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 2020/21 cropping 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 interaction 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,
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 tender. 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 interaction (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 interaction (GEI) is a
complicate process of selecting genotypes with superior
performance. Therefore, 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 (Table 1) 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 m²
(four harvestable rows per plot). A seed rate of 20kg/ha
and fertiliser rate of 100kg/ha NPS and 100kg/ha 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, \( \mu \) 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:

\[ Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^{2} \lambda_k Y_{ik} \delta_{jk} + \epsilon_{ij} \]

Where: \( Y_{ij} \) is the grain yield of the \( i \)-th genotype in the \( j \)-th
environment, \( \mu \) is the grand mean, \( G_i \) and \( E_j \) are
the genotype and environment deviation from the grand
mean, respectively, \( \lambda_k \) is the eigenvalue of the principal
component analysis (PCA) axis \( k \), \( Y_{ik} \) and \( \delta_{jk} \) are
the genotype and environment principal componentscores
for axis \( k \), \( N \) is the number of principal components
retained in the model, and \( \epsilon_{ij} \) is the residual term.
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

\[GSI_i = RASVi + RYi\]

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 and each environment according to the relative contribution of IPCA1 and IPCA2 to the interaction sum of squares as follows:

\[ASV = \sqrt{\left[\frac{SS_{IPCA1} + SS_{IPCA2}}{2}\right] + (IPCA2 \text{score})^2}\]

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:

\[GSI_i = RASVi + RYi\]

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

\[Y = \text{is moisture in % age at threshing}\]

\[X = \text{is standard moisture in % age}\]

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

Table2: List of evaluated released tef varieties

<table>
<thead>
<tr>
<th>No</th>
<th>Variety</th>
<th>No</th>
<th>Variety</th>
<th>No</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abay</td>
<td>6</td>
<td>Flagot</td>
<td>11</td>
<td>Kuncho</td>
</tr>
<tr>
<td>2</td>
<td>Boset</td>
<td>7</td>
<td>Guduru</td>
<td>12</td>
<td>Local</td>
</tr>
<tr>
<td>3</td>
<td>Dagim</td>
<td>8</td>
<td>Hiber1</td>
<td>13</td>
<td>Nigus</td>
</tr>
<tr>
<td>4</td>
<td>Dursi</td>
<td>9</td>
<td>Kena</td>
<td>14</td>
<td>Tesfa</td>
</tr>
<tr>
<td>5</td>
<td>Estub</td>
<td>10</td>
<td>Kora</td>
<td>15</td>
<td>Warekiyu</td>
</tr>
</tbody>
</table>
The performance of the tef varieties for grain yield across locations is 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 (422.3kg/ha⁻¹) at Kuyu sub site to the highest (2072.9kg/ha⁻¹) at Abote sub site. The grain yield across environments ranged from the lowest of 771.9kg/ha⁻¹ for Dursi variety to the highest of 1516.4kg/ha⁻¹ for Dagim.
variation in grain yield (Table 6).
Grain yield is significant (P < 0.01). PCA The first and second components (Table 5) accounted for 77.1% of the total variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total treatment variation, while the G and GEI were significant and accounted for 81.2% of the total variation.

Conversely, Dursi variety ranked the highest 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 results 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 genotype by environment interaction. In additive variance, the portioning of GE 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 297.4 kg ha⁻¹ in E1 to 3112.7 kg ha⁻¹ in E3. Varieties mean grain yield varied from 771.9 kg ha⁻¹ (Dursi) to 1516.4 kg ha⁻¹ (Dagim) with (Table 6).

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

<table>
<thead>
<tr>
<th>variety</th>
<th>Locations</th>
<th>Kuyu</th>
<th>Warajarso</th>
<th>HAbote</th>
<th>Girjaraso</th>
<th>YayaGulafe</th>
<th>Wachale</th>
<th>com.mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abay</td>
<td></td>
<td>396.7</td>
<td>1305.4</td>
<td></td>
<td>2202.4</td>
<td>2278.6</td>
<td>493.3</td>
<td>640.1</td>
</tr>
<tr>
<td>Boset</td>
<td></td>
<td>412.4</td>
<td>880.6</td>
<td></td>
<td>2286.3</td>
<td>1859.5</td>
<td>550.1</td>
<td>638.6</td>
</tr>
<tr>
<td>Dagim</td>
<td></td>
<td>468.8</td>
<td>1186.6</td>
<td></td>
<td>3112.7</td>
<td>2472.9</td>
<td>959.9</td>
<td>898.1</td>
</tr>
<tr>
<td>Dursi</td>
<td></td>
<td>349.4</td>
<td>724.9</td>
<td></td>
<td>1442.8</td>
<td>1375.3</td>
<td>406.4</td>
<td>333.3</td>
</tr>
<tr>
<td>Estub</td>
<td></td>
<td>297.4</td>
<td>1349.3</td>
<td></td>
<td>2009.6</td>
<td>2540.0</td>
<td>866.1</td>
<td>768.3</td>
</tr>
<tr>
<td>Flagot</td>
<td></td>
<td>364.7</td>
<td>1076.7</td>
<td></td>
<td>1946.8</td>
<td>2681.2</td>
<td>621.8</td>
<td>755.3</td>
</tr>
<tr>
<td>Guduru</td>
<td></td>
<td>349.1</td>
<td>1222.6</td>
<td></td>
<td>1501.0</td>
<td>1108.5</td>
<td>336.2</td>
<td>381.7</td>
</tr>
<tr>
<td>Hiber1</td>
<td></td>
<td>575.4</td>
<td>716.7</td>
<td></td>
<td>1294.0</td>
<td>1927.6</td>
<td>570.6</td>
<td>839.4</td>
</tr>
<tr>
<td>Kena</td>
<td></td>
<td>332.1</td>
<td>1220.4</td>
<td></td>
<td>1823.9</td>
<td>1958.3</td>
<td>659.6</td>
<td>733.1</td>
</tr>
<tr>
<td>Kora</td>
<td></td>
<td>298.1</td>
<td>1207.4</td>
<td></td>
<td>2410.6</td>
<td>1757.7</td>
<td>431.3</td>
<td>638.3</td>
</tr>
<tr>
<td>Kuncho</td>
<td></td>
<td>609.3</td>
<td>1444.1</td>
<td></td>
<td>2557.2</td>
<td>1901.4</td>
<td>873.4</td>
<td>804.4</td>
</tr>
<tr>
<td>Local</td>
<td></td>
<td>570.9</td>
<td>868.3</td>
<td></td>
<td>2701.4</td>
<td>1546.5</td>
<td>719.6</td>
<td>695.8</td>
</tr>
<tr>
<td>Nigus</td>
<td></td>
<td>509.7</td>
<td>1453.4</td>
<td></td>
<td>2582.5</td>
<td>2327.4</td>
<td>603.3</td>
<td>709.3</td>
</tr>
<tr>
<td>Tesfa</td>
<td></td>
<td>385.1</td>
<td>1177.4</td>
<td></td>
<td>2113.1</td>
<td>1997.6</td>
<td>682.3</td>
<td>456.4</td>
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<tr>
<td>Warekiyu</td>
<td></td>
<td>370.8</td>
<td>856.0</td>
<td></td>
<td>2110.7</td>
<td>1827.8</td>
<td>777.8</td>
<td>824.1</td>
</tr>
</tbody>
</table>

LSD = least significant difference, R² = R square, CV= coefficient of variation, kg/ha = kilogram per hectare

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

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

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.
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. Therefore, 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).

<table>
<thead>
<tr>
<th>Varieties</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abay</td>
<td>396.7</td>
<td>1305.4</td>
<td>2202.4</td>
<td>2278.6</td>
<td>493.3</td>
<td>640.1</td>
<td>1219.4</td>
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<tr>
<td>Boset</td>
<td>412.1</td>
<td>880.6</td>
<td>2286.1</td>
<td>1859.5</td>
<td>550</td>
<td>638.6</td>
<td>1104.5</td>
</tr>
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<td>Dagim</td>
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<td>724.9</td>
<td>1442</td>
<td>1375.3</td>
<td>406.4</td>
<td>333.3</td>
<td>771.9</td>
</tr>
<tr>
<td>Estub</td>
<td>297.4</td>
<td>1349.3</td>
<td>2009.6</td>
<td>2540</td>
<td>666.1</td>
<td>768.3</td>
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</tr>
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<td>1076.7</td>
<td>1946.8</td>
<td>2681.2</td>
<td>621.8</td>
<td>755.3</td>
<td>1241.1</td>
</tr>
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<td>Guduru</td>
<td>349.1</td>
<td>1222.6</td>
<td>1501</td>
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<td>336.2</td>
<td>381.7</td>
<td>816.5</td>
</tr>
<tr>
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<td>575</td>
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<td>1294</td>
<td>1927.6</td>
<td>570.6</td>
<td>839</td>
<td>987.2</td>
</tr>
<tr>
<td>Kena</td>
<td>332.1</td>
<td>1220.4</td>
<td>1823.9</td>
<td>1958.3</td>
<td>659.6</td>
<td>733.1</td>
<td>1121.2</td>
</tr>
<tr>
<td>Kora</td>
<td>298.1</td>
<td>1207.4</td>
<td>2410.6</td>
<td>1757.7</td>
<td>431.2</td>
<td>638.3</td>
<td>1123.9</td>
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<td>873.3</td>
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<td>695.8</td>
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<tr>
<td>Nigus</td>
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<td>603.3</td>
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<td>2113.1</td>
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<td>682.3</td>
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<td>Mean</td>
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<td>1112.6</td>
<td>2139.6</td>
<td>1970.7</td>
<td>636.8</td>
<td>674.1</td>
<td>1158.8</td>
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E1 = Kuyu, E2 = Warajarso, E3 = HAbote, E4 = Girarjarso, E5 = YayaGulale, E6 = Wachale, E = environment

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).

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 (1516.4kg ha⁻¹), followed by the variety Nigus and Kuncho with the mean grain yield of (1364.3kg ha⁻¹ and 1364.3kg ha⁻¹, respectively). Whereas, variety Dursi and Guduru were with low mean grain yields across the testing locations (Table 7).
The IPC1 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 (Table 7), 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).

<table>
<thead>
<tr>
<th>Variety</th>
<th>ASV</th>
<th>ASV rank</th>
<th>YLD</th>
<th>YLD rank</th>
<th>GSI</th>
<th>IPCA1</th>
<th>IPCA2</th>
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<td>1305.1</td>
<td>4</td>
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<td>771.9</td>
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<td>28</td>
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</table>

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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