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Identification of sorghum (*Sorghum bicolor* L. Moench) landraces tolerant to post flowering drought stress using drought tolerance indices

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Drought stress occurring during the post-flowering growth stage of sorghum can cause considerable reduction in yield. In order to identify drought tolerant Eritrean sorghum landraces and assess efficiency of drought tolerance indices, twenty five sorghum (*Sorghum bicolor* L. Moench) accessions were evaluated in split plot design with three replications. Fully irrigated and drought stress treatments were assigned in main plot and the landraces were evaluated in sub plot for drought stress tolerance at post-flowering. Seven tolerance indices including stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), stress susceptibility index (SSI), tolerance index (TOL), yield index (YI), and yield stability index (YSI) were estimated for each genotype based on grain yield under drought stress (Y_s) and irrigated conditions (Y_{ir}). Significant correlations between Y_{ir} and Y_s with GMP, MP, STI and YI were recorded indicating that these indices were good predictors of drought tolerance among genotypes. The other stress tolerance indices namely, TOL, SSI, YSI and YI were not significantly correlated with Y_{ir} and Y_s indicating that they were poor predictors of drought tolerance. The study further showed that drought stress reduced the yield of some genotypes while others were tolerant to drought and gave stable yield. Based on the tolerance indices, accessions EG 885, EG 469, EG 481, EG 849, Hamelmalo, EG 836 and EG 711 were identified as superior genotypes for post-flowering drought tolerance that could be used by breeders in further sorghum improvement programs.

Key words: Drought stress, drought tolerance, post-flowering, selection index, *Sorghum bicolor.*

INTRODUCTION

The improvement of drought tolerance has been defined as a desirable breeding objective in crops (Clark et al., 1992). Drought tolerance in native plant species is often defined as survival, but in crop species it is defined in terms of productivity (Passioura, 1983). The definition of drought tolerance as the ability of plants to grow

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satisfactorily when exposed to water deficits has little direct applicability to either quantifying or breeding for the character in crop species (Clark et al., 1992). Generally, it is agreed that drought tolerance from a breeding viewpoint is a complex trait that shows a high level of genotype × environment interaction (Cooper et al., 2006). Furthermore, plant responses to drought are also influenced by the time, intensity, duration, and frequency of the stress as well as by diverse plant–soil–atmosphere interactions (Saint Pierre et al., 2012). However, for studies on adaptation of crop plants to complex stress situations arising due to climate change, there is a need to exploit the available biodiversity in crop genotypes growing in diverse environments to understand the mechanisms involved in coping with different stress combinations. Accordingly, genotypes that differ in drought tolerance serve as important systems for studying adaptive responses to drought in crop species (Bhargava and Sawant, 2013). Drought stress affects almost every developmental stage of the plant. However, damaging effects of this stress is more noted when it coincides with various growth stages such as germination; seedling shoot length, root length and flowering (Rauf, 2008; Khayatnezhad et al., 2010).

Several morpho-physiological characteristics have been reported as reliable indicators in selection of genotypes/cultivars for drought tolerance. Information about morpho-physiological traits and the gene effects controlling the highly related traits to drought tolerance makes breeding programs for drought tolerance much more effective and successful (Badieh et al., 2012). A range of stress tolerance indices including yield, morphological, and physiological traits has been suggested that could be utilized to increase selection efficiency and can be used for screening tolerant genotypes under stress conditions (Drikvand et al., 2012). However, yield is the principle selection index used commonly under drought stress conditions. Furthermore, correlation analysis between grain yield and drought tolerance indices can be a good criterion for screening the best genotypes and indices used (Farshadfar et al., 2012). Farshadfar et al. (2001) reported that the most appropriate index for selecting stress tolerant cultivars is an index which has high correlation with seed yield under stress and non-stress conditions. Yield-based estimates of drought tolerance are as follows: geometric mean productivity (GMP) which was proposed to select genotypes based on their performance in stress and non-stress environments (Fernandez, 1992). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the drought stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under irrigated (Y_{ir}) and drought stress (Y_s) conditions. Fischer and Maurer (1978) proposed a stress susceptibility index (SSI). Fernandez (1992) stated that stress tolerance index (STI) can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. Screening and selection of plants of different crops with considerable drought stress tolerance at flowering and post-flowering stage has been considered as an economic and efficient means of utilizing drought-prone areas when combined with appropriate management practices to reduce water loss (Rehman et al., 2005). The objective of this study was therefore to identify drought tolerant sorghum landraces for cultivation in drought-prone areas of Eritrea using stress tolerance indices.

MATERIALS AND METHODS

Germplasm

The germplasm used in this study comprised 25 sorghum genotypes including 23 accessions from the Eritrean sorghum gene bank and two improved (B-35 and Hamelmalo) from ICRISAT and National Breeding Program, respectively (Table 1).

Location

The experiment was conducted under managed irrigated and stress condition at Hamelmalo Agricultural College (HAC) farm in 2014 dry season period in the months of February to June. Geographically the trial site is located at 15° 52'15" N latitude and 38° 27' 55" E longitudes with an altitude of 1,274 m above sea level in a semi-arid agro-ecological zone of Eritrea. The research area is located 12 km away from Keren city towards the north on the Keren-Nakfa road along Anseba River in the Anseba region. The soil type of the experimental site was sandy clay loam with an average maximum and minimum air temperatures during the experimental period reached 38 and 20°C, respectively.

Experimental design and data analysis

Split plot design was used by setting two main plots, fully irrigated and stress plots with three replications planted on 12 February, 2014. The two levels of irrigation treatments including: Full irrigation (fully irrigated based on plant needs of sorghum accessions at different growth stages) and Limited irrigation (Supply plant water needs until flowering stage and then format water until the end of sorghum growth and development).

The spacing between the irrigated and stressed replications was 3 m. The sub plots were the 25 genotypes that were planted in plots of four rows with a spacing of 75 cm x 20 cm between and within rows, respectively and three meter row length. Soil moisture content before sowing, during and after imposing stress (at flowering growth stage) was taken by the department of Land Resources and Environment of Hamelmalo Agricultural College. For determining the final yield, the panicles of the two middle rows of an area of 4.5 m^2 (2 rows of 3 m long) were harvested at maturity and yields recorded that was used for the analysis. Stress tolerance indices were used to identify germplasm accessions with high stress tolerance and overall good agronomic performances. The drought stress indices were calculated according to Agili et al. (2012) as follows:

*Stress Susceptibility Index (SSI) = $[1-(Y_s/Y_{ir})]/SI$, Where $SI = 1- (\overline{Y}_s/\overline{Y}_{ir})$

*Mean Productivity (MP) = $(Y_{ir} + Y_s)/2$

Table 1. Twenty five sorghum accessions along with their sources, names and status.

S/N	Germplasm identifier	Area of collection (administration region)	Local Name	Status
1	EG 469	Gash Barka	Tseda Bazenay	Landrace
2	EG 849	Gash Barka	Hugurtay	Landrace
3	EG 537	South	Anseba	Landrace
4	Hamelmalo	Anseba and Gash Barka	Hamelmalo	Released cultivar
5	EG 806	Gash Barka	Hiriray	Landrace
6	EG 782	South	Tseda Hele	Landrace
7	EG 797	Gash Barka	Wedi-Aker	Landrace
8	EG 791	Gash Barka	Korekora	Landrace
9	EG 815	Gash Barka	Estif	Landrace
10	EG 836	Anseba	Hugurtay	Landrace
11	EG 883	Gash Barka	Kinabiba	Landrace
12	EG 885	Gash Barka	Duruta	Landrace
13	EG 889	Gash Barka	Kileaentu	Landrace
14	EG 1224	Gash Barka	Mahagen	Landrace
15	EG 526	Anseba	Wedi-Aker (Short)	Landrace
16	EG 711	Anseba	Embulbul	Landrace
17	EG 783	Gash Barka	Aklamoy	Landrace
18	EG 813	Anseba	Wedi-Ferej	Landrace
19	EG 830	Gash Barka	Wedi-Arba	Landrace
20	EG 481	Anseba	Wedi-Susa	Landrace
21	H-35-1	South	Tseda Mashela	Landrace
22	B-35	ICRISAT	B-35	Released cultivar
23	EG 870	Gash Barka	Ajebsidu	Landrace
24	EG 473	South	Keih Hele	Landrace
25	EG 843	South	Koden	Landrace

*****Tolerance (TOL) = Y_{ir}-Y_s

*****Stress Tolerance Index $(STI) = Y_{ir} * Y_s / \bar{Y}_{ir}{}^2$

*****Geometric Mean Productivity $(GMP) = \sqrt{Y_{ir} * Y_s}$

*****Yield Index $(YI) = Y_s / \bar{Y}_s$

*****Yield Stability Index (YSI) = Y_s / Y_{ir}

Where:

*****Y_{ir} = Yield of accessions in normal irrigation conditions

*****Y_s = Yield of accessions in drought stress conditions

*$\bar{Y}_{ir}$ = Mean yield in normal irrigation conditions

*$\bar{Y}_s$ = Mean yield in drought stressed conditions

Data collection

After harvesting of the panicles from the two inner rows with a net plot area of 4.5 m^2 were dried, threshed and weighed for final yield data collection which was then converted into g m^{-2}. Analysis of variance was calculated for individual and combine treatments. Besides, the most desirable drought tolerance measures, the correlation coefficient between Y_{ir}, Y_s, and other quantitative indices of drought tolerance were estimated using GenStat 14 statistical software (Payne et al., 2011). Ranking for the drought indices were estimated by taking the sum total of individual drought indices and calculated as a mean. The lowest mean was considered maximum response while highest score was minimum response to drought tolerance. Multivariate analysis for biplot and cluster analysis were also carried out using this Genstat software to identify and classify genotypes under both stress and non-stress conditions.

RESULTS

There was a significant difference among normal irrigated and drought stressed conditions for grain yield at 1% probability level. The genotypes were also showed significant differences in grain yield at 0.1% probability level (Table 2). Grain yield varied from a high yield of 334.0 g m^{-2} (EG 849) to a low yield of 138.6 g m^{-2} (B 35) under normal irrigation conditions and from 285.8 g m^{-2} (EG 885) to 77 g m^{-2} (EG 815) in drought stress conditions. The mean combine grain yield under normal irrigation condition was 240.9 g m^{-2}, while under drought stress conditions it was 211.7 g m^{-2}, thus indicating a reduction of 12.2% compared to full-irrigation conditions (Table 3). The data showed that drought stress in sorghum can noticeably reduce the grain yield.

Table 2. Mean squares from the analysis of variance for grain yield of 25 sorghum genotypes evaluated under normal irrigation (Y_{ir}) and drought stress (Y_s) conditions at the Hamelmalo Agricultural College non rainy seasons of 2014.

Source of variation	Degree of freedom	Grain yield (MS)
Replication	2	5953.2
Irrigation level	1	32215.4**
Accessions	24	17018.1 ***
Irr. x acc.	24	1929.3
Error	96	3150.4
CV (%)		18.0

CV (%) = Coefficient of variance and Fprob. = F probability differences at ** P ≤ 0.01 and *** P ≤ 0.001.

The accessions EG 849, EG 836, EG 481, EG 883, EG 885, EG 783 and EG 469 showed higher grain yield under irrigated conditions, with yield averages higher than 290 g m^{-2}. Accessions EG 885, EG 481, EG 836, EG 469, EG 883, EG 783 and Hamelmalo recorded higher grain yield under stress conditions, with values as high as 260 g m^{-2}. The genotypes EG 481, EG 836, EG 885, EG 883 and EG 469 showed better yield performance under both irrigated and drought stressed conditions when compared with other genotypes (Table 3).

The values of geometric mean productivity (GMP) ranged from 121.6 to 298.9 g m^{-2} and the genotypes EG 836 and EG 885 were the most productive (>296 g m^{-2}). Stability tolerance index (STI) ranged from 0.26-1.54. Values ≥ 1 indicate high stress tolerance, (Majid et al., 2010). Genotypes EG 849, EG 836, EG 885, EG 481, EG 883, EG 783 and EG 469 had higher values of ≥1.35, suggesting that these genotypes were the most tolerant (Table 3). YI ranged from 0.36 to 1.35, with genotypes EG 885, EG 836, EG 481, EG 883 and EG 783 with the higher index (≥1.23). Based on YI index, the same genotypes were selected, correlated in the maximum degree with Y_s (r = 1.00) and moderately with Y_{ir} (r almost 0.79). SSI values varied from -2.49 to 5.05, which were negatively correlated with yield under drought stress (Y_s) and positively associated with the TOL index. YSI ranged from 0.39-1.30 (a higher rate indicated greater stability). Genotypes that showed higher stability indices include EG 843, B-35 and EG 791 whose values were equal or greater than 1.13 (Table 3).

Besides the mean productivity (MP) and geometric mean productivity (GMP) showed similar ranking pattern as in STI. In both indices, the top five genotypes with highest value of MP and GMP were EG 836, EG 885, EG 481, EG 883 and EG 849. Similarly, genotypes B-35, SG 843, EG 791 and Hamelmalo that showed lower SSI values also scored higher yield stability index (YSI) whereas yield index (YI) have almost similar ranking with STI values.

The indices GMP, MP and STI were very similar to the selection based on Y_{ir} and Y_s. This was confirmed by the high correlations between Y_{ir} and GMP (r = 0.94), MP (r = 0.95), and STI (r = 0.95) and the correlation between Ys and GMP (r = 0.96), MP (r = 0.94) and STI (r = 0.93) (Table 4). MP is the mean production under both stress and non-stress conditions, and it was highly correlated with yield under both conditions. Thus, MP can be used to identify cultivars in the tolerant group. Similar to the SSI and TOL, correlations between YSI and GMP, STI and MP were low (r = 0.10, r = 0.05 and r = 0.06 respectively), indicating that similar genotypes were not selected. The correlation between STI and GMP was nearly one and these two were positively correlated with MP but not with SSI. SSI was found to be highly negatively correlated with YSI and positively with TOL (Table 4).

In the biplot a strong negative association was observed between SSI and TOL with YSI, as indicated by the large angles between their vectors. Nearly zero correlation was also recorded between SSI with GMP, MP, and STI, as well as SSI and TOL with Y_s and YI, as indicated by the nearly perpendicular vectors. Besides, positive association between Y_{ir} and Y_s with MP, GMP and STI was observed as indicated by the acute angles (Figure 1). The results obtained from the biplot graph confirmed similarity with the correlation analysis results in Table 4. Thus the same as the correlation analysis the biplot was able to identify superior genotypes for both drought stressed and normally irrigated conditions.

The results of the Dendrogram from UPGMA cluster analysis (Figure 2) were consistent with those of biplot analysis (Figure 1). The advantage of this approach is that it can be used to calculate distances between genotypes. The Cluster analysis showed that the genotypes, based on TOL, MP, GMP, SSI, YI, STI and YSI, tended to group into five clusters. In this analysis, the first group (A) had the highest MP, GMP and STI, and was thus considered to be the most desirable cluster for both growth conditions. The clusters grouped in D and E

Table 3. Mean values of yield in stressed (**Y_s**), yield in irrigated (**Y_{ir}**), tolerance index (**TOL**), mean productivity (**MP**), stress susceptibility index (**SSI**), geometric mean productivity (**GMP**), stress tolerance index (**STI**), yield index (**YI**) and yield stability index (**YSI**) in sorghum

Accessions	Y_{ir} (g m^{-2})	Y_s (g m^{-2})	TOL	MP	SSI	GMP	STI	YI	YSI	Ranking
EG 849	334.00 (**1**)	238.60 (**9**)	95.40 (**2**)	286.30 (**5**)	2.35 (**3**)	282.30 (**5**)	1.47 (**3**)	1.13 (**9**)	0.71 (**23**)	5
EG 836	329.30 (**2**)	271.30 (**3**)	58.00 (**4**)	300.30 (**1**)	1.45 (**7**)	298.90 (**1**)	1.54 (**1**)	1.28 (**2**)	0.82 (**19**)	1
EG 481	313.90 (**3**)	271.60 (**2**)	42.30 (**10**)	292.80 (**3**)	1.11 (**11**)	292.00 (**3**)	1.47 (**4**)	1.28 (**3**)	0.87 (**15**)	2
EG 883	309.10 (**4**)	263.60 (**5**)	45.50 (**6**)	286.40 (**4**)	1.21 (**9**)	285.40 (**4**)	1.40 (**5**)	1.25 (**5**)	0.85 (**17**)	4
EG 885	307.00 (**5**)	285.80 (**1**)	21.20 (**16**)	296.40 (**2**)	0.57 (**18**)	296.20 (**2**)	1.51 **(2)**	1.35 (**1**)	0.93 (**8**)	3
EG 783	303.80 (**6**)	260.50 (**6**)	43.30 (**8**)	282.20 (**6**)	1.17 (**10**)	281.30 (**6**)	1.36 (**6**)	1.23 (**6**)	0.86 (**16**)	6
EG 469	292.70 (**7**)	267.10 (**4**)	25.60 (**13**)	279.90 (**7**)	0.72 (**16**)	279.60 (**7**)	1.35 (**7**)	1.26 (**4**)	0.91 (**9**)	7
EG 711	289.90 (**8**)	259.30 (**8**)	30.60 (**12**)	274.60 (**8**)	0.87 (**15**)	274.20 (**8**)	1.29 (**8**)	1.22 (**8**)	0.89 (**11**)	8
EG 813	259.00 (**9**)	199.60 (**17**)	59.40 (**3**)	229.30 (**13**)	1.89 (**5**)	227.40 (**13**)	0.89 (**13**)	0.94 (**17**)	0.77 (**21**)	11
Hamelmalo	250.20 (**10**)	260.10 (**7**)	-9.90 (**22**)	255.20 (**9**)	-0.33 (**22**)	255.10 (**9**)	1.12 (**9**)	1.23 (**7**)	1.04 (**4**)	9
B35-1	247.90 (**11**)	211.00 (**15**)	36.90 (**11**)	229.50 (**12**)	1.22 (**8**)	228.70 (**12**)	0.90 (**12**)	1.00 (**15**)	0.85 (**18**)	13
EG 830	243.00 (**12**)	222.10 (**12**)	20.90 (**18**)	232.60 (**11**)	0.71 (**17**)	232.30 (**11**)	0.93 (**11**)	1.05 (**12**)	0.91 (**10**)	12
EG 806	242.80 (**13**)	233.30 (**10**)	9.50 (**19**)	238.10 (**10**)	0.32 (**19**)	238.00 (**10**)	0.98 (**10**)	1.10 (**10**)	0.96 (**7**)	10
EG 473	227.40 (**14**)	201.90 (**16**)	25.50 (**14**)	214.70 (**17**)	0.92 (**13**)	214.30 (**17**)	0.79 (**17**)	0.95 (**16**)	0.89 (**12**)	15
EG 526	226.90 (**15**)	220.70 (**13**)	6.20 (**20**)	223.80 (**14**)	0.22 (**20**)	223.80 (**14**)	0.86 (**14**)	1.04 (**13**)	0.97 (**6**)	14
EG 537	215.60 (**16**)	215.70 (**14**)	-0.10 (**21**)	215.70 (**16**)	0.01 (**21**)	215.60 (**16**)	0.80 (**16**)	1.02 (**14**)	1.00 (**5**)	17
EG 797	215.00 (**17**)	158.30 (**21**)	56.70 (**5**)	186.70 (**19**)	2.17 (**4**)	184.50 (**19**)	0.59 (**19**)	0.75 (**21**)	0.74 (**22**)	18
EG 782	205.50 (**18**)	182.60 (**19**)	22.90 (**15**)	194.10 (**18**)	0.92 (**14**)	193.70 (**18**)	0.65 (**18**)	0.86 (**19**)	0.89 (**13**)	19
EG 791	204.50 (**19**)	230.90 (**11**)	-26.40 (**24**)	217.70 (**15**)	-1.06 (**23**)	217.30 (**15**)	0.81 (**15**)	1.09 (**11**)	1.13 (**3**)	16
EG 815	199.20 (**20**)	77.00 (**25**)	122.20 (**1**)	138.10 (**24**)	5.05 (**1**)	123.80 (**24**)	0.26 (**24**)	0.36 (**25**)	0.39 (**25**)	21
EG 889	197.00 (**21**)	154.00 (**23**)	43.00 (**9**)	175.50 (**20**)	1.80 (**6**)	174.20 (**20**)	0.52 (**20**)	0.73 (**23**)	0.78 (**20**)	20
EG 870	185.10 (**22**)	164.00 (**20**)	21.10 (**17**)	174.60 (**21**)	0.94 (**12**)	174.20 (**21**)	0.52 (**21**)	0.77 (**20**)	0.89 (**14**)	22
EG 1224	146.10 (**23**)	101.20 (**24**)	44.90 (**7**)	123.70 (**25**)	2.53 (**2**)	121.60 (**25**)	0.25 (**25**)	0.48 (**24**)	0.69 (**24**)	24
EG 843	140.80 (**24**)	183.40 (**18**)	-42.60 (**25**)	162.10 (**22**)	-2.49 (**25**)	160.70 (**22**)	0.44 (**22**)	0.87 (**18**)	1.30 (**1**)	23
B-35	138.60 (**25**)	158.20 (**22**)	-19.60 (**23**)	148.40 (**23**)	-1.16 (**24**)	148.10 (**23**)	0.38 (**23**)	0.75 (**22**)	1.14 (**2**)	25
Mean	**240.97**	**211.67**	**29.30**	**226.35**	**0.92**	**224.93**	**0.92**	**1.00**	**0.89**	

Number in brackets are ranking for the drought indices. 1: maximum response, 25: minimum response.

had lower yield and were susceptible to drought.

DISCUSSION

Genotypic correlation coefficient between Y_{ir}, Y_s and the other quantitative indices were the most desirable drought tolerance criteria to determine the performance of sorghum landraces. The strong positive association of the yield under well irrigation (Y_{ir}) with the yield under stress (Y_s) conditions depicted that genotypes giving high yield under the best possible conditions could also do so under stress conditions. This means that genotypes under drought stressed conditions have a good response under irrigated conditions. The accessions that give superior yield in both irrigated and drought stressed treatment

Table 4. Genotypic correlation of yield in normal irrigated (Y_{ir}) and stressed (Y_s) conditions with tolerance index (TOL), mean productivity (MP), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield stability index (YSI) and yield index (YI) in sorghum.

Variables	Y_{ir}	Y_s	YSI	MP	GMP	TOL	SSI	STI	YI
Y_{ir}	1.00								
Y_s	0.798 ***	1.00							
YSI	-0.233	0.382*	1.00						
MP	0.952***	0.945***	0.068	1.00					
GMP	0.939***	0.956***	0.103	0.999***	1.00				
TOL	0.410	-0.222	-0.956***	0.111	0.073	1.00			
SSI	0.233	-0.382	-1.000***	-0.068	-0.103	0.956***	1.00		
STI	0.951***	0.935***	0.053	0.995***	0.993***	0.125	-0.053	1.00	
YI	0.798***	1.000***	0.382*	0.945***	0.956***	-0.222	-0.382*	0.935***	1.00

F probability at * P≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001 significant level of probability

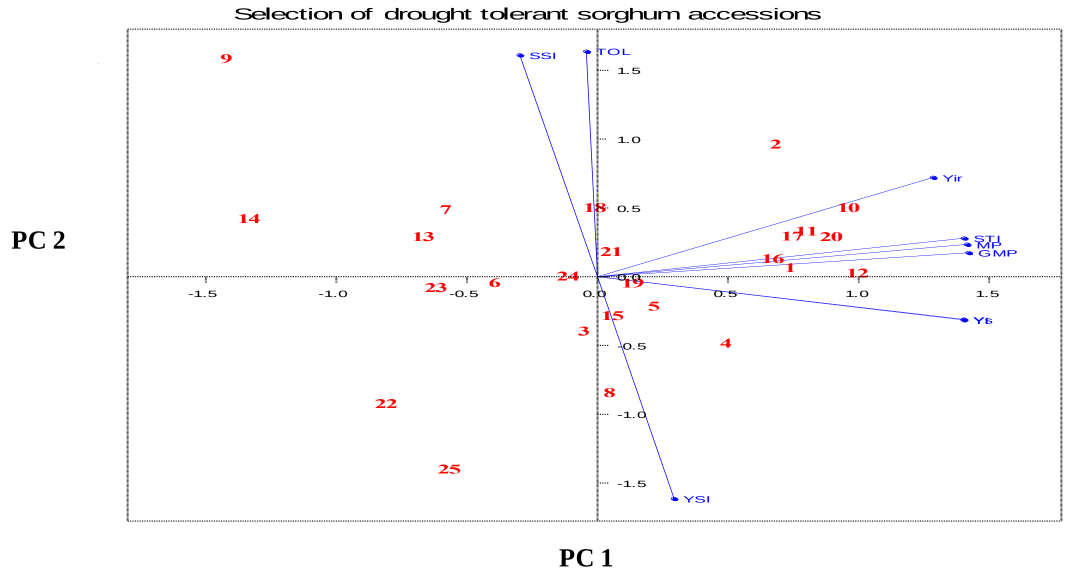

Figure 1. Biplot diagram of 25 sorghum genotypes and 7 drought indices. The indices are indicated using uppercase letters (GMP, MP, STI, YI, TOL, YSI and SSI), and each genotype is represented with numbers (see Table 1 for genotype coding).

conditions include EG 885, EG 469, EG 836, EG 481, and EG 883 as examples of high yielding genotypes. However, there were few accessions like EG 537, Hamelmalo, EG 791 and B-35 that gave better yield under stress condition only and accessions EG 836, EG 481, EG 849 and EG 813 gave superior yield under well irrigation indicated that they were the better predictors of potential yield under stress and normal irrigation respectively.

STI, GMP and MP were strongly correlated with yield under both conditions, suggesting that these parameters are suitable for screening drought tolerant and high yielding genotypes in both drought stressed and irrigated conditions. Similar results were reported by Fernandez (1992) on mung bean (*Vigna radiate*) (for STI), Agili et al. (2012) on sweet potato (*Ipomoea batatas*), Farshadfar and Sutka (2002) on wheat (*Triticum aestivum*), Golabadi et al. (2006) on durum wheat (*Triticum durum*), Sio Se-Mardeh et al. (2006) and Mohammadi et al. (2010) on wheat (*Triticum aestivum*), all of whom found these parameters to be suitable for discriminating the best genotypes under drought stress and irrigated conditions. STI was significantly correlated with Y_{ir} and Y_s and calculated based on the GMP index. High positive correlation was observed between this index (0.993), which is in agreement with those reported by Fernandez (1992) and Mozaffari et al. (1996). TOL appears to be useful for selecting genotypes with high yield under

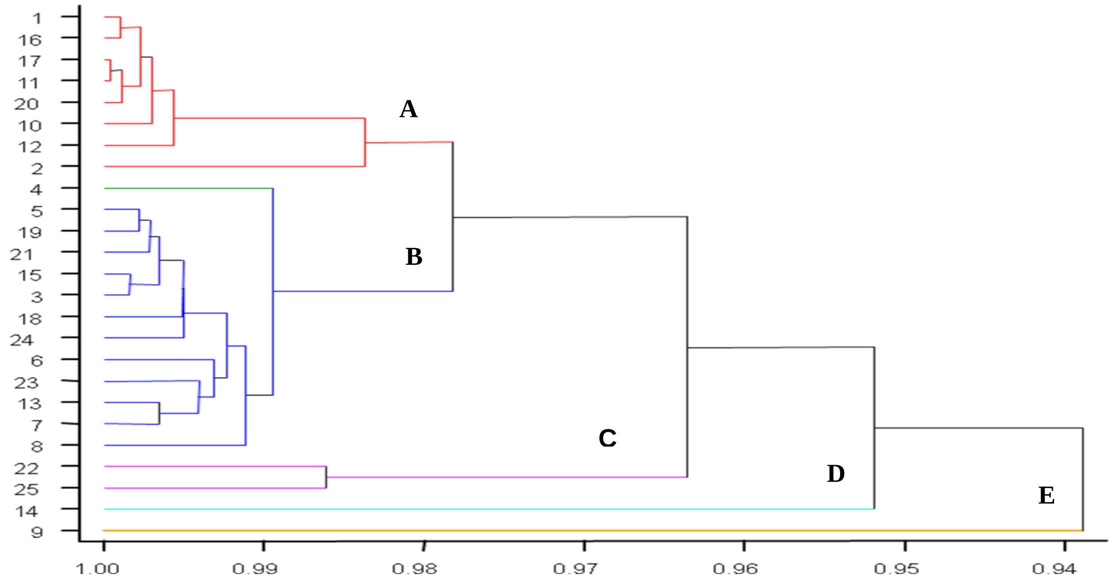

Figure 2. Dendrogram from UPGMA cluster analysis of genotypes based on drought tolerance indices GMP, MP, STI, YI, TOL, YSI and SSI) and grain yield of sorghum accessions, in both irrigated and drought stress condition (for genotype codes: see Table 1).

drought stress, but failed to select genotypes with good yield in both conditions. Similar results were reported on barley (*Hordeum vulgare*) Rizza et al. (2004), on wheat (*Triticum aestivum*) Sio-Se Mardeh et al. (2006), on durum wheat (*Triticum durum*) Talebi et al. (2009); Shiri et al. (2010), and on chickpea (*Cicer arietinum*) Talebi et al. (2011). The significant positive correlation found between SSI and TOL, indicated that these indices are able to select susceptible genotypes.

The biplot vectors for the indices MP, STI, and GMP remained between the Y_{ir} and Y_s vectors, indicating that these indices are very similar for drought selection. In the current study, MP, STI and GMP appeared to be the best indices for dividing the angle symmetrically between Y_{ir} and Y_s. Therefore, these factors can be used to select for genotypes that are better adapted to both conditions. Similar results were reported by Yarnia et al. (2011) on rapeseed (*Brassica napus*). Darvishzadeh et al. (2010) examined sunflower (*Helianthus annuus*) in one location, and found that tolerant indices including MP, STI and GMP were suitable for drought-tolerant genotype selection. However, based on the biplot presented by these authors, GMP is the most appropriate index for selection under stressed and non-stressed conditions. Kharrazi and Rad (2011) suggested that MP and STI are useful indicators for selecting tolerant genotypes. In the cluster analysis, the high yielding and drought tolerant genotypes (1 = EG 469; 2 = EG 849; 10 = EG 836; 11= EG 883; 12 = EG 885; 16 = EG 711; 17 = EG 783 and 20 = EG 481) were grouped in one cluster while the susceptible and low yielding genotypes (9 = EG 815; 14 = EG 1224; 22 = B-35 and 25 = EG 843) grouped in the bottom cluster indicating the efficiency of the drought indices for classifying genotypes under both stress and non-stress conditions.

Conclusion

Yield and yield-related traits under drought stress conditions were positively correlated to yield and yield-related traits under well irrigated conditions. The indices STI, GMP and MP were used to identify tolerant genotypes that produced high yield under both irrigated and drought stress conditions. The indices YSI and YI were used to identify resistant genotypes that are stable in different conditions and produce high grain under stressed conditions. Based on these different methods of selection indices, the current study identified seven outstanding genotypes (EG 885, EG 469, EG 481, EG 849, Hamelmalo, EG 836 and EG 711) for post-flowering drought tolerance that can be used by breeders in sorghum improvement program and conservation of these landraces is important.

Conflict of Interest

The authors have not declared any conflict of interest.

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