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Genotype x Environment Interaction and Grain Yield Stability of Sorghum [*Sorghum bicolor* (L.) Moench] Varieties in Oromia, Ethiopia

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Background and justification: Ethiopia is the third largest sorghum producer in Africa next to Nigeria and Sudan. Shortage of widely adapted and stable high yielding variety is one of the major bottlenecks for production and productivity of sorghum in Ethiopia. Genotype by Environment Interaction results from a change in the relative rank of genotype performance or a change in the magnitude of differences between genotype performances from one environment to another.
Objectives: To determine the magnitude and nature of genotype by environments interaction for grain yield and also to determine the stability of sorghum varieties for grain yield and hence to identify and recommend stable high yielding variety (ies).
Material and methods: A total of 22 sorghum varieties were evaluated across five locations such as Bako, Gute, Biloboshe (Western Ethiopia), Mechara and Mieso (Eastern Ethiopia) in 2017 main cropping seasons. The trial was arranged in a randomized complete block design (RCBD) in three replications.
Summary result and application of the study: The combined analysis of variance revealed that significant effect of locations and genotype by location interactions for grain yield. This showed that, genotypes were inconsistent for grain yield across the testing locations. Birmash gave the highest grain yield with average yield of 3.5 ton ha^{-1} but not widely adapted. Baji was the second high yielding variety with mean grain yield of 3.3 ton ha^{-1} & better wider adaptability. In genotype x environment interaction analysis, the result indicates that, the observed yield variations among varieties were due to the GxE effects rather than main effect of genotypes and environments. Results of ASV parameter showed that, the six relatively better stable and high yielding genotypes are Gambella-1107, Gobiye, Baji, ESH-1, IS9302 and Emahoy. Emahoy and Baji varieties were the 3rd and 2nd top high yielder and relatively better stable varieties as revealed by the two stability models.

Key words*:* ASV, Correlation, GxE Interaction, Sorghum, Stability

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INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a C4 cereal crop belonging to the family *Gramineae*. It has 2n = 20 chromosomes and an estimated genome size of 750 Mb being twice the genome of rice and six times the genome of Arabidopsis (Passardi *et al*., 2004). Sorghum is a dryland cereal crop grown on approximately 44 million hectares of land (Prakash *et al*., 2010), in 99 countries (ICRISAT, 2009) with an annual production of 60 million tons (Iqbal *et al.,* 2010). Nowadays, it is widely cultivated in different parts of Ethiopia. Several authors such as De Wet and Huckabay (1967); Doggett (1988) and Smith and Frederiksen (2000) reported that Ethiopia is the primary center of origin and hence, center of diversity for sorghum. Sorghum is now widely found in the dry areas of Africa, Asia, Americas and Australia (Dickon *et al.,* 2006).

Although sorghum is cultivated both in tropical and temperate climates, it is best known for its adaptation to the drought- prone semi-arid tropical (SAT) regions of the world (Baummhardt, 2000) and among cereal crops used for food for the poorest people who live in semiarid regions of the world (Jiang *et al*., 2013). It is adapted to environments with 400-600 mm annual rainfall that are too dry for other cereals (Dickon *et al*., 2006). 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 lowlands of eastern Ethiopia and in the north and north-eastern parts of the country where the climate is characterized by unpredictable drought and erratic rainfall (Degu *et al*., 2009). With the frequent and cyclical occurrence of drought and erratic rainfall, it could be an insurance crop to the small-scale resource-poor farmers constituting most of the rural farming community in Ethiopia (Abdissa, 1997). It is also one of the most important cereal crops of the tropics grown extensively over wider areas with altitude ranging from 400 to 3000 meters above sea level (m.a.s.l) due to its ability to adapt to adverse environmental conditions. This has made sorghum a popular crop in world wide. It is the major source of energy and protein for millions of people living in arid and semi-arid region of the world. It occupied third position in terms of production in Africa after wheat and maize and fifth in the world after wheat, maize, rice and barley (FAO, 2017).Moreover, it is widely used as a source of nutrition, fodder, biofuel, fiber and confection (Abubakar and Bubuche, 2013). It is able to grow under severe stress conditions. Sorghum can be cultivated successfully on almost all soils and in the temperature range of 16–40^{0}C (Abubakar and Bubuche, 2013).

Ethiopia is the third largest sorghum producer in Africa next to Nigeria and Sudan (FAO, 2012). In Ethiopia, a total of 4.34 million tons of sorghum is being produced per annum. The mean yield level in the country is estimated at 2.4 t ha^{-1}. The crop is the major food cereal after maize and tef in terms of number of growers, area coverage and grain production in the country (FAO, 2017). Oromia, Amhara and Tigray regions are the major three sorghum producers in the country (CSA, 2016). Out of the total sorghum area harvested in 2014 main cropping season, Oromia region accounts 39.92% (669,575.97 hectares), Amhara and Tigray regions contributed 33.31% (558,827.95 hectares) and 12.82% (215,111.82 hectares), respectively.

Genotype x environment interaction is the major concern for plant breeders for developing improved cultivars. GEI results from a change in the relative rank of genotype performance or a change in the magnitude of differences between genotype performances from one environment to another. In multi-environment trials, the phenotype of an individual in each test environment is a measure of an environment main effect, a genotype main effect, and the genotype by environment interaction (GEI) (Yan and Tinker, 2005). The GE interaction reduces the correlation between phenotype and genotype and hence selection progress. More than forty sorghum varieties were released in the country from different regional and national research centers during the last 40 years (MoA, 2017). However, most of the varieties were not evaluated for their specific and wider adaptability and thus exhibit fluctuating yields when grown in different environments or agro-climatic zones. To this end, multi- environment adaptability and stability test is crucial to identify stable high yielding and adaptable cultivars and discover sites that best represent the target environment (Yan *et al*., 2000). Adaptability is the result of genotype, environment and genotype by environment interaction and generally falls into two classes: (1) the ability to perform at an acceptable level in a range of environments, referred to as general adaptability, and (2) the ability to perform well only in desirable environments, known as specific adaptability (Farshadfar and Sutka, 2008). Nevertheless, information on the effect of GEI on the yield performance of sorghum varieties under different environments in Ethiopia is limited. Therefore, the objectives of the current study were to determine the magnitude and nature of genotype by environments interaction for grain yield and also to determine the stability of sorghum varieties for grain yield and hence to identify and recommend stable high yielding variety (ies).

MATERIALS AND METHODS

Description of the Study Area

The field experiment was conducted during 2017 main cropping season at five locations in Ethiopia where sorghum is widely grown. The locations were Bako, Gute, Biloboshe (Western Oromia), Mechara, and Mieso

(Eastern Oromia). The detailed agro-ecological features of the locations are presented in Table 1 & Figure 1

Plant Materials

The experimental plant materials comprised of 22 sorghum varieties including local check and varieties released from different research centers in Ethiopia. The detailed information about the experimental materials is presented in Table 2.

Experimental procedures

The trial was laid out in Randomized Complete Block Design (RCBD) with three replications. The experimental plot consists of two rows, each 5 m in length with 75 cm between row spacing and 15 cm spacing between plants. Seeds were sown by hand drilling at the rate of 12 kg ha^{-1} as per the recommendation for row planting in sorghum. Thinning was done two weeks after emergence to adjust plant to plant spacing. 100 kg ha^{-1} NPS fertilizer was applied at planting. Urea was applied as top dressing at the rate of 50 kg ha^{-1} at knee height stage. The field was kept free of weeds by hand weeding during the whole growing period.

Stability analysis

Eberhart and Russell's model

Yield stability was determined following the Eberhart and Russell (1966) model by regressing of the mean grain yield of individual genotypes on environmental index and calculating the deviation from the regression.

$$Yij = \mu\mathbf{i} + \beta\mathbf{i}\mathbf{I}\mathbf{j} + \delta\mathbf{ij} + \varepsilon\mathbf{ij}$$

Where: Yij = the mean of the ith genotype in the jth environment

μi = the grand mean,

βi = the regression coefficient of the ith genotype on environmental index,

Ij = the environmental index obtained by the difference between the mean of each environment and the grand mean, δij = the regression deviation of the ith cultivar in the jth environment,

Additive Main effect and Multiplicative Interaction (AMMI) mode

In AMMI model the contribution of each genotype and each environment to the GEI is assessed using the biplot method where yield means are plotted against the scores of the IPCA1 (Zobel *et al.,* 1988*)*. The AMMI model was calculated using the following formula:

$$\mathbf{Y}_{ij} = \mu + \alpha_i + \beta_j + \sum_{n=0}^{N} \lambda_n \gamma_{in} \delta_{jn} + \theta_{ij} + \varepsilon_{ij}$$

Where:Y_{ij} = the mean yield of genotype i in environment j,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.

AMMI's stability value (ASV)

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential to quantify and rank genotypes according to their yield stability. This value was calculated according to Purchase (1997) as follow:

$$(ASV) = \sqrt{\left[\left(\frac{IPCA1SS}{IPCA2SS}\right)(IPCA1Score)\right]2 + (IPCA2Score)2}$$

In effect, the ASV is the distance from zero in a two dimensional scatter graph of IPCA1 (Interaction Principal Component Analysis axis 1) scores against IPCA 2 scores. Since the IPCA1 score contributes more to G x E sum of squares, it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to the total G x E sum of squares.

RESULTS AND DISCUSSION

Analysis of variance

The mean grain yield value of varieties averaged over environments indicated that, Birmash, Baji and IS9302 followed by Emahoy gave higher grain yield (3.52, 3.34, 3.21 and 3.19 ton ha^{-1}, respectively) and the lowest for Abshir (1.52 ton ha^{-1}). All varieties showed inconsistent performances across all environments. Overall, the highest (5.44 ton ha^{-1}) grain yield was obtained from variety 07MW6002 at Gute. The result of the combined ANOVA showed that, the total variation in yield was attributed to environmental (19.34%), genotypic (19.78%) and GEI (47.85%) effects (Table 3). This implied that the largest proportion of the variation was due to the Genotypes x Environments Interaction. Asfaw (2007, 2008), Hagos and Fetien (2011), Mahnaz *et al.* (2013), and Sewagegne *et al.* (2013) reported that the largest proportion of the variation was due to the environmental effects among sorghum genotypes.

Table 1. Agro-ecological features of the experimental locations.

Locations	Altitude (m.a.s.l)	Ave. Rain fall (mm)	Soil Type	Geographic coordinates		Ave. Temp. (ºC)	
				Latitude	Longitude	Max.	Min.
Gute	1906	1633.5	Alfisoils	9°00'N	36°38'E	21.6	14.3
Biloboshe	1758	1568.6	Sandy Loam	9 °00'N	38 °10'E	21.4	14.2
Bako	1650	1425.3	Alfisoils	9°6' N	37°09'E	20.4	13.5
Mechara	1760	871	Sandy loam	8°36'N	40°18 'E	23.4	8.9
Mieso	1470	856.8	Vertisoil	16°06'N	37° 08'E	35.0	8.3

Source: Bako and Mechara Agricultural Research Centers

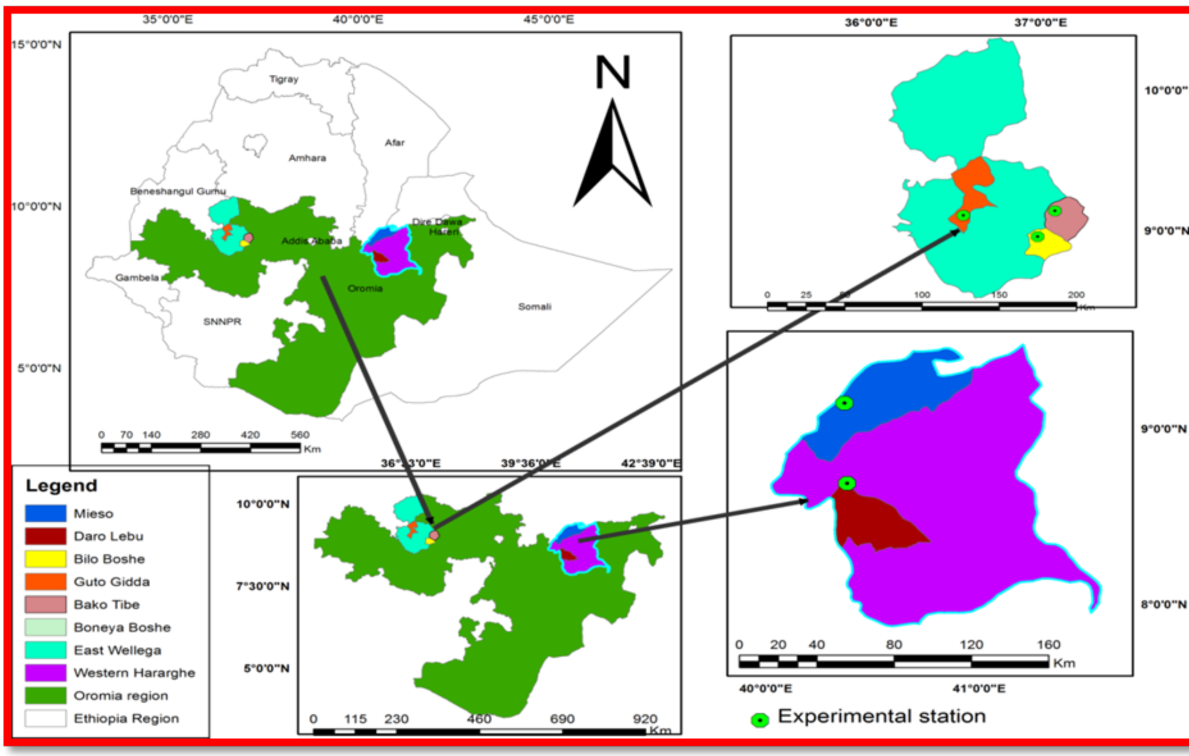


Figure 1. Location map of study sites.

Stability Analysis using Eberhart and Russell Regression Model

According to Eberhart and Russell (1966), a stable genotype should have high yield, unit regression coefficient (b_i) and deviation from regression (Sd_i^2) close to zero. Based on these three parameters, varieties such as Gambella-1107 and Emahoy had regression coefficient closer to unity, deviation from regression very close to zero with and mean grain yield greater than the average and hence could be considered as stable varieties (Table 4). Whereas, Baji and IS9302 were the second and third high yielder with regression coefficient of greater than one, deviation from regression (Sd_i^2) close to zero, respectively, and thus best fit for specific adaptation in favorable environments. Varieties such as Chemeda, ESH-1 and Gobiye had regression coefficients less than one, implying their specific adaptability to marginal environments.

Additive mean effect and multiple interactions (AMMI) model

The combined AMMI ANOVA of the twenty two sorghum varieties over five locations for grain yield (ton ha^{-1}) is presented in Table 5. The ANOVA table indicated highly significant differences (p<0.01) for the environments, genotypes, GEI and the first two IPCA. The total variation explained (%) was 86.44% for treatment and the remaining 13.6% for error. The greater contribution of the treatment over the error indicated the reliability of this multi-location experiment. The treatment variation was

Table 2. Description of different sorghum varieties tested at five locations.

# No	Varieties	Pedigree	Year of Release	Adaptation area (m.a.s.l.)	Breeder/Maintainer
1	Baji	85 MW 5334	1996	1600-1900	MARC/EIAR
2	Birmash	NA	1989	1600-1900	MARC/EIAR
3	Geremew	87 BK -4122	2007	1600-1900	MARC/EIAR
4	Lalo	BRC-245	2006	>1600	BARC/OARI
5	Teshale	3443-2-0P	2002	1450-1850	SRARC/ARARI and MARC/EIAR
6	Melkam	WSV 387	2009	<1600	MARC/EIAR
7	Gobiye	P-9401	1999	<1850	MARC/EIAR
8	Abshir	P-9403	2000	<1850	MARC/EIAR
9	Dagim	IS10892XRS/R-20-8614-2 x IS	2011	1600-1900	SRARC
10	IS9302	NA	1981	1600-1900	MARC/EIAR
11	ESH-1	P-9501 A x ICSR14	2009	<1600	MARC/EIAR
12	Birhan	Key#8566	2002	<1850	SRARC/ARARI
13	Gambella-1107	NA	1981	1450-1850	MARC/EIAR
14	Emahoy	Pw01-092	2007	1600-1900	PARC/EIAR
15	Dekeba	ICSR 24004	2012	<1600	MARC/EIAR
16	Chemeda	Acc-BCC-5	2013	>1600	BARC/OARI
17	Local Check	-	-	-	Farmers
18	07MW6035	(89MW4122*85MW5552)*85MW5340	2016	1600-1900	MARC/EIAR
19	07MW6002	(89MW4122*85MW5552)*85MW5340	2016	1600-1900	MARC/EIAR
20	Assosa_1	Bambasi # 9	2015	1500-1850	AARC
21	Adukara	NA	2015	1500-1850	AARC
22	07MW6052	(89MW4122*85MW5552)*85MW5340	2016	1600-1900	MARC/EIAR

NB: EIAR=Ethiopian Institute of Agricultural Research, MARC=Melkasa Agricultural Research Center, BARC= Bako Agricultural Research Center, SRARC= Sirinka Agricultural Research Center, ARARI=Amhara Regional Agricultural Research Institute, OARI= Oromia Agricultural Research Institute, PARC= Pawe Agricultural Research Center, AARC= Assosa Agricultural Research Center, NA= Not Available

largely due to GEI variation (48.66%), genotype and environment accounted 20.08% and 17.71% of the total variation, respectively. As discussed earlier, the high percentage of GEI is an indication that the major factor that influence yield performance of sorghum in Ethiopia is the interaction effect of genotype and environment. This result revealed that there was a differential yield performance among the varieties across testing environments and the presence of strong genotype by environment (G X E) interaction.

As G x E interaction was significant, further calculation of genotype stability is possible. In the AMMI ANOVA, the GEI was further partitioned using PCA. The number of PCA axis to be retained is determined by testing the mean square of each axis with the estimate of residual using the F-statistics. The result of ANOVA showed that the first two IPCA were highly significant at (P<0.01) implying the inclusion of the first two interactions PCA axes in the model. Hence, the best fit AMMI model for this multi-location yield trial data was AMMI-2 (Table 5). Gauch and Zobel (1996) suggested that the most accurate model for AMMI can be predicted by using the first two IPCAs. Several authors took the first two IPCAs such as for bread wheat (Asnake et al., 2013), common bean (Abeya et al., 2008) and finger millet (Dagnachew et al., 2014, Kebede et al., 2018). (see Figure 2)

Genotype Performance per Environment (GGE biplot Analysis)

It is a genotype to be on average environmental coordinate (AEC) on positive direction and has vector length equal to the longest vector of the genotype and indicated by an arrow pointed to it (Yan *et al*., 2000 and Kaya *et al*., 2006). The Biplot indicated that G2, G1 and G10 were the most ideal genotypes and were nearest to the concentric circles so that these genotypes are more desirable and ideal genotypes than other tested genotypes (figure 3)

The polygon is formed by connecting the markers of the genotypes that are far away from the biplot origin such that all other genotypes are contained in the polygon. Genotypes located on the vertices of the polygon performed either the best or the poorest in one or more locations since they had the longest distance from the origin of biplot. The perpendicular lines are equality lines between adjacent genotypes on the polygon, which facilitate visual comparison of them. For

Table 4. Mean yield, regression coefficients and deviation from regression

Varieties	Yield (ton ha^{-1})	Rank	b_i	Ranks	S^2d_i	Ranks	ri^2	MS-TXL	MS-REG
07MW6002	2.777	10	1.338	13	3.50	22	0.01	2.67	0.15
07MW6035	2.291	14	0.637	8	1.49	17	0.04	1.16	0.18
07MW6052	2.785	9	1.407	14	1.15	14	0.06	0.92	0.22
Abshir	1.521	22	-0.060	2	0.50	7	0.50	0.75	1.49
Adukara	2.664	11	3.830	22	2.69	20	0.17	2.16	1.11
Assosa_1	1.651	21	2.513	21	1.16	15	0.12	0.88	0.32
Baji	3.344	2	2.029	20	0.16	1	0.74	0.47	1.41
Birhan	1.659	20	-.064	1	0.58	9	0.46	0.81	1.50
Birmash	3.515	1	1.966	19	0.41	5	0.50	0.61	1.24
Chemeda	2.385	13	0.375	6	0.66	10	0.21	0.62	0.52
Dagim	2.795	7	1.675	16	1.35	16	0.13	1.17	0.61
Dekeba	2.273	15	1.107	10	0.97	11	0.01	0.73	0.02
Emahoy	3.190	4	1.425	15	0.55	8	0.13	0.47	0.24
ESH-1	2.048	18	0.077	3	0.34	3	0.52	0.54	1.13
Gambella-1107	2.789	8	1.173	11	0.38	4	0.03	0.29	0.04
Geremew	2.813	6	1.680	17	1.06	12	0.16	0.95	0.61
Gobiye	1.828	19	0.184	5	0.45	6	0.39	0.56	0.88
IS9302	3.208	3	1.843	18	0.24	2	0.57	0.41	0.95
Lalo	3.166	5	1.303	12	1.68	18	0.02	1.29	0.12
Local check	2.091	17	0.692	9	2.73	21	0.02	2.08	0.13
Melkam	2.226	16	0.577	7	1.11	13	0.07	0.89	0.24
Teshale	2.584	12	0.182	4	1.73	19	0.15	1.52	0.89

Key: MS-TXL = contribution of each variety to interaction MS, MS-REG = contribution of each variety to the regression component of the treatment by location interaction, MS-DEV (sd_i^2) =deviations from regression component of interaction, ri^2 = squared correlation between residuals from the main effects model and the site index, b_i = regression coefficient

Table 5. AMMI analysis of variance for grain yield (ton/ha) of sorghum varieties tested at five locations during 2017 main cropping season.

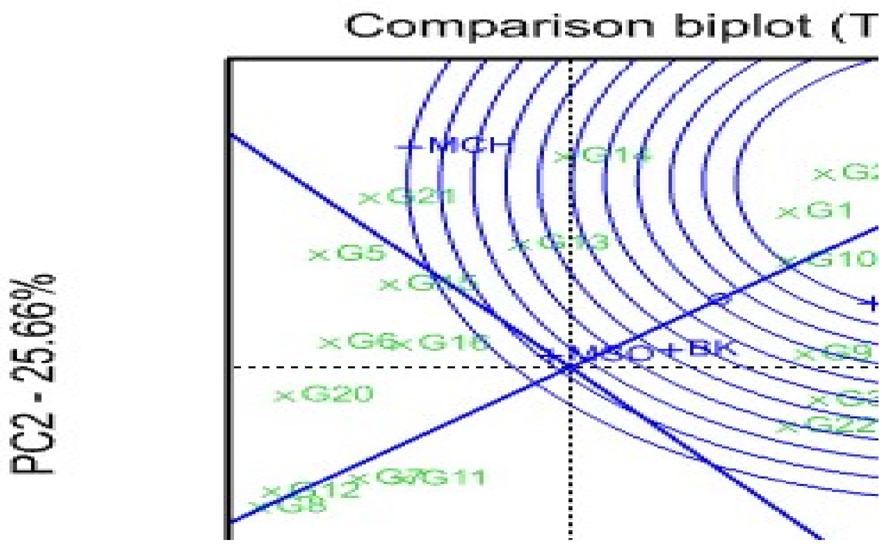
		Sum of squares explained				
Source	DF	SS	%Total	%Contribution to the variation	% G x E	MS
Total	329	523				1.59
Treatments	109	452.1	86.44			4.148**
Genotypes	21	105	20.08			5.001**
Environments	4	92.6	17.71			23.14**
Block	10	6.61				0.661*
G x E	84	254.5	48.66			3.029**
IPCA 1	24	186.2			73.16	7.76**
IPCA 2	22	39.4			15.48	1.79**
Residuals	36	28.9			11.36	0.803
Error	206	64.3	12.29			0.312

Key: DF = degree of freedom, SS =sum of squares, MS = mean of squares and, GxE = Genotype by Environment, * significant (P<0.05), ** = highly significant (P<0.01).

example, Birmash was located on vertex indicates that it was better in Biloboshe, whereas Emahoy, Adukara and Teshale were better in Mechara (Figure 4).

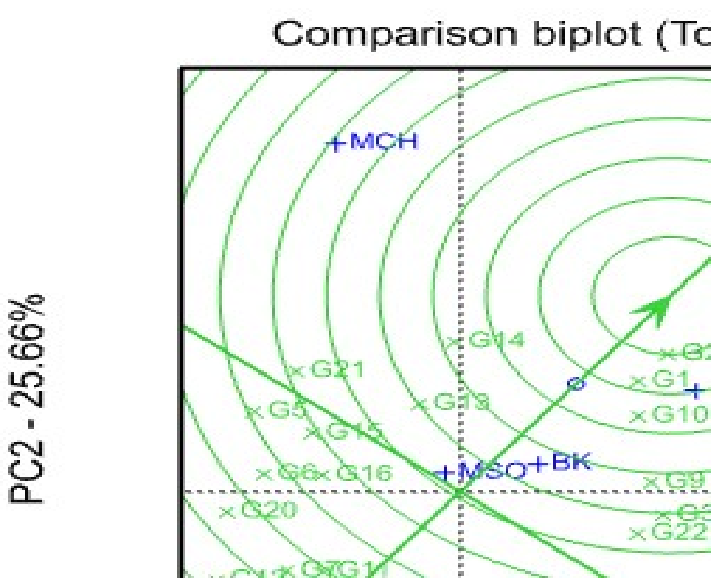
AMMI Stability Values (ASV)

In additive main effect and multiplicative interaction stability value analysis (ASV) method, a genotype with least ASV score is the most stable across environments and the larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments (Purchase, 1997). Accordingly, Gambella-1107 provides optimum grain yield and the least ASV & thus better stable than others (Table 6). Birmash and Baji was the first two high yielder with optimum ASV.



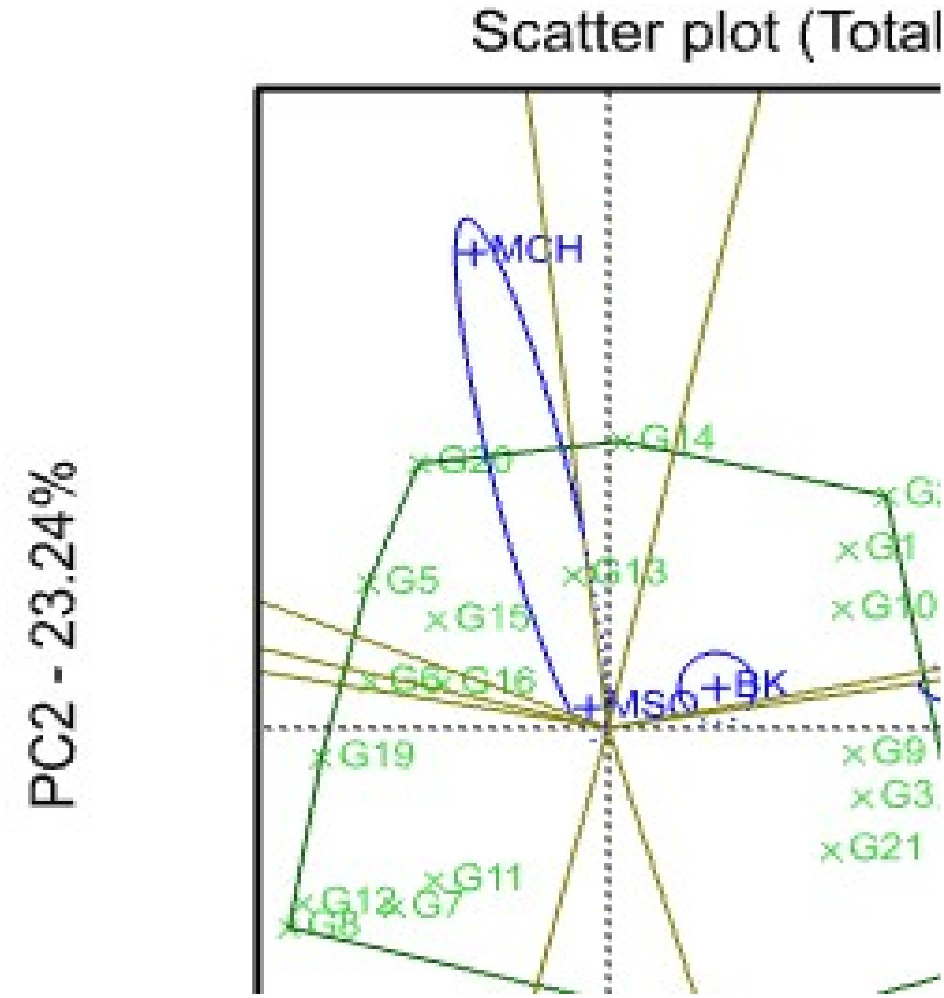
Key: G1=Baji, G2=Birmash, G3=Geremew, G4=Lalo, G5=Teshale, G6=Melkam, G7=Gobiye, G8=Abshir, G9=Dagim, G10=IS9302, G11=ESH-1, G12=Birhan, G13=Gambella-1107, G14=Emahoy, G15=Dekeba, G16=Chemeda, G17=Local check, G18=07MW6035, G19=07MW6002, G20=Assosa_1, G21=Adukara, G22=07MW6052.

Figure 2. GGE biplot analysis showing the stability of genotypes and test environments.



Key: G1=Baji, G2=Birmash, G3=Geremew, G4=Lalo, G5=Teshale, G6=Melkam, G7=Gobiye, G8=Abshir, G9=Dagim, G10=IS9302, G11=ESH-1, G12=Birhan, G13=Gambella-1107, G14=Emahoy, G15=Dekeba, G16=Chemeda, G17=Local check, G18=07MW6035, G19=07MW6002, G20=Assosa_1, G21=Adukara, G22=07MW6052.

Figure 3. The average genotypes coordination (AGC) views to rank genotypes relative to the center of concentric circles.



Key:G1=Baji,G2=Birmash,G3=Geremew, G4=Lalo, G5=Teshale, G6=Melkam, G7=Gobiye, G8=Abshir, G9=Dagim, G10=IS9302, G11=ESH-1, G12=Birhan, G13=Gambella-1107, G14=Emahoy,G15=Dekeba,G16=Chemeda,G17=07MW6035,G18=07MW6002,G19 =Assosa_1, G20=Adukara, G21=07MW6052, MSO=Miesso, BK= Bako, BB= Biloboshe, GT= Gute, MCH= Mechara and PC= Principal Component

Figure 4. The GGE biplot to show which genotypes performed best in which environment.

SUMMARY AND CONCLUSIONS

Multi-location trials are very important for selecting the best genotype for wide or specific environments before any recommendation of genotypes for commercial production. In the AMMI analysis, more than 48.68% was explained for the interaction. Among the varieties, Emahoy had higher mean grain yield and had wide adaptation while Birmash with high mean yield had specific adaptation due to its instability in most stability parameters. Accordingly, varieties can be recommended for specific and wide adaptation. Baji was best at Bako. It was also the most widely adapted variety across the testing environment. Birmash was the best variety at Biloboshe, 07MW6002 performed best at Gute, Adukara performed best at Mechara and Teshale was the best at Miesso. However, from grain yield perspective and also as observed from the majority of stability parameters used, Emahoy variety is best for wider adaptability, followed by Baji and Birmash.

Table 6. Mean grain yield, IPCA scores and ASV of 22 sorghum varieties evaluated at five locations during 2017 main cropping season.

Varieties	Yield (ton ha^{-1})	Rank	IPCA1	IPCA2	IPCA3	IPCA4	ASV	Rank
07MW6002	2.777	10	-1.134	-0.269	0.309	-0.079	2.4791	22
07MW6035	2.291	14	-0.609	-0.491	-0.537	0.190	1.4122	15
07MW6052	2.785	9	-0.615	-0.142	-0.212	0.578	1.3440	13
Abshir	1.521	22	0.509	-0.401	-0.317	-0.270	1.1769	9
Adukara	2.664	11	0.781	0.297	0.680	0.266	1.7236	19
Assosa_1	1.651	21	0.543	0.275	0.066	0.154	1.2125	11
Baji	3.344	2	-0.287	-0.526	-0.108	0.378	0.8146	3
Birhan	1.659	20	0.526	-0.504	-0.224	-0.058	1.2483	12
Birmash	3.515	1	-0.304	0.681	-0.029	-0.186	0.9480	7
Chemeda	2.385	13	0.484	-0.194	0.339	-0.365	1.0690	8
Dagim	2.795	7	-0.604	0.544	-0.322	-0.545	1.4216	16
Dekeba	2.273	15	0.513	0.440	-0.102	-0.287	1.1983	10
Emahoy	3.190	4	0.380	0.393	0.264	0.079	0.9161	6
ESH-1	2.048	18	0.272	-0.648	0.126	0.097	0.8773	4
Gambella-1107	2.789	8	0.318	0.306	-0.118	-0.030	0.7552	1
Geremew	2.813	6	-0.678	0.130	0.192	0.121	1.4802	17
Gobiye	1.828	19	0.328	-0.370	-0.572	0.059	0.8046	2
IS9302	3.208	3	-0.362	0.392	0.074	0.179	0.8793	5
Lalo	3.166	5	-0.783	0.017	-0.328	-0.124	1.7020	18
Local check	2.091	17	-0.772	-0.639	0.858	-0.294	1.7960	20
Melkam	2.226	16	0.636	-0.197	0.234	0.241	1.3958	14
Teshale	2.584	12	0.858	-0.144	-0.275	-0.107	1.8694	21
Mean	**2.553**							

Key: IPCA=Interaction Principal Component Axis 1, 2, 3 and 4; ASV=AMMI Stability Value

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