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Full Length Research Paper

Performance and adaptability of doubled haploid maize testcross hybrids under drought stress and non-stress conditions

Olivia Odiyo*[ab], Kiarie Njoroge[b], George Chemining'wa[b] and Yoseph Beyene[c]

[*a]Pioneer Hi-bred International, P. O. Box 8617-30100, Eldoret, Kenya
[b]University of Nairobi, College of Agriculture and Veterinary Sciences, P. O. Box 29053-00625, Nairobi, Kenya.
[c]International Maize and Wheat Improvement Center (CIMMYT), P. O. Box 1041-00641, Nairobi, Kenya.

*Corresponding authors E-mail: y.beyene@cgiar.org; Tel: +254 20 (0) 722 4654; Fax: +254 (0)20 7224601

Abstract

Haploid breeding via *in vivo* induction of maternal haploids is rapidly replacing the pedigree breeding methods since it reduces the breeding cycle from at least 6 to 1-2 generations to reach a homozygous state. Eighty doubled haploid (DH) lines derived from nine tropical maize backcross populations were crossed to two CIMMYT single cross testers (CML312/CML442 and CML395/CML444) in a North Carolina II mating design. The resultant 160 DH testcross hybrids and five commercial checks were evaluated across four well-watered locations and two drought stressed locations in Kenya using an alpha-lattice design of 15 x 11 replicated twice. Significant differences ($0.05 < p < 0.001$) were observed in location, genotype and genotype by environment interaction for grain yield, days to anthesis, anthesis-silking interval and ear aspect under non-stress conditions. Combined analyses across drought stress and well-watered environments showed that the top 20 hybrids performed better for grain yield and other agronomic traits of maize compared to the commercial checks. Grain yield for the top 20 DH hybrids ranged from 8.15-8.85 t/ha under optimum management and 4.53-5.67 t/ha under drought stress conditions while the best commercial variety yielded 7.67 t/ha and 3.43 t/ha under optimum and drought stress conditions, respectively. The top ten DH testcross hybrids averaged over the four optimum locations yielded 16% higher than the best commercial check while under managed drought the top ten DH hybrids produced 62% higher grain yield than the best commercial check. Three DH testcross hybrids entries 23, 28 and 71 performed highly for grain yield under both stress and non-stress locations high stress tolerance indices (STI) and low stress susceptibility indices (SSI). These results indicated that maize hybrids developed from DH lines produced as high a grain yield and as acceptable agronomic traits as the commercial hybrids developed through conventional pedigree methods. The DH lines identified in the study should be useful in improving grain yields and in the drought prone mid-altitude areas of eastern and southern Africa.

Keywords: Doubled haploids, drought stress, maize, grain yield

INTRODUCTION

Maize is the third most important cereal globally after wheat and rice and ranks top in grain yield per unit area of land. Its demand is expected to surpass that of wheat and rice by 2020. This sudden shift will be reflected in a 50% increase in global maize demand from 558 million tons in 1995 to 837 million tons by 2020 (Pingali and

Pandey, 2001). In developing countries alone, the requirement for maize was expected to increase from 282 million tons level in 1995 to 504 million tons by 2020 (IFPRI, 2000). Worldwide production of maize in 2008 was 785 million tons with the largest producer, the United States of America, producing 42% while Africa produced 6.5%. The consumption per capita of maize is more than 116 million tons worldwide, with Africa consuming 30% and SSA 21% (FAOSTAT, 2011) although the continent produces less than 7% of the world's total. The cereal is the staple food for over 300 million people in sub-Saharan Africa (SSA) countries, but its production is constrained by a number of biotic, abiotic and socio-economic factors causing variation in grain yield as compared to other regions (Olaoye et al., 2009). For example, the average maize yield was estimated at 1.4 tons per hectare in SSA compared to 2.5 t/ha in the Philippines, 3.1 t/ha in Mexico and 3.9 t/ha in Thailand (Smale et al., 2011). Among the aforementioned constraints, drought is the most limiting factor in maize production in SSA. While drought occurring shortly before flowering causes an estimated yield loss of 21-50% (Denmead and Shaw, 1960) drought during flowering and grain filling can cause up to 37% crop loss (Bänziger et al., 1999) or more. Various workers have investigated the performance, adaptation and genetic variability in maize for grain yield and other agronomic traits under drought stress and non-stress conditions (Lafitte and Edmeades 1994; Bänziger et al., 1997; Duvick et al., 2004; Edmeades et al., 2006). All these studies reported that droughts frequently reduce grain maize yields. Drought tolerant varieties developed through conventional breeding methods are commercially available to farmers but more recently, many breeding programs are increasingly being geared towards using haploid breeding technology. Application of doubled haploid (DH) technology reduces the time for inbred line development to 1 to 2 generations (Forster and Thomas, 2004; Prigge et al., 2011) compared to classical pedigree methods that produce 96.9 % homozygous lines after 6 to 10 generations of selfing heterozygous material (Allard, 1960; Hallauer et al., 2010). This leads to several quantitative, genetic, operational, logistical and economic advantages (Melchinger et al., 2005; Smith et al., 2008; Geiger and Gordillo, 2009; Chang and Coe, 2009).

Generally, DH-line breeding programs are based on *in vivo* induction of maternal haploids (Seitz, 2005; Barret et al., 2008; Rotarenco et al., 2009) since other techniques such as androgenesis and gynogenesis, have proven to be too genotype specific or less effective. Progress on *in vivo* haploid induction technology has made it possible to produce large numbers of maternal haploids. Since the last decade, inbred line development by DH technology has been adopted as a routine method in many commercial hybrid maize breeding programs in Europe (Schmidt, 2003), North America (Seitz, 2005) and more recently in China (Chen et al., 2009). Through the Water efficient maize for Africa (WEMA) project, the International Maize and Wheat Improvement Center (CIMMYT) has developed DH lines from several drought tolerant source populations (Beyene et al., 2011; 2013) for use in eastern and southern Africa (ESA) and larger SSA. Various studies have been conducted to compare the performance of DH hybrids with other conventional hybrids. Seitz (2005) and Bordes et al. (2007) on separate studies found the performance of DH lines to be similar to those produced by single seed descent (SSD) and pedigree methods for grain yield, kernel moisture, ear height and plant height. Wilde et al. (2010) found that mean testcross performance of three DH line groups developed from three European landraces yielded 22-26 % less than the corresponding elite flint lines but did not differ significantly from the average testcross performance of their parental landraces. Beyene et al. (2011) reported that 15 DH hybrids derived from tropical adapted backcross populations yielded higher than the best commercial check developed through pedigree breeding while Beyene et al. (2013) further reported that the mean grain yield of DH testcrosses under drought stress was 58% lower than under non-stress environments and the top 15 testcrosses produced 1.3 – 2.2. t/ha higher grain yield than the mean of commercial checks. These studies by Beyene and his co-workers provided an insight into the potential usefulness of DH lines derived from tropical germplasm and information on the testcross performance of the DH lines under drought stress and non-stress conditions are still necessary to develop appropriate cultivars for the drought prone areas of East Africa. The objective of the present study was therefore to evaluate the performance of the DH maize testcross hybrids across six locations in Kenya under drought stress and non-stress conditions.

MATERIALS AND METHODS

Germplasm characterization

The DH lines were derived from BC_1F_1 nine tropical maize backcross populations (Table 1) by means of *in* vivo haploid induction at the Monsanto facility in Mexico. The nine source populations were obtained by crossing four drought tolerant (DT) donor lines with four recurrent parents (CML312SR, CML395, CML444 and CML488). Three of the DT donor lines were extracted from La Posta Seq C7, a drought-tolerant population developed at CIMMYT Mexico through recurrent selection among full sib/S_1 families (Edmeades et al., 1999). The fourth donor parent was developed from M37W, a temperate high yielding line. The recurrent parents are drought tolerant lines with good combining abilities and are adapted across several localities in SSA (Magorokosho et al., 2008; Beyene et al., 2013). Two hundred and fifty BC_1F_1

Table 1. Source population and number of DH lines selected for testcrosses formation

Population number	Pedigree	No. of lines selected
1	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395)	13
2	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444)	14
3	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488)	3
4	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR)	9
5	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395)	16
6	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444)	32
7	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488)	3
8	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395)	6
9	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395)	4

seeds from each of the nine populations were submitted for DH induction. After *in vivo* induction, treatment with colchicine and selfing, a total of 806 DH lines were generated and received from Monsanto. The DH lines were grown at Kenya Agricultural Research Institute-Kiboko nursery site, during the 2009/2010 short rainy season. Based on the results of *per se* evaluation (germination and good stand establishment, plant type, low ear placement, and well-filled ears), the best 100 lines were selected for testcross formation and subsequent field evaluation for this study.

Formation of DH testcrosses

The 100 DH lines were crossed with CML312/CML442 and CML395/CML444 in a North Carolina II mating design (Comstock and Robinson, 1948) to form 200 three-way cross (TWC) hybrids. Based on the grain weight of the harvested ears, only 160 hybrids were selected for field evaluations in multi-locations under stress and non-stress conditions.

Trial sites, experimental design and management of field trials

Agro-climatic descriptions of the sites are given in Table 2. Resultant 160 DH hybrids, 3 commercial checks and 2 local checks were evaluated across four well-watered environments (Kiboko 1, Embu, Kakamega and Kirinyaga Technical Institute) and two drought stressed environments (Kiboko 2 and Homabay) in Kenya during 2012 season. At managed drought sites, trials were grown during a rain-free period. Irrigation was applied at the beginning of the season to establish good plant stand but later on withdrawn at 43 to 57 days after planting to induce stress at flowering. The crops completed their growth cycle without any further irrigation. Under optimal conditions, supplemental irrigation was applied to ensure good growth and development of plants up to harvest. Stem borers were controlled in all trials.

At each location, the experimental design was a 15 x 11 alpha lattice design with two replications. Each entry was planted in two-row plots of 5 m long spaced at 0.75 m between rows by 0.25 m between hills. Two seeds were sown per hill and 3 weeks after emergence, thinned to one plant per hill to give a plant population of 53,333 plants per hectare. A di-ammonium phosphate (D.A.P) fertilizer was applied at the rate of 60 Kg N and 60 Kg P_2O_5 per hectare at planting while nitrogen was given in two applications: at planting and six weeks after emergence. The fields were kept free of weeds by hand weeding. Stem borers were controlled in all rows and plants. For each plot, data were collected on the following traits: anthesis date measured as number of days after planting when 50 % of the plants per plot shed pollen, days to silking measured as number of days after planting when 50 % of the plants per plot show silks, anthesis silking interval (ASI) computed as the difference between anthesis and silking dates, plant height (cm) determined by measuring representative 10 plants from the base of a plant to the insertion of the first tassel branch of the same plant, ear height (cm) determined by measuring representative 10 plants from the base of a plant to the insertion of the top ear of the same plant, ear and plant aspects which were scored using a scale of 1-5, where 1 was a score for clean, uniform and large cobs and free of diseases whereas 5 was a score for small non-uniform and diseased cobs with irregular ear placement, root lodging measured as percentage of plants that were inclined by more than 30°, before harvest, stem lodging measured as percentage of plants whose stems were broken below the ear before harvesting, number of ears per plant counted as number of ears with at least one fully developed grain divided by

Table 2. Agro-climatic description of trial sites

Site	Longitude	Latitude	Elevation (masl)	Rainfall (mm/yr)	Temperature (0°C)		Mega Environment
					Min	Max	
Kiboko	37° 75'E	2° 15'S	975	530	14.3	35.1	Dry Mid-Altitude
Embu	37° 42'E	0° 49'S	1510	1200	14.1	25.0	Wet Lower Mid-Altitude
Kakamega	34° 45'E	0° 16'N	1585	1916	12.8	28.6	Wet Upper Mid-Altitude
Mtwapa	39° 44'E	3° 50'S	15	1200	22.0	30.0	Low land coastal tropic
KTI	37° 19'E	0° 34'S	1282	1500	18.0	24.0	Wet Lower Mid-Altitude
Homabay	34° 27'E	0° 31'S	1751	700	17.1	34.8	Dry Upper Mid-Altitude

the number of harvested plants, ear rot scored on a scale of 1 (clean, no rot) to 5 (completely rotten), foliar diseases under natural infestation for gray leaf spot (*Cercospora zea-maydis*), northern leaf blight (*Exserohilum turcicum*), leaf rust (*Puccinia sorghii*) and maize streak virus were visually scored on a scale of 1 to 5 (1 = resistance; 5 = susceptible) by assessing the severity of the symptoms on plants in the entire plot. In drought stress conditions, ears were harvested from each plot and shelled to determine the percentage grain moisture. In the well-watered experiments, harvested ears of each plot were weighed and the grain yield was estimated based on 800 g grain Kg^{-1} (ear weight) and adjusted to 125 g Kg^{-1} moisture content.

Data analysis

Preliminary data analysis was conducted using Field book (Vivek et al., 2007). Analysis of variance (ANOVA) was done for individual sites as well as across sites, using the mixed procedure (PROC MIXED) in SAS© (Statistical Analysis System) 9.2 (SAS, 2003). Genotypes were considered as fixed effects while environments, replications and blocks within replication as random effects. Adjusted means for individual sites were calculated and separated using the least significant difference (LSD) method (Snecdor and Cochran, 1967). For combined analysis, variances were partitioned into relevant sources of variation to test for differences among genotypes and the presence of GEI.

RESULTS

Analysis of Variance (ANOVA)

The ANOVA showed highly significant ($p<0.001$) differences among the genotypes for grain yield (GY), days to anthesis (AD), anthesis-silking interval (ASI) and ear aspect (EA) under non-stress conditions while these differences disappeared under drought stress (Table 3). Environment had the largest mean square effects on all measured traits compared to those of genotypes and the genotype by environment interaction (GEI) under both moisture regimes. Low effects of GEI were observed for all traits compared to genotype main effects except for grain yield and ASI under drought stress conditions (Table 3). GEI was highly significant ($p<0.001$) for ASI, and significant ($p<0.05$) for days to anthesis and ear aspect under well-watered conditions. A small error of 1.09 and 3.16 for grain yield under non-stress and stress conditions respectively, indicated a high precision and accuracy of the experiments.

Mean performance across locations under drought stress and non-stress conditions

All the top 20 DH hybrids yielded higher than the best commercial check (DK-8053) under both optimum and drought stress conditions (Table 4 and 5). Grain yield ranged from 8.15 to 8.85 t/ha under optimum conditions and 4.53 to 5.67 t/ha under drought stress conditions. DK-8053, commercial hybrid, yielded 7.67 t/ha and 3.43 t/ha under non-stress and stress conditions, respectively. The best DH hybrid, entry 91, had a yield advantage of 13 % over the best commercial check under well-watered conditions (Table 4) and entry 142 had a yield advantage of 40 % over the best commercial check under drought stress (Table 5). Grain yield reduced by 49 % while ASI increased by 87 % under drought stress compared to well-watered conditions. In addition, the DH hybrids were early maturing and had short ASI compared to the check hybrids. The calculated mean values of drought selection indices based on grain yield under stress and non-stress conditions are presented in Table 5. Some DH hybrids performed better for grain yield under both stress

Table 3. Mean squares for grain yield and other agronomic traits of DH testcross hybrids evaluated under diverse water conditions in Kenya during 2012 season.

	Well-watered conditions					Drought stress conditions				
SOURCE	**df**	**Grain yield ($t\ ha^{-1}$)**	**Days to anthesis**	**ASI (days)**	**Ear aspect (1-5)**	**df**	**Grain yield ($t\ ha^{-1}$)**	**Days to anthesis**	**ASI (days)**	**Ear aspect (1-5)**
Environment (E)	3	579.58***	22717.15***	474.16***	63.06***	1	552.16***	137.69***	28.30**	629.05***
Genotype (G)	79	9.52***	8.80***	3.02***	0.33***	79	1.87	5.13	2.11	0.13
G X E	237	1.09	3.77*	2.37***	0.17*	79	1.95	5.07	2.26	0.13
Error	639	1.09	3.15	1.44	0.14	319	3.16	5.06	2.86	0.23
CV%		14.99	2.49	158.5	15.45		49.88	3.39	87.93	48.72

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**
ASI = Anthesis-Silking Interval; df = degrees of freedom; CV = Coefficient of variation.

and non-stress conditions thus creating possibility of getting some drought tolerant genotypes. Using STI as the base index, entries 23 (L_{23} x T_1), 28 (L_{28} x T_1) and 71 (L_{71} x T_1) had high STI scores of 0.96, 0.83 and 0.81 respectively, and low SSI scores of 0.68, 0.88 and 0.89 respectively (Table 6). These DH materials therefore qualify to be considered as drought tolerant since they produced a higher grain yield under both optimal (Ypi) and drought stress (Ysi) conditions.

DISCUSSION

Inbred line development via doubled haploid technology is rapidly gaining adoption in the commercial hybrid breeding of maize since it increases the genetic advance per unit of time at the level of hybrid development. A significant GEI observed for ASI, days to anthesis and ear aspect (Table 3) indicates the differential response of genotypes across environments for these traits. This could be attributed to variations in terms of climatic and edaphic factors in the test environments. Thus hybrids could be developed targeting a particular environment in line with flowering and maturity periods. This is in agreement with findings of Beyene et al. (2011) for DH testcross hybrids developed from tropically adapted drought tolerant backcross populations but deviates from the results of Wilde et al. (2010) for DH testcrosses developed from temperate landraces. Similar to conventionally-derived breeding materials, the DH testcross hybrids used in this study exhibited a broad range of variation in grain yield and other agronomic traits under both water regimes (Table 4 and 5). Similar observations were made by Munyiri et al. (2010) while working on Kenyan maize landraces to characterize them for drought tolerance. The DH hybrids outperformed the commercial hybrids for grain yield and other agronomic traits assessed. The best DH testcross hybrid (entry 91) produced 13 % higher grain yield than the best commercial check DK-8053 under well-watered conditions (Table 4) and entry 142 had a yield advantage of 40 % over the best commercial check under drought stress (Table 5). Similar to the present study, Beyene et al. (2011) reported superiority in performance by DH hybrids over the commercial checks. The best DH hybrid in their study produced 29.5% higher grain yield than the best commercial check and the testcross hybrids were comparable with the best check hybrid in terms of flowering, plant height, ear height and reaction to foliar diseases. This meant that DH lines were superior in performance over the commercially available hybrids that farmers use. Therefore, the DH testcross hybrids indicated that the DH lines used in this study offered potential new sources for producing high yielding and drought tolerant hybrids rapidly.

Table 4. Performance of the top 20 DH testcross hybrids across four locations in Kenya under well-watered conditions during 2012 season.

RANK	ENTRY	CROSS	Grain Yield (t ha^{-1})	Days to anthesis	Anthesis Silking Interval	Ear Aspect (1-5)	Ear Aspect (1-5)	Ear Height (cm)	Plant Height (cm)	Ear Rot (%)	Ears per Plant (#)
1	91	11x2	8.85	69	0.75	2.31	2.74	129	251	9.42	1.01
2	29	29x1	8.57	70	1.13	2.02	2.64	133	259	4.27	1.04
3	110	30x2	8.55	70	1.75	2.11	2.87	139	261	6.81	0.98
4	120	40x2	8.53	72	0.50	2.14	2.96	136	253	2.22	1.01
5	116	36x2	8.53	70	0.99	1.96	2.65	142	265	9.11	0.99
6	26	26x1	8.51	69	-1.14	2.13	2.75	141	267	5.69	1.04
7	93	13x2	8.39	68	1.75	2.00	2.89	128	244	6.45	1.03
8	135	55x2	8.38	72	-0.13	2.62	2.49	133	250	9.43	1.02
9	28	28x1	8.37	69	1.13	2.46	2.77	129	250	4.32	1.05
10	23	23x1	8.34	72	0.37	2.50	2.59	134	256	4.81	1.00
11	148	68x1	8.33	72	-0.63	2.63	2.76	140	245	16.12	0.99
12	71	71x1	8.32	70	0.52	2.36	2.37	130	247	3.85	1.04
13	27	27x1	8.31	75	0.13	2.27	2.56	158	275	4.27	1.08
14	122	42x2	8.28	70	2.01	2.16	2.48	131	257	3.19	1.02
15	114	34x2	8.25	70	2.63	2.12	2.28	124	239	7.60	0.97
16	96	16x2	8.22	70	0.12	2.37	2.49	141	254	4.70	1.00
17	88	8x2	8.20	69	1.00	2.37	2.76	131	254	7.05	1.01
18	144	64x2	8.19	70	-0.51	2.49	2.71	129	246	14.80	1.02
19	85	5x2	8.16	68	1.26	2.59	2.79	123	243	10.36	0.93
20	4	4x1	8.15	71	-0.24	2.23	2.64	145	255	5.31	0.99
Commercial checks	DK-8053		7.67	67	1.38	2.48	2.59	107	231	17.87	0.96
	H513		7.62	67	1.26	2.51	3.12	139	256	10.98	1.07
	PH3253		6.73	67	1.25	2.65	3.03	123	250	10.84	1.02
	Local check 1		7.19	68	1.74	2.45	3.57	135	256	15.75	0.96
	Local check 2		6.93	66	0.89	2.60	3.36	121	262	15.65	0.96
Grand mean of trial			**6.97**	**71**	**0.77**	**2.42**	**2.87**	**130**	**246**	**8.93**	**0.99**
Entry variance			**0.80**	**8.65**	**0.57**	**0.05**	**0.06**	**90.59**	**98.36**	**12.54**	**0.00**
Location variance			**1.79**	**70.65**	**1.46**	**0.20**	**0.02**	**245.9**	**235.9**	**21.99**	**0.01**
Location x entry variance			**0.22**	**1.43**	**0.49**	**0.05**	**0.08**	**8.17**	**11.25**	**17.63**	**0.00**
LSD (0.05)			**1.10**	**2.19**	**1.51**	**0.46**	**0.69**	**9.79**	**12.22**	**7.68**	**0.09**

The DH testcross hybrids (entries 23, 28 and 71) performed well across optimum and stress locations (Table 4 and 5) indicating that it is possible to combine stress tolerance and yield potential in tropical doubled haploid maize hybrids. Moisture stress reduced grain yield by 49 %, days to tasselling by 4 % while ASI increased by 87 % and ear rot by 98 % in addition to

Table 5. Performance of the top 20 DH testcross hybrids across four locations in Kenya under drought stress conditions during 2012 season.

	ENTRY	CROSS	Grain Yield (t ha^{-1})	Days to anthesis	Anthesis Silking Interval	Ear Aspect (1-5)	Ear Height (cm)	Plant Height (cm)	Ear Rot (%)	Ears per Plant (#)	Leaf senescence
1	142	62x2	5.67	66	1.21	0.74	149	226	13.9	0.93	2.50
2	23	23x1	5.58	67	1.19	1.18	152	228	20.1	0.89	4.45
3	92	12x2	5.50	65	1.75	2.06	144	231	24.4	0.94	3.86
4	137	57x2	5.32	65	1.86	1.31	151	227	18.2	0.90	5.05
5	147	67x2	5.30	67	1.59	1.51	149	220	9.1	0.89	3.55
6	140	60x2	5.27	66	1.17	1.30	150	237	6.4	0.93	3.83
7	126	46x2	5.08	66	1.52	1.65	153	240	22.4	0.85	4.29
8	99	19x2	5.04	64	1.83	2.14	152	234	42.1	0.69	5.15
9	138	58x2	5.03	66	2.64	1.39	148	223	15.2	0.76	5.79
10	24	24x1	4.92	62	1.05	1.21	142	230	12.1	0.97	4.04
11	28	28x1	4.79	65	1.60	1.89	152	235	10.4	0.90	5.51
12	71	71x1	4.72	65	2.42	2.05	146	227	17.9	0.88	5.63
13	132	52x2	4.67	67	1.97	1.75	150	229	17.8	0.86	4.42
14	134	54x2	4.64	65	1.14	1.53	141	232	15.4	0.90	6.46
15	146	66x2	4.62	66	1.84	1.90	152	231	9.2	0.87	5.16
16	22	22x1	4.61	66	1.80	2.10	159	236	15.3	0.82	4.30
17	70	70x1	4.60	66	0.75	1.69	151	231	22.8	0.93	3.97
18	25	25x1	4.54	64	1.27	1.74	153	239	9.3	0.84	5.15
19	128	48x2	4.53	66	1.51	1.26	143	228	7.2	0.86	4.85
20	145	65x2	4.53	66	1.63	1.47	155	233	14.4	0.89	4.01
Commercial hybrids	DK-8053		3.43	64	2.17	2.18	126	210	13.9	0.69	5.52
	H513		2.16	64	2.96	3.25	152	226	18.2	0.63	6.78
	PH3253		2.36	65	2.97	1.82	146	227	29.2	0.71	4.71
	Local check 1		2.25	65	3.39	1.81	138	222	17.9	0.79	4.70
	Local check 2		1.93	62	2.90	2.20	132	229	22.5	0.73	5.02
Grand mean of trial			**3.55**	**66**	**1.93**	**1.99**	**147**	**227**	**17.4**	**0.80**	**5.02**
Entry variance			**0.20**	**2.10**	**0.21**	**0.02**	**54.91**	**51.26**	**8.07**	**0.00**	**0.00**
Location variance			**1.77**	**78.47**	**0.07**	**0.00**	**52.14**	**10.03**	**117.20**	**0.01**	**0.00**
Location x entry variance			**0.17**	**1.75**	**0.55**	**0.02**	**2.16**	**0.00**	**3.37**	**0.00**	**0.04**
LSD (0.05)			**1.92**	**2.98**	**2.31**	**1.05**	**12.51**	**16.58**	**15.04**	**0.22**	**1.91**

hastened leaf senescence. In similar working conditions, Menkir et al. (2006) reported that moisture deficit reduced grain yield by 58 %, plant height by 16 %, ears per plant by 30 % and ear height by 19 %, while increasing days to silking by 6 % and ASI by 144 % in comparison with well-watered conditions while drought stress had little effect on days to anthesis compared to well-watered condition. These observations were consistent with a study reported Bruce et al. (2002) for maize. They ascertained that the period during pollination and early grain filling were the most sensitive to water stress as compared with pre-flowering and late grain filling growth stages. This is because water deficits in maize plant during reproductive stage reduces photosynthetic rate due to reduction in

Table 6. Grain yield of top 15 DH testcross hybrids based on Stress Tolerance Index under optimal and drought stress conditions, and calculated drought tolerance indices.

			Yield (t ha^{-1})		Drought Tolerance Indices				
RANK	**ENTRY**	**CROSS**	**Ypi**	**Ysi**	**SSI**	**STI**	**GMP**	**TOL**	**YSI**
1	23	23x1	8.34	5.58	0.68	0.96	6.82	2.76	0.67
2	92	12x2	8.14	5.50	0.67	0.92	6.69	2.64	0.68
3	126	46x2	8.05	5.08	0.76	0.84	6.39	2.97	0.63
4	142	62x2	7.14	5.67	0.42	0.84	6.36	1.47	0.79
5	28	28x1	8.37	4.79	0.88	0.83	6.33	3.58	0.57
6	140	60x2	7.57	5.27	0.63	0.82	6.32	2.30	0.70
7	71	71x1	8.32	4.72	0.89	0.81	6.27	3.60	0.57
8	138	58x2	7.78	5.03	0.73	0.81	6.26	2.75	0.65
9	99	19x2	7.68	5.04	0.71	0.80	6.22	2.64	0.66
10	147	67x2	7.19	5.30	0.54	0.79	6.17	1.89	0.74
11	110	30x2	8.55	4.44	0.99	0.78	6.16	4.11	0.52
12	29	29x1	8.57	4.40	1.00	0.78	6.14	4.17	0.51
13	132	52x2	8.04	4.67	0.86	0.78	6.13	3.37	0.58
14	22	22x1	8.12	4.61	0.89	0.77	6.12	3.51	0.57
15	137	57x2	6.87	5.32	0.46	0.75	6.05	1.55	0.77

Ypi: Potential yield; Ysi: Stress yield; SSI: Stress Susceptibility Index; STI: Stress Tolerance Index; GMP: Geometric Mean Productivity; TOL: Tolerance index; YSI: Yield Stability Index.

light interception as leaves senesce leading to slow ear growth, barrenness and low harvest index.

Several workers have used drought selection indices such as Stress Tolerance Index (STI), Stress Susceptibility Index (SSI), Geometric Mean Productivity (GMP), Tolerance index (TOL) and Yield Stability Index (YSI) to provide a measure of drought based on yield loss under drought stress conditions in comparison to well-watered conditions (Mitra, 2001; Mohammadi et al., 2003; 2010; Akçura et al., 2011). These indices are based on a mathematical relationship used to evaluate response of plant genotypes to drought stress (Clarke et al., 1992; Sio-Se Mardeh et al., 2006). The 160 DH testcross hybrids tested presented a range of variability for grain yield and other agronomic traits of maize. Averaged across four well-watered locations and two managed drought locations, 31 DH testcross hybrids yielded over 8 t/ha under non stress conditions while nine DH hybrids yielded over 5 t/ha under drought stress conditions (Table 6) indicating that the superior DH lines identified in this study should be useful sources for improving yield in maize growing areas of Kenya and other similar agro-ecological zones in eastern and southern Africa. The three best performing DH hybrids under both moisture regimes need to be advanced further for use in the arid and semi-arid areas (ASALs) and low potential areas which experience limited rainfall. The results presented here indicate that maize testcross hybrids developed from DH lines can produce as high a grain yield and as acceptable agronomic traits as commercial hybrids developed through conventional pedigree methods. Thus, superior DH lines can be incorporated in commercial maize breeding programmes in efforts directed towards developing high yielding and drought tolerant varieties.

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