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ASSESSMENT OF YIELD STABILITY IN SORGHUM

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ABSTRACT

Sorghum (*Sorghum bicolor* L. (Moench)) is the third major cereal crop in Ethiopia in terms of area and production next to tef (*Eragrostis tef*) and maize (*Zea mays*). It is the major crop in drought stressed lowland areas that cover 66% of the total arable land in the country. Yield stability is one of the setbacks facing plant breeders in developing widely adapted varieties with superior yield. The present study was carried out to investigate the effect of genotype by environment (GxE) on the yield stability of sorghum *(Sorghum bicolor)* using fifteen genotypes in eight environments (Locations x years combination). There were significant differences among the genotypes, the environments and GxE interactions. Thus, the three types of univariate stability models: Type-1 (CV_i and S^2_i), Type-2 (W^2_i, s^2_i, and b_i) and Type-3 (Sd^2_i) were compared for ranking of the genotypes. The parameters of W^2_i and si^2 had perfect positive correlation (r=1.0) and strong positive correlation with bi (r=0.80), but either weak or no correlation with the rest of the parameters. Similarly, CV_i and S^2_i had strong rank correlation (r=0.97) but both had either very weak or no rank correlation with the rest of the parameters tested. The Sd^2_i had very weak negative correlation with the remaining parameters. Based on the three stability statistics, the different genotypes were classified as stable. To compliment and verify findings of this univariate approach, the GxE which uses a mulivariate approach was used. The multivariate approach (AMMI model) gives a broader inference. Based on the AMMI model, genotypes 2 and 5 were the most stable, although genotypes 1 and 3 had satisfactory levels of yield performance as well as stability. Therefore, these four genotypes with wider adaptation are recommended for sorghum growing dry lowlands of the country.

Key Words: AMMI model, Ethiopia, GxE, hybrids, *Sorghum bicolor*

RÉSUMÉ

Le Sorgho (*Sorghum bicolor* L. (Moench)) représente la 3^e principale céréale en Ethiopie, en termes de superficie de production, après le Tef (*Eragrostis tef*) et le maïs (*Zea mays*). Il est par ailleurs la culture majeure dans les zones de stress due à la sécheresse au sein des basses terres couvrant 66% de la superficie arable totale du pays. La stabilité du rendement constitue l'une des difficultés que rencontrent les agriculteurs dans le développement de variétés largement adaptées et présentant un rendement supérieur. La présente étude était menée dans le but d'établir par investigations l'effet du genotype et de l'environnement (GXE) sur la stabilité du rendement du sorgho (*Sorghum bicolor*) par l'utilisation de 15 génotypes au sein de huit environnements (sites x combinaison-années). Il y avait des différences significatives parmi les génotypes, les environnements ainsi que les interactions GXE. Par conséquent, produisant les 3 types de modèles de stabilité à variable unique: Type -1 (CV_i et S^2_i), Type - 2 (W^2_i S^2_i et b_i) et type -3 (sd^2_i) étaient comparés pour un classement de génotypes. Les paramètres de W^2_i et Si^2 avaient une corrélation positive parfaite (r = 1,0) et une forte corrélation positive avec bi (r = 0,80), mais présentaient une faible ou aucune corrélation avec le reste des paramètres. De façon similaire, CV_i et S^2_i avaient une forte corrélation de classement (r = 0,97) mais le deux avaient soit une très faible ou aucune corrélation de classement avec le reste de paramètres testés. Le sd^2_i avait une corrélation négative très faible avec les autres paramètres restants. Se basant sur les 3 statistiques de stabilité; les différents génotypes étaient classifiés comme stables. En vue de pouvoir compléter et vérifier les résultants par cette approche à variable unique, le GXE qui utilise une approche à multi variants a été utilisé. Cette dernière approche (AMMI Model) donne une large déduction. Se basant sur le modèle MMI, les génotypes 2 et 5 étaient les plus stables bien que les génotypes 1 et 3 montraient des niveaux satisfaisants de performance en matière de rendement et de stabilité. Ainsi ces 4 génotypes a plus stable adaptation sont recommandes pour la culture de sorgho dans les région sèches et a basse altitude dans le pays.

Mots Clés: Modèle AMMI, Ethiopie, GxE, hybrides, *Sorghum bicolor*

INTRODUCTION

Sorghum (*Sorghum bicolor* L. (Moench)) is the third major cereal crop in Ethiopia in terms of area and production next to tef (*Eragrostis tef*) and maize (*Zea mays*). It is the major crop in drought stressed lowland areas that cover 66% of the total arable land in the country (Gebeyehu *et al.*, 2004). These areas are characterised by limited and erratic rainfall, and hot temperature. A major challenge of sorghum production in these parts of the country is lack of high yielding and stable varieties. Variety development for these parts of the country has focussed on selection of early maturing varieties that can escape drought. For the last nearly half a century, a number of early sorghum open-pollinated varieties were developed and released for these areas.

The concepts of GxE and yield stability have been issues to the breeders and biometricians for a long of time. A significant GxE for a quantitative trait is known to reduce the usefulness of the genotype means over all locations or environments for selecting and advancing superior genotypes to the next stage of selection (Pham and Kang, 1988). If there were no GxE associated with the genotype-environment system relevant to a breeding objective, selection would be greatly simplified because the 'best' genotype in one environment would also be the 'best' genotype for all target environments (Basford and Cooper, 1998). Furthermore, variety trials would be conducted at only one location to provide universal results (Gauch and Zobel, 1996).

Though the concept of stability is largely unclear in the plant breeding literature partly due to the myriad of definitions that have been used to represent this concept (Basford and Cooper, 1998), it is a powerful tool to partition the GxE into mean squares responsible for its occurrence. High yield stability usually refers to a genotype's ability to perform consistently, whether at high or low yield levels, across a wide range of environments (Annicchiarico, 2002). The ultimate reason for differential stability among genotypes and for differential results from various test environments is non-repeatable GxE (Yan and Hunt, 2002).

So far, a vast number of univariate and multi-variate, parametric and non-parametric stability models, have been suggested to asses the causes of GxE. The model that has been in frequent use by breeders is one that is based on linear regression. This was first proposed by Finlay and Wilkinson (1963). Eberhart and Russel (1966) later modified it and suggested a different selection measure of stability of a genotype based on high mean yield, unit linear regression and low deviation from regression. This concept of selecting a genotype based on high mean yield and stability was later given the term yield reliability (Kang and Pham, 1991; Eskridge, 1990 and Evans, 1993). A reliable genotype is characterized by consistently high yield across environments (Annicchiarico, 2002), though its occurrence is rare and its measurement is difficult or uncertain. According to Kang (1998) and Piepho (1998) the assessment of yield reliability requires numerous test environments (at least eight).

Lin *et al*. (1986) revised the previous stability models and grouped them into four: namely, groups A, B, C and D, which they further grouped into 3 types of stability: Type-1, Type-2 and Type-3. According to these authors a genotype has Type-1 stability if its environment variance is small. A genotype is considered to have type-2 stability if its response to environments is parallel to the mean response of all genotypes in the trial. On the other hand, a genotype is considered to have type-3 stability if the residual MS from the regression model on the environmental index is small. Type-1 stability, which is analogous to the biological concept of homeostasis, is useful for measuring stability in a limited range of environments, which may be useful for selecting genotypes for specific adaptation. This type of stability was later termed as static (Becker and Léon, 1988). Type-2 stability is based on the genotypes included in the test set (it is a relative measure). As a result, a genotype which was found to be stable in a given set, may not be so if it is organized with another set of genotypes. Becker and Léon (1988) called this type of stability dynamic.

Type-3 stability depends on the measurements of unpredictable irregularities in the response to environment as provided by the deviation from regression (because the regression part is predictable (Eberhart and Russel, 1966)). Static (Type 1) stability may be more useful than dynamic in a wide range of situations, which characterise farming systems in developing countries (Simmonds, 1991).

These types of stability are all univariate as opposed to the GxE which is multivariate. Therefore, the GxE provides a more robust inference based on multivariate stability approaches. The objective of the study was to investigate the effect of GxE on sorghum yield performance in the drought stressed parts of Ethiopia.

MATERIALS AND METHODS

The experiment consisted of 14 sorghum hybrids and one released open-pollinated variety, Teshale (a standard Check OPV, adapted to the moisture stressed lowland areas of Ethiopia), hereafter referred to as genotypes. The parents for the hybrids were originally received from International Crops Research Institute for the Semi Arid Tropics (ICRISAT) and Purdue University, USA (Table 1). The genotypes were evaluated at three locations: Melkassa (E39^{0}21', N08^{0}24'), Mieso (E39^{0}22', N08^{0}41') and Kobo (E39^{0}37', N12^{0}09') representing the dry hot lowlands of Ethiopia (Table 2).

The experiment was conducted during the rainy seasons of 2003, 2004 and 2005 at Melkassa and Mieso and 2003 and 2004 at Kobo. As a result, there were a total of eight environments (location x year combinations). For all trials the design used was RCBD with four replications. Plot size was 5 m x 0.75 m x 3 rows (11.25m^2).

Sowing was by hand drilling in rows. Later the plants were thinned to a spacing of 15cm giving a total density of 88888 plants ha^{-1}. Management practices were uniformly applied at all locations x years following standard agronomic recommendation for sorghum in the dry lowlands.

TABLE 1. Description of the hybrids used in the study

Genotype	Genotype code	Source of A-line/ R-line
ICSA 21 X ICSR 50	1	ICRISAT
ICSA 22 X M4850	2	ICRISAT
ICSA 15 X M5568	3	ICRISAT
P9534A X KCTENT # 17 DTN	4	Purdue/ICRISAT
ICSA 15 X ICSR14	5	ICRISAT
ICSA 34 X ICSR14	6	ICRISAT
ICSA 90003 X SDSL 89426	7	ICRISAT
ICSA 34 X 98 MW 6001	8	ICRISAT/Local cross
ICSA 34 X 98 MW 6002	9	ICRISAT/Local cross
ICSA 34 X 98 MW 6100	10	ICRISAT/Local cross
ICSA 34 X P894108	11	ICRISAT/Purdue
ICSA 21 X 98MW 6001	12	ICRISAT/Local cross
ICSA 21 X 98MW 6002	13	ICRISAT/Local cross
ICSA 21 X 98 MW 6100	14	ICRISAT/Local cross
3443-2-OP (Standard OPV)	15	

TABLE 2. Description of the test environments

Location	Year	Environment code	Altitude (m.a.s.l)[a]	Soil type	Seasonal rainfall (mm) (July-November)
Melkassa	2003-2004-2005	E3-E4-E7	1550	Andosol	541.2-526.1-481.2
Mieso	2003-2004-2005	E1-E5-E8	1470	Vertisol	418-441.7-398.2
Kobo	2003-2004	E2-E6	1513	Vertisol	423.1-374.6-409.7

[a] m.a.s.l., meters above sea level

Data were recorded for grain yield plot^{-1}, which was latter, converted to ha^{-1}. Analysis of variance was done separately for each environment followed by combined analysis of variance using IRRISTAT for Windows Version 4.0. (IRRI, 1999).

Because the genotype-by-environment interaction was significant, five out of the nine stability models, which were grouped into four groups and latter, divided in to three types of stability by Lin *et al.* (1986), were analysed and compared for their effectiveness in partitioning the GxE into parameters that permit a study of phenotypic stability of the sorghum genotypes. These were: environmental variance, S^2_i (Lin *et al.*, 1986); Coefficient of variation, CV_i (Francis and Kannenbert, 1978); Regression coefficient, b_i (Finlay and Wilkinson, 1963), deviation from regression, Sd^2_i (Eberhart and Russel, 1966); Ecovalence, W^2_i (Wricke, 1962); and Stability variance, s_i^2 (Shukla, 1972).

The additive main effects and multiplicative interaction (AMMI) analysis was also performed separately as an individual multivariate model using IRRISTAT for Windows Version 4.0. (IRRI, 1999). Moreover, rank correlation coefficients were calculated between all possible pairs of computed stability parameters and stability parameters and mean yield of the genotypes.

RESULTS AND DISCUSSION

Differences among the environments were significant indicating that they were diverse (Table 3). The GxE was significant showing variable performance of the genotypes in the various environments. The grand mean yield was 4611 kg ha^{-1}. Eight genotypes were above mean yield. The highest genotype yield was produced by genotype 1 followed by genotype 3.

Stability analysis and rank correlation. Because the GxE mean square was significant further analysis was done to disaggregate the kg ha^{-1} causes responsible for the variation. The three types of stability statistics: Type-1 (S^2_i and CV_i), Type-2 (W^2_i, s^2_i and b_i) and Type-3 (Sd^2_i) were compared for ranking of the genotypes. The results of stability models are presented in Table 4. Genotypes with similar ranks received the average value (Table 5). The W^2_i and si^2 had perfect positive rank correlation (r=1.0) and ranked the genotypes in exactly the same way (Table 6). This was in conformation to the findings of Lin *et al*. (1986), Kang *et al*. (1987) and Pham and Kang (1988). These two stability parameters had strong correlation with b_i (r=0.80) but very weak correlation with CV_i (r=0.16), S^2_i (r=0.12) and Sd^2_i (-0.12). CV_i and S^2_i had strong rank correlation (r=0.97) but both had either very weak or no rank correlation with the rest of the parameters tested. This was in agreement with the results of Jalaluddin and Harrison (1993). The Sd^2_i had very weak negative correlation with the remaining parameters.

Type-1 stability parameters (CV_i and S^2_i) ranking indicated that the genotypes are similar. Type-2 parameters (W^2_i, s^2_i and b_i) ranking also indicated similarities among genotypes. However, Type-3 stability parameter (Sd^2_i) ranked the genotypes differently. Accordingly, genotypes 11, 12 and 14 had Type-1 stability. Genotypes 2, 3, and 5 had the highest Type-2 stability; while genotypes 6 and 15 had the

TABLE 3. Grain yield (kg ha^{-1}) of the 15 test hybrids evaluated at the 8 environments in Ethiopia

Genotype code	Environment code								
	E1	E2	E3	E4	E5	E6	E7	E8	Genotype means
1	4800	7650	4475	6275	3600	5218	4934	3689	5080
3	4700	6925	4125	5925	4150	4858	4909	4756	5043
11	4575	6000	4550	5075	4400	5810	5013	4178	4950
4	4650	7450	3225	7125	2675	5686	3658	4267	4842
6	4275	7475	3800	5950	3375	5716	3565	4000	4769
5	4750	6525	4225	6000	3575	4632	4060	3867	4704
2	4375	6375	3675	6375	3325	5043	4126	4089	4673
14	3900	6300	4450	5375	3800	4235	4758	4267	4635
7	4100	7050	3975	7300	2475	5094	4462	1733	4524
9	4700	6900	3650	4975	3500	4554	3891	3378	4444
13	4000	6825	3800	4700	3950	4241	3965	3644	4391
10	4375	5975	3375	5225	3675	5005	3566	3822	4377
12	4525	4950	3875	5300	4425	4196	3138	4044	4307
15	3675	6125	2850	5625	3775	4590	4484	3156	4285
8	4100	5575	3200	5325	3175	4136	3719	3911	4143
Environment Means	4367	6540	3817	5770	3592	4868	4150	3787	4611

TABLE 4. Various models of stability used to partition the GxE for grain yield in the test sorghum genotypes in Ethiopia

Genotypes	Mean grain yield (kg ha^{-1})	W^2_i	CV_i (%)	s_i^2	S^2_i	b_i	Sd^2_i
1	5080	109.7	26.5	15.6	180.6	1.24	10.52
2	4673	57.7	28.3	7.0	174.3	1.07	8.91
3	5043	71.1	18.7	9.2	88.7	0.86	9.12
4	4842	465.2	36.5	74.2	311.5	1.61*	29.99
5	4704	36.8	22.2	3.6	108.9	0.97	5.99
6	4769	186.9	30.5	28.3	211.2	1.33	16.83
7	4524	825.1	43.3	133.5	384.1	1.70	73.80
8	4143	73.4	21.4	9.6	78.7	0.81	7.48
9	4444	101.6	26.0	14.2	133.6	1.04	16.75
10	4377	74.1	21.4	9.7	87.6	0.85	10.60
11	4950	287.5	13.4	44.9	43.7	0.51*	41.09
12	4307	427.0	15.4	67.9	44.2	0.42*	61.02
13	4391	154.7	23.5	23.0	106.8	0.88	22.11
14	4635	187.2	18.1	28.3	70.0	0.69	26.73
15	4285	137.6	26.9	20.2	132.6	1.01	19.66
Mean	4611						
LSD (5%)	556						
CV (%)	17.5						

* indicates slopes significantly different from the slope for the overall regression which is1.00

TABLE 5. Ranks of the sorghum genotypes based on the various stability parameters in Ethiopia

Genotype code	Stability statistic						
	Grain yield	W^2_i	CV_i (%)	σ^2_i	S^2_i	b_i	Sd^2_i
1	1	7	10	7	12	9	5.3
2	6.5	2	12	2	11	4	3.3
3	2.5	3	4	3	6	6	13
4	4.5	14	14	14	14	14	12
5	6.5	1	7	1	8	2	7.5
6	4.5	10	13	10.5	13	11	1
7	9	15	15	15	15	15	3.5
8	15	4	5.5	4.5	4	8	11
9	11	6	9	6	10	3	15
10	11	5	5.5	4.5	5	7	7.5
11	2.5	12	1	12	1.5	12	10
12	13.5	13	2	13	1.5	13	5.5
13	11	9	8	9	7	5	14
14	8	11	3	10.5	3	10	9
15	13.5	8	11	8	9	1	2

TABLE 6. Rank correlation among the sorghum stability parameters and stability parameters-yield in Ethiopia

	CV_i (%)	σ^2_i	S^2_i	b_i	Sd^2_i	Yield
W_{i2}	0.16	1.00	0.12	0.80**	-0.12	0.00
CV_i (%)		0.16	0.97**	0.03	-0.38	-0.09
σ^2_i			0.12	0.80**	-0.12	0.00
S^2_i				0.06	-0.30	-0.28
b_i					-0.12	-0.23
Sd^2_i						0.03

**, significant (p<0.01)

highest Type-3 stability. No single stability parameter had significant rank correlation with mean grain yield of the genotypes.

The absence of positive correlation with b_i and yield is in agreement with the finding of Sudaric *et al*. (2006) but conflicts with earlier findings of Weber and Wricke (1990), Helms (1993), Sneller *et al*. (1997), and Mekbib (2003). This was probably due to the fact that five of the eight environments were considered unfavourable and thus causing poor response of the genotypes.

Type-1 stability is often associated with a relatively poor response and low yield in environments that are high yielding for other cultivars though it has broad inferential base, because its stability definition does not depend on the other genotypes included in the test and is thus unambiguous (Lin *et al.*, 1986). However, it does not provide information on the response pattern over the range of test environments that is so vital for cultivar recommendations (Lin *et al.*, 1986). According to Kang (2002), this type of stability would not be beneficial for the farmer because a genotype in this sense would not respond to high levels of inputs. Type-2 stability is useful for comparing a specific set of genotypes, but by being a relative measure, it does not have a sufficiently broad inferential base for general assessment (Lin *et al*., 1986). This parametric approach gives only the individual aspects (Types 1, 2, 3) of stability but cannot provide an overall picture of the response (Lin *et al*., 1986).

In this study, the three types of stability parameters declared different genotypes to be the most stable. As a result of this inconsistency, it was difficult to reach a conclusion on producing genotype recommendation. Similar inconsistency in ranking using a univariate approach was previously suggested to be difficult to reconcile into a unified conclusion by Lin *et al*. (1986). According to them, the basic reason for the difficulty is that a genotype's response to environments is multivariate, yet the parametric approach tries to transform it to a univariate problem via a stability index.

Furthermore, Lin *et al*. (1986) suggested that clustering of genotypes according to their response structure emerged as a different line of thought to escape the difficulty imposed by the univariate approach. A disadvantage of clustering analysis, however, is that it gives no insight into the yield response of genotypes across environments (Flores *et al*., 1998). This problem has been overcome by using the AMMI model (Romagosa and Fox, 1993).

In this study, the AMMI analysis of variance for grain yield of the 15 genotypes in the eight environments revealed that 73.8% of the total sum of squares was attributable to environmental effects (Table 7). Only 5.9% of the total sum of squares was attributable to genotype effects and the remaining 20.3% was due to GxE effects. The large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. The magnitude of the GxE sum of squares was 3.41 times larger than that of the genotypes, indicating, that there were substantial differences in genotype response across environments.

According to Crossa *et al*. (1990), AMMI with two, three or four IPCA axes is the best predictive model. Similarly, in the present study, the AMMI analysis further revealed that the first two interaction principal component axes (IPCA 1 & IPCA 2) explained 68.7% of the GxE sum of squares. This was in agreement with Sneller *et al*. (1997), who suggested that GxE pattern is collected in the first principal components of analysis. The first interaction principal component axis (IPCA 1) alone captured 50.7% of the GxE sum of squares with 20.41% of the GxE degrees of freedom. The third interaction principal component axis (IPCA 3) was also significant. However, according to Zobel *et al.* (1988) the first two IPCA axes best explain the GxE sum of squares and the remaining can be considered as noise. Therefore, in the present study 31.3% of

TABLE 7. Analysis of variance for the AMMI model of the 15 genotypes in the 8 environments for grain yield

Source	df	Sum of squares	Explained (%)	Mean squares
Total	119	1576000		
Genotypes (G)	14	93658.50		6689.89**
Environments(E)	7	1162810		166115**
G x E	98	319534		3260.55 **
IPCA 1	20	162140	50.74	8107.01**
IPCA 2	18	57365.30	17.95	3186.96**
IPCA 3	16	37313.00	11.68	2332.06**
IPCA 4	14	23006.60		1643.33
G x E residual	30	39708.70		

** significant at P<0.01

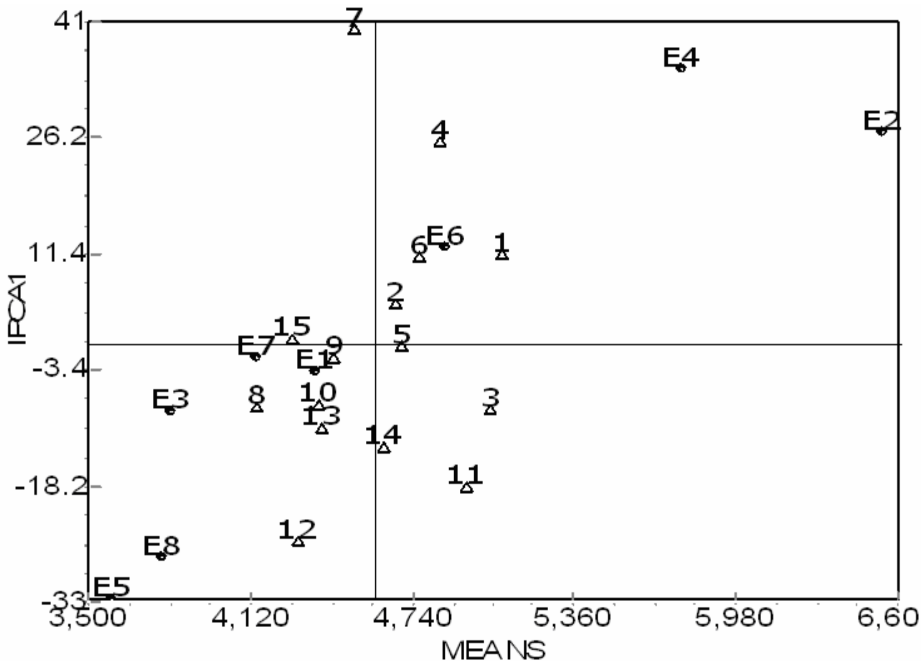

Figure 1. A biplot of grain yield means (Kg ha^{-1}) versus IPCA1 for 15 sorghum genotypes in the 8 environments.

the GxE sum of squares was considered as noise (Table 7).

The AMMI1 biplot, showing main effects means on the abscissa and IPCA 1 values as the ordinates, genotypes (or environments) that appear almost on a perpendicular line have similar means and those that fall almost on a horizontal line have similar interaction patterns (Crossa *et al*., 1990). According to these authors, genotypes (or environments) with large IPCA 1 scores (either positive or negative) have high interactions, whereas genotypes (or environments) with IPCA 1 scores near zero have small interactions. Similarly, in the biplot (Fig. 1) that reveals 90% of the total sum of squres, five of the eight environments had below average main effects and were unfavourable. Environments E2 (Kobo in 2003) and E4 (Melkassa in 2004) had the highest main effects and were favorable to the performance of most of the genotypes. On the contrary, environments E5 (Mieso in 2004), E3 (Melkassa in 2003) and E8 (Mieso in 2005) were the most unfavourable environments. In general Kobo showed higher main effect values in both years (E2 and E6), whereas Mieso showed consistently below average (poor) main effect values. However, Melkassa showed below average main effects in 2003 and 2005 (E3 and E7) but above average main effects in 2004 (E4). The interaction was also variable from year to year. This inconsistency in interaction at Melkassa poses difficulty in producing variety recommendation for that particular location. Genotypes 5, 9, and 15, and environments E1 and E7 were least interactive. Genotypes 2 and 5 placed closer to the biplot origin and were, therefore, the most stable but had average main effects of close to the grand mean. Genotypes 1 and 3 had higher average main and similar lower interaction which makes them most stable genotypes. On the contrary, genotypes 4, 6 and 11 had similar main effects but genotype 4 had larger IPCA 1 score and is more unstable.

CONCLUSION

In this study, attempts have been made to compare the various stability models and with which to select the stable sorghum genotypes in the lowlands of Ethiopia. There are remarkable inconsistencies with the univariate stability estimates (Types 1, 2 and 3), which create difficulty in producing genotype recommendation. However, the multivariate approach, the AMMI model is better for partitioning the GxE into the causes of variation. As a result a more robust inference is that genotypes 2 and 5 are the most stable but genotypes 1 and 3 have very good level of yield performance as well as stability. Therefore, these four genotypes are recommended for the drought stressed sorghum growing areas.

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