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Combining, earliness, short anthesis to silking interval and yield based selection indices under intermittent water stress to select for drought tolerant maize

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Abstract

Maize, the most important staple crop in Kenya, is affected by drought stress at flowering period leading to low yields. Past studies at CIMMYT have demonstrated that a short Anthesis to Silking Interval (ASI) is an important component of drought tolerance in maize. In this study, one hundred and thirty five F_2;F_3 progenies developed from crosses between long ASI, Katumani composites and short ASI, elite CIMMYT genotypes were evaluated for grain yield under drought stressed and well-watered environments, in two seasons in an alpha lattice design of three replications. ASI was significantly negatively correlated with grain yield (GY) under stress (-0.446) but not under well watered condition. ASI was significantly positively correlated with stress susceptible index (SSI) (0.304) but was highly negatively significantly correlated with stress tolerance index (STI) (-0.378). ASI was also significantly positively correlated with geometric mean productivity (GMP) (-0.448), mean productivity (MP) (-0.419), and yield stress index (YSI) (-0.303). Among the computed drought tolerance selection indices, GMP and GY were highly positively correlated with other drought selection indices and negatively correlated with ASI. These two traits are likely to be better measures of drought tolerance than all the other indices. F_3 families from KDV2/CML444-14 and KDV2/CML440-224 generations were earlier maturing, higher yielding, a shorter ASI and higher WUE and GMP indices than the other genotypes, under drought stressed environments.
It is possible to combine earliness and ASI in developing high yielding, early maturing drought tolerant maize for arid and semi-arid areas of Kenya.

Keywords: ASI, geometric mean production, drought indices, grain yield, early maturity.
Abbreviations: AD_ anthesis date, AD-DRT_ AD under stress, AD-IRR_AD under non stress conditions, ASI_ anthesis to silking interval, ASI-DRT_ ASI under stress, ASI-IRR_ ASI under non-stress conditions, BIO_ Plant Biomass, EPP_ ears per plant, GMP_ geometric mean productivity, GY_ grain yield, MP _Mean Productivity, SEN_ senescence, SSI_ stress susceptible index, STI_ stress-tolerance index, TOL_ tolerance index, WUE_ water use efficiency, YI_ Yield index, YTI _yield tolerance index, Ysi _Yield under stress; Ypi _Yield under non-stress conditions, YSI_ Yield Stability Index.

Introduction

In the past, maize breeding research efforts by the Kenya Agricultural Research Institute (KARI) have successfully exploited earliness in the crop to develop drought escaping varieties such as Katumani and Makueni composites. CIMMYT (*Centro internacional de Mejoramiento de Maiz y Trigo*) on the other hand has developed medium to late maturing drought tolerant varieties using anthesis to silking interval (ASI) and other secondary traits. Anthesis to silking interval trait, unlike yield has medium to high heritability under drought stress (Bänziger et al., 2000; Bolanõs and Edmeades, 1996). Past studies (Edmeades et al., 1998; Magorokosho et al., 2003; Magorokosho et al., 1997) established that ASI was an ideal selection criterion under drought stress because it was genetically associated with grain yield under stress, and was highly heritable, cheap and fast to measure and stable within the stress period. To enhance selection for drought tolerance, other criteria such as stress susceptibility index (SSI) and yield tolerance index (YTI) based on the fact that drought susceptibility leads to grain yield reduction have been suggested. Indeed some authors have argued that it is difficult to express drought tolerance in maize without considering the performance of the genotypes being evaluated under both water stress and non-water stress conditions (Fischer and Maurer, 1978; Gavuzzi et al., 1997, Lin et al., 1986). In this respect, such parameters as geometric mean productivity (GMP), mean productivity (MP) and yield stress index (YSI) have been computed to aid in the selection for drought tolerance (Fernandez, 1992; Kristin et al., 1997). This study hypothesized that it was possible to combine both early maturing (drought escape) and drought tolerant genes (short ASI) in the same genotype and enhance the performance of the resultant progenies by utilizing drought selection indices such as SSI, STI, GMP, MP and YTI. Selection of drought tolerant genotypes would help to stabilize grain yield production in the marginal dry areas and also reduce the risks of the frequent crop failures that are common in the arid and semi-arid areas of Kenya (Muhammad et al., 2009).

Results

In general, ASI mean increased to 4.43 under water-stress compared with a mean of 1.6 under well-watered conditions where ASI ranged between -1 to 6 days (Table 1). Also, as

Table 1. Effects of water stress during flowering stage on the phenotypic traits of the F_3 maize genotypes evaluated at KARI, Kiboko substation.

Traits	Water Regimes			
	Drought Stress (DS)		Well Watered (WW)	
	Mean	Range	Mean	Range
Days to anthesis	52.67	46 – 63	57.04	50 – 65
Days to silking	57.23	47 - 72	58.97	51 - 68
ASI (days)	4.43	1 – 9	1.6	-1 – 6
Leaf rolling (1-5)	3.72	2.5 – 5.0	1	1 - 1
Grain yield (tons/ha)	0.53	0.011 – 2.80	2.43	0.628 – 7.763
EPP	0.30	0.093 – 0.93	0.67	0.099 – 1.176
Plant height (m)	146.39	70 – 177.5	139.04	63 – 178.75
Senescence	3.66	2.0 – 4.5	2.07	1 – 3
Above ground biomass	0.08	0.015 – 0.330	0.18	0.043 – 0.670

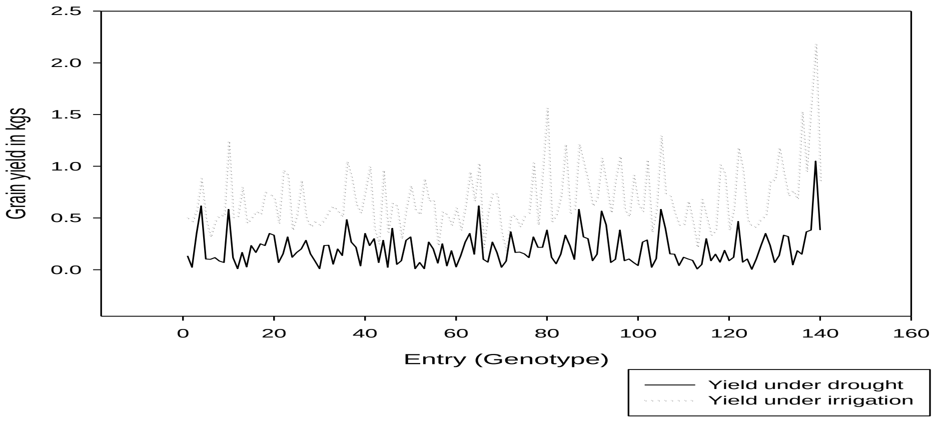

Fig 1. GY Performance of F_3 genotypes under drought and well-watered conditions

expected days to anthesis, grain yield, ears per plant and above ground biomass were reduced drastically under water stress whereas leaf rolling and senescence values remained high under water stress conditions. The F3 genotypes under drought stress gave lower yields compared to those under well-watered environment (Fig. 1) but under drought stress there was increased interval between anthesis and silking as would be expected (Fig. 2). There were significant differences in ASI, GY and AD in the F_3 genotypes under drought stress but under well-watered conditions, only GY and ears per plant (EPP) were significantly different among the genotypes (Table 2).. Under both water -stressed and well -watered conditions, the environmental, genotypic and the Genotype x Environmental variances (G x E) were highly significant for ASI, AD, GY and EPP (Table 3). ASI was highly negatively correlated with grain yield under water stress (-0.448) but was not correlated with grain yield under well-watered conditions (Table 4). ASI was highly negatively correlated with stress tolerance index, (-0.378) geometric mean productivity, (-0.448) mean productivity (-0.419) and yield tolerance index (-0.303). Grain yield under water stress (Ysi) as well as grain yield under well watered conditions (Ypi) were highly positively correlated to STI, GMP and MP but only Ysi was correlated to yield stability index (YSI) (0.739) and to WUE (0.581). STI was highly positively correlated to GMP (0.918) and MP (0.880). As grain yield increased there was a concomitant increase in stress tolerance index (STI) (Fig. 3) whereas, a decrease in grain yield was accompanied by an increase in stress susceptibility index (SSI) (Fig. 4). Genotypes KDV2/CML440-224, KDV2/CML444-14 and KDV2/CML-440-66 had high STI value compared to local checks (Table 5). These genotypes also had high yields under drought stress and performed equally well under optimum conditions. Similarly, the same genotypes with high STI values also showed low stress susceptibility index (SSI) values. The genotypes that produced high SSI values, namely, KDV4/CML440-442 and KDV4/CML440-87 produced low yields (Table 5). From Table 5, the check entry, Duma hybrid out-yielded all the other genotypes with a yield index (YI) of 5.25. However, the F_3 genotypes that ranked behind the hybrid in terms of yield, namely KDV2/CML444-14, KDV2/CML440-224, and KDV2/CML- 440-66 were earlier maturing and had a smaller ASI. Indeed, one of them, KDV2/CML444-14 matured in 48.67 days closer to the local maize check that was ranked 16^{th} according to grain yield (Table 5). Compared to the local maize check, all the generations of crosses in the F_3, involving KDV2 and KDV4 parental lines up to rank 15, had higher STI values confirming the trend shown in Fig. 3. Again, all the F_3 genotypes, with the exception of KDV2/CML442-158 and KDV4/CML440-504 produced higher GMP and GP values than local maize check.

Discussion

ASI has been reported to be a more valuable diagnostic trait for cultivar performance under drought stress than days to silking *per se*, since it is largely independent of maturity differences among cultivars and is highly correlated to yield (Magorokosho et al., 2003). In the work reported here, under drought stress, ASI increased up to 7.7 days under drought stress environment from an average of 1.6 days under non stress environment. ASI was significantly negatively highly

Table 2. ANOVA for ASI, Anthesis date, ears per plant and grain yield under drought stress and well–watered conditions.

Water Regimes Mean Squares									
		Well-watered environment				Drought stress environment			
Source of Variation	df	ASI	AD	EPP	GY	ASI	AD	EPP	GY
Genotypes	139	1.19*	4.84***	0.02	0.02*	1.11	4.91	0.04**	0.08***
Rep	2	0.06	9.56*	0.28	0.15**	1.50	2.35	0.05	0.01
Block	83	0.37	18.27*	0.26*	0.15**	2.31	2.44	0.01	0.01
Rep*Genotype	278	1.03	2.46*	0.02	0.02	1.20	3.28	0.02	0.03
%CV		20.38	2.58	67.77	68.27	59.80	3.51	22.25	22.19
Mean		4.40	52.60	0.30	0.20	1.65	59.05	0.67	0.68

Key: P<0.05; ** P<0.01; *** P<0.001 DF = Degrees of Freedom; ASI = Anthesis-silking interval; AD = Anthesis Date; EPP = Ears per Plant; GY = Grain Yield.

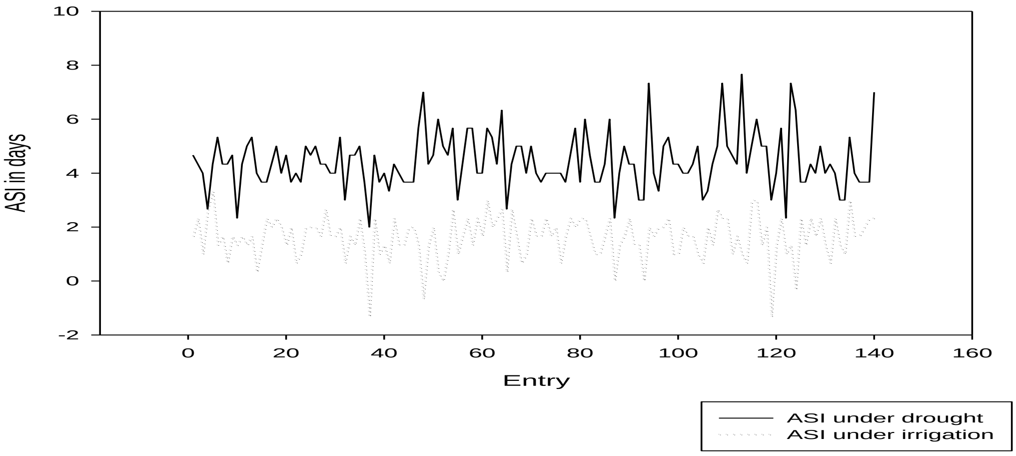

Fig 2. ASI performance of F_3 genotypes under drought stress and well-watered environments.

correlated with grain yield, and the number of ears per plant. This is because of the delayed silk emergence that occurs during drought stress that results into a longer ASI leading to failure in pollination hence lack of grain formation. Richards, (2006) also reported that under moisture stress the ASI period was negatively correlated with grain yield. Equally, Bolanõs and Edmeades (1996), Bolaños and Edemeades, (1993) linked a high grain yield under stress to a shorter ASI. The results of the evaluation of F_3 families from this study are in tandem with these earlier studies. Earliness is a desirable trait in drought prone areas especially with the changing climate and prolonged and unpredictable drought spells. The expectation is that under drought stress, grain yield and earliness would have to be negatively correlated. Late maturing genotypes would be expected to give high grain yields, while early maturing ones would be expected to yield less. However, earliness like other yield determining factors is compounded by G x E effects and the relationship between this trait and grain yield may not be that straight forward as shown by the negative non-significant correlation between GY and AD in Table 4. Under such circumstances, ASI would be a better indicator of GY as shown by the negative but highly significant correlation between ASI and GY of (-0.448) under drought stress (Table 4). Genotypes that had a shorter ASI had a higher chance of yielding better than genotypes with a longer ASI. This was the case of genotypes KDV2/CML440-224, KDV4/CML440-226 and KDV2/CML444-14 that demonstrated short ASI and were superior to other genotypes in respect to grain yield. The relationship between grain yield and ASI from this study that evaluated 135 F_3 progenies was similar to that of Bolanõs and Edmeades, (1993) and Bolanõs and Edmeades (1996) that evaluated Tuxpeno Sequia progenies. The Duma Hybrid yielded significantly higher compared to all other genotypes and local checks in the trial under both environmental conditions as would be expected of a hybrid variety. Nevertheless, genotypes, KDV4/CML440-226, KDV2/ CML440-224, KDV2/CML444-243 and KDV4/CML440-483 were equally high yielding under both drought stress and well-watered environmental conditions and had almost similar grain yields as Duma-43 (Table 5). Under drought stress environments, selection for earliness, short ASI and high grain yield, should be the ideal criterion of constituting a dry-land ideotype. Bänziger et al., (2000) reported that moisture stress leads not only to a reduction in yield due to delayed silking but also to increased abortion and reduced photosynthetic activity. This reduced photosynthetic activity was as a result of less carbon assimilation in the ear. The significant effects of genotypes, environment and the genotype × environment interaction in Table 3 suggested differential response of the genotypes across environments for all the traits measured. Similar observations were reported by Butron et al., 2002 who indicated that G x E effects for grain yield in maize genotypes were mainly due to environmental yield limiting factors. A closer look at yield performance of the individual genotypes is likely to reveal that the G x E found here are of the crossover type, with genotypes that performed well under well-watered environments performing poorly under water stressed environments and vice versa. Although for grain yield (Table 3), the variation due to genotype was almost equal to that of the G x E interaction, the genotypic variance in ASI was less than that due to the G x E interaction meaning that both traits are under strong environmental influences as has also been reported by Epinat-Le et al., (2001) while working with early maize hybrids tested in about 30 locations in northern France.

Table 3. Combined ANOVA ASI, AD, WUE, EPP and GY under both drought-stress and well-watered environment.

Source of Variation	df	Mean Squares				
		ASI	AD	WUE	EPP	GY
Environment	1	615.77***	1397.68***	8.46***	10.30***	17.54***
Genotype	139	1.31**	4.92*	0.18*	0.03**	0.04***
Environment*Genotype	139	0.95***	3.80*	0.05***	0.02**	0.07***
%CV		31.15	3.06	45.75	36.56	33.93
Mean		3.03	54.87	0.81	0.49	0.44

Key: P<0.05; ** P<0.01; *** P<0.001 df = Degrees of Freedom; ASI = Anthesis-silking interval; AD = Anthesis Date; EPP = Ears per Plant; GY = Grain Yield.

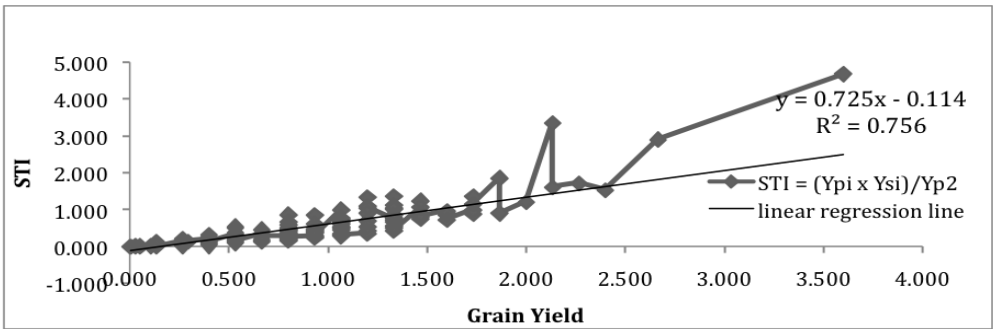

Fig 3. The relationship between grain yield and Stress Tolerance Index (STI) among the F_3 genotypes.

In this study, grain yield, under both drought stress (Ysi) and well-watered condition (Ypi) was highly positively correlated with STI, GMP and with MP. However, grain yield and Yield Stability Index (YSI) were only significantly positively correlated with Ysi and not with Ypi. On the other hand, ASI showed negative correlations with most drought tolerance indices, except for the Stress Susceptibility Index (SSI) with which it had a positive correlation. This is an indication that the longer the ASI the more drought stress susceptible a genotype is (Fig. 3; Table 5). A generalized linear regression model of GY under drought stress against STI (Fig. 3) showed a strong positive relationship (R^2 = 0.756) and helps to confirm that the genotypes that had high grain yields also had high STI values under drought stress (Table 5). The genotypes with high STI value also had low SSI values. This finding confirms that STI values constituted in this study can be used to select for drought tolerance. Even more interesting was the fact that GMP, MP and STI were all highly correlated to each other under drought stress conditions, but ASI was more significantly negatively correlated with GMP and MP than with STI. These results agree with those of Khayatnezhad et al., *(*2010) and of Mhike et al., (2012) who worked on drought stress in wheat and secondary traits in maize respectively and reported similar findings for SSI and STI values with respect to grain yield. It is evident that, these drought selection indices would be useful if they are adopted in the selection process for drought tolerance in maize.

Materials and methods

This work utilized genetic materials developed earlier between early-maturing open-pollinated varieties (OPVs) from KARI Katumani and late maturing inbred lines from CIMMYT. The OPVs included; KCB, KDV1, KDV2, KDV3, KDV4, KDV5 and ZEWA, all being early maturing composites with a long ASI. The CIMMYT inbred lines included were; CML440, CML442, CML444 & CML445 all being late-maturing with a short ASI. From the OPVs two genotypes, namely KDV2 and KDV4 were adopted as females since they were high yielding, had a higher EPP ratio and smaller ASI compared to other OPVs.

F_1 / F_2 Populations

Crosses were made between the CIMMYT genotypes (CML440, CML442, CML444 and CML445) as males and OPVs (KDV2 and KDV4) as females to generate F_1 populations. The F_2 generation was developed by selfing the F_1 generation genotypes on a single row plot during the dry season period of 2010. Each ear in F_1 generation constituted a row. The F_2 germ-plasm formed 12 populations of crosses that had genotypes segregating for long and short ASI and/or early and late maturity period.

F_3 Families

Eight hundred and eighty seven F_2 generation genotypes possessing both early maturing and short ASI traits were selected from the 12 F_2 population of crosses and selfed in order to advance them to F_3 generation under well-watered nurseries in the 2011 season with each ear representing an entry/plot. Each plot consisted of 9 plants, with spacing of 75cm between rows and 25 cm between plants in a completely randomized design. At harvesting, each plant/cob was harvested and stored separately without bulking the seed. In the F_3 generation, only 135 genotypes that had a short ASI of (≤3days), and were early-maturing at (≤56 days) were selected for evaluation under drought stress and well-watered trials.

F_3 family evaluation under contrasting stress environments

In the 2012 dry season, two trials, each consisting of 135, F_3 selected genotypes and 5 checks (CML440/CML445, P100C6/CML78, CML312/CML442, Duma 43 hybrid and Local Katumani composite) were laid out, under artificially imposed drought stress and well-watered conditions separately in an alpha-lattice design (Bänziger et al., 2000), replicated three times**.** Experimental plots were sown in one

Table 4. Correlation coefficients between drought tolerance selection indices under drought stress and well-watered environments.

	ASI	AD	Ysi	Ypi	SSI	STI	GMP	MP	WUE	LR	SEN
ASI	1										
AD	0.102*	1									
Ysi	-0.303***	-0.167*	1								
Ypi	-0.366^{NS}	0.01^{NS}	0.091^{NS}	1							
SSI	0.304***	0.167*	-0.100***	-0.089^{NS}	1						
STI	-0.378***	0.054^{NS}	0.418***	0.790***	-0.417***	1					
GMP	-0.448***	-0.029^{NS}	0.579***	0.831***	-0.578***	0.918***	1				
MP	-0.419***	0.063^{NS}	0.295***	0.974***	-0.294***	0.880***	0.933***	1			
WUE	-0.365***	0.035^{NS}	0.431***	0.383***	-0.431***	0.478***	0.565***	0.472***	1		
LR	0.219***	0.242**	-0.539***	-0.322***	0.534***	-0.443***	-0.556***	-0.426***	-0.373***	1	
SEN	0.153*	0.083^{NS}	-0.067^{NS}	0.174*	0.069^{NS}	0.073^{NS}	0.085^{NS}	0.143^{NS}	-0.141*	-0.087^{NS}	1

Key: ^{NS} = Not Significant; * P<0.05; ** P<0.01; *** P<0.001 STI = Stress Tolerance Index; WUE = Water Use Efficiency; GMP = Geometric Mean Productivity; SSI = Stress Susceptibility Index; YSI = Yield Stability Index; Ysi = Yield under stress; Ypi = Yield under non-stress; LR= leaf rolling; SEN=senescence.

Table 5. Mean values of yield in non-stressed (Ypi), yield in drought stress (Ysi), ASI under stress (ASI-DRT), ASI under non-stress (ASI-IRR), AD under stressed (AD-DRT), AD under non stress (AD-IRR) environments and drought indices.

Ysi Rank	Genotype	ASI-DRT	ASI-IRR	AD-DRT	AD-IRR	Ysi	Ypi	YSI = (Ysi / Ypi)	SSI =[1-YSI]/SI	YI = Ysi/Ys	STI = (Ypi x Ysi)/Yp2	GMP = √(Ypi x Ysi)	MP = (Ypi + Ysi)/2
1	DUMA HYBRID	3.67	2.00	60.00	62.67	2.80	7.76	0.36	0.82	5.25	3.70	4.66	5.28
2	KDV2/CML444-14	2.67	0.33	48.67	54.33	1.64	3.67	0.45	0.71	3.09	1.03	2.46	2.66
3	KDV2/CML440-66	2.67	2.67	55.67	59.00	1.64	3.14	0.52	0.61	3.09	0.88	2.27	2.39
4	KDV2/CML440-224	2.33	1.33	51.33	55.67	1.56	4.44	0.35	0.83	2.92	1.18	2.63	3.00
5	KDV2/CML444-243	2.33	0.00	49.33	54.00	1.56	4.33	0.36	0.82	2.92	1.14	2.59	2.94
6	KDV4/CML440-226	3.00	0.67	49.00	53.33	1.56	4.62	0.34	0.85	2.92	1.22	2.68	3.09
7	KDV2/CML444-234	3.00	1.33	50.33	58.00	1.51	3.85	0.39	0.78	2.84	0.99	2.41	2.68
8	KDV2/CML442-126	3.67	1.00	49.67	53.00	1.29	3.73	0.35	0.84	2.42	0.82	2.19	2.51
9	KDV4/CML440-483	2.33	1.00	50.33	57.33	1.24	4.21	0.30	0.90	2.33	0.89	2.29	2.73
10	KDV2/CML444-237	3.00	0.00	54.00	58.00	1.16	2.96	0.39	0.78	2.17	0.58	1.85	2.06
11	KDV2/CML442-158	3.67	2.00	52.67	57.33	1.07	2.31	0.46	0.69	2.00	0.42	1.57	1.69
12	KDV4/CML440-504	3.33	2.00	51.33	56.00	1.07	2.61	0.41	0.76	2.00	0.47	1.67	1.84
13	CML312/CML442	3.67	2.00	54.67	63.00	1.02	5.81	0.18	1.06	1.92	1.01	2.44	3.41
14	KDV2/CML444-271	3.67	2.33	49.67	54.67	1.02	5.57	0.18	1.05	1.92	0.97	2.39	3.30
15	KDV4/CML445-652	3.33	2.00	51.33	56.33	1.02	3.91	0.26	0.95	1.92	0.68	2.00	2.47
16	LOCAL MAIZE	7.00	2.33	46.67	51.00	1.02	3.02	0.34	0.85	1.92	0.53	1.76	2.02
17	P100C6/CML78	3.67	1.67	59.33	63.33	0.98	3.38	0.29	0.91	1.83	0.56	1.82	2.18
18	KDV2/CML444-352	3.67	1.67	50.33	54.33	0.98	1.90	0.52	0.62	1.83	0.32	1.36	1.44
19	KDV2/CML442-138	4.00	1.33	51.00	54.00	0.93	2.73	0.34	0.84	1.75	0.43	1.60	1.83
20	KDV2/CML440-182	4.00	1.00	54.33	57.67	0.93	2.07	0.45	0.70	1.75	0.33	1.39	1.50
LSD		1.669	1.879	2.360	3.083	0.552	0.940	0.241	0.309	1.036	0.344	0.684	0.553

Key: ASI under stress (ASI-DRT), ASI under non-stress (ASI-IRR), AD under stressed(AD-DRT), AD under non stress (AD-IRR), tolerance index (TOL); YI = Yiled index; STI = Stress Tolerance Index; BIO = Plant Biomass; GMP = Geometric Mean Productivity; SSI = Stress Susceptibility Index; YSI = Yield Stability Index; Ysi = Yield under stress; Ypi = Yield under non-stress, MP = Mean Productivity.

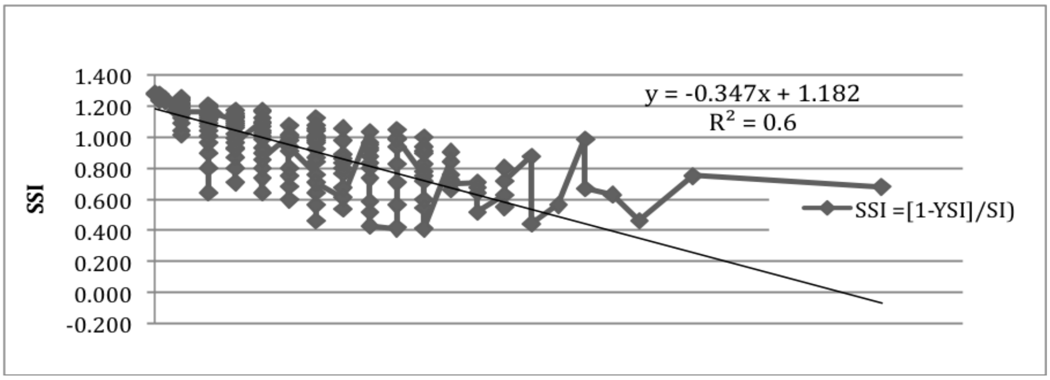

Fig 4. The relationship between grain yield and stress susceptibility index (SSI) among the F_3 genotypes.

row of 3.75m long, with a total of 16 hills for well-watered field and in one row of 5m long plots, with a total of 21 hills for the drought stressed field. The hills were hand made to a depth of 3-5cm deep. The intra and inter- row spacing was 25cm x 75cm respectively for both trials. All the plots were initially sown with two to three plants per hill but were later thinned to one plant per hill, fourteen days after emergence to give an established plant density of 56,888 and 56,000 plants ha^{-1} under well-watered and drought-stressed fields respectively (Bruce et al., 2002). The trial fields were irrigated before ploughing to sprout volunteer seeds and after sowing to ensure uniform emergence. All the trials were irrigated by overhead irrigation according to Bänziger et al., (2000). The plots under the well-watered field were irrigated at an interval of 4 days for three-hours every day from emergence up to physiological maturity. The plots under imposed drought stress were irrigated at an interval of 4 days for three hours, from germination stage until one week (7 days) before anthesis (male flowering) when water was withdrawn. Two additional irrigation regimes were applied for the drought -stressed trial as follows; the first one was applied, 14 days after 50% anthesis (male flowering) while the second one was applied, 26 days after 80-100% of the plots had completed male flowering (Bänziger et al., 2000). The trials were conducted during a rain-free period and stress induced so that the leaves were rolled during flowering (Bänziger et al., 2000). Anthesis to silking interval was estimated to be between 3 to 8 days during the stress period with 0.3 to 0.7 ears per plant being produced. Nitrogen (N) fertilization for both trials was applied at two dates (before sowing and at the V6 stage), using a dose of 8g per hill for di-ammonium phosphate (DAP 18:46:0) translating to a rate of 25kg for N and 60kg for P_2O_5 per hectare. Top dressing was done at the V6 stage using a dose of 10g per hill of calcium ammonium nitrate (26%N) translating to a rate of 40kg N per hectare. Bulldock® (5% cyfluthrin) an insecticide was applied to maize funnels 15-20 days after emergence to control maize stalk borer. Hand weeding was performed three weeks after emergence and two weeks to anthesis.

Data scoring, drought selection indices and statistical analysis

Days to anthesis (AD) and days to silking (SD) were recorded at 50% flowering and 50% silking respectively in each plot. The ASI was calculated as SD - AD. Senescence (SEN) during milk dough was estimated by visual notation and/or by counting the number of green leaves below the ear (Bänziger et al., 2000). A score of 1-10 was used where 1 was when 10% of leaves below the ear, senesced and 10 was when 100% of the leaves below the ear senesced (Bänziger et al., 2000). Leaf rolling (LR) was assessed 2 weeks after anthesis and scored on a scale from 1 to 5 (Bänziger et al., 2000). Each plot was hand harvested. Ears were counted (an ear was defined as having one or more grains on it) and the number of ears per plant was calculated. Grain weight (GW) per plot was used to calculate grain yield (GY) per hectare at 12.5°C grain moisture content (dry weight). To compare the intensity of stress in each genotype, drought stress indices were calculated for all the genotypes grown under stressed conditions as follows:

Yield stability index (YSI)

YSI = Ysi / Ypi (Lin et al., 1986)………………..……..…. (i)

Stress susceptibility index (SSI)

SSI = [1-YSI]/SI (Fischer and Maurer, 1978)..................... (ii)

Yield index (YI)

YI = Ysi/Ys (Gavuzzi et al., 1997, Lin et al., 1986)…..… (iii)

Stress tolerance index (STI)

STI = (Ypi x Ysi)/Yp^2 (Fernandez, 1992)………..……... (iv)

Geometric mean productivity (GMP)

GMP = sqrt (Ypi x Ysi) (Fernandez, 1992; Kristin et al., 1997)…………………..…………………………………. (v)

Mean productivity (MP)

MP = (Ypi + Ysi)/2 (Hossain et al., 1990)........................ (vii)

Stress intensity (SI)

SI = 1-(Ys /Yp) (Fernandez, 1992)……......................... (viii)

Ysi = yield of genotype under stress condition, Ys = total mean yield under stress condition.

STI the inverse of SSI was used in order to establish whether a high tolerance index can translate to high yields whereas SSI was used to confirm if indeed a high susceptible index translates to poor yields under drought stress. The analysis of variance was calculated considering genotypes as fixed, and replicates, plots and incomplete blocks within replicates as random factors by using PROC GLM procedure from SAS 9.2 computer program (SAS Institute 2000) and Gen-Stat program (Gen Stat 14th edition) to establish differences in genotypes and environment. A probability level of ≤0.05 was considered statistically significant. Simple-Pearson phenotypic correlations were calculated to estimate the relationship among traits and drought indices with respect to yield within drought stress environment using PROC CORR procedure SAS 9.2 (SAS Institute 2000). A probability level of ≤0.05 was considered statistically significant.

Conclusion

ASI is a reliable heritable, consistent secondary trait for phenotypic selection of drought tolerance in maize. F_3 progenies generated here resulted in transgressive segregation for ASI and other secondary traits. In this work, the selected F_3 families that were earlier-maturing and had a shorter ASI than the rest, were also high yielding under drought stressed environments and had the highest STI values confirming that they were the most drought tolerant ones. Genotypes, KDV2/CML444-14 and KDV2/CML440-224 consistently demonstrated that they combined alleles for short ASI, earliness and high grain yield values. Considering the complexity of selection for drought tolerance under varying water stress levels, selection indices, GMP, MP and STI together with selection of a shorter ASI would enhance the drought tolerance of maize genotypes bred for water limited environments.

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