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Yield Stability for Some Selected Drought Tolerant Sorghum Genotypes in Dry Lowlands of Ethiopia

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Author's contribution

The sole author designed, analysed, inteprted and prepared the manuscript.

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ABSTRACT

Sorghum [*Sorghum bicolor* (L.) Moench] called as camel of crops due to high tolerance of prolonged drought, has been cultivated for millennia. Thus, this study aimed to identify high yielding and stable drought tolerant sorghum genotypes in the dry lowland areas of Ethiopia. The field experiment was conducted during the 2016 cropping season using a randomized complete block design with three replications across six environments. The combined analysis of variance result revealed highly significant ($P \leq 0.01$) difference among genotypes (G), environments (E) and genotype by environment interactions (GEI) for grain yield. Melkam was found to be the highest yielding genotype followed by Meko-1 with mean grain yield of 3650 and 2932 kg ha^{-1}, respectively. GGE bi-plot stability model was used to identify stable genotype for partitioning the GEI into the causes of variation and the best multivariate model in this study. The first two principal components explaining significant shares 97.83% (PC1=93.26% and PC2=4.57%) of the total variation caused by GGE for gran yield. Besides, the which-won-where bi-plot classified the study areas into a unique (same) mega-environment with the winning genotype Melkam. Therefore, the GGE biplot identified Melkam variety as stable and high-yielding genotype owing to consistent performance across the test environments (dry lowland agro-ecologies) of Ethiopia.

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Keywords: Drought tolerant; genotype; GEI; GGE; stability.

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a versatile and resilient cereal grain that has been cultivated for millennia. Originating from Africa, it has spread across the globe due to its adaptability to diverse climates and its numerous uses ranging from food and feed to industrial applications. Sorghum is called as camel of crops due to the high tolerance of drought and heat stress. Ethiopia is believed to be the center of origin and diversity for the four (bicolor, guinea, caudatum and durra except kafir) of the five major races of sorghum with wide agro-ecological adaptations. Sorghum ranks 4th in Ethiopia in terms of total production (45.2 million quintal), area cultivated (1.7 million hectare), and number of farmers (4.3 million) producing the commodity [1].

There are numerous varieties of sorghum cultivated globally, each adapted to different environmental conditions and intended uses. These varieties can be broadly categorized into grain sorghum, sweet sorghum, and forage sorghum. It is utilized in various ways. Sorghum flour (fermented or unfermented) is used for human food such as bread, porridge, couscous, and snacks and beverages. The grain and fresh or dry biomass have diverse uses and good sources for sugar, syrup, and molasses industry [2]. It is also the second most important crop for “injera” quality next to tef in Ethiopia. In addition, sorghum stalks and leaves are an important source of dry season feed for livestock, source of energy for cooking their daily foods, for construction of houses and fences, and as fuel wood [3].

However, drought and parasitic weed (*striga)* are the most important abiotic and biotic constraints limiting the production and productivity of sorghum in the north and eastern dry lowland parts of the country, *viz.* Tigray, Wollo, and Hararghe [4,5]. The research emphasis for drought is developing early maturing sorghum varieties that can be able to escape terminal drought. However, yield stability is one of the setbacks to select and recommend genotypes for different environments. Therefore, a study was carried out to assess the presence of GEI using GGE biplot analysis and identify high yielding and stable sorghum varieties that show promise for adaptation to different conditions under dry lowland areas of Ethiopia.

2. MATERIALS AND METHODS

2.1 Study Locations

The field experiment was carried out at six locations in the 2016 main growing season. These environments represent the main dry lowland sorghum-growing agro-ecologies in Ethiopia (Table 1).

2.2 Planting Materials

Six stress tolerant sorghum genotypes including check (farmer variety) were evaluated across six research sites. The genetic materials were brought from Melkassa national sorghum improvement center of the Ethiopian Institute of Agricultural Research (EIAR) as summarized in Table 2.

Table 1. Agro-ecological description of study sites

Sites	Altitude (masl.)	Global position		Rain Fall	Temperature (ºC)		Soil type
		Latitude	Longitude	(mm)	Min	Max	
Humera	610	14° 06’N	39° 38’E	576	27.0	42.0	*Vertisol*
Abergelle	1560	13° 14’06”	38°58’50”	570	18.0	37.0	*Sandyclay*
Kobo	1450	12° 08’21”	39°18’21”	637	16.0	30.0	*Eutricfluvisol*
Fedis	1700	9° 07’N	42° 04’E	710	15.0	25.0	*Alfisols*
Mehoni	1578	12° 41’N	39°42’E	540	18.0	32.0	*Vertisol*
Sheraro	1028	14° 24’ N	37° 45’E	700	19.0	40.0	*Vertisol*

Source: Metrology data, 2016; masl = meters above sea level, mm = millimeter.

Table 2. Description of experimental materials used in the experiment

Variety	Pedigree	Release year	Maintainer	Main characteristics/ Adaptation
Birhan	PSL85061	2002	MARC	Early maturing, drought and heat resistance varieties. Additional attribute is their resistance to the parasitic weed striga.
Gobye	P9401	2000	MARC	
Abshir	P9403	2000	MARC	
Melkam	WSV387	2009	MARC	Early maturing, drought and heat resistance varieties
Meko-1	M-36121	1997	MARC	
Local	Landrace	-	-	Late maturing and susceptible to stresses

MARC = Melkassa Agricultural Research Center.

Table 3. Mixed model ANOVA in RCBD used in this study

Sources	Degrees of freedom	Mean squares	Computed F
Blocks/within environment	e(r-1)	RMS	
Genotype (G)	(t-1)	TMS	TMS/MSE
Environment (E)	(e-1)	EMS	EMS/RMS
GxE Interaction	(e-1) (t-1)	ExTMS	ExTMS/MSE
Pooled error	e(r-1) (t-1)	MSE	

Where: e = # environments (locations); r = # replications (blocks); t = number of treatments (genotypes); EMS = environment mean square; RMS is blocks/replications mean square; TMS = treatment mean squares and MSE = mean square error.

2.3 Trial Design and Procedures

The trial was conducted in a randomized complete block design (RCBD) with three replications across six locations. Each unit (plot) was consist of 5 rows of 5m length with inter and intra row spacing of 0.75m and 0.20 m, respectively. The gross and harvestable experimental unit area had a size of 18.75 m^2 (3.75 m x 5 m) and 11.25m^2 (2.25 m x 5 m), respectively. Fertilizers were applied at the recommended rates of 100 kg/ha di-ammonium phosphate (DAP; 18% N and 46% P2O5) and 50 kg/ha urea (46% N). DAP was applied at the time of planting while Urea was side-dressed when the crop reached knee height. All other agronomic practices were applied as per the recommendations for the crop in dry lowland areas of Ethiopia.

2.4 Data Collected

Grain yield (kg ha^{-1}): It was adjusted to standard moisture level at 12.5% to get the grain yield per plot in grams and converted to kg per hectare for analysis based on descriptors developed by IBPGR/ICRISAT [6].

2.5 Data Analysis

Bartlett's test was used to check the homogeneity of error variances before combining the analysis [7]. Analysis of variance (ANOVA) from combined data was conducted for grain yield according to Gomez and Gomez [8]. Analysis of variance (ANOVA) for each location, combined analysis of variance over locations and GGE biplot analysis were computed using Genstat 16th edition [9]. Comparison of treatment means was done using Fisher's least significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Combined ANOVA and Mean Performance of Genotypes across Locations

The combined analysis of variance of six drought tolerant sorghum genotypes over six locations for grain yield (kg ha^{-1}) was presented in Table 5. The result revealed that genotypes, locations, and their interaction (GEI) had the presence of highly significant difference ($p<0.01$), demonstrating that the performances of genotypes varied across different environments. The genotype (G) explained 53.93% to the treatment (total variation) sum squares for grain yield, while location (E) and genotype by environment interaction contributed 38.13% and 7.42% respectively, signifying that the environmental conditions were relatively consistent across locations while the influence of GEI to the total variation exhibited least share. The significant GEI indicated that a particular genotype may not exhibit the same phenotypic performance under different environmental conditions or different genotypes may respond differently to a specific environment

Based on the result obtained over locations, grain yield of environments ranged from 1670 kg ha^{-1} to 3422 kg ha^{-1} (Table 4). The lowest average yield (1730 kg ha^{-1}) was recorded from local and the highest yield (3650 kg ha^{-1}) was recorded from Melkam and the average grain yield of genotypes was 2421 kg ha^{-1}. Melkam and Meko-1 gave above average mean yield across locations while Gobye, Abshir, Birhan and local scored below average mean yield. In agreement with this finding, several studies [10-22] have been conducted to scrutinize genotype by environment interaction and reported significant variation for grain yield on sorghum in Ethiopia.

3.2 GGE Biplot Stability Analysis

In order to investigate environmental variation and interpret GE interaction, graphical methods were used (Fig. 1, and 2). Fig. 1 represents the results of "which-won-where" pattern" to identify the best genotypes for each environment, and Fig. 2 demonstrates the results of genotypes' performance and their stability. In the GGE model, genotype (G) main effect plus genotype by environment interaction (GEI), are the two sources of variation where principal component analysis automatically removes the environmental effects from the data.

3.3 "Which-Won-Where" Pattern and Identification of Mega-Environment

As graphically described in Fig. 1, the polygons view of a GGE biplot displayed the "which-won-where" pattern and mega environment differentiation from the GEI and gives a precise summary of the G × E pattern on a MET. The model classified the study areas into a unique (same) mega-environment with the winning genotype Melkam. This pattern suggested that Melkam was vertex genotype for the sector that gave consistent gain yield across locations i.e. broadly adapted. Conversely, the varieties Meko-1, Gobye, Abshir, Birhan and local fall in sectors where there were no locations at all; these genotypes are poorly adapted to the testing environments. In agreement with this finding Belay et al. [14]; Habte et al. [19] and Nesrya et al. [21] are among the many authors who used GGE bi plot to evaluate sorghum genotypes and to identify mega environments in Ethiopia.

Table 4. Mean grain yield (kg ha^{-1}) of six sorghum genotypes tested across six locations

Variety (Gen.)	Environments (Loc.)						Combined mean
	Humera	Abergelle	Kobo	Fedis	Mehoni	Sheraro	
Abshir	1300^{cd}	1708^{c}	2000^{cd}	2255^{c}	2509^{c}	3600^{b}	2230^{c}
Birhan	1429^{c}	1700^{c}	2110^{c}	2152^{d}	1707^{f}	2700^{d}	1966^{d}
Gobiye	1290^{cd}	1689^{c}	1970^{cd}	1977^{e}	2077^{d}	3100^{c}	2018^{d}
Local	1100^{d}	1367^{d}	1950^{d}	1567^{f}	1867^{e}	2533^{e}	1730^{e}
Melkam	2700^{a}	3100^{a}	3600^{a}	3200^{a}	4300^{a}	5000^{a}	3650^{a}
Meko-1	2200^{b}	2300^{b}	3300^{b}	2400^{b}	3800^{b}	3600^{b}	2932^{b}
Grand mean	1670	1977	2488	2258	2710	3422	2421
LSD (5%)	220.4	147	143	101.7	140.7	123.8	132.8
CV (%)	6.6	4.1	3.2	2.5	2.9	2.0	3.4

Where: LSD = least significance difference, CV (%) = coefficient of variation in percent and values with the same letters in a column are not significantly different at P≤ 0.05.

Table 5. Combined analysis of variance for six sorghum genotypes (G) across six locations (E)

Source of variation	DF	SS	MS	% SS explained
Reps. within Env.	12	6032	3016	
Genotype (G)	5	47818986	9563797**	53.93
Environment (E)	5	33805294	6761059**	38.13
GxE Interaction	25	6571853	262874**	7.42
Pooled error	60	465680	6653	

***= significant at P≤ 0.01, DF = degree of freedom, SS = sum of squares, MS = mean squares*

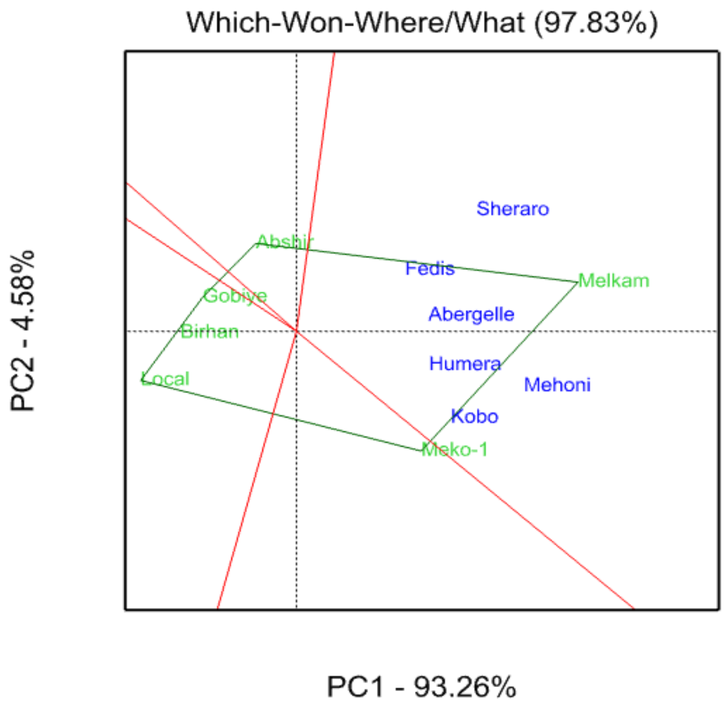

Fig. 1. "Which-won-where" pattern" to identify the best sorghum genotypes for each environment

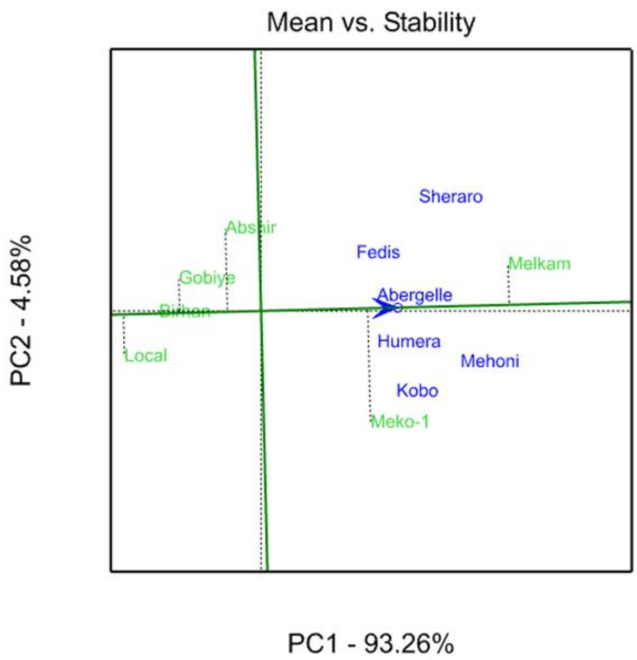

Fig. 2. Ranking of sorghum genotypes based on their mean yield and stability

3.4 Identification of High Yielding and Stable Genotypes

Fig. 2 shows grain yield and genotype stability evaluated from average environment coordinate (AEC) Axis, line passing through the bi-plot origin and the average environment indicated by small circle, which is defined by the average PC1 and PC2 scores of all environments. In this graph the first two PCs explained 97.83% (PC1=93.26%, PC2=4.57%) of the total GGE variation for grain yield. Genotypes on the right side most of this line have high yield (above average mean yield). Hence, Melkam and Meko-1 gave above average mean yield across locations while Gobye, Abshir, Birhan and local scored below average mean yield (left side to AEC). Therefore, genotypes Gobye, Abshir, Birhan and local are more variable and less stable than others genotypes. Genotypes placed close to either side of the AEC abscissa, namely, Melkam was more stable than the others. For specific adaptation, genotypes that have high mean yield but low stability and respond well to a particular environment could be selected. For example Meko-1 has specific adaptability. Based on the grain yield of genotypes, Melkam was the most stable genotype, hence desirable, i.e., the shorter the genotype vector is the more stable than others. Many authors such as Belay et al. [14]; Habte et al. [19] and Nesrya et al. [21] used this stability parameter to identify high yielding and stable sorghum genotypes [23,24].

4. CONCLUSION

The present investigation revealed highly significant difference among genotypes, environments and their interaction (G x E). Based on mean performance of genotypes over locations, the mean grain yield of environments ranged from 1670 kg ha-1 to 3422 kg ha-1. The lowest average yield (1730 kg ha-1) was recorded from local while the highest yield (3650 kg ha-1) was attained from Melkam and the average grain yield of genotypes were 2421 kg ha-1. Multivariate stability model such as GGE bi-plot was used to identify high yielding and stable drought tolerant sorghum genotypes in this study. Accordingly, the model identified sorghum genotype Melkam as stable and high yielding variety that demonstrate consistent performance across different environments, therefore, it is recommended for the dry lowland agro ecologies of Ethiopia.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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