried out in a greenhouse on movable trays (under rainout shelter) during May-September 2003 using randomised design with four replications. The plants were sown at a density of 10 plants/ pot. Each pot contained 11 kg of artificial mixture of soil, well mixed with 26 g fertilizer (N 12%, P_2O_5 12%, K_2O 17%, MgO_2% and SO_2 15%) before sowing. The pots were pre-irrigated with distilled water (500 ml/pot) to maintain similar soil moisture conditions. After sowings, the pots were covered by polyethylene net to reduce evaporation during germination.

At the three to four-leaves stage, the number of plants was reduced to two plants per pot. Throughout the experimental period, the pots were irrigated with distilled water to about 70% and about 40% maximum water holding capacity. These values were assumed to represent normal and stress treatments, respectively. The values of 70% and 40% will give an idea about the difference in amount of depleted water for each treatment. The daily mean temperature during the experiment period ranged from 14.5^{o}C in May to a maximum of 22.5^{o}C in August.

Data were collected on fourteen plant traits: Days to 50% flowering, plant height, grain per panicle, growth rate, root dry weight, protein percentage of dry matter, K content, grain yield/plant, primary branches, panicle weight, 1000-grain weight, biomass weight/plant and harvest index.
Dry weight of shoots and roots were determined after drying the plants in an oven at 80˚C for 48 hours, and samples were ground and used for K and protein analysis. Potassium content was determined by Atomic Absorption Spectrometer, and the protein percentage of dry matter was calculated using N-analyser (Caro Erba, Italy), following Dumas method (William 1943), where the total nitrogen per sampled weight of dry matter was multiplied by the factor 6.25. The collected data were statistically analysed, according to Gomez and Gomez (1984), using the software programme SPSS 11.5 (www.SPSS.com). The differences between the means of the studied traits were separated by Tukey's multiple-range test.

The performance of the genotypes under drought stress and normal conditions was used to estimate relative performance (drought tolerance index) for the studied traits, and was calculated as follows:

$$\text{Relative performance (\%)} = \frac{\text{Performance under stress conditions}}{\text{Performance under normal conditions}} \times 100$$

In order to obtain useful information on selection criteria that could be used in breeding programmes for drought tolerance, correlation coefficients between traits were calculated using Pearson' correlation coefficient.

RESULTS

Yield and reproductive traits

The genotypic differences were significant for yield and most of the studied reproductive traits. The results showed reduction in most of the measured traits of plants grown under drought stress (Table 1). The average grain yield/plant under drought stress was 45 g compared to 96 g under normal conditions. The highest yield/plant under drought stress was shown by the cultivar Wad Ahmed (61 g), followed by SAR 41 (55 g) and ICSR 91030 (54 g), and the lowest yield/plant by Tabat (28 g). Based on relative yield, the best genotypes were SAR 41 (56%), Wad Ahmed (55%) and Red Mugud (53%).

The number of primary branches was significantly affected by drought stress; it ranged from 38 (Arfa Gadamak) to 52 (SAR 41) with a mean of 45 branches, the range of relative performance of this trait was 81% (Red Mugud) to 100% (Wad Ahmed), and the mean was 93% (Table 2). The means of number of grains per panicle, 1000-grain weight and panicle weight were reduced by drought stress, and their relative performance was 46%, 93%, and 69%, respectively. Mean biomass and harvest index were also affected by drought stress (Table 2). Harvest index under drought stress showed wide variation and ranged from 28% (Arfa Gadamak) to 49% (Wad Ahmed). However, the relative performance of harvest index ranged from 57% for Tabat to 156% for Wad Ahmed.

Vegetative and physiological traits

Drought stress also affected all the measured vegetative traits (days to 50% flowering, plant height, stem diameter, growth rate and root dry weight) as well as physiological traits (potassium content and protein percentage of the dry matter). Significant differences were detected among genotypes for the vegetative and physiological traits (Tables 1 and 3).

Table 1. Means, ranges and significance levels for agronomic and physiological traits of eight sorghum genotypes averaged over normal and drought-stress conditions, during 2003, at Giessen, Germany

Trait	Unit	Mean	Range		Signif. level
			Min.	Max.	
Days to 50% flowering (DFF)	days	82	71	94	**
Relative DFF	%	105	97	117	**
Plant height (PHT)	cm	95	75	125	**
Relative PHT	%	61	52	68	**
Growth rate (GR)	cm/day	1.2	0.8	1.5	**
Relative GR	%	58	53	66	**
Potassium content (KC)	mg/g	18	14	22	**
Relative KC	%	140	112	180	*
Grain/panicle (GP)	No.	1607	1242	2138	**
Relative GP	%	46	28	75	**
Grain yield (GY)	g	45	28	61	**
Relative GY	%	47	30	56	**
1000-grain weight (TGW)	g	24.5	19	27	**
Relative TGW	%	93	91	97	**
Biomass (BM)	g	121	102	173	**
Relative BM	%	45	35	53	**
Harvest, index (HI)	g/g	37	18	49	**
Relative HI	%	106	57	156	NS
Stem diameter (SD)	cm	5.1	4.7	5.4	**
Relative SD	%	94	88	104	NS
No. of primary branches (PB)	No.	44.6	38	51	**
Relative PB	%	93	81	100	**
Panicle weight (PW)	g	48	37	56	**
Relative PW	%	69	50	87	**
Root dry weight (RDW)	g	48.7	26	67	**
Relative RDW	%	87	79	98	NS

NS * ,**=Non-significant, significant at P=0.05 and 0.01, respectively

Table 2. Grain yield and yield components of eight sorghum genotypes under drought stress in pots, and their relative performance to control (normal) at Giessen (Germany) in 2003

	Grain yield/plant (g)			PB (No.)		GP (No.)		TGW (g)		PW (g)		BM (g)		HI (%)	
Genotype	Stress	Relative	Mean	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative
Red Mugud	42	53	62	51	81	1242	39	24	94	42	87	234	44	41	120
Arfa Gadamak	29	31	61	38	91	736	28	28	97	52	79	264	39	28	79
Tabat	28	30	60	47	91	1659	48	23	91	55	73	196	52	27	57
SAR 41	55	56	77	52	98	2681	75	19	85	56	77	246	53	43	106
ICSR 91030	54	50	81	44	100	1671	37	26	94	56	61	336	51	31	97
Gadamballia	46	47	72	38	88	1266	51	31	96	36	50	244	46	42	104
PI 569695	48	52	70	44	94	1466	48	27	96	38	55	300	40	40	129
Wad Ahmed	61	55	85	43	100	2138	41	20	93	50	68	347	35	49	156
Mean	45	47**	71	45	93	1607	46	25	93	48	69	271	45	37	106
SE±	2.2**	2.1	1.8**	0.9**	1.8	103*	2.6	0.74**	1.4	1.6**	2.4	9.0**	1.2	1.6**	5.9

PB= Primary branches, GP= Grains/plant, TGW= Thousand grain weight, PW=Panicle weight, BM=biomass, HI (%) = Harvest index
* , ** = Significant at P = 0.05 and 0.01, respectively

Table 3. Vegetative and physiological traits of eight sorghum genotypes under drought stress in pots and their relative performance to the controls, at Giessen (Germany) in 2003

Genotype	DFF (days)		PHT (cm)		SD (cm)		KC (mg/g)		GR (cm/day)		RDW (g)		PPDM (%)	
	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative	Stress	Relative
Red Mugud	82	117	125	63	4.8	103	14	133	1.5	54	50	98	14.1	99.9
Arfa Gadamak	94	106	81	60	5.4	91	22	165	0.9	57	54	88	15.1	99.8
Tabat	88	103	85	64	5.1	94	17	132	1	63	47	90	16.7	109.6
SAR 41	85	103	96	68	5.0	86	20	112	1.1	66	26	82	16.3	103.5
ICSR 91030	83	108	113	65	5.2	91	17	118	1.4	60	47	87	15.0	99.1
Gadamballia	71	97	82	52	5.4	99	20	162	1.2	53	52	79	15.6	97.2
PI 569695	73	98	103	61	5.3	104	20	180	1.4	62	67	94	15.2	101.2
Wad Ahmed	88	104	75	55	4.7	88	17	117	0.8	53	47	81	14.3	106.0
Mean	83	105	95	61	5.1	94	18	140	1.2	58	49	87	15.3	102.
SE±	1.3**	1.1**	3.0**	1.0**	0.1NS	2.2NS	0.6**	6.6*	0.1**	0.9**	2.0**	3.0	0.24*	2.0NS

PHT= Plant height, DFF= days to 50%flowering, SD= Stem diameter. KC= Potassium content, GR= Growth rate, RDW= Root dry weight, PPDM (%) = Protein percentage dry matter

NS, *, ** = Non-significant, significant at P = 0.05 and 0.01, respectively

Table 4. Phenotypic correlation coefficients among 12 traits of eight sorghum genotypes evaluated under drought stress and normal conditions, during 2003, at Giessen (Germany).

Traits	RY	DFF	PHT	SD	PB	PW	TGW	PW	BM	HI	KC	PPDM
YS	0.89**	-0.307	0.095	-0.280	0.152	0.662*	-0.367*	0.001	0.555*	0.810**	-0.172	-0.22
RY		-0.400*	0.311	-0.293	0.116	0.523**	-0.309	-0.181	0.357*	0.83**	-0.229	-0.22
DFF			-0.24	-0.187	0.072	0.026	-0.421*	0.702**	0.092	0.364	.038	-0.04
PHT				-0.119	0.524**	0.059	0.011	0.077	0.334	-0.066	-0.356*	-0.20
SD					-0.381**	-0.335	0.515**	-0.193	0.038	-0.369*	0.435*	0.14
PB						0.539**	-0.594**	0.277	0.029	0.157	-0.436*	0.16
GP							-0.75**	.0412**	0.357*	0.502**	-0.124	0.20
TGW								-0.494**	-0.126	-0.304	0.208	-0.09
PW									0.314	-0.249	0.037	0.19
BM										-0.029	-0.115	0.10
HI											-0.157	-0.20
KC												0.11

RY= Relative yield, YS= Yield per plant under stress conditions, DFF= days to 50% flowering, PHT= plant height, SD= Stem diameter, PB= Primary branches, GP= Grains/plant, TGW= Thousand grain weight, PW=Panicle weight, BM=biomass, Harvest index, KC= Potassium content

*, ** = Significant at P=0.05 and 0.01 level of probability, respectively

Mean Potassium content (KC) under drought stress was 18 mg/g, and it ranged from 14 mg/g (Red Mugud) to 22 mg/g (Arfa Gadamak). The mean of relative performance was 140%, with a range of 112% (SAR 41) to 180% (P1 569695), as compared to the controls. Significant differences among genotypes were also recorded for protein percentage of the dry matter under drought stress, with a range of 14.2 (Red Mugud) to 16.7 % (Tabat).

Association between grain yield and other traits

Grain yield under drought stress was positively correlated with relative yield (r = 0.89), total biomass (r = 0.56), number of grains/panicle (r = 0.66) and harvest index (r = 0.81), but negatively correlated (r = - 0.37) with 1000-grain weight (Table 4). Relative yield was significantly and positively correlated with number of grains/panicle and harvest index and negatively and significantly associated with days to 50% flowering (Table 4). The number of grains/panicle had a significant negative correlation (r = -0.75) with 1000-seed weight. Potassium content exhibited positive significant association (r = 0.44) with stem diameter and negative significant correlation (r = - 0.44) with number of primary branches. However, its correlation with relative yield was negative and non-significant (Table 4). Protein percentage of the dry matter showed non-significant positive associations with some characters and negative with others (Table 4).

DISCUSSION

Reproductive and vegetative traits

Water deficits often occur in the production of most crops, and numerous studies have indicated that they can have substantial negative impacts on plant growth and development (Carrow 1996). In this study the genotypes suffered drastically under drought stress and showed reduction in most of the measured traits.

Water stress reduced mean yield by 55%. The highest yield per plant under drought conditions was obtained from the cultivar Wad Ahmed, followed by SAR 41 and ICSR 91030. These three genotypes also had the best yield under normal or non-limiting water conditions. Based on relative yield, the best genotypes were SAR 41, Wad Ahmed and Red Mugud. Therefore, it is clear that the cultivars Wad Ahmed and SAR 41 were superior under drought stress. The variability in yield under stress and normal conditions is in agreement with the findings of other researchers, e. g., Acevedo and Ceccarelli (1989). The means of 1000-grain weight and biomass were reduced by drought stress to 93% and 45%, respectively. This indicates that 1000-grain weight was relatively unaffected by the environment (drought stress) and therefore it could be highly genetically controlled.

There is evidence to suggest that plants avoiding drought have adaptation mechanisms leading to acquisition of higher amounts of available water or can restrict their growth activities to the periods of water availability. An example of these is the enhancement and increase of root dry matter and consequently high root/shoot ratio which may reach 60% to 90% of plant biomass (Fitter and Hays 1987). However, under the stress conditions of this study the drought-tolerant genotypes SAR 41 and Wad Ahmed had relative performance of root dry weight of 81% and 82%, respectively, which were less than the relative performance of the susceptible genotype Tabat (90%). This result indicates that with a decrease in water availability, not only the root growth of tolerant genotypes is enhanced at the expense of shoot growth (Dwyer and Stewart 1985) but other mechanisms and plant strategies could be used and involved to increase the water-use-efficiency of the plant under the drought conditions.

Days to 50% flowering are an important trait especially in marginal areas where crops are able to escape drought by completing their life cycle before the onset of the drought (Blum *et al* 1989). On the other hand, late flowering can be useful in escaping early season drought, if drought is followed by rains (Ludlow and Muchow 1990). In this study, days to 50% flowering under water stress was delayed by up to 12 days. This delay may be due to the interaction of day length, high humidity and low temperature of European climate in comparison to the semi-arid climatic conditions. The relatively high yield of Wad Ahmed and SAR 41 under stress was not associated with escape mechanism, as they were slightly late in heading than Gadamballia and PI 569695. Growth rate under drought conditions was associated with delayed flowering and shorter plants.

The findings of this study showed that drought stress had resulted in significant genotypic differences in potassium content, which was higher under drought stress compared to the normal conditions. Abu Assar *et al* (2002) observed that drought–tolerant sorghum varieties accumulate more potassium than the susceptible varieties. Furthermore, plants well-supplied with potassium had a higher stomatal resistance resulting in a lower transpiration rate. Potassium also plays an important role in sorghum osmotic adjustment and stomata opening (Sanchez *et al*. 2002). In this study, the maximum potassium content of the stressed plants was detected in the cultivars Arfa Gadamak and Wad Ahmed. This finding confirms previous results when the Energy–Dispersive X-ray Fluorescence Technique was used to quantify trace elements in sorghum genotypes under drought stress condition (Abu Assar *et al.* 2002). Since potassium plays an important role in osmotic adjustment and stomata movement, therefore consideration of this trait as a selection criterion for drought resistance will be useful.

Protein stability plays an essential role in dehydration tolerance (Acevedo and Ferreres 1993) and also as osmotic inactive molecules (Francisco *et al.* 1999). The cultivars behaved differently regarding protein percentage of dry matter, and only the cultivar Gadamballia had shown reduction in protein content under stress conditions, while the highest protein content was detected in the cultivar Tabat, followed by SAR 41. Dehydration tolerance can be realized when high protein percentage is placed in a genetic background that has other mechanisms related to maintenance of production under deficit environments. Plant growth rates are generally reduced to match all levels of resource acquisition when the soil water supply is limited. In this study, the mean growth rate (as measured by increase in plant height) was reduced under stress to 1.2 cm/day; the minimum was 0.8 cm/day (Wad Ahmed) and the maximum 1.5 cm/day (Red Mugud). This is in agreement with Crasta and Cox (1996) who reported a negative impact of water deficit on plant growth and development**.**

Association between grain yield and other traits

Yield under stress conditions is associated with morphological and physiological characters, which are different from those associated with high yield under optimum conditions (Acevedo and Ceccarelli 1989).

However, in this study, grain yield under drought stress was positively and significantly correlated with relative yield, biomass, number of grains/panicle and harvest index, but negatively correlated with 1000-grain weight. Thus, it is anticipated that selection to improve biomass, number of grains/panicle and harvest index would be effective in improving grain yield under stress conditions. These results agree with those of Blum *et al.* (1992**)** who reported that association of harvest index and above ground dry mass of sorghum cultivars indicates that further improvement may be possible. The character of early flowering can be introduced for sorghum growing under drought stress.

The identification and incorporation of particular physiological or morphological traits that are separately inherited and positively correlated with yield under stress into high yielding lines improve drought tolerance (Blum 1979). However, in this study, the potassium content and protein percentage of dry matter exhibited negative and non-significant associations with yield under stress and relative yield, which does not encourage the use of these characters as selection criteria for yield and drought tolerance in sorghum.

CONCLUSIONS

1- High variability exists among the studied genotypes. It seems that the semi-controlled environment used to stimulate water stress was effective and can be used in further plant breeding researches on drought tolerance.
2- Relative performance for most of the measured characters differentiated the genotypes SAR 41, Wad Ahmed, and Red Mugud as the most drought-tolerant.
3- The genotypes Wad Ahmed, SAR 41, and ICSR 91030 are the best potential candidates for improving drought tolerance in sorghum.
4- Date of flowering, biomass, number of grains/panicle, harvest index and root dry weight could be used effectively for selection to improve grain yield of sorghum under drought stress conditions.

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موجز البحث: هدفت هذه الدراسة للتعرف على الصفات الحقلية والفسيولوجية ذات العلاقة بصفة تحمل الجفاف فى محصول الذرة الرفيعة [*Sorghum bicolor* (L.) Moench] . تم تقييم ثمانية طرز وراثية في تجربة أصصية في مدينة قيسن بألمانيا . تم إجراء الإجهاد المائي بمنع الري عندما تكون كمية الماء في التربة علي مستوى 40% و 70% من السعة الحقلية . أظهرت الطرز الوراثية إختلافات معنويةً في معظم الصفات التي تم قياسها . تراوحت الإنتاجية تحت تاثير الإجهاد المائي بين 28 و 61 جم للنبات ، والإنتاجية النسبية بين 30% و 56% بمتوسط قدره 47%. إعتماداً على الإنتاجية كانت الطرز الوراثية ود أحمد (61 جم للنبات) و SAR 41 (55 جم للنبات) و ICSR 91030 (54 جم للنبات) من أحسن الأصناف تحت ظروف الإجهاد المائي . وإعتماداً على الإنتاجية النسبية ، كانت الطرز الوراثية SAR41 (56%) وود أحمد (55%) والمقد الأحمر (53%) هى الأفضل . كان متوسط محتوى البوتاسيوم 18 ملجم/جم ، والمدى 14 ملجم/جم (المقد الأحمر) إلى 22 ملجم/جم (أرفع قدمك) . وظهرت إختلافات معنوية بين

الطرز الوراثية للنسبة المئوية للبروتين تحت ظروف الإجهاد المائي ، حيث كان المدى بين 14.1% (المقد الأحمر) و 16.7% (طابت) وكان المتوسط 15.3% . وقد إرتبطت الإنتاجية تحت ظروف الإجهاد المائي إرتباطاً موجباً مع كل من الإنتاجية النسبية (r = 0.89) والكتلة الحية الكاملة (r = 0.56) وعدد الحبوب للقندول (r = 0.66) ودليل الحصاد (r = 0. 81) وارتباطاً سالباً مع وزن الـ 1000 حبة (r = - 0.37) .