

# GGE Biplot Stability Analysis of Seed Yield in Teff (*Eragrostis tef* (zucc.) Varieties in South West Ethiopia

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**Abstract:** Teff (*Eragrostis tef* (zucc.) is one of the major cereal crop grown in Ethiopia where it is staple food for about 50 million people. Among many factors contributed to low production and productivity of tef lack of widely adopted improved tef variety is one of the factors. The experiment was conducted in south western Ethiopia across six test locations during the 2019 cropping seasons to study the nature of GEI on grain yield of tef and to classify environments based on the performance of genotypes. A total of seven tef varieties were laid out randomized complete block design with three replicates at each site. The Analysis of variance revealed highly significant difference for environment, genotype and genotype by environment interaction ( $p < 0.001$ ). Large proportion of the variation was explained by the environmental effect (69.22%) followed by the GEI effect (20.19%) and genotypes (7.5%) of the overall variation. GGE biplot analysis showed that PC1 and PC2 accounted for 42.37% and 30.42% of GGE sum of squares, respectively, explained 72.79% of the total variance. The six locations were divided in to three mega environments G28, G22 and G25 being the best varieties in each of the mega environments. However, G28 had the highest stability out of these three varieties. E6, E5 and E3 were ideal environments or the most suitable taste location for Teff breeding in the region, while E4 followed by E1 and E2 is a less desirable as testing environment.

**Keywords:** Biplots Analysis, Genotype by Environment Interaction, GGE, Grain Yield, Stability, Teff

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## 1. Introduction

Teff (*Eragrostis tef* (zucc.) Trotter,  $2n=40$ ) is the poaceae family native to Ethiopia, which is centre of diversity for this important cereal crop [1]. It is one of the major cereal crop grown in Ethiopia where it is staple food for about 50 million people [2]. It is cultivated on approximately about 3 million hectare producing 5.02 million tons [3].

Teff is an important rain fed crop adopted wide range of climatic and edaphic conditions. It needs an optimum total annual rainfall of 750 to 850 mm, growing season rainfall of 450-550 mm and a temperature range of 10 to 27°C [4]. The suitable Teff 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 to 2200 meter above sea level [4].

Major factors contributing to low productivity of Teff is susceptibility to lodging, low yield potential of landraces under widespread cultivation, poor agronomic management

practices, biotic and abiotic stresses [5]. Nevertheless, it is possible to increase the yield up to 4.5 ton per hectare by using improved varieties and proper management practices [6]. Determining the magnitude and nature of the production environment is also the most important strategy to maximize grain yield and ensure stable performance of tef varieties across varying environments [7]. Genotype by environment interaction testing over diverse environment is very important to ensure that whether there is a need to develop a widely adapted cultivar for all environments of interest, or specifically adapted cultivars for specific target environments [8, 9]. In crop improvement programs multi-environment performance tests across a wide range of environments are conducted to reduce the effect of GEI and to ensure that the selected genotypes have a high and stable performance across several environments as it is easier and cost effective both in terms of variety evaluation and seed multiplication [10]. However, the need to develop a stable variety across the environment is dependent up on the kind of

interaction prevailing [9]. Previous studies of G x E interaction on Tef have illustrated significant interaction of genotypes with environment for yield and yield related traits and use different parametric methods for partitioning GEI [11-13], but only a few studies use the GGE- bi-plot model for stability analysis [14]. Therefore, the present study was conducted to examine the pattern of genotype by environment interaction (GEI) of tef yield by using GGE biplot analysis, to identify the most stable tef genotype for wide and/or specific adaptations.

## 2. Materials and Methods

### 2.1. Plant Materials and Test Locations

A multi environment trial was conducted using seven tef varieties (Table 3) for each location. The trial was conducted during the 2019 main cropping seasons at, Gechi, Omonada, Gooma, Somodo, Melko and Kersa. Average weather data and geographical coordinates of the test sites are presented in table 1. Seven nationally released tef varieties were included in the study (Table 2). They were obtained from Debre Zeit Agricultural Research Center (DZARC).

**Table 1.** Description of the test environments.

Locations	Altitude (m.a.s.l)	Coordinates	Soil type	Temp (°C)	Rainfall (mm)
Gechi	2087	8°27'N 36°21'E	Nitosols	20.7	1800
Gooma	1,560	7°51'N 36°35'E	Nitosols	19.7	1764
Kersa	>1780	NA	Nitosols	20.3	2000
Mana	1770	7°45'N 36°45'E	Nitosols	18.9	1624
Melko	1753	7°47'N 36°47'E	Nitosols	22	1639
Omonada	1975	7°41'N 37°12'E	Nitosols	20	1600

**Table 2.** Description of experimental materials used in the study.

Variety name	Year of release	Days to maturity	Released center	Rainfall (mm)	Altitude (m.a.s.l)	Grain yield (t/ha)	
						On station	On farm
Dagim	2016	112-115	DZARC	-	-	2.6-3.2	-
Kora	2014	110-117	DZARC	-	-	2.5-2.8	2.0-2.2
Felagot	2017	108-112	DZARC	-	-	2.2-2.9	-
Abola	2016	110-118	Adet	-	-	2.1-2.8	1.5-1.7
Gibe	1993	114-126	DZARC	-	1850	2.0-3.0	1.6-2.2
Heber-1	2017	112-124	Adet	-	-	2.2-2.7	-
Tesfa	2017	112-120	DZARC	-	-	2.3-3.0	-

### 2.2. Experimental Design and Management

The trial was conducted using randomized complete block design (RCBD) with three replications at all locations under rain-fed conditions. Sowing was done manually. Fertilizer rate, seed rate, and crop cultivation were applied based on agronomic recommendations for each site. Spacing between plots was 1 m, whereas between replications was 1.5 m and the total plot size was 2mx2m. Seed rates was based on the recommendation which was 15kg/ha. Planting was done on the onset of rain in the respective locations. As per the recommendations, plots were fertilized with 40 kg of N and 60 kg of P<sub>2</sub>O<sub>5</sub> per hectare for light soils and 60kg N and 60kg P<sub>2</sub>O<sub>5</sub> per hectare for black soils (Vertisols). All DAP was applied at planting, while urea was applied in split half at planting and the remaining half at tillering stage. All other relevant field trial management practices were carried out throughout the experimentation period across all locations as per the recommendations for the respective locations.

### 2.3. Data Collection

Data were recorded on plot and single plant basis. Individual plant based data were taken from five plants in each plot taken randomly from the centre of each plot.

#### 2.3.1. Data Collected on Plot Basis

Days to heading (DH): The number of days from 50% of the

plots showing emergence of seedlings 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 50% of the plots showing seedling emergence up to 90% of the plants in the plot reaching phenological maturity stage (as evidenced by eye-ball judgment of the plant stands when the color is changed from green to yellow color of straw)

Grain filling period (GFP): The number of days from 50% heading to 90% maturity of the stands in each plot

Lodging index (X): The value recorded following the method of Caldicott and Nuttall (1979) 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.

Total biomass yield (g/plot): The weight of all the central row plants including tillers harvested at the level of the ground

Grain yield (g/plot): The weight of grain for all the central row plants including tillers harvested at the level of the ground

Straw yield (g/plot): The weight of straw plus chaff of all the central row plants including tillers harvested at the level of the ground

Thousand seed weight (gram): It is the weight of thousand seeds at 12.5% moisture content

Harvest index: The value computed as the ratio of grain

yield to the total (grain plus straw) biomass multiplied by 100.

### 2.3.2. Data Collected on Plant Basis

**Plant Height (cm):** Measured as the distance from the base of the stem of the main tiller to the tip of the panicle at maturity

**Panicle Length (cm):** The length from the node where the first panicle branch starts up to the tip of the main panicle at maturity

**Culm Length (cm):** The length of the main shoot node from the ground level up to the point of emergence of the panicle branches

**Fertile Tillers:** The number of panicle-bearing fertile tillers produced per plant

**Statistical analysis**

Combined analysis over years and locations was done separately for Gechi, Omonada, Gooma, Somodo, Melko and Kersa SAS software (SAS 9.0) after testing for homogeneity of variance.

GGE biplot analysis was conducted on the mean best linear unbiased estimate (BLUE) values of eight Tef genotypes in the respective locations using GenStat 18 [15].

## 3. Results and Discussions

The Analysis of variance revealed highly significant

**Table 3.** ANOVA for grain yield (kg/ha) of eight Tef genotypes tested at six environments.

Source of variation	Df	Mean square	Pr>f	Proportion of TSS
Genotype (G)	7	13.835**	<.0001	7.50%
Location	5	178.811**	<.0001	69.22%
Rep within location	2	0.04778	0.8934	
Genotype X Environment (GxE)	35	7.452**	<.0001	20.19%
Pooled error	94	0.4232		3.08%
Mean=7.5 R-square=0.96		CV=8.9		

\*CV= coefficient of variation df=degree of freedom, TSS= total sum square

**Table 4.** Combined Analysis of variance and mean performance of different traits of tef varieties tested at different locations.

Varieties	Traits								
	HD	MD	PH	PL	CL	LI (%)	SHB	GY	HI
Dagim	56.4	107.3	106.1	41.4	64.6	54.9	35.8	8.3	23.2
Negus	54.3	106.6	96.9	38.2	58.7	58.9	37.4	7.8	22.6
Tesfa	55.6	106.9	97.8	36.5	61.3	56.2	35.8	6.5	18.2
Felagot	54.8	101.8	85.3	31.7	53.6	62.2	35.2	7.9	23.4
Abola	55.6	107.4	101.7	39.3	62.7	57.2	40.6	7.6	19.7
Heber-1	55.3	109.2	106.2	42.6	63.5	54.6	40.1	7.7	20.1
Gibe	55	110.2	95.4	39.3	56.1	61.7	32.3	5.8	19.1
Kora	55.4	108.6	110.7	43.7	67	58.8	35.7	8.3	24.0
Mean	55.3	107.3	100.2	39.1	60.9	58.1	36.6	7.5	21.2
F test	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001
LSD value	0.67	0.89	3.1	1.8	2.3	2.51	3.52	0.445	0.0218
CV (%)	1.82	1.25	4.6	7.3	5.7	6.5	14.5	8.98	15.5
R-square	0.94	0.953	0.94	0.83	0.92	0.89	0.89	0.97	0.86

HD=Days to heading, MD= days to maturity, PH=plant height, PL=Panicle length, CL=culm length, LI=lodging index, SHB=shoot biomass, GY=grain yield, HI=harvest index

### Polygon View of GGE biplot Analysis /Which Won Where Pattern

The polygon view of GGE biplot (Figure 1) is important for studying the possible existence of different mega environments in a region [16, 17]. In the present investigation,

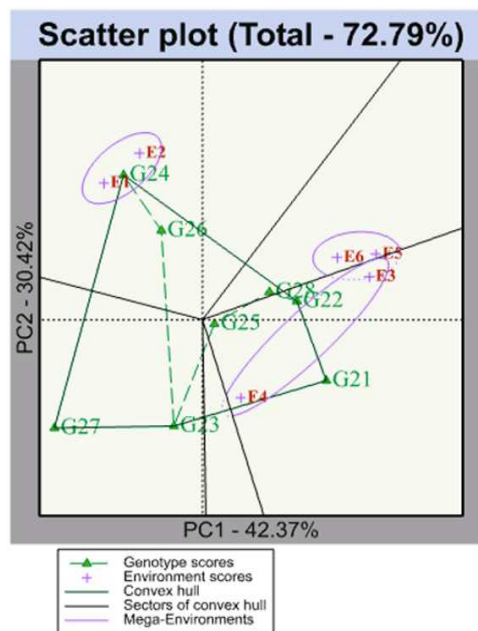
difference for environment, genotype and genotype by environment interaction (Table 1). Highly significant variation was observed for genotype by environment interaction of Tef grain yield, indicating that possibility of stability analysis. Large proportion of the variation was explained by the environmental effect (69.22%) followed by the GEI effect (20.19%). Genotypes accounted for (7.5%) of the overall variation. There still remains some proportion of variation left unexplained by the model pooled into the error term (3.08%). The high percentage of the environment sum square is an indication that the major factor that influence yield performance of Tef genotypes is the environment. The relatively large percentage of the Genotype x Environment interaction sum square, when compared to that of genotypes as a main effect, is a very important consequence. The G x E interaction is highly significant ( $p<0.01$ ) accounting for 69.22% of the sum of squares implying the need for investigating the nature of differential response of the genotypes to environments.

Highly significant variations observed for most of the traits (Days to heading, days to maturity, plant height, Panicle length, culm length, lodging index, shoot biomass, grain yield, harvest index) tested among genotypes across all locations, indicating the existence of variability among the tested genotypes (Table 4).

the partitioning of GE interaction through GGE biplot analysis showed that PC1 and PC2 accounted for 42.37% and 30.42% of GGE sum of squares, respectively, explained 72.79% of the total variance (Figure 1). The polygon view of GGE biplot was formed by connecting the vertex genotypes with straight

lines and the rest of the genotypes were placed within the polygon. The rays in Figure 1 were formed as perpendicular to the sides of the polygon or their extensions. There are four rays, which divided the biplot into four sections. The genotypes fell into four sections and all the tested environments fell into three sections (mega environments) as shown in Figure 1.

The first section contains two genotypes G24, and G26 and the vertex genotype for this section was G24, suggesting the high yielding genotype for the environments that fall in this sector. The second section contains two genotypes G27 (vertex genotypes) and G23 (vertex genotypes) were poorest yielding genotypes in any environments. The other vertex genotype G21 gave high yield in environment (E3 & E4) which fell in section 3. On the other hand, the genotype, which was located near the origin, was less responsive than the corner (vertex) genotypes. Hence, the G25, G28 and G26 were located apparently near the biplot origin showed Poorest, Moderately and average; respectively performance and these genotypes were less responsive to environments than the vertex genotypes. According to the findings of Yan and Tinker (2006), the vertex genotypes were the most responsive genotypes, as they have the longest distance from the origin in their direction. The vertex genotypes were G22, G24, G27, G23 and G21 far from the origin. These genotypes are the best or poorest in some or all environments because they are farthest from the origin of biplot [9], which were more responsive to environmental change and are considered as specially adapted genotypes.

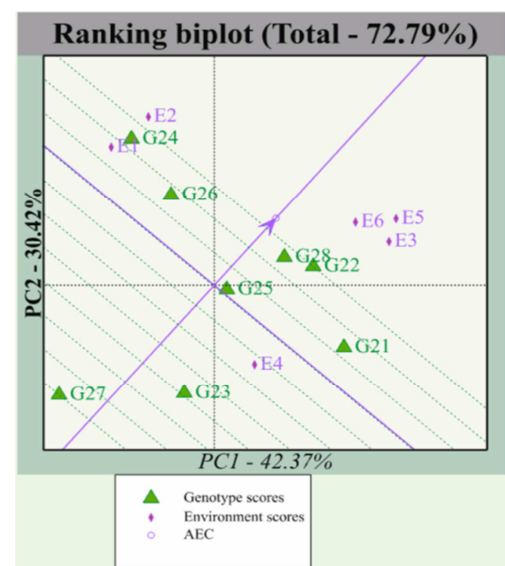


**Figure 1.** The polygon view of GGE biplot to the identification of winning genotypes and their related Mega environments (where G=genotype, E=environment). Where G21= Dagim, G22=Negus, G23=Tesfa, G24= Felagot, G25=Abola, G26=Heber-I, G27=Gibe, G28=Kora, E1= Kersa, E2=Melko, E3=Somodo, E4=Gooma, E5= Omonada and E6= Gechi

#### Genotypes Mean Yield and their Stability

Visualization of mean performance and stability analysis of

genotypes is an important issue in crop genotype evaluation. The estimation of yield and stability of genotypes were done by using the average environment (tester) coordinate (AEC) methods (Figure 2) [19, 20]. The line passing through the biplot origin is called the average environment (tester) coordinate (AEC), which is defined by the average PC1 and PC2 scores for all environments [9]. More close to concentric circle indicates higher mean yield. The line, which passes through the origin and is perpendicular to the AEC with double arrows, represents the stability of genotypes. Either direction away from the biplot origin, on the axis, indicates greater GE interaction and reduced stability. For selection, the ideal genotypes are those with both high mean yield and high stability. In the biplot, they are close to the origin and have the shorter vector from the AEC. Thus, genotypes G27, G23, G24 and G25 were the least stable and genotypes G28, G22, G26 and G25 were the most stable. On the other hand, the genotypes on the right side of the line with double arrows have yield performance greater than mean yield and the genotypes on the left side of this line had yields less than mean yield. In this study, the genotypes G22, G28 and G25 had the higher stability as well as higher mean yield and eventually had been constellated into the same group. However, G28 had the highest stability out of these three genotypes. These results are in agreement with those obtained by [21] in rice and [22] in wheat.



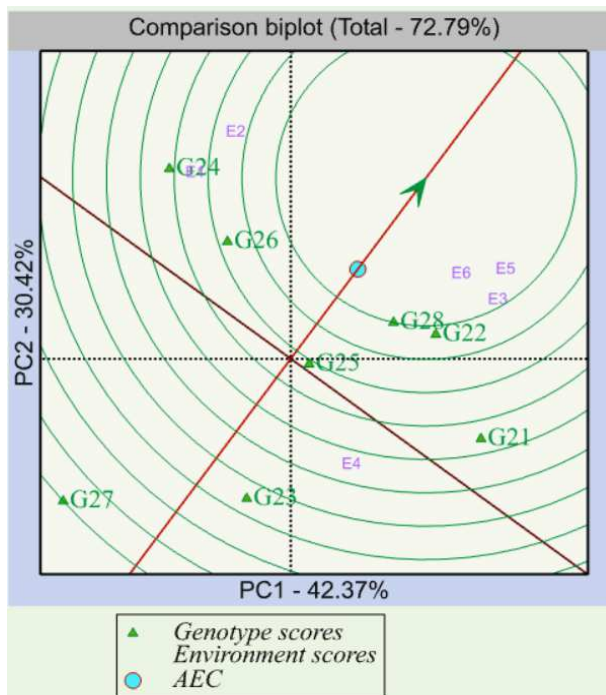
**Figure 2.** GGE biplot visualization of the genotypes ranking for both yield and stability performance over environments. Where G21= Dagim, G22=Negus, G23=Tesfa, G24= Felagot, G25=Abola, G26=Heber-I, G27=Gibe, G28=Kora, E1= Kersa, E2=Melko, E3=Somodo, E4=Gooma, E5= Omonada and E6= Gechi

#### Evaluation of Genotypes Relative to Ideal Genotypes

The ideal genotype as virtual genotype is one that has both high mean yields across test environments and is absolutely stable in performance [23, 9, 24]. This genotype has large PC1 scores (high mean yield) and small (absolute) PC2 scores (high stability). The center of the concentric circles (Figure 3) represents the position of an ideal genotype, which is defined by a projection onto the mean-environment axis that equals



the longest vector of the genotypes that had above-average mean yield and by a zero projection onto the perpendicular line (zero variability across environments). A genotype is more desirable if it is closer to the ideal genotype [25, 18, 26]. Although such as ideal genotype may not exist in reality, it can be used as a reference for genotype evaluation. Therefore, G28 was closer to the 'ideal' genotype followed by G22 and G25 being more desirable than other genotypes (Figure 3). On the other hand, the low yielding genotypes (G27 and G23) were considered to be undesirable because they are placed far from the ideal genotypes. It seems that identification of ideal genotype through GGE biplot methodology is a proper tool for identifying most stable high yielding genotypes.

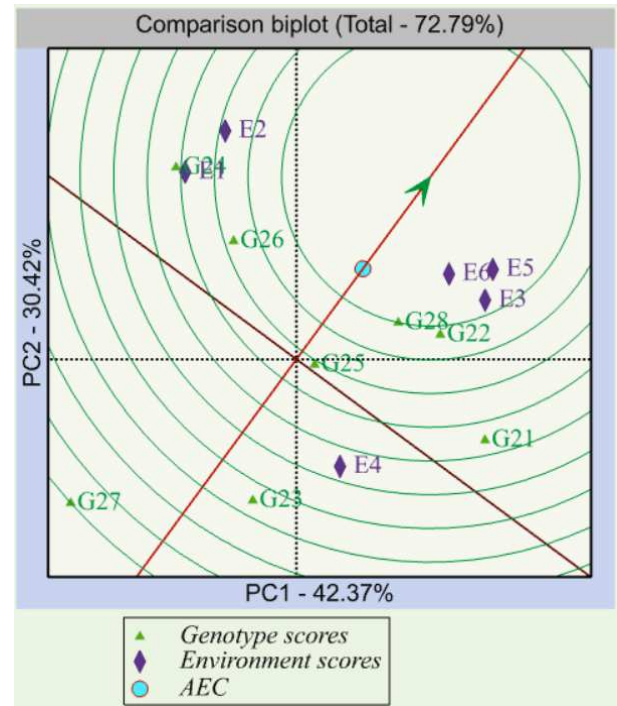


**Figure 3.** GGE biplot of ideal genotypes and comparison of the genotypes with respect to the ideal genotype. Where G21= Dagim, G22=Negus, G23= Tesfa, G24= Felagot, G25=Abola, G26=Heber-I, G27=Gibe, G28=Kora, E1= Kersa, E2=Melko, E3=Somodo, E4=Gooma, E5= Omonada and E6= Gechi

#### Evaluation of Environments Relative to Ideal Environments

Discriminating ability and representativeness are the important properties of a test environment. An ideal environment should be highly differentiating for the tested genotypes and at the same time representative of the target environment [9, 19]. Similar to ideal genotype, an ideal environment is defined and showed by the small circle with an arrow pointing to it. As shown in Figure 4 the environments E6, E5 and E3 were ideal environments. The environments E2, E1 and E4 rank first, second and third, respectively based on the ideal nature of environments (Figure 4). The environment E6, E5 and E3 has large PC1 score and small PC2 score. Hence, this environment is more stable and suitable for all genotypes following E2. On the other hand, E4 is a less desirable as testing environment because it has large PC2 score. The discriminating ability of a location is concerned

with the composition of genotypes, but the presence of GE interaction complicates the identification of an ideal test location [27]. The test environments should have large PC1 scores in order to discriminate genotypes in terms of the genotypic main effect and absolute small PC2 scores in order to be more representative of the overall locations [23].



**Figure 4.** GGE biplot of ideal environments and comparison of the environments with respect to the ideal environment. Where G21= Dagim, G22=Negus, G23= Tesfa, G24= Felagot, G25=Abola, G26=Heber-I, G27=Gibe, G28=Kora, E1= Kersa, E2=Melko, E3=Somodo, E4=Gooma, E5= Omonada and E6= Gechi

## 4. Conclusion

The Analysis of variance revealed highly significant difference for environment, genotype and genotype by environment interaction. In the present investigation, the partitioning of GE interaction through GGE biplot analysis showed that PC1 and PC2 accounted for 42.37% and 30.42% of GGE sum of squares, respectively, explained 72.79% of the total variance. The polygon views of the GGE biplot pointed out that there existed three possible mega environments. The first mega environment consisted of two environments (E6 and E5), the second mega environment consisted of two environments (E1 and E2) and the third mega environment consisted of two environments (E3 and E4). The vertex genotypes were G22, G24, G27, G23 and G21 having the largest distance from the origin. In this study, the genotypes G22, G28 and G25 had the higher stability as well as higher mean yield and eventually had been constellated into the same group. However, G28 had the highest stability out of these three genotypes. E6, E5 and E3 were ideal environments or the most suitable taste location for Tef breeding in the region. However, one season research data is not enough to identify the ideal environments so research across many years is

required to firmly conclude the identified mega environments and devise a breeding strategy for those mega environments separately.

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