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Genetic Variation of Plant Height and Stem Diameter Traits in Maize (Zea mays L.) under Drought Stress at Different Growth Stages

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Abstract
Plant height and stem diameter are essential traits in maize breeding. A study was carried out to estimate the extent of genetic variability in genotypes of Maize (Zea mays L.). Fifteen genotypes of maize were evaluated on season (2003/2004) across the two environments in Sudan, to obtain information on morphological and genetic diversity in plant height and stem diameter traits were estimated in a split-plot layout within randomized complete block design with three replications. Significant differences among genotypes were found in all traits, except stem diameter (45 days). High genotypic coefficient of variation, genetic advance and heritability were exhibited by plant height at 60 days and stem diameter at 60 days. Grain yield was significantly and positively associated, at the phenotypic level, with a plant height at 45 days and a stem diameter at 45 days. Based on the results the characters plant height and a stem diameter to be the important characters which would be used in selection for maize improvement under drought stress at vegetative and reproductive stages.
Keywords: Maize (Zea mays L.), Genetic variability, plant height, stem diameter, drought.

1. Introduction 1

Drought is a multilateral stress affecting plants at various stages of growth and metabolic processes. The effect of water stress on crop growth and yield depends upon the duration, degree of stress and the developmental stage at which the stress occurs (Sullivan and Eastin, 1974; Chapman et al., 1997). A limited water supply reduced plant height (Sari-Gorla et al., 1999). Bǎnziger et al., (2000) found that selection for reduced growth of stems and plant height may reduce competition for assimilates at flowering and thereby decrease kernel abortion. The genetic variances were larger under stress conditions (Ceccarelli et al., 1992; Hohls, 2001). Johnson and Geadelmann (1989) reported that for many crops, a low genetic correlation with other traits is often observed to yield in high-and low-productivity environments, indicating that different sets of genes may be important, which they yield in different environments. Positive correlations between plant height and grain yield were reported (Mohamed et al., 1999; Debelo et al., 2001).

Katerji et al., (1994) reported that changes in stem diameter are frequently used to assess plant water status. Since these measurements can be fully automated, they may have practical applications for detecting the beginning of water stress or for triggering irrigation by automatic systems. A possibility therefore existed that the plant water status, as measured by variations in stem diameter, would not give reliable information on the change of the plant behavior with increasing water constraints. The genetic variances were larger under stress conditions (Ceccarelli et al., 1992; Hohls, 2001). Many secondary traits for drought tolerance were of low heritability (Bãnziger et al., 2000). These traits are leaf and stem elongation rate, canopy temperature and seedling survival under drought.

Ibrahim et al., (1998) suggested that the ranking of genotypes was not the same at the different locations. They studied the effects of minimum and maximum temperatures, rainfall and relative humidity on the Genotype by Environment Interaction in corn yield. Sallah et al., (2002) found that effects due to environment (E), genotype (G) and GxE interaction were highly significant ($p<0.01$) for grain yield and plant height. Reduced plant height and increased stem diameter in cereal crops were the basis for plant improvement under drought stress (Upadhyaya et al., 2013). The main objectives were (1) to estimate the genetic variability for the plant height and a stem diameter under drought stress at different growth stages, (2) To determine the correlations between grain yield, plant height and the stem diameter traits under normal and stress conditions.

1.1 MATERIALS AND METHODS 2

Study site and experimental design:

Two field experiments were used to achieve the objectives of this study. The experiments were conducted during the 2003/04 season at two sites Khartoum and Medani in Sudan were previously described (Sabiel et al., 2014). Fifteen genotypes of maize used in the study, were obtained from the national program, Agricultural Research Corporation, Sudan. The experiment was laid out as a split plot design with three replications. Each replication consisted of three main plots in which the water treatments were distributed randomly. The 15 genotypes were grown as subplots and were assigned randomly. Each genotype was sown on two ridges, of 3 meters long. Planting was on ridges at a rate of two seeds per hole, spaced at 25 cm between holes and 80 cm between ridges. The seedlings were thinned to one plant per hole, three weeks after germination to achieve a stand of approximately 5x104 plants/ha. Planting date was 7th July in 2003 at Shambat and 15th July in 2003 at Medani. All the recommended agronomic practices were followed throughout the season at both sites.

Data collection:

Plant height (cm) measured at 30, 45and 60 days from planting; it was measured from the ground surface to the tip of the plant. Stem diameter (mm) was measured using the Vernier Caliper, at 30, 45 and 60 days from planting; it was measured at 10cm above the ground level. Grain yield (kg/ha), this was estimated from the grain yield per subplot.

Statistical analysis:

Analysis of variance (ANOVA) was carried out for each trait using the computer system PLABSTAT version (2N of 1997/09 /15), to detect significant effects among the genotypes and environment. Based on the analysis of variance, phenotypic and genotypic variation, genetic advance, heritability, genotypic coefficient of variation and phenotypic correlation between grain yield, plant height and stem diameter traits were evaluated. Means for each location and two locations were used to compute simple linear correlation coefficients.

1.1.1 RESULTS 3

Phenotypic Variability

Highly significant differences (P ≤ 0.01) among the genotypes were found at Medani for plant height at 45 and 60 days and for 30 days at Shambat, while non-significant differences for 45days, 60 days at Shambat and 30 days at Medan (Table 1). The genotypes showed significant differences (P≤ 0.05) for stem diameter at Shambat at 60 days and 30 days at Medan. However, non-significant differences were detected in 30 and 45 days at Shambat, for 45 and 60 days at Medani (Table 1).

Table 1. Mean squares from the analysis of variance due to Treatments (T), Genotypes (G) and their Interactions (G x T) for plant height and stem diameter characters of 15 maize genotypes, evaluated over three water treatments at two locations (Shambat and Medani) during the 2003/04 season.

Characters		Shambat			Medani		
		T	G	G x T	T	G	G x T
		d. f = 2	d. f =14	d. f =28	d. f =2	d. f =14	d. f =28
Plant	30 days	127.26^{ns}	263.42**	101.34^{ns}	1196.22*	145.14^{ns}	251.10*
height	45 days	1094.14^{ns}.	771.31^{ns}	695.96^{ns}	6040.13*	1335.34**	1489.40**
(cm)	60 days	756.68^{ns}	299.32^{ns}	290.58^{ns}	2746.94*	837.10**	523.92**
Stem	30 days	241.67^{ns}	170.43^{ns}	192.52^{ns}	94.54^{ns}	19.13*	17.59**
diameter	45 days	6.96^{ns}	3.40^{ns}	1.71^{ns}	6.62^{ns}	5.44^{ns}	6.60*
(mm)	60 days	19.98^{ns}	3.93*	2.39^{ns}	2.63^{ns}	5.65^{ns}	3.78^{ns}

*, ** Significant at 0.05 and 0.01 levels, respectively. ns = Non significant.

The combined analysis showed highly significant differences among the genotypes for stem diameter at 45 days and significant at 60 days, while non-significant at 30 days. However, non-significant differences among the genotypes for plant height were found (Table 2).

Table 2. Mean squares from combined analysis due to Locations (L), Treatments (T), Genotypes (G) and their Interactions for plant height and stem diameter characters in 15 maize genotypes evaluated over three water treatments at two locations (Shambat and Medani) during the 2003/04 season.

Characters		L	T	T x L	G	G x T	G x L
		d. f = 1	d. f = 2	d. f = 2	d. f = 14	d. f = 28	d. f = 14
Plant height (cm)	30 days	73666.1**	301.30^{ns}	1022.2^{ns}	61.05^{ns}	138.84^{ns}	247.51*
	45 days	44496.0**	1851.70^{ns}	5282.6*	1234.29^{ns}	1229.3^{ns}	772.36^{ns}
	60 days	607.20^{ns}	2289.68^{ns}	1213.9^{ns}	807.15^{ns}	426.60^{ns}	329.22^{ns}
Stem diameter (mm)	30 days	3318.01**	187.84^{ns}	148.38^{ns}	88.38^{ns}	109.46^{ns}	100.90^{ns}
	45 days	60.02*	0.01^{ns}	13.57^{ns}	7.30**	4.22^{ns}	1.54^{ns}
	60 days	96.12**	17.96^{ns}	4.65^{ns}	7.00*	3.55^{ns}	2.58^{ns}

*, ** Significant at 0.05 and 0.01 level, respectively. ns = Non significant

The overall means of plant height at 30, 45 and 60 days were (86, 163 and 180cm) at Shambat, (53, 137 and 177cm) at Medani and (69,150 and 179cm) for the average of both locations (Table 3). For the plant height at 30 days, the tallest genotypes were PR-2 at Shambat, D-3 at Medani and E-7 for the average of both locations, while the shortest genotypes were Z-2 at Shambat, PR-2 at Medani and D-2 for the average of both locations (Table 3). For the plant height at 45 days the tallest genotype was E-7 at Shambat, Medani and for the average of both locations, while the shortest genotypes were D-6 at Medani, G-3 at Shambat and for the average of both locations (Table 3). For the plant height at 60 days the tallest genotypes were Z-2 at Shambat, E-7 at Medani and for the average of both locations, while the shortest genotypes were D-7 at Shambat, V-113 at Medani and for the average of both locations (Table 3).

Table 3. Means of plant height for 15 genotypes of maize evaluated under three water treatments at Shambat, Medani and over two locations during the 2003/04 season.

Serial No.	Genotypes	Shambat			Medani			Combined		
		30 days	45 days	60 days	30 days	45 days	60 days	30 days	45 days	60 days
1	G-1	78	155	178	55	136	176	66	146	177
2	G-2	78	170	187	55	134	185	71	152	186
3	G-3	80	144	176	54	127	171	67	135	173
4	G-4	93	179	189	50	130	175	72	155	182
5	V-113	92	159	177	55	135	165	73	147	171
6	Z-2	77	170	191	58	150	190	73	160	190
7	M-45	81	165	180	49	118	172	65	142	176
8	PR-1	90	165	178	49	152	184	70	159	181
9	PR-2	94	169	176	46	137	171	70	153	173
10	D-2	85	160	184	48	133	169	57	146	176
11	D-3	80	150	176	59	144	188	69	147	182
12	D-6	83	169	181	48	124	168	66	147	175
13	D-7	80	155	172	52	129	174	66	142	173
14	E-7	90	171	188	58	166	199	74	168	194
15	C-12	86	160	175	56	141	176	71	151	175
Mean		86	163	180	53	137	177	69	150	179
LSD5%		9	25	17	12	23	11	11	21	13
CV%		10.8	16.2	10.2	24.3	17.5	6.8	16.1	16.8	8.7

The overall means of stem diameter at 30, 45 and 60 days were (21, 21 and 20 mm) at Shambat, (14, 20 and 19 mm) at Medani and (18, 20 and 19 mm) for the average of both locations (Table 4). For the stem diameter at 30 days, the largest genotypes were PR-1 at Medani, E-7 at Shambat and for the average of both locations, while the smallest genotypes were D-7 at Shambat, M-45 at Medani and G-4, D-2 and D-7 for the average of both locations (Table 4). For the stem diameter at 45 days, the largest genotypes were Z-2 and D-6 at Shambat (Table 4), Z-2, D-3 and E-7 at Medani and for the average of both locations, while the smallest genotypes were G-3 at Shambat, G-2, G-3, G-4, PR-1, D-2 and D-7 at Medani and G-4, G-3 and D-7 for the average of the locations (Table 4). For the stem diameter at 60 days, the largest genotypes were Z-2 and E-7 at both locations, while the smallest genotypes were G-2 and D-7 at both locations (Table 4).

Table 4. Means of stem diameter for 15 genotypes of maize evaluated under three water treatments at Shambat, Medani and over two locations during the 2003/04 season.

Serial No.	Genotypes	Shambat			Medani			Combined		
		30 days	45 days	60 days	30 days	45 days	60 days	30 days	45 days	60 days
1	G-1	20	21	20	16	20	19	18	20	20
2	G-2	20	20	19	14	19	18	17	20	18
3	G-3	19	19	19	14	19	18	17	19	19
4	G-4	21	21	20	12	19	<u>17</u>	16	20	19
5	V-113	20	20	19	15	20	19	17	20	19
6	Z-2	21	<u>22</u>	21	15	21	20	18	21	20
7	M-45	20	21	20	<u>13</u>	20	19	17	20	19
8	PR-1	20	20	19	<u>17</u>	19	20	18	20	20
9	PR-2	21	21	20	14	20	19	17	20	20
10	D-2	20	21	21	12	19	19	16	20	20
11	D-3	20	21	20	16	21	20	18	21	20
12	D-6	21	<u>22</u>	21	14	20	19	18	21	20
13	D-7	<u>18</u>	20	19	15	19	18	16	19	18
14	E-7	<u>22</u>	21	21	16	21	20	19	21	20
15	C-12	20	20	19	15	20	19	17	20	19
Mean		21	21	20	14	20	19	18	20	19
LSD5%		13	1	1	3	2	2	7	1	1
CV%		6.4	6.9	7	20.4	9.6	11.3	5.7	8.3	9.2

Genotypic Variability

High genotypic variance relative to phenotypic variance, at Shambat was recorded for plant height at 30 days and stem diameter at 45 days. At Medani, slightly high genotypes x treatments interaction variance relative to phenotypic variance was obtained for plant height at 45 days, plant height at 60 days and stem diameter at 45 days. Whereas at Shambat it was recorded for stem diameter at 60 days (Table 5).

Table 5. Phenotypic (σ^2ph), genotypic (σ^2 g), experimental (σ^2 e) and genotypes x treatments interactions (σ^2gt) variances for plant height and stem diameter characters in 15 maize genotypes evaluated under three water treatments at two locations (Shambat and Medani) during the 2003/04 season.

Characters	σ^2 ph		σ^2 g		σ^2 e		σ^2 g t	
	Shambat	Medani	Shambat	Medani	Shambat	Medani	Shambat	Medani
Plant height at 30 days	103.21	152.44	18.01	-11.77	85.20	64.21	5.38	28.96
Plant height at 45 days	710.32	558.73	8.37	-17.12	66.95	57.85	1.34	30.51
Plant height at 60 days	341.63	180.98	0.97	34.79	34.66	46.19	-16.70	25.91
Stem diameter at 30 days	19.27	8.84	-2.45	0.17	2.02	8.67	0.60	2.97
Stem diameter at 45 days	2.23	3.46	0.19	-0.13	2.04	3.59	-0.11	1.00
Stem diameter at 60 days	2.12	4.67	0.17	0.21	1.95	4.46	0.15	-0.23

Phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all characters at both locations. Most of the characters showed high values of phenotypic coefficient of variation at Medani than Shambat, except plant height at 60 days and stem diameter 30 days (Table 6). The highest phenotypic coefficient of variation (64%) at Shambat and (23%) at Medani, were found for stem diameter at 30 days and plant height at 30 days, respectively. The highest values of heritability (68% and 83%) were found for plant height (30 and 60 days) at Shambat and Medani, respectively. The highest values of genetic advance were obtained for plant height (30 and 60 days). They were (3.7%) at Shambat and (5.3%) recorded at Medani (Table 6).

Table 6. Estimates of phenotypic (PCV) and genotypic coefficient of variation (GCV), broad sense heritability (h^2), and expected genetic advance from selection (GA) for plant height and stem diameter characters measured on 15 maize genotypes evaluated under three water treatments at two locations (Shambat and Medani), during the 2003/04 season.

Characters	PCV (%)		(GCV (%)		h^2 (%)		GA (%)	
	Shambat	Medani	Shambat	Medani	Shambat	Medani	Shambat	Medani
Plant height at 30 days	11.8	23.4	4.9	#	68	28	3.7	#
Plant height at 45 days	16.3	17.3	1.8	#	10	57	0.7	#
Plant height at 60 days	10.2	7.6	0.6	3.3	28	83	0.1	5.3
Stem diameter at 30 days	64.0	20.6	#	2.9	13	55	#	0.1
Stem diameter at 45 days	7.2	9.4	2.1	#	50	34	0.3	#
Stem diameter at 60 days	7.3	11.5	2.1	2.4	50	21	0.2	0.2

= the value was not calculated because their variance was negative.

Grain yield (kg/ha) was positively correlated with plant height 45 days (r = 0.588) at Shambat and stem diameter 45 days (r = 0.539) at Medani, while it was negatively correlated with stem diameter for 30 days at Medani(Table 7).

Table 7. Simple linear correlation coefficients between 7 pairs of traits in maize using locations Shambat (above the diagonal) and Medani (below the diagonal) averaged over three water treatments in season 2003/2004.

Traits	GY	Hght 1	Hght 2	Hght 3	StDi 1	StDi 2	StDi 3
GY	1	0.321	0.588*	0.237	-0.232	0.131	0.089
Hght 1	0.342	1	0.067	0.476	0.569*	-0.338	0.960**
Hght 2	0.254	0.358	1	0.177	0.524*	0.570*	-0.475
Hght 3	0.352	0.652**	0.519*	1	-0.247	-0.475	-0.091
StDi 1	0.212	0.493	0.595*	0.554*	1	0.388	0.701**
StDi 2	0.539*	0.582*	0.584*	0.691**	0.625*	1	0.700**
StDi 3	0.371	0.854**	0.4	0.617*	0.817**	0.530*	1

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively. GY: grain yield; Hght 1: Plant height at 30 days; Hght 2: Plant height at 45 days; Hght 3: Plant height at 60 days; StDi 1: Stem diameter at 30 days; StDi 2: Stem diameter at 45 days; StDi 3: Stem diameter at 60 days.

1.1.2 DISCUSSION 3

Highly significant different among the genotypes were found for plant height at both locations. A similar conclusion was reported by Salami et al., (2007); Hajibabaee et al., (2012). The decreased in plant height at Medani and average of both locations as a result of drought stress during the vegetative growth stage. The same results have been reported in previous studies by Sari-Gorla et al., (1999). This indicates that water stress during the vegetative growth stage reduced plant height. The combined analysis showed that the genotypes differed highly significantly for stem diameter at 45 days and significant at 60 days. Drought stress affects maize production to some degree at vegetative and reproductive growth stages (Grant et al., 1989; De Souza et al., 1997; Sabiel et al., 2014). Ahmed (2002) reported that heavy losses in yield may occur in maize growing under water-limited conditions and high temperatures.

The high heritability and genetic advance were recorded for plant height, have been also revealed in previous studies by Salami et al., (2007); Ali et al., (2012); Bekele and Rao, (2014) and Kumar et al., (2014). Drought stress at vegetative growth stage reduced vegetative traits slightly at the two locations. This also was found by Mangobe et al., (1996) and Ribaut et al., (1997). Stem diameter was not affected by stress during vegetative and reproductive stages at Medani. However, it was reduced when stress occurred during reproductive growth stage at Shambat. Similar results were observed by Katerji et al., (1994) and (Guei et al., 1993). Bãnziger et al., (2000) reported that drought leads to reduce stem expansion. Grain yield was a significant and positive correlation with plant height (45days) at Shambat. This result agrees with Mohamed et al., (1999); Debelo et al., (2001); Salami et al., (2007) and Bekele and Rao, (2014). At Medani the positive correlation was revealed between grain yield and stem diameter (45 days). This finding is in agreement with results of Sallam et al., (2014). Selection for the correlated traits like plant height and stem diameter will simultaneously improve potential grain yield and accumulate desirable genes.

Conclusions

It could be concluded from this study that there is adequate genetic variability in the material studied. The genotypic coefficient of variation, genetic advance and broad sense heritability were found that the selection for plant height at 60 days and stem diameter at 60 days would be more effective as compared to other traits for boosting grain yield performance of maize genotypes under normal and stress conditions. The positive correlations of the characteristic plant height at 45 days and a stem diameter at 45 days with grain yield indicate that generally the plant height and a stem diameter would be the important traits for maize improvement under drought stress at vegetative and reproductive growth stages.

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