Phenotypic Variations of Drought Tolerance Parameters in Maize (Zea mays L.) under Water Stress at Vegetative and Reproductive Stages

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Abstract
Two field experiments were conducted at Shambat and Medani in Sudan under water stress in vegetative and reproductive growth stages during the season (2003/2004). The objective of the study was to assess phenotypic variability and phenotypic correlation between drought tolerance parameters in maize genotypes. A split-plot layout within randomized complete block design with three replications was used for the experiment. Fifteen genotypes of maize were examined through the study. The effect due to genotypes x location was highly significant for all drought tolerance parameters studied. Highly significant and favorable correlation for Yw with SSI2, SSI3, GMP2, GMP3, STI2 and STI3, while highly significant and negative with Yd2/Yw and Yd3/Yw. Based on the result's drought stress at vegetative and reproductive stages of maize results in a drastic reduction in grain yield, and the strong positive correlation of Yw with SSI, GMP and STI, indicates that selection for high values of these parameters improves yield under stress and non-stress environments. Drought tolerance parameters can be used for improving grain yield and facilitate further efforts in maize breeding programs.
Keywords: Correlation, drought, genetic variability, heritability, Maize (Zea mays L.).

1. INTRODUCTION 1

Maize grows over wider geographical and environmental ranges than any other cereals. It is cultivated at latitudes varying from the equator to slightly north and south of latitude 50°, from sea level to over 3000 meters elevation, under heavy rainfall and in semi-arid conditions, cool and very hot climates and with growing cycles ranging from 3 to13 months. Sixty-four percent of the world's maize area is found in developing countries. However, the average yield is only 2.5 t/ha compared to 6.2 t/ha for industrialized countries (Timothy et al., 1988; Dowswell et al., 1996). In the Sudan, maize is normally grown as a rain-fed crop in Darfur and Kordofan States or in small-irrigated areas in the Northern States (Ahmed and El Hag, 1999). Recently, there has been an increased interest in maize production in the Sudan (Nour et al., 1997).

Maize is more sensitive to drought. It is susceptible to more hazards, and it is a higher-risk cereal crop in general (Misovic 1985). Improvement of productivity of maize cultivars under drought conditions becomes one of the objectives of breeding programs in maize. During the last 50 years, considerable effort has been devoted to improving yield performance through breeding and understanding the mechanisms involved in drought tolerance (Ribaut et al., 1997). The study objectives were to estimate the phenotypic variability for drought tolerance parameters under water stress at vegetative and reproductive stages, to determine the correlations between drought tolerance parameters under normal and stress conditions.

MATERIALS AND METHODS

Study site and experimental design

Two field experiments were conducted during the 2003/04 season at two sites. The first one was Gezira Research Station Farm, at Medani (latitude 14°24``N., longitude 33°29``E. and 407m above sea level). The second site was the Demonstration Farm of the Faculty of Agriculture, University of Khartoum, at Shambat (latitude 15°40``N., longitude 32°32``E. and 380m above sea level). Means of monthly temperatures (C°), relative humidity (%) and rainfall distribution (mm) for the two sites, Shambat and Medani, during the 2003/04 season were previously described (Sabiel et al., 2014) . Fifteen genotypes of maize were used for the study, obtained from the Agricultural Research Corporation, Maize Program Sudan. These genotypes were G-1, G-2, G-3, G-4, V-1, Z-2, M-45, PR-1, PR-2, D-2, D-3, D-6, D-7, E-7 and C-12. The experiment designs a split-plot layout within randomized complete block design with three replications was used. The main plots were three levels of irrigation; normal (S1), water stress during the vegetative stage (S2) and water stress during the reproductive stage (S3), and subplots included 15 genotypes of maize. At both sites, weeding was estranged by hand two times per season

Data collection

Drought tolerance parameters were based on collecting data of grain yield kg/ha. The parameters were developed in the present study as:

Yw = seed yield (kg/ha) under non-stress or well-watered conditions, S1.

Yd = seed yield (kg/ha) under drought-stress conditions for S2 or S3 treatments.

Yd/Yw (%) = Ratio of grain yield kg/ha (drought) to grain yield kg/ha (non-drought).

SSI = stress susceptibility index of Fischer and Maurer (1978), it was determined by using the formula:

SSI = [Yw-Yd] / [Yw (1-yd/yw)]

Where:

yd and yw = mean yields of all genotypes that evaluated under drought and well-watered conditions, respectively.

[Yw-Yd] = relative yield reduction due to stress.

1-yd/yw = drought intensity index.

GMP = Geometric mean of productivity in kg, it is measured as (Yd x Yw)0.5 as described by Fernandez (1993).

STI = stress tolerance index (Fernandez ,1993). It is measured as (Yd)(Yw)/(yw), where yw is the mean yield under well-watered conditions over all genotypes.

Data Analysis

Analysis of variance (ANOVA) was performed for each character using the computer system PLABSTAT version (2N of 1997/09 /15), to reveal significant effects among the genotypes and environment. Analysis of variance was carried out for all studied characters in each location separately, according to the procedures described by Gomez and Gomez (1984) for split plot design. Furthermore, combined analysis of variance is given.

RESULTS

Phenotypic variability

Combined analysis (Table 1) shows the variability of the different drought tolerance parameters. Highly significant differences between genotypes ($P\leq 0.01$) were recorded for Yd2 and significant differences between genotypes ($P\leq 0.05$) were recorded for Yd3. All other drought tolerance parameters exhibited non-significant differences among genotypes (Table 1). The effect due to genotypes x location's interaction showed highly significant differences ($P\leq 0.01$) for all drought tolerance parameters (Table 1).

The performance of genotypes was variable according to the difference in time of incidence of drought stress (Figure 1). The highest grain yield under non-stress condition (Yw = 4914.7 kg/ha) was achieved by genotype PR-1, while the lowest grain yield (Yw = 3783.8 kg/ha) was obtained by genotype G-3 (Table 2). When drought was induced during the vegetative stage (S2) the highest grain yield (Yd2 = 4165.8 kg/ha) was produced by genotype M-45 and the lowest grain yield (Yd2 = 2705.9 kg/ha) was obtained by genotype PR-1. When drought was induced during the reproductive stage (S3) the highest grain yield (Yd3 = 3555.5 kg/ha) was achieved by genotype Z-2 and the lowest grain yield (Yd3 = 2736.7 kg/ha) was reached by genotype S-3 (Table 2).

The highest value of drought tolerance as measured by Yd/Yw, when drought occurred during the vegetative stage (S2) (100.5%) was produced by genotype PR-2, while the lowest Yd/Yw (55.1%) was obtained by genotype PR-1. When drought occurred during reproductive stage (S3), the highest Yd/Yw (86.6%) was obtained by genotype G-3, while the lowest Yd/Yw (56.3%) was obtained by genotype PR-1 (Table 2).

The most tolerant genotype was genotype PR-2 under (S2) the stress susceptibility index (SSI) (-0.02) and genotype G-3 under (S3) the SSI (0.6). The highest drought sensitive genotype was genotype PR-1 during both growth stages. Stress susceptibility indices (SSI) were (2.1) under S2 and (2.0) under S3 (Table 2). The highest values (4416.2 kg/ha and 4058.5 kg/ha) of geometric mean productivity (GMP) were attained by genotype M-45 during both growth stages (S2 and S3), respectively, while the lowest value of GMP (3356.7kg/ha) under S2 was attained by genotype G-3 and under S3 (3294.5kg/ha) was attained by genotype D-3 (Table 2). The highest values (1.0 and 0.9) of stress tolerance index (STI) were exhibited by genotype M-45 under both drought periods (S2and S3), respectively, while the lowest value (0.6) of STI was obtained by genotype G-3 under S2 and the three (PR-2, D-3 and C-12) genotypes under S3 (Table 2).

Phenotypic correlation between the drought tolerance parameters

The phenotypic correlations between the studied drought tolerance parameters under different water treatments were exhibited in Table 3. The correlation for Yw was highly significant and negative with Yd2/Yw and Yd3/Yw, while highly significant and positive with SSI2, SSI3, GMP2, GMP3, STI2 and STI3. The correlation between Yw and Yd2 was negative and non-significant, but it was positive and non-significant with Yd3 (Table 3).

The correlation for Yd2 was highly significant and positive with Yd2/Yw, GMP2 and STI2, while highly significant and negative with SSI2. The correlation for Yd2 was negative and non-significant with Yd3, SSI3, GMP3, and STI3, but it was positive and non-significant with Yd3/Yw. Highly significant positive correlations were recorded for Yd3 with Yd3/Yw, GMP3 and STI3, while non-significant and negative correlation with Yd2/Yw, SSI2, GMP2 and STI2 (Table 3). The correlation for Yd2/Yw was highly significant and positive with Yd3/Yw, GMP2 and STI2, but it was highly significant and negative with SSI2, SSI3, GMP3 and STI3. Highly significant negative correlations were recorded for Yd3/Yw with SSI2, SSI3, GMP2 and STI2, while highly significant positive correlation with STI3 (Table 3).

The correlation for SSI2 was highly significant and positive with SSI3 and GMP3, while it was highly significant and negative with GMP2. The correlation between SSI2 and STI3 was positive and significant, but it was negative and significant with STI2. Highly significant positive correlations were recorded for SSI3 with STI2. However, highly significant negative correlation was found for SSI3 with GMP2 (Table 3). The correlation for GMP2 was highly significant and positive with STI2 and significant and positive with GMP3. Significant positive correlation was found for GMP3 with STI2. However, non-significant and negative correlation was obtained for GMP3 with STI3 (Table 3). The highly significant and positive correlation was recorded for STI2 with STI3, while it was highly significant and negative with Yd3/Yw. Highly significant positive correlation was found for STI3 with Yd3 while it was highly significant and negative with Yd2/Yw. (Table 3).

DISCUSSION

The differences in sensitivity among maize genotypes to water stress during various growth stages depended on the reaction of each genotype to the drought at vegetative as well as reproductive growth stages. Drought stresses affect's maize grain yield to some degree at almost all growth stages (Grant et al., 1989, Ahmed, 2002). In this study, there were reductions in the estimate of genetic variability of traits under the different water-stress treatments depending on the severity of drought. The least reduction of grain yield was achieved by genotype M-45 under S2 and genotype Z-2 under S3 treatment. The effect due to genotypes x location was highly significant for all drought tolerance parameters, indicating that the genetic variance in stress environment was more than non-stress conditions (Hohls, 2001).

The least value of SSI for genotype PR-2 under S2 and genotype G-3 under S3, indicates that the response of genotypes to drought intensity differs according to their genetic structure and adaptability. Wenzel (1999) reported that some genotypes yielded more under moisture stress than under near-ideal moisture conditions. Johnson and Geadelmann (1989) reported that a low genetic correlation was often observed to yield in high-and low-productivity environments, indicating that unusual sets of genes may be important, indicating the yield in different environments. The negative relationship between Yw with Yd/Yw in this study was also recorded by Hohls (2001). The strong positive correlation of Yw with SSI, GMP and STI, indicates that selection for high values to these parameters improves yield under stress and non-stress environments. Similar results were found by Ceccarelli et al., (1992).

Conclusions

These results indicated that water stress at vegetative, and reproductive stages of growth reduced grain yield significantly. The drought parameters to be important characters, which would be used in selection for maize improvement. The strong positive correlation of Yw with SSI, GMP and STI, indicates that selection for high values of these parameters improves maize grain yield under stress and non-stress environment

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Table 1. Mean squares from the analysis of variance due to genotypes (G) and their interaction with locations (GxL) between 15 maize genotypes for drought tolerance parameters during the 2003/04 season.

Drought tolerance	G	G x L
DF	14	14
Yw	600116.76^{ns}	1951574.03**
Yd 2	1770186.50**	2856124.33**
Yd 3	516391.70*	1404481.56**
Yd2/Yw	0.18^{ns}	0.35**
Yd3/Yw	0.06^{ns}	0.18**
SSI 2	3.37^{ns}	5.92**
SSI 3	0.89^{ns}	2.23*
GMP 2	468860.30^{ns}	1495409.14**
GMP 3	360756.29^{ns}	991377.46**
STI 2	0.07^{ns}	0.23**
STI 3	0.05^{ns}	0.13**

*,** = significant at probability of 0.05 and 0.01, respectively; ns: non significant;Yw: well watered. Yd, Yd/Yw, SSI, GMP and STI: Drought tolerance parameters; 2, 3: level of drought stress.

Table 2. Means of drought tolerance parameters of 15 maize genotypes evaluated at three water treatments across two locations (Shambat and Medani) during the 2003/04 season.

Genotypes	Yw	Yd2	Yd3	Yd2/Yw%	Yd3/Yw %	SSI2	SSI3	GMP2	GMP3	STI2	STI3
G-1	4538.3	3542.7	2757.4	78.1	60.8	1.0	1.8	4009.7	3537.5	0.9	0.7
G-2	4010.7	3295.4	3381.9	82.2	84.3	0.8	0.7	3635.5	3682.9	0.7	0.7
G-3	3783.8	2977.8	3275.5	78.7	86.6	1.0	0.6	3356.7	3520.5	0.6	0.7
G-4	4762.6	2938.7	3354.2	61.7	70.4	1.8	1.4	3741.1	3996.8	0.8	0.8
V-1	4058.0	3754.5	3091.5	92.5	76.2	0.3	1.1	3903.6	3542.2	0.8	0.7
Z-2	4323.9	3451.5	3555.5	79.8	82.2	0.9	0.8	3862.9	3920.9	0.8	0.8
M-4	4681.6	4165.8	3518.3	89.0	75.2	0.5	1.1	4416.2	4058.5	1.0	0.9
PR1	4914.7	2705.9	2765.7	55.1	56.3	2.1	2.0	3646.7	3686.8	0.7	0.7
PR2	4077.1	4096.5	2788.5	100.5	68.4	-0.02	1.5	4086.8	3371.8	0.9	0.6
D-2	4146.6	3089.7	3139.3	74.5	75.7	1.2	1.1	3579.4	3608.0	0.7	0.7
D-3	3966.0	3148.9	2736.7	79.4	69.0	1.0	1.4	3533.9	3294.5	0.7	0.6
D-6	4425.2	3603.9	3095.0	81.4	70.0	0.9	1.4	3993.5	3700.8	0.9	0.7
D-7	4679.7	2982.0	2854.8	63.7	61.0	1.7	1.8	3735.6	3655.1	0.8	0.7
E-7	4310.7	3786.7	2893.1	87.8	67.1	0.6	1.5	4040.2	3531.5	0.9	0.7
C-12	3984.3	3068.9	2782.7	77.0	69.8	1.1	1.4	396.8	3329.7	0.7	0.6
Mean	4310.9	3373.9	3066.0	78.3	71.1	1.0	1.3	3813.7	3635.5	0.8	0.7
LSD5%	538.5	443.1	351.4	0.2	0.2	1.0	1.7	424.3	343.6	0.2	0.1

Yw: Yield under well watered; Yd, Yd/Yw, SSI, GMP and STI: Drought tolerance parameters.

Table 3. Phenotypic coefficient of correlations between the different drought tolerance parameters for maize genotypes under two locations (Shambat and Medani) during the 2003/04 season.

Parameters	Yw	Yd2	Yd3	Yd2/Yw	Yd3/Yw	SSI2	SSI3	GMP2	GMP3	STI2	STI3
Yw	1	-0.003	0.067	-0.530**	-0.588**	0.529**	0.580**	0.478**	0.602**	0.482**	0.601**
Yd2		1	-0.069	0.733**	0.010	-0.681**	-0.051	0.861**	-0.049	0.847**	-0.069
Yd3			1	-0.032	0.664**	-0.011	-0.652**	-0.028	0.822**	-0.063	0.822**
Yd/Yw 2				1	0.501**	-0.915**	-0.526**	0.326**	-0.340**	0.297**	-0.348**
Yd/Yw 3					1	-0.481**	-0.989**	-0.310**	0.163	-0.336**	0.312**
SSI 2						1	0.289**	-0.282**	0.307**	-0.251*	0.231*
SSI 3							1	-0.310**	-0.164	0.289**	0.215*
GMP2								1	0.252*	0.985**	0.163
GMP3									1	0.230*	-0.161
STI2										1	0.991**
STI3											1

*,** = significant of probability 0.05 and 0.01, respectively; Yw: well watered; Yd, Yd/Yw, SSI, GMP and STI: Drought tolerance parameters; 2 and 3: level of drought stress.

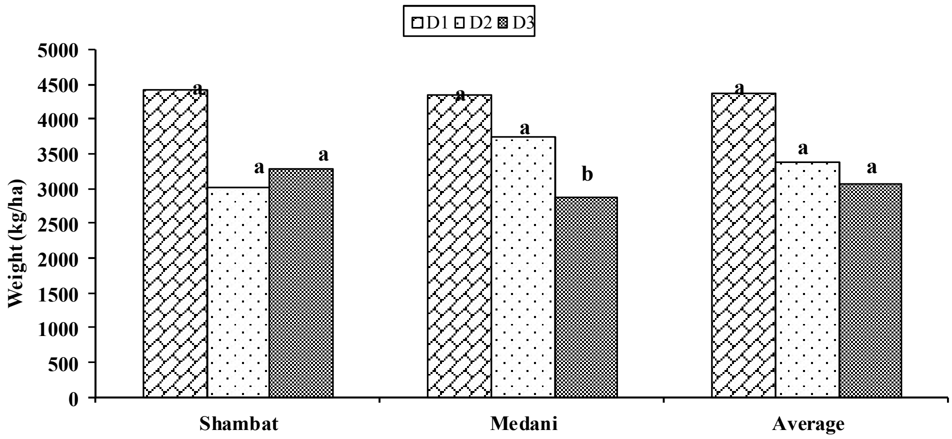

Fig. 1. Grain weight (kg/ha) for 15 maize genotypes evaluated under three water treatments at two locations (Shambat and Medani) during 2003/04 season