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Research Article

AMMI BIPLOT ANALYSIS OF GRAIN YIELD PERFORMANCES OF TEF (*ERAGROSTIS TEF* [ZUCC.] TROTTER) VARIETIES ACROSS DIFFERENT LOCATIONS OF SOUTH AND SOUTHWESTERN ETHIOPIA

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ABSTRACT

Objective: The objective of the study was to identify high yielding and stable tef varieties across different locations of South and Southwestern part of Ethiopia.

Methods: The experiment was conducted using 21 tef varieties obtained from a tef breeding program based at Debre Zeit Agricultural Research Center. The trial was laid out using a randomized complete block design with three replications at six locations during the 2018 cropping season. Data for all relevant agronomic traits were collected, but only plot yield data converted to kg/ha was subjected to statistical analysis.

Results: The results of combined analysis of variance for grain yield of 21 tef varieties across six locations revealed that there is a highly significant difference among the locations, genotypes, and interaction effects with the contributions of 67.4, 8.1, and 17.8% of sum of squares, respectively. Analysis of variance of AMMI model revealed the two interaction principal component analysis (IPCA1 and IPCA2) were highly significant according to Gollob's test and accounted for 42.8 and 20.6% of variance, respectively.

Conclusion: Based on AMMI Biplot analysis, Ambo location could be the representative area among tested locations to determine the tef varieties and the variety Heber-1 (G11) and Dukem (G15) were recommendable for broad adaptation since they were stable and high yielding across locations.

Keywords: AMMI model, *Eragrostis tef*, Varieties, Yield performance.

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INTRODUCTION

Tef (*Eragrostis tef* [Zucc.] Trotter) is an indigenous staple cereal crop of Ethiopia. It exhibits high level of phenotypic plasticity in phenology and agronomic traits depending on the growing environment. Tef can grow under both low moisture and water logging conditions and is suitable for double and relay cropping [5]. Its grain and straw are nutritious and well suited for human food and livestock feed, respectively. It is a gluten-free cereal [15], and as such it can be used as an alternative for people allergic to gluten such as wheat products. Due to its gluten free nature and other merits, the current acceptance of tef in Europe, USA, and other regions of the world is increasing. All available information, therefore, confirm that tef is a healthy, reliable, and low risk crop.

Tef is the major Ethiopian cereal grown on 3.02 million hectares annually [22], and serving as staple food grain for over 70 million people. The crop constitutes 30% of the total area allocated to cereals and contributes more than 20% of the total cereals production [22]. The major constraints in Ethiopia's husbandry are low productivity (national average 1.6 t/ha [19] and susceptibility lodging). The peculiar meritorious features of the tef crop that are of importance with respect to farming include: (i) Broad and versatile agro-ecological adaptation under varied climatic, edaphic, and socioeconomic conditions; (ii) tolerance to both drought and water-logging conditions; (iii) fitness for various cropping systems and crop rotation schemes; (iv) usefulness as a reliable and low risk catch crop at times of failures of other long season crops such as maize and sorghum due to drought or pests; and (v) little vulnerability to epidemics of pests and diseases in its major growing regions.

Tef growing agro-ecological zones of Ethiopia have different ranges of altitude (from sea level up to 2800 M.A.S.L.). The ideal altitude ranges between 1700 up and 2200 m above sea level [7]. Major factors contributing to low productivity of tef at southwestern Ethiopia were diseases, soil acidity, susceptibility to lodging, and low yield potential of landraces and others [25]. The productivity of tef at Southwestern Ethiopia was very low (below 1 ton) comparing to national average [25-27].

Phenotypic expression and yield potential of a given genotype is the result of its genetics, the environment, and the GEIs [10,11]. GEIs are considered to be one of the key factors limiting response to selection and the efficiency of breeding programs. Environment change can affect the performance a genotypes, and breeders should give due attention to the impact of GEI in the genetic exploitation to be efficient in selection. Ghaderi *et al*. [2] observed that analysis of variance procedure helps to estimate the magnitude of GEI; but is unable to provide information on the contribution of each genotypes and environment to GEIs.

The AMMI model ensures a multivariate analytical parameter for interpreting GEI [4]. When main effects and interaction are both important; AMMI is the model of first choice to improve accuracy of yield estimates [3]. AMMI method combines ANOVA and principal component analysis (PCA) into a united approach. The most important feature of this analysis is that adjustment is carried out using information from other locations to refine the estimates within a given location [18]. It removes residual or noise variation from GEI [4]. Therefore, the objective of the study was to identify tef varieties that have both high grain yield and stable performance across different environments for south and southwestern part of Ethiopia using AMMI stability model.

METHODS

Experimental materials

Twenty one tef varieties which were obtained from Debre Zeit Agricultural Research Center were used to conduct the experiment (Table 1).

Design and environments

The varieties were examined in randomized complete block design (RCBD) in three replications in six locations (Table 2) of South and Southwestern Ethiopia. Sowing was done manually in rows and the spacing between rows and plants was 20 cm and 10 cm, respectively. Spacing between plots was 1 m, whereas that between replications was 1.5 m and the total plot size was 2 m × 2 m. Seed rates was based on the recommendation which was 15 kg/ha. Planting was done on the onset of rain in the respective locations. Plots were fertilized with 40 kg of N and 60 kg P_2O_5 per hectare for light soils and 60 kg N and 60 kg P_2O_5 per hectare for black soils (Vertisols). All DAP was applied at planting, while urea was applied in split; half at the time of planting and the remaining half at tillering stage. In addition, other relevant field trial management practices were carried out throughout the experimentation period across all locations as per the recommendations. Data were taken on 13 quantitative traits on plot basis and from randomly selected five plants of tef from the central rows of each plot.

The following data were taken on whole plot basis

Days to heading (DH): The number of days from sowing up to the emergence of the tips of the panicles from the flag leaf sheath in 50% of the plot stands.

Days to maturity (DM): The number of days from sowing up to 50% of the plants in the plot reaching physiological maturity stage (as evidenced by eye-ball judgment of the plant stands when the color of the vegetative parts changed from green to color of straw).

Grain filling period (GFP): Number of days from 50% heading to 50% maturity of the stands in each plot obtained by subtracting the former from the latter.

Lodging index (X): The value recorded following the method of Caldicott and Nuttall [1] who defined lodging index as the sum of product of each scale or degree of lodging (0–5) and their respective severity percentage divided by five, where 0 value is fully upright (90°), 1 = 0–15° lodging, 2 = 15–30° lodging 3 = 30–45° lodging, 4 = 45–60° lodging, and 5 = 60–90° lodging and the plants become completely flat.

Thousand seed weight (TSW): The weight of thousand kernels in gram sampled from the entire plot.

Biomass yield (BY): Above ground total (shoot plus grain) biomass in gram for the entire plot.

Straw yield (SY): Measured as the weight in grams of sun dried above ground parts of the obtained after the grain removed.

Grain yield (GY): The weight of seeds harvested in gram from each plot.

Harvest index (HI): It is the ratio of grain yield to shoot biomass sampled from the entire plot expressed in percent.

The following observations were recorded on the basis of measurements made on five randomly selected and pre-tagged plants from the three central rows of each plot.

Plant height (PH): The length from the base of the stem of the main tiller to the tip of the main shoot panicle at maturity recorded as the average of five plants per plot and measured in centimeter.

Panicle length (PL): The length from the base of the main shoot panicle where the first branch emerges to the tip of the panicle at maturity recorded as the average of five plants per plot and measured in centimeter.

Table 1: Description of 21 tef varieties evaluated in six environments during the 2018 main cropping season

No.	Variety name	Common name	Released Center	Year of release
1.	DZ-Cr-387 RIL355)	Quncho	DZARC	2006
2.	DZ-01-1880	Guduru	Bako	2006
3.	23-Tafi Adi-72	Kena	Bako	2008
4.	DZ-01-3186	Etsub	Adet	2008
5.	DZ-Cr-438 RIL133 B	Kora	DZARC	2014
6.	DZ-Cr-438 RIL91A	Dagim	DZARC	2016
7.	DZ-Cr- 438 RIL7	Abola	Adet	2016
8.	DZ-Cr-429 RIL125	Negus	DZARC	2017
9.	DZ-Cr-442 RIL77C	Felagot	DZARC	2017
10.	DZ-Cr-457 RIL181	Tesfa	DZARC	2017
11.	DZ-Cr-419 (DZ-Cr-974 X PI 222988)	Heber-1	Adet	2017
12.	DZ-01-787	Wellenkomi	DZARC	1978
13.	DZ-Cr-255	Gibe	DZARC	1993
14.	DZ-01-99	Asgori	DZARC	1970
15.	DZ-01-974	Dukem	DZARC	1995
16.	DZ-01-1285	Koye	DZARC	2002
17.	DZ-01-2053	Holetta Key	Holetta	1998/99
18.	DZ-Cr-37	Tsedey	DZARC	1984
19.	DZ-CR-409 (sel. 50D)	Boset	DZARC	2012
20.	DZ-01-196	Magna	DZARC	1970
21.	DZ-01-354	Enatite	DZARC	1970

Table 2: Description of experimental site

Locations	Geographic position		Altitude	Soil type	Temp (°C)	Rainfall (mm)
	Latitude (N)	Longitude (E)	(M.A.S.L)			
Ambo	8°57′	38°07′	2175	Vertisol	18	1018
Areka	7°09′	37°41′	1830	Alfisol	27	1539
Arjo	8°74′	36°50′	2457	Nitosol	18	1850
Bedele	8°27′	36°21′	2087	Nitosol	18	1700
Melko	7°47′	36°47′	1753	Nitosol	22	1639
Omonada	7°41′	37°12′	1975	Nitosol	20	1600

Source: Research Centers and Agricultural Offices of the Respective Woredas

Culm length (CL): The length of the main shoot culm from the ground level to the point of emergence of the panicle branches at maturity recorded as the average on five of plants per plot and measured in centimeter.

Number of fertile tillers per plant (FT): It is recorded as the number of all tillers produced per plant assessed as the mean of five random plants per plot.

Data analysis

All data were subjected to analysis of variance using SAS software 9.0 [12]. Bartlett's test for homogeneity of variances was carried out to determine the validity of the individual experiment and thereafter, combined analysis of variance was performed using PROC GLM. Additive main effect and multiplicative interaction (AMMI) model used to investigate GEI. Statistical analysis was performed by statistical packages of Genstat 16th version [23] and GEA-R [24] (Genotype by environment interaction with R-software).

RESULTS AND DISCUSSION

The analysis of variance for grain yield (kg/ha) of 21 tef varieties tested in six locations is presented in Table 3. The analysis revealed that variances due to environments, genotypes, and GEI were significant at 5% confidence level. This obviously indicates the presence of substantial variation in the mean performance of all the tested genotypes over the environments and on the environmental means over tested genotypes. The presence of the GEI indicates that the phenotypic expression of one genotype might be superior to another in one environment, but inferior in a different environment [6]. The main effects of G and E accounted for 8.1 and 67.4%, respectively, and GEI accounted 17.8% of the total variation for grain yield. The large sum squares for environment indicated that the environments were diverse, with large differences among genotypic means causing most of the variation in grain yield (Table 4).

Results from AMMI analysis (Table 4) also indicated that the IPCA1 of the interaction captured 42.8% of the interaction sum of squares and IPCA2 explained further 20.6% of the GEI sum squares. The mean squares for the IPCA1 and IPCA2 were highly significant ($p<0.01$) and cumulatively contributed to 63.4% of the total GEI. The model was adequate enough to explain the total GEI component. Besides Yan and Rajcan [13], reported that the GT (genotype–by-trait biplot) for each of the six years explained 52–63% of the total variation of the standardized data. Furthermore, the prediction assessment showed that the AMMI with only two interaction principal component axes was the best predictive model [3] and had 58 degrees of freedom. Further interaction principal component axes captured mostly noise and therefore, did not help to predict validation observations [17].

Thus, the interaction of the 21 tef varieties with six environments in this study was predicted by the first two principal components of genotypes and environments Table 4. The IPCA scores of a genotype provide indicators of the stability of genotype across environments [9]. The inferences drawn from biplots will be valid only when the IPCA or the first two IPCAs explain maximum interaction variation. Furthermore, biplots are commonly used to explain AMMI results considering one or two PCAs at a time. Plant breeders would like to identify varieties which are stable and high yielding when more than two PCA axes are retained in the AMMI model which cannot be explained with the help of biplots [17]. In general, factors such as type of crop, diversity of the germplasm, and range of environmental conditions will affect the degree of complexity of the best predictive model [4].

AMMI 1 biplot analysis for grain yield

The AMMI model 1 biplot of the tef varieties was demonstrated in Fig. 1. AMMI bi-plot analysis represents graphical representation (bi-plot) to summarize information on main effects and interaction effect of both genotypes and environment simultaneously. The interaction principal component (IPCA1) represented in Y-axis where as genotype and environment mean represented in X-axis (Fig. 1). Genotype or locations placed on the right side of the original (above grand mean) were high yielding genotypes or locations where as genotypes or locations placed in the left side (below grand mean) were low yielding.

The IPCA scores of genotypes in AMMI analysis are an indication of stability of genotypes over the environments [8]. The greater the IPCA

Table 3: Mean grain yield (kg/ha) and scores of genotypes and environments to the first IPCA of 21 tef varieties grown at six locations in South and Southwestern Ethiopia, 2018 cropping season

Varieties	Locations						Mean	IPCA Scores	
	Omonada	Melko	Bedele	Areka	Arjo	Ambo		IPCA-1	IPCA-2
G1	1250	521	525	1330	608	1510	959.0	11.72	0.914
G2	330	1013	580	1108	430	1120	765.9	−18.41	6.190
G3	500	740	390	1040	425	882	664.4	−10.30	−0.410
G4	540	680	360	1330	540	1250	786.8	−7.150	−3.710
G5	790	790	208	1220	580	1260	812.9	−2.936	−5.681
G6	790	713	330	1340	660	1360	869.5	−2.009	−5.359
G7	916	528	790	1330	560	1520	949.7	3.397	8.259
G8	1250	420	225	1490	460	908	759.6	12.27	−14.47
G9	330	530	275	1140	940	1005	704.8	−12.036	−11.37
G10	660	730	350	1130	350	1101	723.3	−4.791	0.652
G11	1000	720	580	1460	808	1625	1034.1	1.895	−1.436
G12	708	707	300	1060	330	1170	713.7	−2.717	2.137
G13	790	480	280	1080	416	1340	735.0	3.392	1.81
G14	1083	574	508	1120	850	1250	899	4.645	−2.296
G15	1250	715	641	1420	790	1690	1086.3	7.738	1.345
G16	958	658	675	1080	416	1250	841.5	1.380	8.912
G17	875	460	340	1030	480	1520	787.2	5.994	5.097
G18	916	520	625	1101	760	1310	874	2.062	2.888
G19	958	678	625	1210	470	1170	774.5	3.206	−6.637
G20	1000	604	560	930	370	1210	781.6	4.365	9.640
G21	830	679	480	968	540	1104	768.4	−1.707	3.531
Mean	844	641	459.4	1187.6	561.1	1264.5			
CV (%)	113	138	107	188	192	343			
LSD at 5%	8.8	13	17.4	9.6	20.6	9.9			

Where, G1=Quncho, G2=Guduru, G3=Kena, G4=Etsub, G5=Kora, G6=Dagim, G7=Abola, G8=Negus, G9=Felagot, G10=Tesfa, G11=Heber1, G12=Wellenkomi, G13=Gibe, G14=Asgori, G15=Dukem, G16=Koye, G17=Holetta Key, G18=Tsedey, G19=Boset, G20=Magna, G21=Enatite

Table 4: Additive main effects and multiplicative interactions analysis of variance for grain yield (kg ha^{-1}) of the tef varieties across six environments in 2018 cropping season

Source of variation	df	Sum squares	Mean squares	% of GEI Explained	Cumulative variance explained (%)	Percent of total variation Explained (%)
Total	377	54236321	143863			
Genotypes	20	4353373	217669			8.1
Environments	5	36573950	7314790			67.4
Blocks	12	506073	42173			
Interactions	100	9330951	93310			17.8
IPCA1	24	4000566	166690	42.8	63.4	
IPCA2	22	1928952	87680	20.6		
Errors	240	3471973	14467			

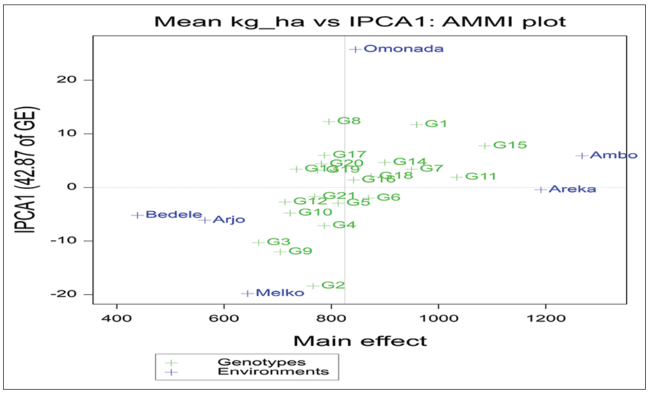

Fig. 1: AMMI 1 Biplot of IPCA 1 against grain yield of 21 tef varieties across six enviroments. Where, G1=Quncho, G2=Guduru, G3=Kena, G4=Etsub, G5=Kora, G6=Dagim, G7=Abola, G8=Negus, G9=Felagot, G10=Tesfa, G11=Heber1, G12=Wellenkomi, G13=Gibe, G14=Asgori, G15=Dukem, G16=Koye, G17=Holetta Key, G18=Tsedey, G19=Boset, G20=Magna, G21=Enatite

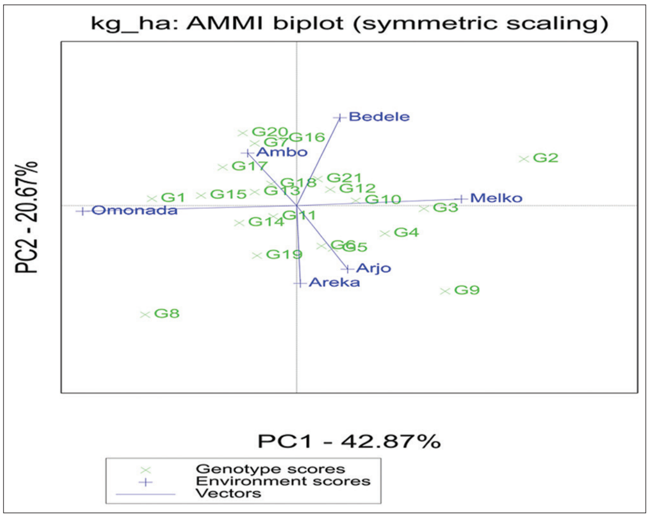

Fig. 2: AMMI2 Biplot for grain yield of 21 tef varieties showing the plotting of IPCA1 and IPCA2 of varieties. Where, G1=Quncho, G2=Guduru, G3=Kena, G4=Etsub, G5=Kora, G6=Dagim, G7=Abola, G8=Negus, G9=Felagot, G10=Tesfa, G11=Heber1, G12=Wellenkomi, G13=Gibe, G14=Asgori, G15=Dukem, G16=Koye, G17=Holetta Key, G18=Tsedey, G19=Boset, G20=Magna, G21=Enatite

score (−ve or +ve), the more specifically adapted a genotype is to a specific environment. The closer the IPCA score is to zero, the more stable the genotypes are over the tested locations. Adaptability unlike stability is the result of GEI. Stability explains the stable performance of a genotype across locations usually above a standard acceptable range which in this experiment is the mean genotype performance. On the other hand, adaptability is the ability of a genotype to perform well in a specific environment. The mean grain yield value of 21 tef varieties averaged over the six environments showed that the varieties G15 and G3 had the highest (1084.3 kg/ha) and the lowest (662.8 kg/ha) mean grain yield, respectively (Table 3). Different varieties showed inconsistent performance across all the environments. The variety G15 (1084.3 kg/ha) was the top performers, while G5 (808 kg/ha), G8 (792.2 kg/ha), and G17 (784.2 kg/ha) were moderate and G3 (662.8 kg/h) to G9 (703.3 kg/ha) were the poor yielders. Among environments, the mean grain yield ranged from 459.4 kg/ha to 1264.5 kg/ha and average grain yield over environments and genotypes was 826.2 kg/ha. On the other hand, the genotypes G15, G11, G1, G7, G14, G18, G6, G19, and G16 had higher average yields with positive index values, which indicated these genotypes were adapted to favorable environments, while genotypes G3 to G9 were adapted in poor environments.

The varieties Dagim (G6), Koye (G16), Tseday (G18), Kora (G5), and Heber-1 (G11) were high yielding and variety Enatite (G21) and Wellenkomi (G12) with low yields, exhibited score near to zero. Therefore, these varieties were stable varieties or widely adapted varieties across diverse locations and contribute less to the magnitude of GEI. Similar results were reported by Roostaei *et al.* [21] and Ferney *et al.* [16]. The varieties Kena (G3), Felagot (G9), and Guduru (G2) showed mean grain yield less than the overall mean with the negative highest IPC1 score. Moreover, varieties Dukem (G15) and Quncho (G1), with mean yield more than average mean and with positive IPCA1 score, tended to contribute less GEI, and accordingly can be regarded as the most stable varieties. A similar finding was reported by Roostaei *et al.* [21].

Similar to varieties, location Bedele, Arjo, and Melko were low yielding locations during the experimental year as well as unfavorable environments and contributed highly to GEI. The locations Omonada and Areka were high yielding environments and contributed to high GEI furthermore, since these locations had a high principal component 1 axis, these were unstable locations. Ambo was a high yielding location and relatively contributed to a low GEI. Moreover, it was located on the biplot graph nearest to the origin relative to the other locations. Therefore, the location was considered as a favorable location relative to the others. A similar result was reported by Purchase *et al.* [9] and by Ferney *et al.* [16].

According to Anley *et al.* [20], genotypes that are close to each other tend to have similar performance and those that are close to environment indicates their better adaptation to that particular environment similar to that genotype Tesfa (G10) and Wellenkomi (G12) had similar performance and showed less adaptation at Arjo, but the varieties showed good performance at Areka and Ambo. The variety (G15) had similar performance and showed the best adaptation at Ambo.

AMMI 2 biplot analysis for grain yield

In AMMI 2 biplot, (Fig. 2) the environmental scores are joined to the origin by side lines. Sites (locations) with short spokes do not exert strong interactive forces. Those with long spokes exert strong interaction. An example of this is shown in Fig. 2 where the points representing the environments Melko, Bedele, Omonada, Areka, Arjo, and Ambo are connected to the origin. The environments Ambo, Areka, and Arjo had short spokes and they do not exert strong interactive forces. The genotypes occurring close together on the plot will tend to have similar yields in all environments, while genotypes far apart may either differ in mean yield or show a different pattern of response over the environments. Hence, the genotypes near the origin are not sensitive to environmental interaction and those distant from the origins are sensitive and have large interaction. In the present study, G2 (Guduru), G8 (Negus), and G9 (Felagot) were more responsive, since they were located away from the origin, whereas the genotypes G11 (Heber-1), G12 (Wellenkomi), G13 (Gibe), G14 (Asgori), G15 (Dukem), G18 (Tseday), and G21 (Enatite) were close to the origin and hence they were non-sensitive to environmental interactive forces.

CONCLUSION AND RECOMMENDATION

The analysis of variance for the AMMI model of grain yield showed that genotypes, environments, GEI, and AMMI components 1 and 2 were significant. Thus, both yield and PCA1 and PCA2 scores should be taken into account simultaneously to utilize the useful effect of GEI and to make recommendation of the genotypes more accurate. Based on AMMI biplot analysis, Ambo location could be the representative area among tested locations to determine the tef varieties. Furthermore, the AMMI result showed that the variety Heber-1 (G11) and Dukem (G15) were recommendable for broad adaptation since they were stable and high yielding across locations.

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CONFILCTS OF INTEREST

The authors have not declared any conflicts of interest.

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