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Full length Research paper

Evaluation of Improved Tef (Eragrostis tef) varieties at North Shewa, Oromia, Ethiopia

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Tef is endemic to Ethiopia and its major diversity is found only in that country as with several other crops. The exact date and location for the domestication of tef is unknown. The information of the interface between varieties and environment with yield and yield components is important aspect of effective selection in crop improvement. Therefore, the objective of this study was: to evaluate and identify tef varieties with high grain yield and yield stability with good agronomic performance across locations. The study was conducted on fifteen enhanced tef varieties, against local check at Fitche Agricultural Research Center in 2020/21cropping season. Analysis of variance detected significant difference, among varieties in separated and combined analysis of variance. The combined ANOVA and AMMI analysis for grain yield across environments indicated significantly affected by environments, explained 81.23% of the total variation. Varieties and variety x environmental interation were significant and accounted for 6.73% and 7.58 %, respectively.PCA1 and PCA2 accounted for 3.59 % and 2.71 % of the GEI, respectively, with a total of 6.3 % variation. Generally, Dagim and Nigus were identified as better varieties for yielding ability and stability across environments and will be demonstrated and widely disseminated for end user.

Key words: AMMI, GGEI, Performance, Stability, Eragrostis tef

INTRODUCTION

Tef (Eragrostis tef) is belongs to the family Poaceae. It is self-pollinated, chasmogamous annual cereal crop. It is an allotetraploid plant with a chromosome number of 2n =40 and the basic chromosome number of the genus Eragrostis is x =10 (Tavassoli, 1986). Tef is endemic to Ethiopia and its major diversity is found only in that country as with several other crops. The exact date and location for the domestication of tef is unknown. However, there is no hesitation that it is a very ancient crop in Ethiopia. According to Ponti (1978), tef was introduced to Ethiopia well before the Semitic invasion of 1000 to 4000 BC.

In Ethiopia, tef is traditionally grown as a cereal crop. The grain is ground to flour which is mainly used for making popular pancake-like local bread called enjera and sometimes for making porridge. The grain is also used to make local alcoholic drinks, called tela and katikala. Tef straw, in addition being the most appreciated feed for cattle. Is also used to reinforce mud and plaster the walls of tukuls and local grain storage facilities called gotera.

Tef is adapted to a wide range of environments and is currently cultivated under diverse agro climatic conditions from sea level up to 2800masl, under various rainfall, temperature and soil regimes. However, according to experiences from different locations across the country, tef performs excellently at an altitude of 1800-2100masl, annual rainfall of 750-850 mm, growing season rainfall of 450-550 mm and a temperature range of 10°C-27°C.

In Ethiopia, tef cultivation is the same way as wheat and barley. Under current farmers' practices, tef field is ploughed two to five times depending on the soil type,

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weed conditions and water logging. Seed bed packing is done before sowing of tef to make the seed bed firm, prevent the soil surface from drying quickly, assist germination of seeds and minimize the damaging effect of high moisture during late onset of rain. Packing of the seed bed is also practiced to free the seed bed from weeds by turning them tinder. Overcoming low grain yield, and production constraints such as lodging, drought, water logging, heat and frost is overcoming production constraints and improving productivity of the crop.

Introduction for sustainable and stable food production and sustain food security, maintaining genetic diversity within and between crop types is increasingly being realized as the most appropriate and indispensable action.

This is further emphasized by unpredictable human food needs, changes in taste, technological demand and the biotic and a biotic production constraint that change with the environments. Identifying, maintaining and using crop types that can grow under various stress and limiting conditions with capable of environmental fluctuations is the most indispensable.

Environmental instabilities and interaction with crop plant are the major constraint of cereal crops including tef production and productivity. Genotype/variety x environment (GE) interaction reduces genetic progress in plant breeding programmes through minimising the association between phenotypic and genotypic values (Comstock and Moll, 1963). Consequently,multi-environment yield trials are significant in assessment of genotype by environment interactionn (GEI),identification of superior and stable genotypes in the final selection cycles (Kaya et al., 2006; Mitrovic et al., 2012).

Phenotypes are a mixture of genotype (G) and environment (E) components and their interactions (G x E).Genotype by environment interactionn (GEI) is a complicate process of selecting genotypes with superior performance. Terefore, multi-environment trails (METs) are commonly used by plant breeders to assess the relative performance of genotypes for target environments (Delacy et al., 1996).

The additive main effects and multiplicative interaction (AMMI) model have directed to more understanding of the complicated forms of genotypic responses to the environment (Gauch, 2006).

These patterns have been successfully related to biotic and abiotic factors. Yan et al. (2000), proposed another methodology known as GGE-biplot for graphical exhibit of GE interaction pattern of MET data with many advantages. GGE biplot is an effective method based on principal component analysis (PCA) which fully explores MET data. It allows visual inspection of the associations among the test environments, genotypes and the GE interactions.

The first two principle components (PC1 and PC2) are used to produce a two dimensional graphical display of genotype by environment interaction (GGE-biplot). If a large portion of the variation is explained by these components, a rank-two matrix, represented by a GGE-biplot, is appropriate (Yan and Kang, 2003). Using a mixed model analysis may present superior results when the regression of genotype by environment interaction on environment effect does not explain all the interaction (Yan and Rajcan, 2002).

Therefore, the objective of this study was: to identify tef varieties with high level of grain yield and yield stability across locations.

MATERIALS AND METHODS

Study Area

The multi-location yield evaluation (MLYT) was conducted on six locations at Fitche Agricultural Research Center sub sites (H.Abote, Kuyu, W.Jarso, Wachale,Y.Gulale and G. Jarso) in North shewa, Oromia, Ethiopia, during the 2020/21 main cropping season.

Breeding materials and experimental design

Totally, fifteen released tef varieties (Table1) including local check were evaluated using randomised completed block design (RCBD) with three replications. Six rows per plot of 0.2 m spacing between rows and 3m row length and harvestable plot size was 2.4 m^2 (four harvestable rows per plot) . A seed rate of 20$kgha^{-1}$ and fertiliser rate of 100$kgha^{-1}$ NPS and 100$kgha^{-1}$ UREA were used.

Statistical analysis

Analysis of variance was calculated using the model:

$$Y_{ij} = \mu + G_i + E_j + GE_{ij}$$

Where: Y_{ij} is the corresponding variable of the i^{-th} genotype in j^{-th} environment, μ is the total mean, G_i is the main effect of i^{-th} genotype, E_j is the main effect of j^{-th} environment, GE_{ij} is the effect of genotype x environment interaction.

The AMMI model used was:

$$Y_{ij} = \mu + g_i + e_j + \sum_1^N \lambda_k \Upsilon_{ik} \delta_{jk} + \varepsilon_{ij}$$

Where: Y_{ij} is the grain yield of the i^{-th} genotype in the j^{-th} environment, μ is the grand mean, g_i and e_j are the genotype and environment deviation from the grand mean, respectively, λ_k is the eigenvalue of the principal component analysis (PCA) axis k, Υ_{ik} and δ_{jk} are the genotype and environment principal componentscores for axis k, N is the number of principal components retained in the model, and ε_{ij} is the residual term.

Table1: List of evaluated released tef varieties

No	Variety	No	Variety	No	Variety
1	Abay	6	Flagot	11	Kuncho
2	Boset	7	Guduru	12	Local
3	Dagim	8	Hiber1	13	Nigus
4	Dursi	9	Kena	14	Tesfa
5	Estub	10	Kora	15	Warekiyu

GGE-biplot methodology, which is composed of two concepts, the biplot concept (Gabriel, 1971) and the GGE concept (Yan et al., 2000) was used to visually analyse the METs data. This methodology uses a biplot to show the factors (G and GE) that are important in genotype /varieties evaluation and that are also the sources of variation in GEI analysis of METs data (Yan, 2001).The GGE-biplot shows the first two principal components derived from subjecting environment centered yield data (yield variation due to GGE) to singular value decomposition (Yan et al., 2000)

AMMI Stability Value (ASV)

ASV is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). Because the IPCA1 score contributes more to the GxE interaction sum of squares, a weighted value is needed. This weighted value was calculated for each genotype and each environment according to the relative contribution of IPCA1 and IPCA2 to the interaction sum of squares as follows:

ASV=

$$\sqrt{[(\mathrm{SSIPCA1} + \mathrm{SSIPCA2})\ (\mathrm{IPCA1score})]2 + (\mathrm{IPCA2score})2}$$

Where: SS_{IPCA1}/SS_{IPCA2} is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments. A smaller ASV values indicate more stable genotypes across environments (Purchase, 1997).

Genotype Selection Index (GSI): stability is not the only parameter for selection as most stable genotypes would not necessarily give the best yield performance.

Therefore, based on the rank of mean grain yield of genotypes (RYi) across environments and rank of AMMI stability value (RASVi), genotype selection index (GSI) was calculated for each genotype/varieties as:

GSIi = RASVi + RYi

A genotype with the least GSI is considered as the most stable (Farshadfar, 2008). Analysis of variance was carried out using Statistical Analysis System (SAS) version 9.2 Software (SAS, 2008). Additive Main Effect and Multiplicative Interaction (AMMI) analysis and GGE bi-plot analysis were performed using Gen Stat 15th edition statistical package (VSN, 2012).

Data collection method

Sample were selected randomly before heading from each row (four harvestable rows) and tagged with thread and plant-based data were collected from the sampled plants.

Plant-based

Such as Plant height, Spike length and productive tillers, Plant height (cm); was measured and recorded when it reached at 95% physiological maturity from the ground level to the base of the spike of plant. Spike length (cm); was measured from the base of the spike to the tip of the highest spikelet.

Plot based

Like Days to heading, days to maturity, grain filling period, biomass, grain yield and harvesting index. Days to heading; was recorded by counting the number of days from sowing to the time when at least 50% of the heads of the plot fully exerted from the boom or flowered. Days to maturity; was recorded by counting the number of days from sowing to the days when 95% of the heads of the plot were physiologically matured; yield per plot was taken and moisture was adjusted to the standard moisture content of 12% moisture basis after threshing the crop using moisture tester by the following formula.

It was calculated as: Adjusted yield per plot = Actual yield per plot (100-Y/100-X)

Where =Actual yield is yield per a given area in a unit at threshing

Y = is moisture in % age at threshing

X= is standard moisture in % age

RESULTS AND DISCUSSIONS

Combined analysis of variance (ANOVA)

The mean square of analysis of variance for all varieties at different environmental conditions, for grain yield and yield related traits, are presented (Table 2). Highly significant differences were noticed among treatments ($P \leq 0.01$) for all parameters. The combined analysis of

Table: 2 combined analysis of variance (ANOVA) for grain yield and yield related traits

S. V	DF	DH	DM	GFP	PTL	SL	PH	BMkgha	YLDkgha	HI
loc	5	7984.9**	11420.3**	3399.7**	72.3**	1205.0**	7996.8**	289548369**	22947243.3**	737.9**
rep	2	20.3*	72.6**	20.6 ns	24.2**	79.9**	124.0*	731835 ns	107178 ns	3.4ns
trt	14	85.9**	485.1**	329.3**	8.9**	180.4**	179.4**	2617662**	742875.9**	169.1**
loc*trt	70	33.1**	126.1**	147.4**	3.5**	29.6**	44.8**	2752225**	187871.4**	90.6**
rep*trt	28	4.7 ns	5.9 ns	8.8 ns	1.2 ns	9.9 ns	21.14	148473	23495.5 ns	24.2 ns

ns * ** non –significant, significant at 5% and 1% respectively, Loc *trt = location by treatment, Loc= location, trt = treatment, rep = replication, rep*trt = replication by treatment, DF = degree of freedom, DH = Days to Heading, DM = Days to Maturity, PH = Plant Height, GFP= grain filling period, PTL= productive tillers, SL= spike length, BMkgha= biomass kilogram per hectare, YLD kgha^{-1} = Yield in kilogram per hectare and HI% = harvest index in percent

variance showed that location by treatment effects was significant for all parameters. Treatment by environment interaction mean square was highly significant (P≤0.01) for all parameters.

Agronomic performance

Combined mean grain yield and other agronomic traits are presented in Table 3. Medium days to heading, days to maturity, grain filling period, productive tillers, spike length, plant height and biomass were recorded by Dagim, Nigus and Kuncho varieties (Table3). These bargain great flexibility for recommended improved varieties suitable for various agro-ecologies with variable length of growing period and high in grain yield status.

In contrary, Tesfa variety was with short plant height, indicating that, the variety might be resistant against lodging problems. Furthermore, Dagim, Nigus and Kuncho varieties were recorded the highest grain yield and had 1511.7kgha^{-1}, 1379.3kgha^{-1} and 1379.3kgha^{-1} respectively and they recorded 28.11%, 15.25% and 15.26% of yield advantages over the local check, respectively (Table 3).

Table 3: Combined mean for grain yield and yield related traits

variety	DH	DM	GFP	PTL	SL	PH	BM kgha^{-1}	YLD kgha^{-1}	HI%	YLA%
Abay	80.3^{bc}	144.6^{de}	64.3^{de}	3.9^{d-g}	32.6^{ab}	42.6^{abc}	4643.9^{abc}	1219.4^{cde}	25.2^{efg}	3.02
Boset	77.6^{fg}	140.9^{gh}	63.3^{def}	4.4^{bcd}	25.3^{fg}	37.46^{bcd}	3804.1^{efg}	1104.5^{efg}	29.7^{bc}	-6.69
Dagim	78.2^{def}	138.9^{h}	60.7^{fg}	3.9^{d-g}	27.6^{def}	35.4^{cde}	4682.2^{ab}	1511.7^{a}	33.6^{a}	28.11
Dursi	82.3^{a}	151.4^{b}	69.1^{b}	3.4^{fgh}	33.6^{a}	34.8^{cde}	3656^{g}	771.9^{h}	27.8^{b-f}	-34.79
Estub	77.5^{fg}	151.2^{b}	73.7^{a}	4.1^{def}	31.6^{ab}	32.6^{de}	4659.9^{abc}	1305.1^{bc}	28.4^{b-e}	10.26
Flagot	76.9^{fg}	135.5^{i}	58.6^{g}	5.3^{a}	25.3^{fg}	34.3^{cde}	4352.9^{bcd}	1241.1^{cd}	26.9^{c-g}	4.85
Guduru	81.7^{ab}	153.5^{a}	71.8^{a}	2.9^{h}	32.6^{ab}	38.2^{bcd}	4175.6^{de}	816.5^{h}	21.4^{h}	-31.02
Hiber1	79.3^{cde}	148.3^{c}	69^{b}	3.5^{fgh}	31.4^{ab}	46.1^{ab}	4292.3^{cd}	987.2^{g}	23.8^{gh}	-16.60
Kena	80.9^{abc}	144.8^{de}	63.9^{de}	3.6^{efg}	26.0^{ef}	34.5^{cde}	4170.3^{de}	1121.3^{def}	29.5^{bcd}	-5.28
Kora	80.9^{abc}	143.1^{ef}	62.1^{ef}	3.4^{fgh}	31.1^{b}	32.7^{de}	4082.7^{def}	1123.9^{def}	27.7^{b-f}	-5.05
Kuncho	79.8^{cd}	140.4^{gh}	60.7^{fg}	3.3^{gh}	30.3^{bc}	48.1^{a}	4644.4^{abc}	1379.3^{b}	29.8^{bc}	15.26
Local	74.3^{h}	138.9^{h}	64.6^{de}	5.1^{ab}	23.2^{g}	31.9^{de}	3977.9^{d-f}	1183.8^{cde}	26.1^{d-g}	0.00
Nigus	76.5^{g}	141.6^{fg}	65.1^{cd}	4.9^{abc}	28.4^{cde}	37.5^{bcd}	4746.5^{a}	1379.3^{b}	29.2^{bcd}	15.25
Tesfa	78.6^{def}	141.6^{fg}	63^{def}	4.3^{cde}	27.5^{def}	26.6^{e}	3746.4^{fg}	1135.3^{def}	30.9^{ab}	-4.09
Warekiyu	77.7^{efg}	145.2^{d}	67.5^{bc}	3.8^{d-g}	28.6^{cd}	35.3^{cde}	4715.1^{ab}	1127.9^{def}	24.8^{fgh}	-4.72
LSD (5%)	1.71	1.97	2.7	0.7	2.4	9.3	382.9	128.9	3.5	
R^2	97.7	98.2	92.8	81.3	84.1	92.9	97.1	96.4	75.7	
CV%	3.3	2.1	6.3	27.9	12.9	10.0	13.6	17.0	19.2	
Mean	78.8	144	65.2	4	29	48.8	4290.0	1148.9	27.7	

LSD = least significant difference, R^2 = R square, CV= coefficient of variation, DF = degree of freedom, DH = Days to Heading, DM = Days to Maturity, PH = Plant Height, GFP= grain filling period, PTL= productive tillers, SL= spike length, BMkgha= biomass kilogram per hectare, YLD kgha^{-1} = Yield in kilogram per hectare and HI% = harvest index in percent, YLA= yield advantage

Yield performance across environments

The performance of tef varieties for grain yield across locations are presented in Table 4. Some varieties such as Dagim, Nigus and Kuncho are constantly performed best in a group of environments, while other varieties (for instances, Dursi, Guduru and Hiber1) are varying across locations. The average grain yield ranged from the lowest (422.3kgha^{-1}) at Kuyu sub site to the highest (2072.9kgha^{-1}) at Abote sub site. The grain yield across environments ranged from the lowest of 771.9kgha^{-1} for Dursi variety to the highest of 1516.4kgha^{-1} for Dagim

Table 4: Across Locations mean performance of grain yield (kg/ha)

variety	**Grain Yield in kg/ha** 2020/21 Locations						
	Kuyu	Warajarso	HAbote	Girarjarso	YayaGulale	Wachale	com.mean
Abay	396.7^{cde}	1305.4^{ab}	2202.4^{b-e}	2278.6^{ab}	493.3^{e-h}	640.1^{c}	1219.4
Boset	412.1^{cd}	880.6^{cd}	2286.1^{bcd}	1859.5^{cd}	550^{d-h}	638.6^{c}	1104.4
Dagim	468.8^{c}	1186^{ab}	3112.7^{a}	2472.9^{a}	959.9^{a}	898.1^{a}	1516.4
Dursi	349.4^{efg}	724.9^{d}	1442^{gh}	1375.3^{ef}	406.4^{gh}	333.3^{d}	771.9
Estub	297.4^{g}	1349.3^{ab}	2009.6^{c-f}	2540^{a}	866.1^{ab}	768.3^{abc}	1305.1
Flagot	364.7^{def}	1076.7^{bc}	1946.8^{def}	2681.2^{a}	621.8^{c-f}	755.3^{abc}	1241.1
Guduru	349.1^{efg}	1222.6^{ab}	1501^{gh}	1108.5^{f}	336.2^{h}	381.7^{d}	816.5
Hiber1	575^{b}	716.7^{d}	1294^{h}	1927.6^{bcd}	570.6^{c-g}	839^{ab}	987.2
Kena	332.1^{fg}	1220.4^{ab}	1823.9^{efg}	1958.3^{bcd}	659.6^{b-e}	733.1^{abc}	1121.2
Kora	298.1^{g}	1207.4^{ab}	2410.6^{bc}	1757.7^{cde}	431.2^{fgh}	638.3^{c}	1123.9
Kuncho	609.3^{a}	1444.1^{a}	2557.2^{b}	1901.4^{bcd}	873.3^{ab}	800.4^{abc}	1364.3
Local	570.9^{b}	868.3^{cd}	2701.4^{fgh}	1546.5^{de}	719.5^{bcd}	695.8^{bc}	1183.7
Nigus	509.7^{b}	1453.4^{a}	2582.5^{b}	2327.4^{ab}	603.3^{c-g}	709.3^{abc}	1364.3
Tesfa	385.1^{def}	1177.4^{ab}	2113.1^{c-f}	1997.6^{bc}	682.3^{b-e}	456.4^{d}	1135.3
Warekiyu	370.8^{def}	856^{cd}	2110.7^{c-f}	1827.8^{cd}	777.8^{abc}	824.1^{ab}	1127.9
LSD	62.5	276.9	425.5	417.7	213.9	172.4	
R2	92.7	79.4	85.6	82.5	75.4	80.2	
CV%	8.8	14.9	12.3	12.7	20.1	15.2	
Mean	422.3	1109.9	2072.9	1974.0	636.3	677.6	

LSD = least significant difference, R^2 = R square, CV= coefficient of variation, kg/ha = kilogram per hectare

variety .This wide variation might be due to their genetic potential of the varieties. Dagim variety was the top ranking variety in all environments, except at Kuyu sub site. Similarly, Nigus and Koncho varieties were well performed across location except at Kuyu sub site.

Conversely, Dursi variety ranked the least in all environmental sites throughout cropping season. The difference in yield rank of varieties across the environments exhibited the high crossover type of varieties x environmental interaction (Yan and Hunt, 2001).

Additive main effects and multiplicative interaction (AMMI) model

The combined ANOVA and AMMI analysis of grain yield at six locations are presented in Table 5.The result indicated, tef grain yield was extensively exaggerated by environments. This was explained 81.23% of the total treatment variation, while the G and GEI were significant and accounted for 6.73% and 7.58%, respectively .Similar findings have been reported in previous studies (Kaya et al., 2006; Farshadfar et al., 2012). A study conducted by Gauch and Zobel (1997) reported in standard multi-environment trials (METs), environment effect contributes 80% of the total sum of treatments and 10% effect of genotypes/varieties and interaction.In additive variance, the portioning of GEss data matrix using AMMI analysis, indicated the first PCAs were significant ($P < 0.01$). PCA1 and 2 accounted for 3.59 % and 2.71% of the GE interaction,respectively; representing a total of 6.3% of the interaction variation .A comparable results have been reported in earlier studies (Mohammadi and Amri, 2009). Large yield variation explained by environments indicated that environments were diverse,with large differences between environmental means contributing maximum of the variation in grain yield (Table 6).Grain yield of environments ranged from 297.4kgha^{-1} in E1 to 3112.7 kgha^{-1} in E3, Varieties mean grain yield varied from 771.9kgha^{-1} (Dursi) to 1516.4kgha^{-1} (Dagim) with (Table 6).

Table 5: AMMI for grain yield of 15 tef varieties evaluated on six locations

Source variation	DF	SS	SS%	MS
Total	269	8260108	100.00	30707
Treatments	89	7891891	95.54	88673**
Varieties	14	555977	6.73	39713**
Environments	5	6709968	81.23	1341994**
Block	12	108674	1.32	9056**
Interactions (G x E)	70	625946	7.58	8942**
IPCA 1	18	296241	3.59	16458**
IPCA 2	16	224239	2.71	14015**
Residuals	36	105465	1.28	2930*
Error	168	259543		1545

DF = degree of freedom, SS = sum of squares, MS = mean squares, IPCA = Interaction Principal Component Axis, EX. SS% = Explained Sum of square ns * ,** non-Significant,Significant at the 0.5% and 0.1% level of probability, respectively

Table 6: Average grain yield (kgha^{-1}) of 15 tef varieties tested across six locations in 2020/21 main cropping season

Varieties	E1	E2	E3	E4	E5	E6	Mean
Abay	396.7	1305.4	2202.4	2278.6	493.3	640.1	1219.4
Boset	412.1	880.6	2286.1	1859.5	550	638.6	1104.5
Dagim	468.8	1186	3112.7	2472.9	959.9	898.1	1516.4
Dursi	349.4	724.9	1442	1375.3	406.4	333.3	771.9
Estub	297.4	1349.3	2009.6	2540	866.1	768.3	1305.1
Flagot	364.7	1076.7	1946.8	2681.2	621.8	755.3	1241.1
Guduru	349.1	1222.6	1501	1108.5	336.2	381.7	816.5
Hiber1	575	716.7	1294	1927.6	570.6	839	987.2
Kena	332.1	1220.4	1823.9	1958.3	659.6	733.1	1121.2
Kora	298.1	1207.4	2410.6	1757.7	431.2	638.3	1123.9
Kuncho	609.3	1444.1	2557.2	1901.4	873.3	800.4	1364.3
Local	570.9	868.3	2701.4	1546.5	719.5	695.8	1183.7
Nigus	509.7	1453.4	2582.5	2327.4	603.3	709.3	1364.3
Tesfa	385.1	1177.4	2113.1	1997.6	682.3	456.4	1135.3
Warekiyu	370.8	856	2110.7	1827.8	777.8	824.1	1127.9
Mean	419.3	1112.6	2139.6	1970.7	636.8	674.1	1158.8

E1 = Kuyu, E2=Warajarso,E3=HAbote ,E4= Girarjarso, E5= YayaGulale,E6=Wachale, E= environment

The average environment is defined by the average values of PC1 and PC2 for the all environments and it is presented with a circle (Purchase, 1997). The average ordinate environment (AOE) is defined by the line which is perpendicular to the AEA (average environment axis) line and pass through the origin. This line divides the varieties in to those with higher yield than average and in to those lower yield than average. By projecting the varieties on AEA axis, the varieties are ranked by yield;where the yield increases in the direction of arrow. In this case, the highest yield varieties are Dagim , Nigus and Kuncho. In contrary, Dursi and Guduru varieties recorded the lowest grain yield (Figure 1).Stability of the varieties depends on their distance from the AE abscissa. Those varieties closer to or around the center of concentric circle indicated these varieties are more stable than others. Therfore, the greatest stability in the high yielding group had varieties Dagim, Nigus and Kuncho, whereas the most stable and yielder of all was Dagim variety (Figure.1)

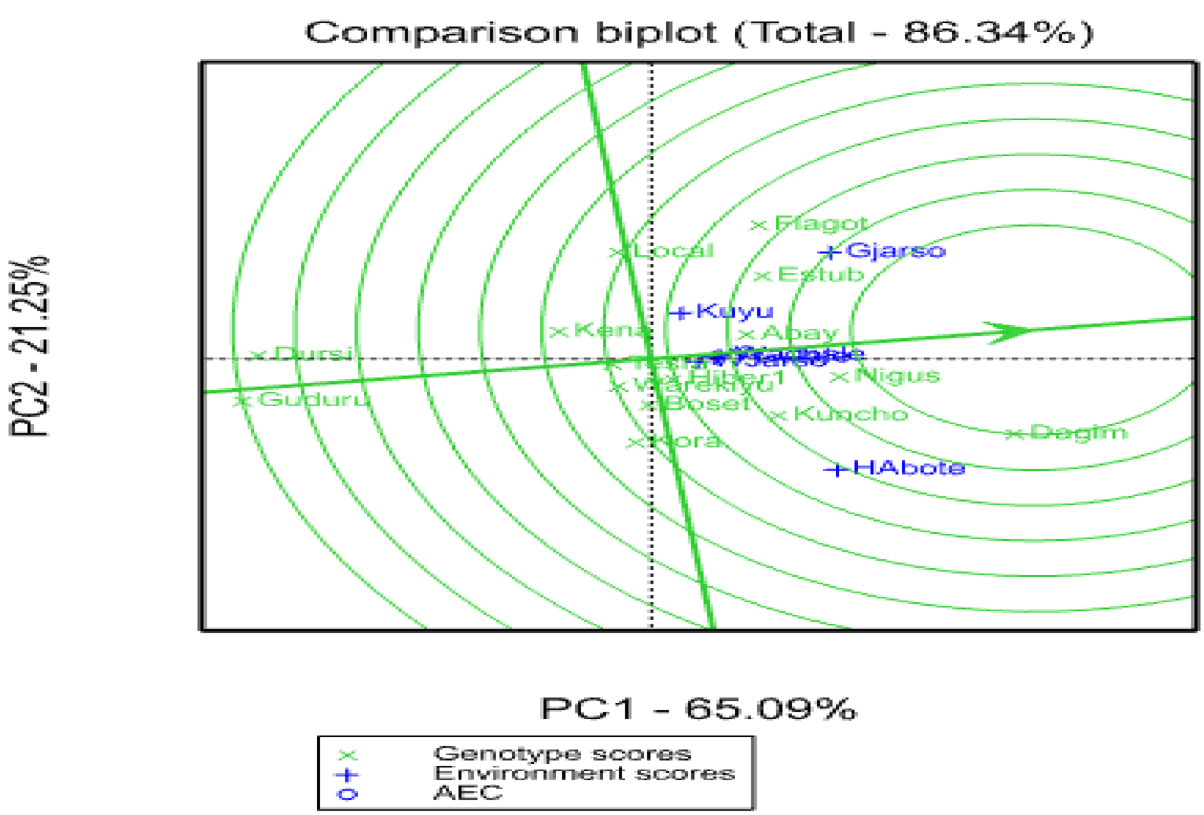

Figure 1: GGE bi-plot comparison of varieties for their yield potential and stability

The variety ranking is shown on the graph of variety so-called “ideal” variety (Figure. 1). An ideal variety is defined as one that is the highest yielding across test environments and it is completely stable in performance that ranks the highest in all test environments; such as Dagim , Nigus and Kuncho (Farshadfar et al., 2012; Yan and Kang, 2003). Even though such an “ideal” variety may not exist in reality, it could be used as a reference for variety evaluation (Mitrovic et al., 2012)

A variety is more appropriate if it is located closer to “ideal” variety (Kaya et al., 2006; Farshadfar et al., 2012). So, the closer to the “ideal” variety in this study was Dagim (Figure. 1). The ideal test environment should have large PC1 scores (more power to discriminate variety in terms of the genotypic main effect) and small (absolute) PC2 scores (more representative of the overall environments). Such an ideal environment was represented by an arrow pointing to it (Figure. 2). Actually, such an ideal environment may not exist, but it can be used as an indication for variety selection in the METs. An environment is more desirable if it is located closer to the ideal environment.

Therefore, using the ideal environment as the centre, concentric circles were drawn to help visualize the distance between each environment and the ideal environment (Yan and Rajcan, 2002). Accordingly, E4 (Gjarso), which fell into the centre of concentric circles, was an ideal test environment in terms of being the most representative of the overall environments and the most powerful to discriminate varieties (Figure.2).

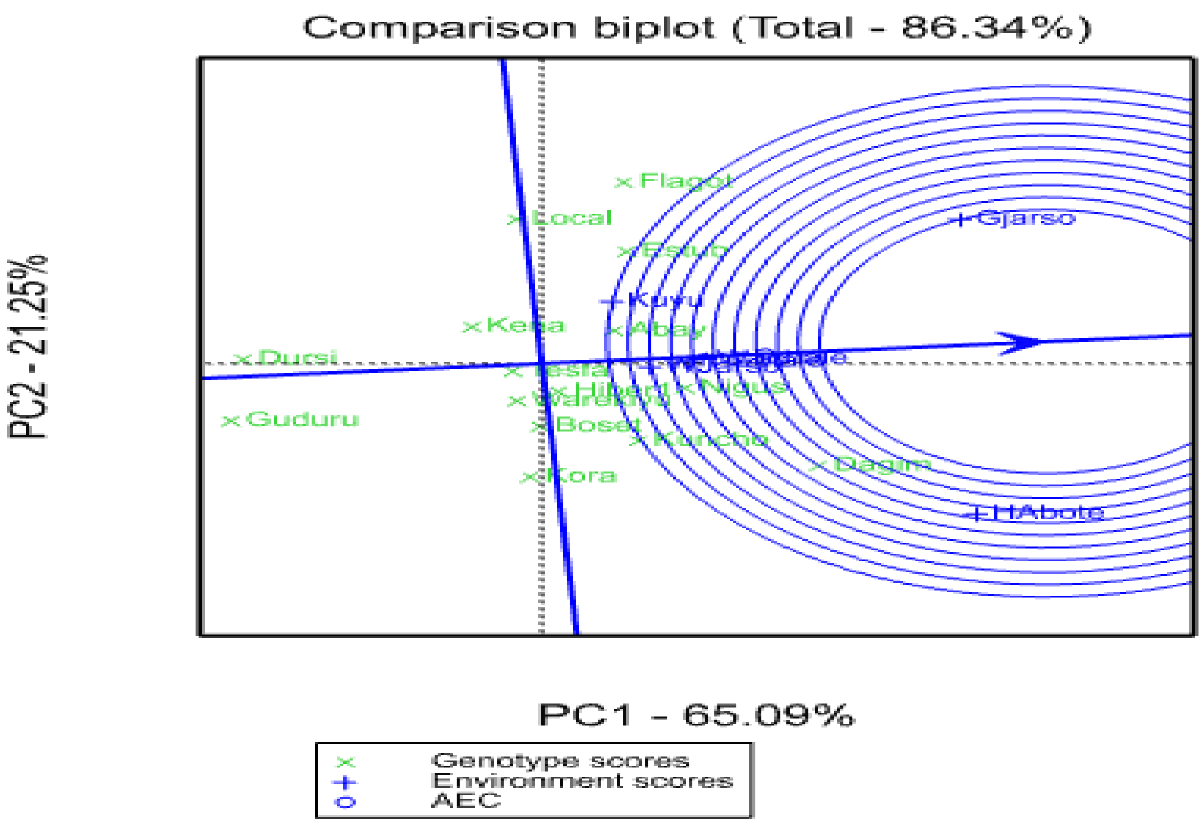

Figure 2: GGE bi-plot based on tested environments-focused comparison for their relationships

Additive main effects and multiple interactions (AMMI)

AMMI stability value (ASV).

Varieties exhibited significant varieties by environment interaction effects and the additive and multiplicative interaction effect stability analysis (ASV) implied splitting the interaction effect. In view of the mean grain yield as a first criterion for evaluating, Dagim variety was the highest mean grain yield (1516.4kgha^{-1}), followed by the variety Nigus and Kuncho with the mean grain yield of (1364.3kgha^{-1} and 1364.3kgha^{-1}, respectively). Whereas, variety Dursi and Guduru were with low mean grain yields across the testing locations (Table 7).

The IPCA1 and IPCA2 scores in the AMMI model are indicators of stability (Purchase, 1997). Considering IPCA1, Dagim variety was the most stable variety with IPCA1 value (-11.19), followed by Kuncho and Nigus with IPCA1 value of -2.59 and -4.38 respectively. Likewise, in IPCA2, Flagot variety was the most stable with interaction principal component value (-9.74) but recorded low grain yield. The two principal components have their own extremes; however, calculating the AMMI stability value (ASV) is a balanced measure of stability (Purchase, 1997).Varieties with lower ASV values are considered more stable and varieties with higher ASV are unstable. According to the ASV ranking in the (Table7), a Dagim variety was the most stable with an ASV value of 15 followed by Kuncho and Nigus with ASV value of 7 and 11 respectively.

The stable variety was followed with mean grain yield above the grand mean and this result was in agreement with Hintsa and Abay (2013), who has used ASV as one method of evaluating grain yield stability of bread wheat varieties in Tigray and similar reports been made by Abay and Bjørnstad (2009); Sivapalan et al. (2000) in barley in Tigray and bread wheat using AMMI stability value. A variety with the least of genotype/variety selection index (GSI) is considered as the most stable genotype (Farshadfar, 2008). Accordingly, Dagim variety was the most stable variety since with the low of genotype/variety selection index (GSI) and the highest mean grain yield of all (Table 7).

Table7: AMMI stability value, AMMI rank, yield, yield rank and genotype/variety selection index and principal component axis

Variety	ASV	ASV rank	YLD	YLD rank	GSI	IPCAg1	IPCAg2
Dagim	142.77	15	1516.4	1	16	-11.19	-1.58
Kuncho	5.32	7	1364.3	2	9	-2.59	3.96
Nigus	25.10	11	1364.3	3	14	-4.38	-1.35
Estub	8.51	9	1305.1	4	13	1.10	-6.30
Flagot	21.56	10	1241.1	5	15	2.75	-9.74
Abay	2.37	3	1219.4	6	9	-0.40	-2.14
Local	32.45	12	1183.7	7	19	7.42	-3.07
Tesfa	1.39	1	1135.3	8	9	-0.86	-0.61
Warekiyu	3.07	4	1127.9	9	13	0.33	2.87
Kora	4.19	6	1123.9	10	16	-4.23	3.83
Kena	5.77	8	1121.2	11	19	2.69	-0.56
Boset	3.34	5	1104.4	12	17	-1.76	2.80
Hiber1	1.65	2	987.2	13	15	-0.64	1.54
Guduru	95.90	14	816.5	14	28	6.52	8.13
Dursi	38.74	13	771.9	15	28	5.22	2.20

CONCLUSION AND RECOMMENDATION

In general, based on the two analyses of AMMI and GGE-bi-plot models, **Dagim and Nigus** varieties were considered as high yielder and more stability, consequently, close to ideal variety, so these varieties are adaptable to a wide range of environmental conditions.

Therefore, the two varieties were identified as better varieties in terms of yielding ability and stability and better agronomic performance across locations.

CONFLICT OF INTERESTS

The authors declare that there is no any conflict of interest

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