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# Evaluation of released tef [*Eragrostis tef (*Zucc.) Trotter] varieties for the adaptability and stability using univariate stability parameters

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## Abstract

The objective of the experiment was to identify high yielding and stable tef varieties using univariate parametric and non-parametric stability parameters and to find out association among stability methods. Eight released tef varieties were obtained from tef breeding program based at Debre zeit Agricultural Research center and evaluated in 2019 main cropping season. The experiment was conducted using randomized complete block design in three replication across six locations. Data for all relevant agronomic traits were collected, but only plot yield data converted to qt/ha was subjected to statistical analysis. Result revealed that the most stable genotype according to the parametric and non-parametric methods was Abola,Heber-1 and Kora. Varieties Negus and Gibe were unstable according to both parametric and non-parametric methods. The result shows that both the parametric and nonparametric methods gave a relatively similar result but it is based on one data set. So to prove that both the parametric and nonparametric methods give a relatively similar result, it needs simulation study. In conclusion, several stability statistics that have been used in this study quantified stability of genotypes with respect to either yield level, stability, or both. Therefore, both yield and its stability should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of the genotypes more precise.

**Keywords: Adaptability, Stability, Tef, Varieties.**

## Introduction

Tef [*Eragrostis tef (*Zucc.) Trotter] is an endemic tropical cereal crop of Ethiopia and it has been cultivated for thousands of years in high lands Ethiopian (Abebe, 2000).It is an unidentified specific cereal crop in the world, while in Ethiopia; it is the major staple grains primarily used to make injera a delicious traditional fermented pancake. The peculiar meritorious features of tef crop that are of importance with respect to farming include: (i) broad and versatile agro-ecological adaptation under varied climatic, edaphic and socio-economic 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 is mainly serve as staple food, majority of people are preferring grain of tef for consumptions by making Enjera and local beverage.In a country of over 90 million people, tef accounts for about 15% of all calories consumed (Lester and Bekele,1981).It is highly nutritious, excellent in amino acid composition, its lysine content is higher than that of all cereals except rice and oats (Jansen *et al*.,1962),it has good mineral content and considerable amount of iron content when compared with other cereal crops (Melak H,1965).Tef is free of protein known as gluten which found in wheat, barley and rice, and can cause celiac disease by aberrant T-cell (Spaenij *et al*.,2005).The crop is not only important for grain consumption but also its straw is highly nutritious and more palatable for livestock compared to straw of other cereal crops especially during dry season.

Tef is cultivated similarly like other cereals in Ethiopia depending on agro-ecology of the area and growing period of the variety that mostly takes place once in a year, but it can rarely produce twice a year in areas receiving bimodal nature of rain. The adaptability of tef to wide ranges of environmental conditions enables its adaptability to a varied range of altitudes reaching up to 3000 meters above sea level under various climatic and soil regimes (Seyfu, 1993), However, it performs best at altitudes between 1700 and 2200 m a.s.l., annual rainfall of

750-850 mm or growing season rainfall of 450–550 mm, and temperature range of 10–27 °C. Tef usually grows from heavy black to light red soils and chemically adapted from acidic to alkaline soils, but better agronomic performance is obtain when grown under light sandy to heavy clay soils, and under moderate acidic to low alkaline conditions (Abuhay,2000). According to Seyfu (1997) tef performs very well with an annual rain-fall of 750-850mm and growing season rain-fall of 450-550mm.Despite its staple importance in the overall national food security of the country (Kebebew *et al*., 2013), tef [*Eragrostic tef* (Zucc.) *trotter*] productivity is relatively low.

The most crucial bottlenecks constraining the productivity and production of tef in Ethiopia are;a)The small size of tef seed poses several problems during sowing, and indirectly during weeding and threshing b) Shattering is also causes significant yield loss in tef production) Lodging is the major constraint to increase yield in tef,while a number of genetic and agronomic factors are involved) a limited attention has been paid to mechanization, processing and storage e) low yield potential of farmers varieties under widespread cultivation) biotic stresses such as diseases, weeds and insect pests ;g) abiotic stresses such as drought, soil acidity and low and high temperatures') the culture and labor intensive nature of the tef husbandry) inadequate research investment to the improvement of the crop as it lacks global attention; and j) weak seed and extension systems (Tadesse,1975),Bekabil *et al.,*2011;Kebebew *et al*.,2013).

Major goal of plant breeding programs is to increase stability and stabilize crop yield across environments. Seed yield is a quantitative trait, which expression is the result of genotype, environment and genotype by environment interaction (Engqvist and Becker,1993). Genotype x environment interaction (GEI) is of major importance to the plant breeder in developing improved varieties. When varieties are compared over a series of environments, the relative rankings usually differ (Eberhart and Russell).GEI is a major problem when comparing the performance of genotypes across environments (Kang 1990).

Interpretation of performance for a number of genotypes in a broad range of environments is always affected by large GEI (Gauch and Zobel 1996). The study of the GEI may assist understanding of stability concept. Understanding the structure and nature of GEI is important in plant breeding programs because a significant GEI can seriously impair efforts in selecting superior genotypes relative to new crop introductions and cultivar development programs. It can help determine if they need to develop cultivars for all target environments or if they should develop specific cultivars for specific target environments.

GEI occurs when the performance of the genotypes is not consistent from one environment to another. A significant GEI for a quantitative trait such as grain yield can reduce the correlation between phenotype and genotype, and decreases progress in selection (Comstock and Moll, 1963). The basic cause of differences between genotypes in their yield stability is the wide occurrence of GEI, i.e. the ranking of genotypes depends on the particular environmental conditions where they are grown. These interactions of genotypes with environments can be partly understood as a result of a differential reaction to environmental stress factors like drought or diseases, and consequently resistance breeding is of significance in improving yield stability (Becker and Leon, 1988).

When discussing these unexpected variations in yield the term "phenotypic stability" is often used to refer to fluctuations in the phenotypic expression of yield while the genotypic composition of the varieties or populations remains stable. Several methods have been developed by statisticians and applied by plant breeders to explain the GEI at the end of plant breeding programs like phenotypic variances (Roemer, 1917), interaction sums of squares (Shukla, 1972), slope of regression on an environmental index (Finlay and Wilkinson 1963), nonparametric measures (Nassar and Huehn 1987).

The occurrence of GEI has led to the development of several stability parameters that can be used to estimate the stability of cultivar performance. Romagosa and Fox (1993) and Huehn (1996) indicated that there are two major approaches for studying GEI to determine the adaptation of genotypes. First, is the parametric (empirical and statistical) approach, which is based on statistical assumptions about distribution of genotype, environment and GEI effects. Second, is the nonparametric (analytical clustering) approach, which does not need any assumptions when relating to environment and phenotypic relative to biotic and abiotic environmental factors. Although several models for the statistical measurement of stability have been proposed no single method adequately explains genotype performance across environments. For practical applications, however, most breeding programs are now incorporating some elements of both parametric and nonparametric approaches (Becker and Leon 1988).

Parametric methods for estimating phenotypic stability are widely used in plant breeding and they were mostly related to the variance components and related statistics.The parametric methods range from univariate to multivariate models. Joint regression is the most popular among the univariate methods because of its simplicity of calculation and application (Becker & Leon 1988).Lin *et al*. (1986) mentioned that, the stability statistics fall into four groups depending on whether they are based on the deviations from the average genotype effect or on the GEI term, and whether or not they incorporate a regression model on an environmental index. These groups of parametric stability are shown to be related to three concepts: A genotype may be considered to be stable (I) if its among-environment variance is small, (II) if its response to environments is parallel to the mean response of all genotypes in the trial, or (III) if the residual mean square from a regression model on the environmental index is small. In first concept, Becker and Léon, (1988) called this stability a static, or a biological concept of stability.

Parameters used to describe this type of stability are coefficient of variability (CVi) used by Francis and Kannenburg (1978) for each genotype and the genotypic variances across environments ($Si^2$), and the coefficient of determination ($r^2$). As for second concept, Becker and Léon, (1988) called this stability the dynamic or agronomic concept of stability. Parameters used to describe this type of stability are regression coefficient bi (Finlay and Wilkinon, 1963), Wricke's (Wricke, 1962) ecovalence (Wi) and Shukla's stability variance $\sigma^2i$ (Shukla, 1972). The third concept is also part of the dynamic or agronomic stability concept according to Becker and Léon (1988).

The advantage of the nonparametric approach is that a cultivar's response characteristics can be assessed qualitatively, without the need for a mathematical characterization (Lin *et al*., 1986).These parametric estimates have good properties under certain statistical assumptions, like normal distribution of errors, homogeneity of variance and interaction effects; they may not perform well if these assumptions are violated, for example, in the presence of outliers (Huehn,1990). That means parametric tests for significance of variances and variance-related measures could be very sensitive to the underlying assumptions. Thus, it is wise to search for alternative approaches that are more robust to departures from common assumptions, such as nonparametric measures. The objectives of this study were 1) to analyze GEI 2) to identify promising high-yielding and stable genotypes 3) to study the relationships, similarities and dissimilarities among the parametric stability statistics on grain yield of tef varieties at southwestern Ethiopia

## Materials and Methods

The experiment was conducted during the 2019 main cropping season at six locations, namely:Melko (On station), Gechi, Omonada, Kersa,Somodo and Gooma weredas of Southwestern Ethiopia. (Table 1).

**Experimental Materials:** Eight 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 ($^0$C) | Rainfall (mm) |
|---|---|---|---|---|---|
| Gechi | 2087 | 8$^0$27′N 36°21′E | Nitosols | 20.7 | 1800 |
| Gooma | 1,560 | 7$^0$51′N 36°35′E | Nitosols | 19.7 | 1764 |
| Kersa | >1780 | NA | Nitosols | 20.3 | 2000 |
| Mana | 1770 | 7$^0$45′N 36°45′E | Nitosols | 18.9 | 1624 |
| Melko | 1753 | 7$^0$47′N 360 47′′E | Nitosols | 22 | 1639 |
| Omonada | 1975 | 7$^0$ 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 | - |
| Negus | 2017 | 112-116 | DZARC | - | - | 2.0–2.6 | - |

**Experimental Design and Management:** The trial was conducted using randomized complete block design (folded RCBD) with three replications at all locations under rain-fed conditions. Sowing was done manually. Spacing between plots was 1 m, whereas that 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 $P_2O_5$ per hectare for light soils and 60kg N and 60kg $P_2O_5$ 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.

**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.

**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 ($90^o$), 1 = 0- $15^0$ lodging, 2=15-$30^0$ lodging 3 = 30-$45^0$ lodging, 4 = 45-$60^0$ lodging and 5 = 60-$90^0$ 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

**Harvest index:** The value computed as the ratio of grain yield to the total (grain plus straw) biomass multiplied by 100.

**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:**

**Separate and combined ANOVA:** Homogeneity of residual variances was tested prior to a combined analysis using Bartlet's test (Steel and Torrie, 1980). As error variance were homogenous, seed yield continued to combined analysis of variance from the mean data of all environments to detect the presence of GEI and to partition the variation due to genotype, environment and GEI. The environments (locations) in the study were assumed as random effects and the genotype effects were treated as fixed. Moreover, mean comparison using Fisher‟s Least Significant Difference (LSD) was performed to explain the significant differences among means of genotypes and locations (environments). GenStat 16th edition (2010) statistical software was used for statistical analyses. The model employed in the analysis was;

In the combined analysis of variance, each combination of location x growing season was treated as an environment (E) and the data were analyzed according to the following model

$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + Bk_{(j)} + \epsilon_{ijk}$ Where: $Y_{ijk}$ = Observed value of genotype i in block k of environment (location) j, μ = Grand mean, capitalize the first letters, like this $G_i$ = Effect of genotype i,$E_j$= Environment or location effect, $GE_{ij}$ = The interaction effect of genotype i with environment j, $Bk_{(j)}$ = The effect of block k in location (environment) j, $\epsilon_{ijk}$= Error (residual) effect of genotype i in block k of environment j.The combined analysis of variance was carried out to estimate the additive effects of environment, genotype and GEI. Significance levels of these components were determined using F- test.

## Result and Discussion

Mean values of grain yield of tef varieties across six locations for one year were shown in Table (3). Mean yields of varieties across environments ranged from 3.3qt/ha (Tesfa) to 6.4 (Felagot) at Melko, 3.9 (Negus) to 8.3 (Felagot) at Kersa, 4.2(Gibe) to 7.5(Dagim) at Omonada, 5.7(Negus) to 8.7(Dagim) at Gooma, 6.3(Tesfa) to 11.3(Kora) at Manna) and 6.3 (Gibe) to 15qt/ha (Negus) at Gechi. Mean yield of varieties ranged from 8.29q/ha to 5.83/ha across environment, with overall mean grain yield of 7.5qt/ha. From out of seven varieties, Variety Kora and Dagim were high yielders and ranked first and second and varieties Gibe and Tesfa were low yielders and ranked eight and seventh respectively.Varieites performed differently at different locations. For example, Varieites Heber-1 and Felagot were high yielders at Melko and Kersa,Dagim and Negus at Omonda, Dagim and Gibe at Gooma, Kora and Dagim at Manna and Negus and Dagim at Gechi. These varieties produced the best values of the studied traits at different locations, (Table 5) but some varieties could not, indicating their inconsistent relative performance and high sensitivity to environmental variation. Consistent performances across different sites and/or years are referred to as yield stability (Thillainathan and Fernandez, 2002). This differential yield ranking of genotypes across the environments showed that the GE interaction effect was of the crossover type (Yan and Hunt, 2001).Generally, location Gechi was favorable and high yielding environment and at Melko varieties showed poor performance and low yielding environment.

**Table 3. Analysis of variance and mean performance of grain yield qt/ha across locations**

| | Locations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Varieties** | **Melko** | **Kersa** | **Omonada** | **Gooma** | **Mana** | **Gechi** | **Mean** | **Rank** |
| Dagim | 4.0 | 4.6 | 7.47 | 8.67 | 11.0 | 13.9 | **8.27** | 2 |
| Negus | 4.8 | 3.9 | 7.4 | 5.67 | 10.0 | 15.0 | **7.80** | 4 |
| Tesfa | 3.3 | 4.4 | 5.15 | 5.97 | 6.3 | 13.8 | **6.49** | 7 |
| Felagot | 6.4 | 8.3 | 5.7 | 5.97 | 7.5 | 13.8 | **7.95** | 3 |
| Abola | 4.6 | 6.1 | 6.4 | 7.07 | 9.0 | 12.5 | **7.61** | 6 |
| Heber-1 | 5.7 | 7.6 | 6.55 | 6.47 | 8.5 | 11.3 | **7.69** | 5 |
| Gibe | 4.6 | 5.8 | 4.2 | 7.77 | 6.3 | 6.3 | **5.83** | 8 |
| Kora | 4.8 | 6.4 | 7.15 | 7.57 | 11.3 | 12.5 | **8.29** | 1 |
| **Mean** | **4.8** | **5.9** | **6.3** | **6.9** | **8.7** | **12.4** | **7.5** | |
| **CV (%)** | **7.4** | **6.2** | **8.4** | **6.89** | **11.96** | **7.5** | | |
| **LSD value** | **0.62** | **0.63** | **0.92** | **0.83** | **1.82** | **1.6294** | | |
| **F test** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **0.0001** | **<.0001** | | |

**Genotype by Environment interaction effects and genotypic mean performance:** Combined analysis of variance was performed to determine the effects of environment, genotype, and GE interaction on grain yield of tef varieties regarding to result of Bartlett's homogeneity test. Combined analysis of variance for grain yield showed that main effects of genotypes and environments, as well as GEI were significant at p<0.05 (Table 4). The significance of the GEI effects suggests that there were significant difference in response of genotypes to environments and hence sensitivity and instability (Akcura *et* *al*.,2006).Genotypic rank differences over environments showed the existence of crossover GEIs (Crossa,1990),which showed the necessity to assess the response of the genotypes to environmental variation.

Grain yield is a quantitative trait, which its expression is the result of genotype, environmental factors and GE interaction. The large magnitude of GEI, cause to the more dissimilar genetic systems, which controlling the physiological processes conferring yield stability to different environments (Cooper *et al*., 2001).

The total variation explained was 69.2% for environment, 7.5% for genotype and 20.2% for GEI (Table 4). The high percentage of the environment sum square is an indication that the major factor that influence yield performance of tef varieties was the environment. The relatively large percentage of the GEI sum square when compared to that of genotypes as a main effect is a very important consequence. The GEI is highly significant (p<0.01) accounting for 20.2% of the sum of squares implying the need for investigating the nature of differential response of the genotypes to environments.

**Table 4. Combined ANOVA for grain yield (kg/ha) and the percentage sum of squares of the eight tef varieties tested at different environments during 2019 cropping season**

| Source of variation | df | SS | %SS | MS |
|---|---|---|---|---|
| Location | 5 | 894.1 | 69.2 | 178.8*** |
| Replication with loc (R/loc) | 12 | 1.9 | 0.15 | $0.158^{ns}$ |
| Genotype | 7 | 96.8 | 7.5 | 13.8*** |
| Interaction (GEI) | 35 | 260.8 | 20.2 | 7.45*** |
| Residuals | 84 | 37.9 | | |
| Total | 143 | 1291.6 | | |
| **Mean=**7.5 | **CV=**8.9 | **$R^2$**=0.970598 | | |

**Table 5. 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 qt/ha** | **GY qt/ha** | **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=above ground biomass,GY =grain yield and HI =harvest index**

**Stability Analysis:** In the presence of variable abiotic stressors, a desirable, ideal genotype has consistent, good performance in the target region. According to the Shukla's stability variance, a genotype is considered as stable genotype when its contribution to the total GEI sum of squares is small as compared to the contribution of other genotypes in a given test. A relatively large value of will thus indicate greater instability of genotype. Thus a varieties Abola,Kora and Heber-1 with low value of stability variance and mean grain yield above the average were stable and the varieties Gibe, Negus and Felagot with high stability variance were considered as unstable (Table 6).

Based on Pinthus's (1973) coefficients of determination ($R^2$), the stability parameter values are the predictability of estimated response. The coefficient of determination ($R^2$) represents agronomic stability (Becker, 1981). A genotype with a high coefficient of determination can be considered to be stable. The predictability of genotypes for the grain yield ranged from 0.15 to 0.99, indicating that 15 -99% of the mean grain yield variation was explained by genotype response across different environments. In terms of this parameter, the variety Abola has the highest mean grain yield and coefficient of determination ($R^2$ =0.99), was considered to be most stable genotype. Varieties with low coefficient of determination were considered as unstable. The varieties Gibe and Felagot were with low value were unstable (Table 6).

According to the parameters of Eberhart & Russell model, regression coefficients and deviation from regression ranged from 0.2 to 1.4 and from -0.13 to 2.78, respectively, indicating that genotypes already had different responses to environmental changes. According to this model a stable genotype should have a high mean yield, $b$=1.0 and $S^2di$ =0. It is however specifically the deviation from the regression ($S^2di$) which is used as a measure of a genotype's stability across environments. Thus the varieties Abola and Heber-1 with regression coefficient close to 1 and deviation from regression close to zero were considered as stable (Table 6).

Lin and Binns (1988) suggested the use of stability index (*Pi*) when describing the performance of one genotype across a range of environments. The superiority can be assessed by the index *pi* based on the GEI. The estimate of *pi* could be partitioned into a portion attributed to genetic deviation, that is, the sum of the squares of the genotypes. This would be troublesome to breeders since it does not necessarily imply alteration in the genotypes ranking or in the portion attributed to GEI. Therefore, the genotypes of most stable must be those with the lowest *pi* values, most of which would be attributed to genetic deviation (Lin and Binns, 1988).Accordingly, the genotypes Kora,Dagim and Abola have the highest mean grain yield, the lowest *pi* values and were the most stable genotypes, whereas the genotypes Gibe and Tesfa were the least stable ones (Table 6).

Regarding to Francis and Kannenberg's (1978) Coefficient of variation stability parameter (CVi), genotypes with minimum value are considered more stable. The coefficient of variation ranged from 22.1 to 57.6. Hence, the genotypes Gibe and Heber-1 with the low value of coefficient of variation were considered to be stable although they had low performance, and the varieties Negus and Tesfa with the high value of coefficient of variation were considered as unstable (Table 6).Wricke (1962) suggested the use of ecovalance (Wi) as a stability parameter. According to this stability parameter, genotypes with the smallest ecovalance ($Wi^2$) values are considered stable. The Wi was lowest for varieties Abola,Kora and Heber-1 and highest for Gibe and Negus (Tab. 6).

Nassar and Hühn (1987) described non-parametric measures of stability based on ranks and provide a viable alternative to existing parametric analyses. This non-parametric test is based on the ranks of the genotypes across locations. This gives equal weight to each location or environment. Genotypes with less change in rank are expected to be more stable. The mean absolute rank difference ($S^1$) estimates are all possible pair wise rank differences across locations for each genotype. The $S^2$ estimates are simply the variances of ranks for each genotype over environments (Nassar and Hühn, 1987; Hühn, 1990). For $S^1$, entries may be tested for significantly less or more stable than the average stability/instability For the variance of ranks ($S^2$), smaller estimates may indicate relative stability. Often, $S^2$ has less power for detecting stability than $S^1$. The $S^1$ may loose power when genotypes are similar in their interactions with the environments. Usually $S^1$ is the preferred parameter because of its ease of computation; it's clear and relevant interpretation. Furthermore, an efficient test of significance is available (Hühn, 1990). Abola, Tesfa and Heber-1 had highest grain yield and lowest absolute mean rank difference and they were stable varieties according to the principle of Nassar and Hun's mean absolute rank difference. Varieties Negus and Gibe had highest absolute mean rank difference value indicating to be highly unstable varieties (Table 6).

In AMMI stability value model, genotypes or varieties with least AMMI stability value were considered as the most stable, where as those which have highest AMMI stability value are considered as unstable (Purchase, 1997). Accordingly, Abola was found to be the most stable variety, followed by Kora and Heber-1, using this method (Table 7).

**Table 6. The various models of stability used to partition the GEI for grain yield in the test tef varieties and their ranking**

| Varieties | Mean | CV(%) | bi | $S^2di$ | $R^2$ | $\sigma^2$ | Wi | Pi | Si(1) | $Si^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Dagim | 8.3 | 45.8 | 1.3 | 1.57 | 0.9 | 2.45 | 10.7 | 1.74 | 0.53 | 7 |
| Negus | 7.8 | 53.2 | 1.4 | 1.62 | 0.91 | 3.52 | 14.7 | 2.71 | 1.13 | 9.25 |
| Tesfa | 6.5 | 57.6 | 1.3 | 0.97 | 0.93 | 1.81 | 8.4 | 5.3 | 0.43 | 2.75 |
| Felagot | 7.9 | 38.1 | 0.95 | 2.78 | 0.74 | 2.74 | 11.8 | 2.16 | 0.57 | 6.5 |
| Abola | 7.6 | 36.8 | 1.025 | -0.13 | 0.99 | -0.3 | 0.13 | 1.94 | 0.37 | 0.85 |
| Heber-1 | 7.7 | 26.2 | 0.7 | 0.31 | 0.91 | 0.94 | 5.1 | 2.34 | 0.47 | 3.8 |
| Gibe | 5.8 | 22.1 | 0.18 | 1.6 | 0.15 | 8.1 | 31.8 | 10.17 | 0.93 | 5.65 |
| Kora | 8.3 | 35.9 | 1.04 | 0.8 | 0.91 | 0.7 | 4.18 | 1.15 | 0.5 | 2.1 |

CV =Coefficient variation $R^2$=Coefficient of determination, (S(1) and S(2))=Nassar and Hühn's (1987) absolute rank difference and variance of ranks respectively, Wi=Wriecke's ecovalence Pi =Cultivar superiority,IPCA1=First interaction principal component analysis,ASV=AMMI stability value,YSI=Yield stability index, $\sigma^2$ **=** Shukla's (1972) stability variance and bi and $S^2di$=Eberhart and Russell (1966) stability value of regression coefficient (bi) and deviation from regression ($S^2di$)

**Table 7. Mean grain yield (qt/ha), AMMI Stability Value (ASV), and IPCA 1 and IPCA 2 scores of the eight tef varieties tested across six environments**

| Varieties | Mean yield | Rank | IPCA1 | IPCA2 | ASV | Rank | YSI | Rank |
|---|---|---|---|---|---|---|---|---|
| Dagim | 8.257 | 2 | 0.76499 | 1.08706 | 1.29 | 5 | 7 | 2 |
| Negus | 7.783 | 4 | 1.34545 | 0.06967 | 1.6 | 7 | 11 | 7 |
| Tesfa | 6.467 | 7 | 0.6666 | -0.67287 | 1.04 | 4 | 11 | 6 |
| Felagot | 7.933 | 3 | -0.25041 | -1.50529 | 1.53 | 6 | 9 | 5 |
| Abola | 7.592 | 6 | 0.0391 | 0.08302 | 0.1 | 1 | 7 | 3 |
| Heber-1 | 7.674 | 5 | -0.67092 | -0.36947 | 0.88 | 3 | 8 | 4 |
| Gibe | 5.812 | 8 | -1.99863 | 0.5901 | 2.44 | 8 | 16 | 8 |
| Kora | 8.264 | 1 | 0.10382 | 0.7178 | 0.73 | 2 | 3 | 1 |

IPCA1= interaction principal component axis one, IPCA2= interaction principal component axis two and ASV= AMMI stability value

**Interrelationships Among Stability Parameters:** The ranks of eight tef varieties and six environments after applying the methods of stability analysis were used to assess the relationships among stability parameters. The results of the Spearman's rank correlation coefficient among the 11 parametric and non-parametric stability statistics and mean yield are presented in Table 8. Mean yield performance across environments was significantly positively correlated with Coefficient of determination ($R^2$) and negatively correlated with YSI and Pi measures (P<0.05 and P<0.01 respectively), but it was not significantly correlated with Wi, $Si^1$ , $Si^2$ , CV,bi,$S^2di$,$R^2$,SH,Wi and ASV (Table 8).The high correlation between mean yield and stability measures is expected as the values of these statistics were higher for high yielding genotypes. The non-significant correlation and negative significant correlation between yield and stability parameters suggest that stability parameters provide information that cannot be gleaned from average yield alone (Mekbib, 2002).

Shukla stability value showed strong correlation with Wi,Pi,ASV and YSI.Wi positively correlated with Pi,ASV and YSI.There is positive and strong correlation among Pi and YSI,ASV with YSI and $Si^2$,$Si^1$ and $Si^2$,CV with bi and $R^2$ with bi.Coefficient of determination ($R^2$) showed strong and negative correlation with stability variance,Wi,Pi,ASV and YSI (Table 8). Positive correlation among stability parameter means they can gave similar pattern in ranking of the genotypes and this implying that they can be used interchangeably in the study of genotype by environment interaction of tef and the result was in agreement with (Bantayehu, 2009).

**Table 8. Spearman's coefficient of rank correlation for twelve genotype x environment interaction stability parameters of eight tef varieties evaluated in six environments in South and Southwestern Ethiopia, 2019.**

| | Yield | CV (%) | bi | $S^2$di | $R^2$ | $\sigma^2$ | Wi | Pi | S(1) | S(2) | IPCA1 | ASV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CV (%)** | 0.18752$^{ns}$ | | | | | | | | | | | |
| **bi** | 0.57224$^{ns}$ | 0.90428** | | | | | | | | | | |
| **$S^2$di** | -0.005$^{ns}$ | 0.14909$^{ns}$ | 0.0078$^{ns}$ | | | | | | | | | |
| **$R^2$** | 0.70423* | 0.57359$^{ns}$ | 0.82103** | -0.40059$^{ns}$ | | | | | | | | |
| **$\sigma^2$** | -0.65883$^{ns}$ | -0.27902$^{ns}$ | -0.57105$^{ns}$ | 0.55226$^{ns}$ | -0.91884** | | | | | | | |
| **Wi** | -0.65772$^{ns}$ | -0.2756$^{ns}$ | -0.56845$^{ns}$ | 0.55597$^{ns}$ | -0.91721** | 0.99993** | | | | | | |
| **Pi** | -0.95153** | -0.29346$^{ns}$ | -0.66124$^{ns}$ | 0.16868$^{ns}$ | -0.86631** | 0.84389** | 0.843 | | | | | |
| **S(1)** | -0.25789$^{ns}$ | 0.0329$^{ns}$ | -0.1317$^{ns}$ | 0.46125$^{ns}$ | -0.49293$^{ns}$ | 0.73081* | 0.73065* | 0.42696$^{ns}$ | | | | |
| **S(2)** | 0.09224$^{ns}$ | 0.22223$^{ns}$ | 0.14315$^{ns}$ | 0.74505* | -0.25126$^{ns}$ | 0.557* | 0.55974$^{ns}$ | 0.10028$^{ns}$ | 0.77078** | | | |
| **IPCA1** | 0.56735$^{ns}$ | 0.89451** | 0.99046** | 0.00051$^{ns}$ | 0.79874** | -0.52074$^{ns}$ | -0.51826$^{ns}$ | -0.64016$^{ns}$ | -0.01975$^{ns}$ | 0.21688$^{ns}$ | | |
| **ASV** | -0.50612$^{ns}$ | -0.16695$^{ns}$ | -0.43724$^{ns}$ | 0.72507* | -0.81855* | 0.95562** | 0.95819*** | 0.70639* | 0.74804** | 0.71502* | -0.38888$^{ns}$ | |
| **YSI** | -0.85104** | -0.0929$^{ns}$ | -0.46421$^{ns}$ | 0.34666$^{ns}$ | -0.74052* | 0.84146** | 0.84059*** | 0.88423** | 0.60919$^{ns}$ | 0.41495$^{ns}$ | -0.4207$^{ns}$ | 0.77198** |

*, **, ns =significant, highly significant and non-significant at the level of P<0.01 and 0.05 respectively,CV =Coefficient variation $R^2$=Coefficient of determination, (S(1) and S(2))=Nassar and Hühn's (1987) absolute rank difference and variance of ranks respectively, Wi=Wriecke's ecovalence Pi =Cultivar superiority,IPCA1=First interaction principal component analysis,ASV=AMMI stability value,YSI=Yield stability index, $\sigma^2$ = Shukla's (1972) stability variance and bi and $S^2$di=Eberhart and Russell (1966) stability value of regression coefficient (bi) and deviation from regression ($S^2$di)

## Conclusion

In crop improvement programmes, genotypes are tested in different seasons and locations to determine performance and adaptation of genotypes. Thus, evaluation based on several seasons and locations is the best strategy. Farmers in developing countries, who use no or limited inputs, or under unpredicted environments will prefer yield stability than increment. In these cases, genotypes with good performances and stability should be the most preferred. Genotypes with good stability are most targeted for environmental conditions which are highly unpredictable. This ultimate goal can be achieved using the screening and shuttle breeding of segreganting populations in contrasting environments, followed by the multi locational evaluation of performance of varieties. Stability analysis can help to characterize the response of varieties to changing environments and to determine the best locations representative of the environmental diversity (Mohammed *et al.*, 2008).

The most stable genotype according to the parametric and non parametric methods was Abola,Heber-1 and Kora.Varieties Negus and Gibe were unstable according to both parametric and non parametric methods. The result shows that both the parametric and nonparametric methods gave a relatively similar result, but it is based on one data set. So to prove that both the parametric and nonparametric methods give a relatively similar result, it needs simulation study. In conclusion, several stability statistics that have been used in this study quantified stability of genotypes with respect to either yield level, stability, or both. Therefore, both yield and its stability should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of the genotypes more precise.

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