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Additive Main Effect and Multiplicative Interaction Analysis for Grain Yield of Early Maturing Sorghum *[Sorghum Bicolor* (L.) Moench] Varieties in Drought Prone Areas of Temben, North Ethiopia.

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Abstract

Shortage of widely adapted and high yielding variety is one of the major bottlenecks for production and productivity of sorghum in dry lowlands of Tigray region, Northern Ethiopia. A field experiment was conducted during the main seasons of 2018 and 2019 at four environments using randomized complete block design with three replications to evaluate the performance of ten early maturing sorghum varieties for grain yield using AMMI (Additive Main Effects and Multiplicative Interaction) model. The combined analysis of variance revealed highly significant (P≤0.01) genotype (G), environment (E) and genotype × environment interaction (GEI). The significant genotype by environment interaction effects were further partitioned in to two significant interaction principal components by using AMMI model. The AMMI analysis of variance showed that the genotype, environment and interaction sum squares contributed 41.55 %, 28.67 % and 29.78 % to the treatment sum squares for grain yield respectively. In addition, the first two IPCAs and interaction residual were significant. The first two IPCAs accounted for a total of 82.20 % of the interaction sum square. The results revealed that the observed yield variation among genotypes were due to genetic potential of genotypes and interaction rather than location differences. The highest yield was obtained from Melkam (3276 kg ha^{-1}), while the lowest was from Grana-1 (2094 kg ha^{-1}) and the average grain yield of genotypes was 2462 kg ha^{-1}. Therefore, Melkam is selected as the best stable variety with consistent yielding performance across the testing environments in dry lowland areas of Temben and similar agro-ecologies in Tigray region, Northern Ethiopia.

Keywords: AMMI, IPCA, Moisture stress, Sorghum

INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench] belongs to the grass family Poaceae is among the dominant staple cereals for the majority of Ethiopians. Sorghum is grown in Ethiopia in 12 of the 18 major agro-ecological zones, most importantly in the moisture stressed parts of the country, where other crops can least survive and food insecurity is rampant (Asfaw, 2007). In lowland areas of Ethiopia, where moisture is the limiting factor, sorghum is one of the most important cereal crops planted as food insurance, especially in the eastern, north and north-eastern parts of the country where the climate is characterized by unpredictable drought and erratic rainfall (Degu et al., 2009). Sorghum has four features which make it one of the most drought resistant crops of all i.e., i) it has a very large root to leaf surface area ii) in times of drought it will roll its leaves to reduce water loss by transpiration iii) if drought continues, it will go into dormancy rather than dying, and iv) its leaves are protected by a waxy cuticle.

Sorghum is one of the important indigenous food crops and is only second to tef as injera (leavened local flat bread) making cereal. Sorghum grain is used for human food like porridge, "injera", "Kitta", "Nifro", infant food, syrup, and local beverage such as "Tella", and "Areke" (MoANR, 2016). Sorghum grain has a high nutritive value, with 70-80% carbohydrate, 11-13% protein, 2-5% fat, 1-3% fiber and 1-2% ash. Protein in sorghum is gluten free and thus, it is a specialty food for people who suffer from celiac disease (gluten intolerance), including diabetic patients and is a good substitute for cereal grains such as wheat, barley and rye (Dial, 2012). In Ethiopia, sorghum is grown in almost all regions, ranked 3rd in area coverage after tef and maize and ranked 2nd in total production after maize, tef and wheat with national average productivity of 2.71 tons/ha (CSA, 2018). However, a number of constraints have been standing on the way towards sorghum production.

The major problems that check sorghum production in the dry land areas of the country include: lack of early maturing varieties that can escape drought, poor soil fertility, poor stand establishment due to reduced emergence in characteristically crusty soils, insect pests like the spotted stalk borers (Chilo partellus) and birds (Gebeyehu *et al*., 2004). The national and regional sorghum improvement programs have been released a number of open pollinated sorghum varieties for the moisture deficit dry lowland areas of Ethiopia. However, shortage of widely adapted and stable high yielding variety is one of the major bottlenecks for production and productivity of sorghum in moisture stress areas of Abergelle district, Northern Ethiopa. Therefore, the objectives of the study were:

1. To evaluate the performance of early maturing sorghum varieties under random moisture stress conditions and
2. To identify high yielding and stable sorghum genotypes using AMMI stability analysis in Abergelle areas of Northern Ethiopia.

MATERIALS AND METHODS

Description of the Study Areas

Field experiment was conducted under rain-fed conditions at Abergelle Agricultural Research Center mandate areas for two consecutive years; 2018 and 2019 main cropping seasons at Agbe-1, Agbe-1, Yechila-1 and Yechila-2. They are representing the moisture stress areas of

Temben, Central Tigray, Ethiopia. The mandate area is identified as the most drought prone in Tigray region, Northern Ethiopia. It is agro-ecologically characterized as hot warm sub-moist lowland (SMl-4b) located below 1500 meter above sea level and situated at $13^{0}14'06"$ N latitude and $38^{0}58'50"$ E longitudes. Plains, hills and river valley, characterize the topography of the district and it is highly exposed to soil erosion. Most soils of the district are dominated by sandy textured with poor water holding capacity and less fertile; in turn most of the crops failed to produce good yield.

The rainfall status of the study areas is unpredictable and erratic from season to season. The average annual rainfall varies from 350-650 mm and the temperature of the study area ranges from 21-42^{o}C. The distribution of rainfall is erratic and variable, which results in strong variation in crop yields. The rain may start late and/or ends early. It is obvious that this kind of rainfall has a negative impact on the agricultural activities of the community causing uncertainty. The rainfall distribution from the agricultural point of view is mono-modal, concentrated during the summer (July to August). The farmers grow only one crop per season (Dereje et al., 2007).

Experimental Materials

Nine early maturing sorghum varieties, namely, Argiti, Dekeba, Melkam, Girana-1, Messay, Miskir, Chare, ESH-1, ESH-4 and one local check obtained from different (Sirinka, Melkassa and Debrebirhan) agricultural research centers in Ethiopia were used and /or evaluated in this study as presented in Table 1.

Table 1: Description of genotypes used in the study

Genotype	Pedigree	Year of release	Maintainer
Miskir	PGRC/E#69441x P-9401	2007	SARC
Messay	Meko x Gobye-2	2011	SARC
Dekeba	ICSR24004	2012	MARC
Melkam	WSV387	2009	MARC
Chare	PGRC/E #222880/	2011	DBARC
ESH-1	P-9501A x ICSR14	2009	MARC
ESH-4	PU207 x PU304	2016	MARC
Girana-1	CR:35 x DJ1195 x N-13	2007	SARC
Argiti	WSV387 x P-9403	2017	MARC
Woitozera	Local check	-	-

Where: SARC, MARC and DBARC = Sirinka, Melkassa and Debrebirhan agricultural research centers in Ethiopia, respectively.

Experimental Design and Management

The trial was carried out in randomized complete block design (RCBD) with three replications across locations which were employed with experimental plot size of 3.75m x 5m with 1m between plots and 1.5 m between blocks keeping inter and intra row spacing of 75 cm and 20 cm, respectively. Each plot had a total area of 18.75 m^2 and total of five rows and 11.25 m^2 net plot areas with three harvestable rows. The experimental plots were ploughed two times (first

time before sowing and secondly during sowing) to maintain fine seedbed suitable for crop establishment. Seeds were drilled in rows at the rate of 10 kg per ha, and seedlings were thinned by adjusting the distance between plants to 20 cm. Each experimental plot was fertilized uniformly with NPSZnB (100 kg/ha) and Urea (50 kg/ha) fertilizer. Full dose of NPSZnB and half of N were applied at the time of planting and the remaining half was side dressed at knee height stage of the crop. Weeding and other agronomic practices were done equally and properly as per the recommendations for sorghum in dry lowland areas of Ethiopia.

Data Collection

Grain yield was measured as the total weight of clean grains from the central three rows (harvestable net plot size of 11.25m^2), leaving a border row from both sides of the plot and measured with sensitive balance, adjusted at 12.5% seed moisture content and the obtained grain yield per plot in grams was converted to kg ha^{-1} for analysis.

Data Analysis

First data were checked for homogeneity of variance using Bartlett's test (Steel and Torrie, 1998) and the error variance were homogenous for grain yield continued to combined analysis of variance from the mean data of all environments to detect the presence of GEI and to partition the variation due to genotype, environment and GEI. The environments (locations) in the study were assumed as random effects and the genotype effects were treated as fixed. The model employed in the analysis was; Yijk = μ + Gi + Ej + Bk + GEij + εijk where:

Yijk is the observed mean of the ith genotype (Gi) in the jth environment (Ej), in the kth block (Bk); μ is the overall mean; Gi is effect of the ith genotype; Ej is effect of the jth environment; Bk is blocking effect of the ith genotype in the jth environment; GEij is the interaction effects of the ith genotype and the jth environment and εijk is the error term. Analysis of variance for each environment, combined analysis of variance over locations and AMMI analysis was computed using Genstat software package 16th edition. Moreover, Fisher's Least Significant Difference (LSD) was used to separate means.

AMMI Analysis

The additive main effects and multiplicative interaction (AMMI) method Additive main effects and multiplicative interaction (AMMI) model was performed for the mean data of grain yield (kg/ha) from each location using GenStat Discovery Edition 16th software. The AMMI model equation is given as:

$$\mathbf{Y_{ij}} = \mu + \boldsymbol{\alpha_i} + ß_j + \sum_{\mathbf{n=0}}^{\mathbf{N}} \boldsymbol{\lambda_n \gamma_{in} \delta_{jn}} + \boldsymbol{\theta_{ij}} + \boldsymbol{\varepsilon_{ij}}$$

Where**:** Y_{ij} = the mean grain yield of ith genotype in the jth environment, μ = the grand mean, α_i = the deviation of the genotype mean from the grand mean, β_j = the deviation of the environment mean from the grand mean, λ_n= the singular value for the IPCA n, N = the number of PCA axis retained in the model, γ_{in} = the PCA score of a genotype for PCA axis n, δ_{jn} = the

environmental PCA score for PCA axis n, θ_{ij} = the AMMI residual and E_{ij}= the residuals. The number n is judged on the basis of empirical consideration of F-test of significance. The degrees of freedom (DF) for the IPCA axis were calculated based on the following method (Zobel *et al.,* 1988): DF = G + E – 1 – 2n; Where: G = the number of genotypes, E = the number of environments and n = the n^{th} axis of IPCA.

RESULTS AND DISCUSSION

Combined Analysis of Variances

Mean grain yield of early maturing sorghum genotypes tested at four environments is presented on Table 2. Homogeneity of error variances from results of the Bartlett test detected that the mean square of sorghum genotypes across environments were homogenous and combined analysis of variance (ANOVA) depicted highly significant variation ($p<0.01$) among genotypes for grain yield. Based on the combined result the highest yield was obtained from Melkam (3276 kg ha^{-1}), while the lowest was from Grana-1 (2094 kg ha^{-1}) and the average grain yield of genotypes was 2462 kg ha^{-1}.

Since yield is the final result of many plant characters, which are interacting with numerous external factors during the life span of the plants, ranking of genotypes based on grain yield may be considered as a reliable measure for genotypic performance. In the current research finding highly significant effect of genotypes for grain yield was observed which is in agreement with the findings of Amare *et al*. (2019) Gebeyehu *et al*. (2019) and Mohammed (2020). The bold and underlined mean grain yield is for those genotypes that were the highest yielding in each environment as presented in Table 2.

Table 2. Mean grain yield (kg ha^{-1}) of ten sorghum genotypes evaluated in four environments

GENOTYPE	ENVIRONMENTS (LOC)				
	AGBE-1	AGBE-2	YECHILA-1	YECHILA-2	GM
ARGITY	1958^{DE}	1415^{F}	2284^{EF}	2933^{D}	2148^{EF}
CHARE	2537^{B}	1823^{E}	2325^{EF}	2524^{E}	2303^{D}
DEKEBA	1870^{EF}	1796^{E}	2684^{C-E}	2364^{EF}	2179^{D-F}
MELKAM	$\underline{2758^{A}}$	$\underline{3141^{A}}$	$\underline{3484^{A}}$	$\underline{3721^{A}}$	$\underline{3276^{A}}$
ESH-4	2151^{CD}	2231^{D}	2496^{D-F}	2136^{FG}	2253^{DE}
GIRANA-1	1372^{F}	2684^{BC}	2222^{F}	2098^{G}	2094^{F}
LOCAL	2402^{B}	2504^{CD}	2328^{EF}	3360^{B}	2648^{C}
ESH-1	2550^{B}	2871^{AB}	3175^{AB}	3057^{CD}	2913^{B}
MESAY	2175^{C}	1687^{EF}	2919^{BC}	3307^{BC}	2522^{C}
MISKIR	1726^{G}	1687^{EF}	2773^{B-D}	2951^{D}	2284^{DE}
EM	2150	2184	2669	2845	2462
LSD (5%)	196	287	404	252	280
CV (%)	5.3	7.7	8.8	5.2	7.7

Where: GM=Genotypic means, EM=Environment means; 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.

AMMI Analysis

The most important agronomic and economic traits such as grain yield are quantitative in nature and usually exhibit genotype by environment interaction (Fan *et al*., 2007). Based on this, AMMI analysis of ten early maturing sorghum genotypes grown over locations for grain yield (kg ha^{-1}) is presented in Table 3. The combined analysis of variance indicated highly significant differences (P≤ 0.001) to mean squares for treatments (genotypes, environments and GEI). The genotype, environment and interaction sum squares contributed 41.55 %, 28.67 % and 29.78 % to the treatment sum squares for grain yield, respectively. The results revealed that the observed yield variation among genotypes were due to genetic potential of genotypes and interaction rather than location differences. The larger sum of square and highly significant mean squares of genotypes indicated that the environments were not diverse.

In the AMMI ANOVA, the GEI was further partitioned by PCA. Based on Gollob (1968) F-test the two interaction principal components were significant at P≤ 0.001 probability level and accounted for a total of 82.20 % of the interaction sum square. Moreover, the interaction residual was significant; indicating, the presence of unpredictable source of variation for the sum of squares of the interaction. Therefore, that is impossible to express the GEI of the ten sorghum genotypes tested at four locations using the first two principal components axes and no need of going further to graphically display in AMMI1 biplot. Hence, the best fit AMMI model for this multi-location yield trial data was AMMI-2.

Table 3. The combined analysis of variance for AMMI model.

SOURCE	DF	SS	MS	SUM OF SQUARES % EXPLAINED		
				TOTAL	GEI	GEI CMU.
REPS. WITHIN ENV.	8	195211	2440^{NS}			
ENVIRONMENT (E)	9	15842012	1760224***	28.67		
GENOTYPE (G)	3	10932548	3644183***	41.55		
GXE INTERACTION	27	11351990	420444***	29.78		
IPCA 1	11	6952946	632086***		61.25	61.25
IPCA 2	9	2378571	264286***		20.95	82.20
RESIDUALS	7	2020474	288639***		17.80	100
POOLED ERROR	72	2124357	29505			
TOTAL	119	40446118				

***= significant at P-value≤ 0.001 and ns = non-significant, IPCA=interaction principal component axis, GEI = Genotype by Environment Interaction explained and GEI cum. = GEI cumulative, SS=Sum of Squares, MS= Mean Square.

Genotypes Selection by AMMI model

Multi-location trials are very important for selecting the best genotype for wide or specific environments before any recommendation of genotypes for future commercial production. The four best hybrids selected by AMMI model for each environment are presented in Table 4. In this study, genotypes were reacted differently to environmental fluctuation, as a result the best AMMI model allows as to select relatively better genotypes that suit to a specific environment.

Accordingly, Melkam followed by ESH-1 were the best adapted genotypes for each testing environment and stable across locations, whereas Mesay was the best genotype specifically for medium to high yielding environment of E-3 and E-4 (Yechila). The other genotype that was selected did not show a distinct pattern of adaptation and more specific adapted either lower or higher yielding environments. Thus, the variety Melkam selected in all environments is an indication of the best adapted genotype for each testing environment were obtained from the AMMI model, which is in agreement with the previous findings of Abebe *et al*. (2020) and Melese (2020) reported that Melkam variety has been found better in drought prone/dry lowland areas Konso and Wag Last in Ethiopia as a result of earliness, better adaptation and stability.

Table 4. The AMMI model's best four sorghum varieties selection for grain yield per environment

Environment	Sites	Mean	IPCA 1 Score	The first four AMMI selected varieties			
				1	2	3	4
E4	Yechila-2	2845	21.76	Melkam	Local	ESH-1	Mesay
E3	Yechila-1	2669	3.27	Melkam	ESH-1	Mesay	Miskir
E2	Agbe-2	2184	-31.55	Melkam	ESH-1	G-1	Local
E1	Agbe-1	2150	6.53	Melkam	ESH-1	Chare	Local

CONCLUSION

In the present investigation, significant variation was observed among early maturing sorghum varieties for grain yield. Melkam, ESH-1 and Weitozera were found the best sorghum genotypes that yielded above average. The highest yield was obtained from Melkam (3276 kg ha^{-1}), while the lowest was from Grana-1 (2094 kg ha^{-1}) and the average grain yield of genotypes was 2462 kg ha^{-1}. AMMI model was employed in determining the most stable and high yielding sorghum genotypes in this study.

Accordingly, the model revealed that Melkam was considered as high yielder and stable variety with consistent grain yield performance across the testing environments; therefore, can be recommended for further demonstration and popularization in terminal moisture stressed areas of Temben and areas with similar agro-ecologies in Tigray region, northern Ethipia.

Conflict of Interest

The authors have not declared any conflict of interest.

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