Molecular and Agro-Morphological Variation in Sorghum (Sorghum bicolor (L.) Moench) Germplasm from Sudan and ICRISAT under Drought Stress Condition.

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Genetic Variation for Plant Breeding

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Genotypic response of sorghum (Sorghum bicolor L. Moench) to drought stress

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ABSTRACT: This study aimed at assessing the genotypic variability for drought tolerance in sorghum (Sorghum bicolor L. Moench). Eight genotypes were selected out of a set of 96 which had already been analysed by SSRs. Three field experiments were conducted in Sudan at two locations (Medani and El Rahad) in two seasons (2002-2003) under two water regimes, and a pot experiment was carried out at Giessen, Germany. In field tests drought was imposed naturally, while under pot conditions drought was imposed at 40 % and 70 % water hold capacity. In the pot trial and field experiments, genotypes differed significantly in most of the traits measured. In the pot experiment grain yield under drought stress ranged from 28 - 61 g plant\(^{-1}\) and relative yield ranged from 30 - 56 % with an average of 47 %, while in the field, the yield varied from 26 - 53 g plant\(^{-1}\), with an average of 41 g plant\(^{-1}\), and the relative yield ranged from 59 - 85 % with a mean of 75 %. The yield under field stress condition was moderately but significantly correlated with yield under pot stress condition (r = 0.52\(*\)). Based on yield, genotypes ‘Wad Ahmed’, ‘ICSR91 030’ and ‘SAR 41’ turned out to be the best under both stress conditions, and based on the relative yield the best genotypes were ‘Arfa Gadamar’ (85 %), ‘Wad Ahmed’ (84 %) and ‘Gadambalia’ (81 %) under field conditions, and ‘SAR 41’ (56 %), ‘Wad Ahmed’ (55 %) and ‘Red Mugud’ (53 %) in the pot experiment.

Key words: Drought stress – genotypic variability – Sorghum bicolor

Introduction

Sorghum (Sorghum bicolor L. Moench) is widely grown in the semi-arid tropics (SAT) of Africa, where various types of stress exist, i.e. drought and high temperatures. Drought is one of the major limiting factors of agriculture in this area and has to be considered as the most important cause of yield reduction in crops (Boyer 1982, Sari-Gorla 1999). Some of the devastating effects of drought stress on crops could be overcome by exploiting genetic variation for drought tolerance (Sari-Gorla et al. 1999). Breeding drought tolerant sorghum varieties and hybrids which cope with water stress in a most suitable manner (Sari-Gorla et al. 1999) is an urgent issue in this crop, since sorghum as an important crop in SAT is widely grown under drought stress conditions (Blum et al. 1989). Genetic variation for drought tolerance in sorghum is depending on divergent mechanisms involved. Identification of 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, particular physiological or morphological traits that are separately inherited and positively correlated to yield under stress should be identified and introduced into high yielding lines to improve drought tolerance (Blum 1979). The objective of this study is to assess genotypic variability for drought tolerance in sorghum and to obtain information on physiological differences among the genotypes tested.
Materials and methods

Plant material

Eight genotypes i.e. 'Red Mugud', 'Wad Ahmed', 'Tabar', 'Gadamballia', 'Arfa Gadamak', 'SAR 41', 'PI 569695' and 'ICSR 91030' from different morphological groups and geographical origins were selected out of a set of 96 genotypes based on genetic diversity estimated by SSR analyses (Abu Assar et al. 2004).

Pot experiment

A pot experiment was carried out in the greenhouse on movable trays (under rainout shelter) during May-September 2003 using a randomised design with four replications. Plants were sown at a density of 10 plants pot⁻¹. The soil of each pot (11 kg per Mitscherlich pot) contained 26 g fertilizer (N 12 %, P₂O₅ 12 %, K₂O 17 %, and SO₄ 15 %) well mixed with the soil before sowing. Pots were pre-irrigated by distilled water (500 ml/pot) in order to get equal soil moisture conditions. After sowing pots were covered by polyethylene net to reduce evaporation during germination. At the three- to four-leaf stage the number of plants was reduced to 2 plants pot⁻¹. Further on, pots were irrigated with distilled water 70 % and 40 % maximum water holding capacity for normal and stress treatments, respectively, throughout the experimental period. The daily mean temperature during the experiment period ranged from 14.5°C in May to a maximum of 22.5°C in August. Dry weight of shoots and roots were determined by drying the plants in an oven at 80°C for 48 h. Seven different traits were considered in the pot experiment and field trials: days to 50 % flowering (days), plant height (cm), growth rate (cm day⁻¹), grain yield/plant (g), 1000 grain weight (g), biomass weight/plant (g) and harvest index (%).

Field evaluation

In a field trial the same eight genotypes were evaluated in Sudan at two locations (Medani and El-Rahad) in two seasons (2002 and 2003) under two water regimes (normal and stress). A split-plot design with 3 replications was adopted, with water treatments assigned in main plots and genotypes randomised in sub-plots. Statistical analysis was performed using SPSS 11.5 software. Tukey's multiple range test was used to separate the means. The genotypes' performance under stress and normal conditions were used to estimate drought parameter index (relative performance) for the studied traits as follows:

\[ P_{rel}(\%) = \frac{P_{stres}}{P_{normal}} \times 100 \]

In order to obtain useful information on selection criteria usable in breeding programs for drought tolerance a correlation analysis (Pearson's correlation coefficient) among traits was performed.

Results and discussion

Performance of reproductive and vegetative traits under drought stress conditions

Significant differences were found among the genotypes for all of the traits measured in the field and greenhouse, with the exception of relative harvest index under pot stress condition. Genotypes suffered drastically under the water stress in both environments, showing reduction on means of all measured traits (Table 1). The effect of drought stress on grain yield of each genotype was assessed as absolute yield under stress and as relative yield under stress in percent of the controls. Regarding the grain yield in response to drought, a clear reduction was registered in both trials. In pot stress condition, yield ranged among genotypes from 28 - 61 g plant⁻¹ with an average of 45 g plant⁻¹, corresponding to a relative reduction of 70 - 40 % (mean 53 %). Evidently, water stress reduced yield to more than half on average. However,
The highest yield under pot stress condition was achieved by the cultivar ‘Wad Ahmed’ (61 g), followed by ‘SAR 41’ (55 g) and ‘ICSR 91030’ (54 g). On the other hand, in field trials, the yield/plant ranged from 26 - 57 g with an average of 41 g, while the relative yield varied from 59 - 85 % with an average of 75%. It is interesting to note that the same three genotypes that revealed high productivity in the pot experiment showed the same trends in field trials, i.e., ‘Wad Ahmed’ (57 g), ‘ICSR 91030’ (52 g) and ‘SAR 41’ (44 g). Based on the relative yield, the best three genotypes were ‘Arfa Gadarnak’ (85 %), ‘Wad Ahmed’ (84 %) and ‘Gadamballia’ (81 %). Mean relative 1000-grain weight and biomass were reduced to 93 % and 45 % in pot experiment and to 87 - 75 % in field trials, respectively. Harvest index under pot stress varied in a wide range from 28 - 39 % among genotypes. Regarding the relative HI, a clear trend was determinable among genotypes ranging from 57 - 156 % in the pot experiment to the range of 79 - 123 % in the field as compared with controls. Days to 50 % flowering under water stress was delayed up to 117 %, depending on genotypes. Genotypic differences with regard to days to 50 % flowering in the pot experiment may be due to an interaction with European climate conditions regarding differences in day length, humidity and temperature, while in field conditions, the plants were slightly later heading than ‘Gadamballia’ and ‘PI 569695’. Plant height under drought stress varied from 75 to 125 cm in pot experiment and from 123 cm to 210 cm in the field experiment according to the genotypes. There was a relative reduction of plant height ranging from 52 - 68 % with a mean of 61 % in the pot experiment and from 82 - 93 % with a mean of 85 % in the field in comparison to the controls. The mean growth rate was 1.2 cm day\(^{-1}\) ranging between 0.8 - 1.5 cm day\(^{-1}\) in the pot experiment and was 2.2 cm day\(^{-1}\) varying between 1.6 - 3.4 cm day\(^{-1}\) in the field experiment. Relative growth rate in pot ranged from 55 - 66 % with a mean of 58 %, while in the field, it ranged from 73 - 87 % with a mean of

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<td>HI(_{rel})</td>
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\(^1\) YLD, yield per plant (g); DF50, days to 50 % flowering (d); PH, plant height (cm); GR, growth rate (cm d\(^{-1}\)); TGW, 1000 grain weight (g); BMP, biomass plant\(^{-1}\) (g); HI, harvest index (%); relative performances are indicated by a appended and subscripted ‘rel’.
These data point out a large variability among the tested genotypes in phenology and morphology. The use of the relative indices revealed effective in estimating different genotypic responses to drought stress.

**Association among grain yield and related traits**

The grain yield per plant under field drought stress condition was moderately but significantly correlated with yield under pot stress condition \( (r = 0.52^*) \). Grain yield under pot stress was positively correlated with relative yield \( (0.89^{**}) \), total biomass \( (0.56^*) \) and harvest index \( (0.81^{**}) \), but negatively correlated with 1000-grain weight. From the positive and significant association between total biomass and harvest index, it appears that selection would be effective to simultaneously improve the yield under stress. This finding is in agreement with Blum et al. (1992), who reported the association of harvest index and above-ground dry mass of sorghum suggesting that further improvement might be possible if higher harvest index, larger dry mass and early flowering could be combined in sorghum under drought conditions.

Based on the results obtained, it seems that the semi-controlled environment (pot condition) used to stimulate water stress was effective and could be used in further plant breeding research to develop tolerance to drought stress. Based on drought tolerance parameters the best three genotypes under drought stress in the pot experiment with regard to the relative yield were: 'SAR41' (56%), 'Wad Ahmed' (55%) and 'Red Mugud' (53%). Regarding the field trials, 'Wad Ahmed' (84%) was again one of the three best along with 'Arfa Gadamak' (85%) and 'Gadamballia' (81%). On drought stress productivity (absolute yield/plant), three superior genotypes identified in both experiments were: 'Wad Ahmed' (61 and 57 g plant\(^{-1}\)), 'SAR 41' (55 and 43 g plant\(^{-1}\)) and 'ICSR 91030' (54 and 52 g plant\(^{-1}\)). Therefore, these cultivars should be good candidates for improving sorghum for drought tolerance.

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**References**


