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Hybrid Performance and Inbred-hybrid Relationship of Early Maturing Tropical Maize under Drought and Well-watered Conditions

M. OYEKUNLE[1,2] and B. BADU-APRAKU[1]*

[1]International Institute of Tropical Agriculture (IITA), IITA (UK) Ltd, Carolyn House, 26 Dingwall Road, CROYDON CR9 3EE, United Kingdom
[2]Department of Agronomy, University of Ibadan, Ibadan, Oyo State, Nigeria

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Drought tolerant maize (*Zea mays* L.) hybrids are crucial to sustainability of maize production in West and Central Africa (WCA). Two studies were conducted at three locations in Nigeria for 2 yr to (i) assess performance of 156 early-maturing maize inbreds and three hybrid types and (ii) determine heterosis among the lines and relationship between lines *per se* and hybrid performance. The inbreds and their hybrids were evaluated separately under drought and well-watered conditions. Genotype, environment and genotype × environment interactions were significant for grain yield under the research conditions. Grain yield of inbreds ranged from 0.06 t ha^{-1} for TZEI 123 to 1.92 t ha^{-1} for TZEI 17 under drought. While differences in grain yield among hybrid types (single, three-way and double-cross hybrids) were not significant under drought, significant differences were detected among hybrid types under optimal conditions. GGE biplot analysis identified three inbreds, TZEI 18, TZEI 56, and TZEI 1 and hybrids TZEI 129 × TZEI 16, (TZEI 17 × TZEI 16) × TZEI 157 and (TZEI 16 × TZEI 157) × TZEI 129 as ideal across research conditions. Midparent heterosis (MPH) and high-parent heterosis (HPH) for grain yield were higher in the well-watered conditions than under drought. Positive and significant correlations existed between MPH, HPH and yield under both research conditions. Drought tolerant hybrids with stable and high yield are available for promotion for adoption by farmers in WCA.

Keywords: drought tolerant inbreds, drought susceptibility index, early-maturing hybrids, GGE biplot, maize (*Zea mays* L.)

Introduction

Maize (*Zea mays* L.) is a major staple food crop consumed by both rural and urban dwellers in West and Central Africa (WCA). The savanna agro-ecologies of WCA have the greatest potential for increased maize production because of its higher solar radiation and lower incidence of pests and diseases. However, maize productivity in these regions is

* Corresponding author; E-mail: b.badu-apraku@cgiar.org

greatly constrained by several biotic and abiotic factors, including drought, low soil fertility, and the parasitic weed, *Striga hermontica* (Del.) Benth (Badu-Apraku et al. 2003). Drought is a major abiotic constraint contributing to fluctuations in yields in the lowland savanna belt of WCA (Badu-Apraku et al. 2005). As persistently recurrent drought reduces water resources for agronomic uses, drought tolerant varieties and hybrids become increasingly important for the sustainability of maize production and productivity in the drought-prone areas.

The effects of drought stress on maize production are severe particularly in the Sudan savanna zone due to unreliable and erratic distribution of rainfall (Eckebil 1991). Annual maize yield loss resulting from drought in WCA has been estimated to be about 15%. However, if drought stress coincides with the most drought-sensitive stages of maize growth, such as flowering, it can reduce grain yield by 50% and at grain-filling periods by 20% (Denmead and Shaw 1960). An average of 40 to 90% maize yield losses due to drought stress during the flowering and grain-filling periods have been reported by several workers (Nesmith and Ritchie 1992; Menkir and Akintunde 2001; Badu-Apraku et al. 2005).

The proportion of total land area cultivated to open-pollinated cultivars (OPs) by farmers in WCA has been estimated to be about 95% while hybrids accounted for only 5% (Abdoulaye et al. 2009). During the last couple of years, maize farmers in Nigeria have increasingly adopted hybrids and a large number of new seed companies have started to provide farmers with good quality hybrid seeds. Similarly, in countries such as Ghana and Mali, a number of seed companies have emerged and are engaged in large-scale hybrid production (Badu-Apraku et al. 2011). The availability of good quality seeds of maize hybrids with tolerance to stresses is invaluable for the sustainability of the productivity of small- and large-scale maize-based faming system of WCA (Badu-Apraku et al. 2011).

Inbred line information indicative of hybrid performance is desirable to reduce costs and time associated with hybrid production and evaluation. Such information makes it possible to develop productive hybrids without testing all possible hybrid combinations among the inbred lines available in a program. The positive association between mid-parent heterosis (MPH) of hybrid grain yield and parental lines has been reported by Makumbi et al. (2011) and Betrán et al. (2003). In the development of drought tolerant hybrids, maize breeders need to consider inbred and hybrid relationship under drought and optimum growing conditions.

Several studies have been conducted to determine the level of drought tolerance in the IITA early maturing inbred lines (Badu-Apraku et al. 2011). Therefore, evaluation of hybrids derived from these inbred lines under controlled drought stress would be invaluable in determining the breeding strategy for exploiting the gene action inherent in the inbred lines. The objectives of the present study were, therefore, to (i) assess the yield performance and stability of 156 early maturing inbreds, and the three hybrid types (single, three-way and double-cross hybrids) under drought and well-watered conditions, as well as across research environments, and (ii) estimate heterosis among the parental lines and determine the inbred hybrid relationships.

Materials and Methods

Two experiments were carried out in the present study. One hundred and fifty-six early-maturing maize inbred lines extracted from six diverse germplasm sources with tolerance or resistance to *Striga* and maize streak virus, and/or tolerance to drought were used in the present study. The 156 early maturing maize inbred lines were evaluated under drought at Ikenne (forest-savanna transitional zone, 6º87' N, 3º70' E, 60 m asl, 1500 mm annual rainfall) in Nigeria during 2007/08 and 2008/09 dry seasons and in well-watered environments at Ikenne and Bagauda (Sudan savanna, 12º00' N, 8º22' E, 580 m asl, 800 mm annual rainfall) during the growing seasons of 2008 and 2009. A 12 × 13 alpha lattice design with two replications was used for the inbred evaluation trial. Each experimental unit was a one-row plot, 4 m long with row spacing of 0.75 m.

In the second experiment, 10 drought tolerant, early maturing inbred lines (five white- and five yellow-grained), selected based on the results of the evaluation of the 156 inbred lines under induced drought at Ikenne during the dry season of 2007/09 (Table 1) were crossed in all hybrid combinations to form a diallel set of 10 single-cross hybrids without reciprocals. Within the 10 single-cross hybrids, all possible 15 double-cross- and 30 three-way-cross hybrids were produced. A total of 110 hybrids (20 single-cross, 30 double-cross and 60 three-way-cross) along with 11 drought tolerant checks (six OP cultivars and five single-cross hybrids) were evaluated using 11 by 11 alpha lattice design with two replications under drought and well-watered conditions. The hybrids were evaluated under both research conditions during the dry seasons of 2008/09 and 2009/10 at the IITA experimental station in Ikenne and during the growing season of 2009 at Bagauda and Zaria (northern Guinea savanna, 11º11' N, 7º38' E, 640 masl, 1200 mm annual rainfall).

The drought experiment was conducted at Ikenne during the dry season (December to March) under rain-free conditions. The hybrids were evaluated in adjacent trials in two blocks that received different irrigation treatments. One (the well-watered environment), received irrigation each week until physiological maturity. In the second, the drought treatment was imposed by withdrawing irrigation water from 28 days after planting (DAP) so that the plants relied on stored soil moisture till physiological maturity. Sprinkler irrigation was used to supply sufficient water (17 mm) every week to the two blocks from planting to the end of fourth week. Experiments at Bagauda, a terminal drought prone site and Zaria, a high yield environment were conducted under rain-fed conditions. The management practices were the same for all the experiments under both research conditions, except for the well-watered treatment.

At all locations, a single-row plot was used with a row length of 4 m and 22 plants /row. Row and hill spacings were 75 cm and 40 cm. Three seeds/hill were planted and seedlings were thinned to two plants/hill 2 weeks after emergence, giving a population density of 66 666 plants ha^{-1}. A compound fertilizer (NPK 15:15:15) was applied at the rates of 60 kg N, 60 kg P and 60 kg K ha^{-1} at planting in all experiments. An additional 60 kg N ha^{-1} urea was top-dressed 3 weeks later. The experiment was kept weed-free by applying 5 l ha^{-1} each of a mixture of gramoxone as a foliar contact herbicide and primextra as a pre-emergence herbicide. Subsequently, manual weeding was done as necessary to maintain the trials weed-free.

Table 1. Grain yield and other agronomic traits of parental lines of the different types of hybrids evaluated under drought and well-watered conditions at Ikenne and Bagauda, 2007–2009

Name	Pedigree	Grain yield, t ha^{-1}		Days to silk		ASI		Plant height, cm		Plant aspect		Ear aspect		LD	EPP	
		DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	DS	WW
TZEI 17	TZE COMP5-Y C6 S6 Inb 35	1.92	2.31	51	58	0.0	1.0	123.0	104.4	1.7	2.4	1.0	1.9	2.3	0.9	1.0
TZEI 129	TZE-Y Pop STR C0 S6 Inb 16-1-3	1.67	2.27	52	56	0.5	0.4	156.6	138.0	1.5	1.7	1.7	1.9	2.3	0.9	1.0
TZEI 63	TZE-W Pop STR C0 S6 Inb 136-2-3	1.65	1.50	54	61	1.8	2.2	127.4	115.4	1.7	2.8	1.8	2.1	4.3	0.9	0.9
TZEI 87	TZE-W Pop × 1368 STR S7 Inb 11	1.63	2.23	52	54	2.9	0.2	139.0	140.2	1.8	2.0	2.2	1.7	4.4	0.7	1.0
TZEI 2	TZE-W Pop × 1368 STR S7 Inb 2	1.49	1.92	53	58	1.9	1.6	135.7	117.2	2.2	2.3	2.0	1.9	4.3	0.7	1.0
TZEI 16	TZE COMP5-Y C6 S6 Inb 31	1.42	2.15	54	59	1.2	1.3	120.8	120.7	2.0	2.0	1.8	1.6	1.3	0.8	0.9
TZEI 59	TZE-W Pop STR C0 S6 Inb 80	1.42	1.39	54	60	1.6	1.5	123.5	116.6	1.5	2.4	2.6	2.4	4.4	0.8	0.7
TZEI 108	WEC STR S7 Inb 7	1.27	1.61	52	58	1.1	1.6	130.5	132.8	2.0	2.1	2.5	1.9	4.2	0.8	0.7
TZEI 135	TZE-Y Pop STR C0 S6 Inb 17-2-3	1.27	2.29	53	57	2.8	1.0	128.5	131.3	2.7	2.0	2.1	1.5	2.5	0.6	0.8
TZEI 157	TZE-Y Pop STR C0 S6 Inb 102-1-2	1.27	2.07	53	58	2.2	1.3	118.8	124.0	2.2	2.0	2.1	1.5	3.4	0.8	1.0
Grand mean		0.84	1.62	56	59	2.5	1.8	115.6	119.0	3.0	2.6	2.6	2.2	3.7	0.7	0.8
LSD		0.54	0.70	3	2	2.1	1.3	16.8	43.1	1.2	1.2	0.8	0.6	1.2	0.3	0.4
Environment (E)		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Genotype		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Genotype × E		**	**	**	**	**	**	**	*	**	**	**	**	**	**	**

*, ** Significantly different from zero at $P < 0.05$ and $P < 0.01$ levels, respectively.
ASI = Anthesis-silking interval, EPP = Number of ears per plant, LD = Leaf death score

Observations were made in the inbred and hybrid trials for days to anthesis and silking, and plant and ear heights. Anthesis-silking interval (ASI) was computed as the interval in days between silking and anthesis. Plant aspect were rated on a scale of 1 to 5, where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. Ear aspect was scored on a 1 to 5 scale, where 1 = clean, uniform, large, and well-filled ears and 5 = rotten, variable, small, and partially or poorly filled ears. Leaf death (LD) was scored at 70 DAP on a scale of 1 to 10, where 1 = less than 10% dead leaf area and 10 = more than 90% dead leaf area. The number of ears per plant (EPP) was computed as the proportion of the total number of ears at harvest divided by the number of plants at harvest. Grain yield, adjusted to 150 g/kg moisture, was computed from the shelled grain weight.

Separate analysis of variance (ANOVA) was performed for inbred and hybrid trials on data collected across years and locations for drought stress and well-watered conditions using PROC GLM from SAS (SAS 2001). Test environments, inbreds and replications were considered as random effects while hybrids were considered as fixed effects. Drought susceptibility index (DSI) was used as a measure of drought tolerance for the hybrid trial (Fischer and Maurer 1978). Twenty-nine each of inbreds and hybrids comprising the top 24 and the worst five entries selected based on combined ANOVA across research environments were subjected to GGE biplot analysis to identify the best single-, three-way- and double-cross hybrids and inbreds in terms of yield and stability as well as the ideal genotypes across research environments. The analyses were done using GGE biplot (Yan 2001). Mid-parent (MPH) and better-parent heterosis (HPH) were computed using the adjusted means of the inbred lines and hybrids. Correlations were computed between parental lines *per se* and the trait means of F1 hybrids under drought and well-watered conditions. The relationship between yield under well-watered conditions and drought was determined for each hybrid type using regression analysis.

Results

Results of the ANOVA of the inbreds combined across years under drought showed significant genotype (G), environment (E), and G × E interaction (GEI) mean squares for all traits (Table 1). Similarly, mean squares of inbreds were significant for all traits under well-watered conditions. Mean grain yield of the inbreds ranged from 0.06 t ha^{-1} for TZEI 123 to 1.92 t ha^{-1} for TZEI 17, averaging 0.84 t ha^{-1} under drought whereas, it ranged between 0.58 t ha^{-1} for TZEI 123 and 2.31 t ha^{-1} for TZEI 17 with an average of 1.62 t ha^{-1} under well-watered conditions. The top seven ranking inbreds were not significantly different from one another except TZEI 17 that was significantly different from the last three inbreds under drought. On the average, drought reduced grain yield of inbreds by 48% (Table 1).

Significant ($P < 0.01$) differences were detected among the genotypes for all measured traits except plant and ear heights, husk cover and EPP under induced drought stress and ASI and EPP under well-watered conditions (data not shown). Genotypic groups were significant ($P < 0.01$) only for days to anthesis and silking, and plant aspect under drought whereas significant differences were detected among genotypic groups for all measured traits except grain yield, husk cover, ear aspect and EPP under well-watered conditions. Single-cross hybrids were significantly ($P < 0.01$) different from three-way-cross hybrids for days to anthesis and silking, plant aspect and EPP under drought. In contrast, single-cross hybrids did not differ significantly from double-cross hybrids for any trait except days to anthesis under drought. Genotypic differences were observed between single- and double-cross hybrids for most traits except plant and ear heights, ear aspect and EPP under well-watered conditions. Genotype × environment interaction was significant ($P < 0.01$) for grain yield and days to anthesis under both research conditions. Genotypic group × environment interaction mean squares were significant for grain yield, plant height and plant aspect under drought and days to anthesis, plant height and stalk lodging under well-watered conditions (data not shown). The ranking of genotypes under drought stress was significantly correlated (r = 0.20 to 0.43, $P < 0.01$) with the rankings under well-watered conditions for all traits except plant height, plant aspect and EPP (data not shown).

Grain yield of the hybrids ranged from 1.04 to 2.51 t ha^{-1} , averaging 1.73 t ha^{-1} under drought and 2.53 to 5.00 t ha^{-1} with an average of 3.76 t ha^{-1} under well-watered conditions. On average, induced moisture deficit reduced grain yield by 54%, days to anthesis by 4%, days to silking by 2%, plant height by 13%, ear height by 10% and EPP by 20%. On the other hand, the ASI increased by 33%, plant aspect deteriorated by 7% and ear aspect by 11% (data not shown). The yield loss in the hybrids resulting from induced moisture stress compared with the yield in well-watered conditions ranged from 41 to 66% for single-, 26 to 69% for three-way-, 23 to 68% for double-cross, and from 26 to 63% for the checks, with an average of 54% (data not shown). The highest yielding single-cross (TZEI 129 × TZEI 16), three-way-cross [(TZEI 59 × TZEI 108) × TZEI 63] and double-cross [(TZEI 63 × TZEI 108) × (TZEI 59 × TZEI 87)] out-yielded the best OP check, TZE-W DT Pop STR C4 by 18, 19 and 20%, respectively, under induced drought (data not shown). The variation in grain yield under well-watered conditions accounted for 39% of the total variation in grain yield under induced drought for single-cross, 4% for three-way, 2% for double-cross, and 9% for the checks (data not shown).

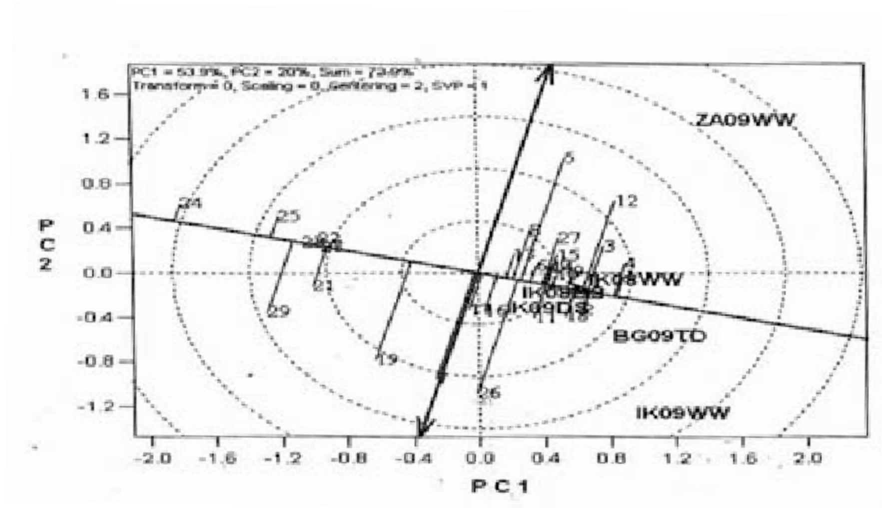
The highly significant genotype × environment interaction for inbreds and hybrid grain yield and most other measured traits necessitated the use of the GGE biplot to decompose the G + GE to determine the yield performance and stability of the inbreds and hybrids across research environments. The principal component (PC) axis 1 captured 61.7% of the total variation for grain yield of the inbreds while PC 2 captured 17.8% (data not shown). Thus, PC1 and PC2 together accounted for 79.5% of the total variation for grain yield of inbreds. In contrast, the GGE biplot of grain yield of the hybrids revealed that PC1 and PC2 together accounted for 74% of the total variation (Fig. 1). The average performance of a genotype is approximated by the projection of its marker on the average-tester coordinate (ATC). The stability of the genotypes is measured by their projection onto the average-tester coordinate y axis single-arrow line (ATC abscissa). The greater the absolute length of the projection the less stable is the genotype (Yan et al. 2007). Based on these criteria, inbreds, TZEI 18, TZEI 56, TZEI 1 and TZEI 19 had outstanding yield performance and short projection onto the average-tester coordinate y axis and hence high yield stability across research environments (data not shown). Similarly, the single-cross, TZEI 129 ×

TZEI 16 and the three-way-cross hybrids (TZEI 16 × TZEI 157) × TZEI 129 were identified as the highest yielding hybrids while, hybrid (TZEI 129 × TZEI 157) × TZEI 135 was the lowest-yielding across environments (Fig. 1). In contrast, the hybrids, TZEI 129 × TZEI 16, (TZEI 17 × TZEI 16) × TZEI 157 and (TZEI 135 × TZEI 17) × (TZEI 129 × TZEI 157) had outstanding yield performance and short projection onto the average-tester coordinate y axis and hence high yield stability across research environments. Based on the discriminating ability and representativeness of genotypes Yan (2001), hybrids TZEI 129 × TZEI 16, (TZEI 17 × TZEI 16) × TZEI 157 and (TZEI 16 × TZEI 157) × TZEI 129 (data not shown) and inbreds TZEI 18, TZEI 56 and TZEI 1 (data not shown) were located in the innermost concentric circle and were identified as ideal across research environments.

MPH and HPH for grain yield were higher in the well-watered conditions than under induced drought environments (data not shown). MPH ranged from 0 to 59% in the drought environment, with the largest MPH for hybrid TZEI 129 × TZEI 16. Under well-watered conditions, MPH ranged from 17% for TZEI 135 × TZEI 129 to 201% for TZEI 129 × TZEI 16 (data not shown). A similar trend was observed for HPH under both research conditions. There was no significant correlation between hybrid grain yield and MP and HP under drought or well-watered conditions (Table 2). However, significant positive correlations were obtained between grain yield and MPH, HPH, EPP, days to anthesis and silk, but negative correlation with plant and ear aspect and LD under drought (Table 2). Similarly, grain yield had significant positive correlations with MPH, HPH, plant and ear height, and EPP but negative correlations with plant and ear aspect under well-watered conditions. Positive and significant correlation existed between days to silk and anthesis, ASI, and plant aspect while negative correlations were observed between days to silk, EPP and grain yield under drought.

Discussion

Single-cross maize hybrids are normally more productive and uniform and have greater appeal than three-way and double-cross hybrids under optimal growing conditions and are preferred by both commercial seed companies and farmers. However, seeds of three-way- and double-cross hybrids are relatively cheaper than those of single-cross hybrids because of the lower seed yield of the parental inbreds. The lack of significant differences among the three different classes of hybrids under drought indicates the importance of dosage effects of the drought tolerance genes in the parental inbred lines used in the present study. The dosage effects of the drought tolerance genes in the three and four parental inbreds involved in the three-way- and double-cross hybrids compared with the two parental inbreds of the single-cross hybrids might have enabled them to out-yield some of the single-cross hybrids under drought. Furthermore, the broader genetic constitution of the three-way- and double-cross hybrids might have buffered them better than single-crosses against the diverse growing conditions of the trial sites. These findings are in agreement with the results of Pixley and Bjarnason (2002). The observed wide adaptation and stability of double-cross hybrids could also be due to the aggregation of genes from diverse parental lines.



Genotype	Code
TZEI 129 × TZEI 16	1
(TZEI 17 × TZEI 16) × TZEI 157	2
(TZEI 129 × TZEI 16) × TZEI 157	3
(TZEI 16 × TZEI 157) × TZEI 129	4
(TZEI 135 × TZEI 16) × TZEI 157	5
(TZEI 135 × TZEI 17) (TZEI 129 × TZEI 157)	6
(TZEI 135 × TZEI 129) (TZEI 16 × TZEI 157)	7
(TZEI 2 × TZEI 63) × TZEI 59	8
(TZEI 17 × TZEI 16) × TZEI 129	9
(TZEI 129 × TZEI 17) × TZEI 157	10
(TZEI 17 × TZEI 157) × TZEI 129	11
(TZEI 135 × TZEI 17) × TZEI 157	12
(TZEI 63 × TZEI 87) (TZEI 59 × TZEI 108)	13
TZEI 63 × TZEI 59	14
(TZEI 129 × TZEI 157) (TZEI 17 × TZEI 16)	15
(TZEI 135 × TZEI 157) (TZEI 17 × TZEI 16)	16
TZEI 135 × TZEI 17	17
TZEI 17 × TZEI 157	18
(TZEI 63 × TZEI 108) (TZEI 59 × TZEI 87)	19
TZEI 129 × TZEI 157	20
(TZEI 17 × TZEI 157) × TZEI 16	21
TZEI 135 × TZEI 129	22
TZEI 108 × TZEI 87	23
(TZEI 129 × TZEI 157) × TZEI 135	24
TZEI 17 × TZEI 16	25
CHECK 9 - TZEI 24 × TZEI 17	26
CHECK 1 - TZE-W DT POP STR C4	27
CHECK 10 - TZEI 11 × TZEI 17	28
CHECK 4 - Pool 18 SR/AK 94 – DMR ESR - $Y^{\times 2}$	29

Figure 1. The 'mean vs. stability' view of the GGE biplot based on a genotype × environment yield data of 29 early maturing maize hybrids evaluated across six environments between 2008 and 2009. Principal component (PC) 1 and PC 2 explained 74% of yield variation. IK08DS and IK09DS = Ikenne under drought stress in 2008 and 2009; IK08WW and IK09WW = Ikenne under well-watered in 2008 and 2009; BG09TD = Bagauda terminal drought stress in 2009; ZA09WW = Zaria under rainfed condition in 2009

Table 2. Correlation coefficient between maize inbred line *per se* and F_1 hybrid grain yield and other agronomic traits under drought (above diagonal) and well-watered conditions (below diagonal)

	MP	HP	MPH	HPH	Days to silk	Plant height	Ear height	Plant aspect	Ear aspect	ASI	EPP	Grain yield	LD
MP		0.88**	–0.05	–0.09	–0.21	0.15	–0.14	–0.01	–0.57**	–0.11	0.22	0.34	–0.13
HP	0.90**		–0.20	–0.32	–0.19	0.14	–0.15	0.04	–0.34	–0.02	0.02	0.14	–0.12
MPH	–0.76**	–0.72**		0.92**	–0.44	0.19	0.27	–0.71**	–0.68**	–0.38	0.67**	0.87**	–0.56**
HPH	–0.65**	–0.73**	0.96**		–0.29	0.20	0.28	–0.58**	–0.66**	–0.36	0.54*	0.76**	–0.49*
Days to anthesis	0.02	–0.19	0.01	0.12	0.85**	–0.23	–0.01	0.49*	0.33	0.42	–0.50*	–0.47*	0.01
Days to silk	0.02	–0.20	0.02	0.14		–0.24	–0.14	0.52*	0.39	0.83**	–0.54*	–0.54*	–0.18
Plant height	0.10	0.22	0.18	0.14	–0.28		0.68*	–0.24	–0.41	–0.17	–0.07	0.20	0.13
Ear height	–0.09	–0.06	0.43	0.43	–0.13	0.73**		–0.34	–0.36	–0.24	0.22	0.28	–0.01
Plant aspect	–0.24	–0.14	–0.35	–0.45	–0.09	–0.56**	–0.65**		0.50*	0.37	–0.63**	–0.74**	0.34
Ear aspect	0.21	0.16	–0.55*	–0.55*	0.11	–0.25	–0.39	0.51*		0.33	–0.66**	–0.85**	0.43
ASI	–0.16	–0.26	0.11	0.16	0.44	–0.26	–0.28	–0.07	–0.19		–0.41	–0.43	–0.32
EPP	–0.06	–0.14	0.54*	0.62**	–0.15	0.40	0.38	–0.63**	–0.64**	0.07		0.83**	–0.37
Grain yield	–0.03	–0.03	0.66**	0.69**	–0.02	0.47*	0.60**	–0.79**	–0.69**	0.02	0.79**		–0.49*
Rank correlation between drought and well-watered conditions	–	–	–	–	0.34**	0.13	0.20*	0.10	0.20*	0.20*	0.14	0.29**	–

*, ** Significantly different from zero at $P < 0.05$ and $P < 0.01$ levels, respectively.

MP = Mid-parent, HP = Better-parent, MPH = Mid-parent heterosis, HPH = Better-parent heterosis, ASI = Anthesis-silking interval, EPP = Number of ears per plant, LD = Leaf death score

This result is in agreement with that of Rahaman et al. (2009) who reported that aggregation of genes to segregants from diverse parents provides wide adaptation and stability in yield contributing traits and tolerance to key stresses in lentil.

The rankings of genotypes under induced drought were found to be similar to those under well-watered conditions. However, the variation in grain yield under well-watered conditions captured 39% of the total variation in grain yield under induced drought for single-cross hybrids, 4% for three-way-, 2% for double-cross, and 9% for improved varieties. It appears that the similarity observed in the ranking of genotypes under the two research conditions was mainly attributable to the consistency in the ranking of single-cross hybrids. The implication of this result was that performance of single-cross hybrids under well-watered conditions could be used to predict the performance under drought conditions. Therefore, field testing of three-way- and double-cross hybrids under induced drought is crucial for successful identification and development of the complex drought tolerant hybrids.

The high variation and low yield potential of the tested inbred lines (0.06 to 2.31 t ha^{-1}) and hybrids (1.04 to 2.51 t ha^{-1}) under drought indicated that adequate genetic variability existed among the early-maturing maize inbreds and hybrids to allow significant progress from selection for improvements in grain yield under drought. The reduction in grain yield resulting from induced moisture stress was similar for the three classes of hybrids when compared with well-watered conditions. These results fall within the range reported by earlier workers (Nesmith and Ritchie 1992; Menkir and Akintunde 2001; Badu-Apraku et al. 2005; Badu-Apraku et al. 2011). The best single, three-way, and double-cross hybrids out-yielded the best OP cultivar, TZE-W DT Pop STR C_4 by 18–20% under induced drought suggesting that superior hybrids are now available in WA and should be vigorously promoted for adoption by farmers to contribute to food security in the sub-region. Significant differences in DSI were also observed among the hybrids and the checks. The results of this study revealed that the higher the yield under drought stress, the lower the DSI. This result is in agreement with the findings of Bruckner and Frohberg (1987).

An important objective of this study was to identify hybrids that have stable and high yield performance across both research conditions. It is striking to note the superior performance of TZEI 129 × TZEI 16 and (TZEI 16 × TZEI 157) × TZEI 129 across test environments. Furthermore, TZEI 129 × TZEI 16 was not only the highest-yielding single-cross hybrid under drought stress, but was also identified as one of the ideal hybrids across research environments. These hybrids should therefore be vigorously promoted for adoption by farmers in WCA, especially those in the drought prone areas.

The absence of correlation between inbred line *per se* and hybrid performance under drought and optimum growing conditions indicated that the performance of inbred lines cannot be used to predict the performance of inbred lines in hybrid combinations under the research conditions. These results are consistent with the findings of Lafitte and Edmeades (1995), but contrary to those reported by Betrán et al. (2003). This implied the need to evaluate hybrids under stress conditions to identify superior hybrids for stress environments. The presence of positive and significant correlation between MPH and grain yield in this study is consistent with the findings of Makumbi et al. (2011) and Betrán et al. (2003).

In conclusion, the results of the present study suggest that the dosage effects of the drought tolerance genes in the three and four parental inbreds involved in the three-way- and double-cross hybrids might have enabled them to out-yield many of the single-cross hybrids under drought. The absence of correlation between inbred line *per se* and hybrid performance under drought and optimum growing conditions indicated that the performance of inbred lines cannot be used to predict their performance in hybrid combinations under the contrasting research conditions. The hybrids, TZEI 129 × TZEI 16, (TZEI 17 × TZEI 16) × TZEI 157 and (TZEI 16 × TZEI 157) × TZEI 129 identified as outstanding and stable should be commercialized and promoted for adoption to contribute to food security and the sustainability of emerging seed companies in the sub region.

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