Agricultural Science; Vol. 2, No. 1; 2020
ISSN 2690-5396 E-ISSN 2690-4799
https://doi.org/10.30560/as.v2n1p70

# Grain Yield Performance and Parametric Stability Statistics of Tef {*Eragrostis tef (Zucc) Trotter*} Genotypes in Tigray, Ethiopia

Chekole Nigus[1], Yonas G/mariam[1], Hailegbreal Kinfe[2], Brhanu Melese[1] & Ataklty Mekonen[1]

[1] Tigar Agricultural Research Institute, Axum Agricultural Research center, Axum, Ethiopia

[2] Tigar Agricultural Research Institute, Maytsebrie Agricultural Research center, Ethiopia

Correspondence: Chekole Nigus, Tigar Agricultural Research Institute, Axum Agricultural Research center, P. O. Box. 230, Axum, Ethiopia. E-mail: chekolenigus@gmail.com

Received: February 24, 2020 Accepted: March 27, 2020 Online Published: April 2, 2020

**Abstract**

The most constraints of tef productions are lodging, drought, low yield cultivars; insect and disease affected the growth of tef. These, factors causes inconsistence performance yield due to GEI. The objective was to evaluate tef genotypes on their yield performance, stability and parametric stability to select most independent and informative statistics method. The experiment was conducted at four locations for two seasons; with design of RCBD three replications, two standard checks and 19 tef genotypes. Data was collected on grain yield and analyzed by R software and STABILITYSOFT. The analysis of variance for the combined mean of grain yield showed that there was significance difference ($P<0.001$) between genotypes, environments and GEI. Yield performance was influenced by Environments and GEI. The mean grain yield of genotypes over GEI varies from 820.94kg/ha to 2438.90kg/ha, while the genotype grain yield was ranged from 1382 to 1989kg/ha. G19, G17 and G6 were identified the higher grain yield performance over seven environments. Whereas, G8 and G11 were the lowest yielding tef genotypes. Nine parametric methods and GGE biplot were used to evaluate the stability of the genotypes. G19 was the most stable following G17 and would be grown for unfavorable growing environments. However, G6 was stable for favorable environmental condition. G19 and G17 had static stability and fitting for area faced with erratic rain fall. Even though, parametric stability did not show a positive and statistically significant correlation with mean yield the Mean variance component ($\theta i$) is selected with GGE biplot for evaluation of tef genotypes in the development of cultivar. Effective selection of variety would be best if mega-environment, representative and discriminating testing areas are identified.

**Keywords:** Genotype by environment interaction, tef yield Stability, stability parametric methods of tef

## 1. Introduction

Then national tef breeding program working on the development of high yielding varieties for wider adaptable, lodging tolerant, tolerant to low moisture stress, desirable grain quality (Kbebew et al. 2011) and introducing nontraditional areas of tef production. The development of tef variety for wider adaptable is a major interest and a challenging condition for breeders (Kassa et al. 2013). This challenge is due to the genotype by environment interaction (GEI) which causes limiting for identifying superior genotypes. GEI is the relative performance of genotypes varies from one environment to others (Y ali et al. 2004). Fluctuation in the performance yield reduced by classifying heterogeneous region into mega-environment (small region with homogeneous) to develop genotypes for specific location (Mohammadi et al. 2007) and selection of higher yielding and stabile genotypes across different environments (Eberhart and Russell 1966). Plant breeders test genotypes in multi environmental trial (MET) to solve the difficulty of selection on grain yield due to GEI (Ülker et al. 2006). Selection of genotype is valuable in plant breeding, when the environment is variable and unpredictable (Mohammadi et al. 2010).

Due to the different factors the productivity of tef is low 17.5qt/ha (CSA 2018). The most constraints of tef production are lodging, drought, low yield cultivars; insect and currently different types of disease affected the growth of tef. Despite the national tef research program attend to develop up to 42 tef varieties (MoALR 2017), yet, from the released tef varieties achieved the potential yield of the crop. It shows there is higher difference between the potential of tef and the actual yield called yield gap which is less than half. This is due to the limitation of well performing and stable tef genotypes in wider areas of the region.

Tef adapted to highly diverse climatic condition and soil types of the country (Ebba 1969). The optimum altitude ranges from 1700-2200 m and growing-season rainfall of 300 mm (Seyfu 1993). The Central Statistics Agency (CSA 2018) reported that the area covered by tef is more than 3 million hectare and 23.85% of the total land allocated to cereal crops. Tef has a plenty of merits; of them cope from erratic climate, generate house hold income (grain and straw), fulfill nutritional needs(Assefa et al. 2015), its grain is free of gluten (Spaenij-Dekking et al. 2005) and it has relatively few disease and insect pest problems(Kebebew, 2009).

Stability of yield is consistently performing genotypes over a range of environments (Heinrich et al., 1983). Stable genotype has a minimum interaction with environment caused by genetic traits (Eberhart and Russel 1966). Whereas, unstable genotypes had higher interaction due to the environmental factors (rain fall, temperature, soil type etc.) vary their performance per location and season. The stability of variety existed by three cases; with small variance among environments, parallel response of variety to mean response of all varieties in the trial and small residual MS from the regression (Binns and Lefkolitch 1985). As Kassa et al. (2013) report shows that there is a significance difference of environments and genotypes of tef. This reveal that the environments influence on tef genotypes diversely to express their performance and stability and tef genotypes which have higher grain yield and stabile (small variance of deviation) are responsive to favorable growing condition.

Genotype performance would predicted their adaptability and stability through different method of evaluation because of there is different level of association between them (Silva and Duarte 2006; Roostaei et al. 2014). Therefore, a comparative study among the more widely used methods is important. From varies methodologies nine parametric and GGE biplot were selected to evaluate the adaptability and stability of method for the present study. These methods were regression coefficient (bi; Finlay and Wilkinson,1963), variance of deviation from the regression(S2di; Ebrehart and Russel 1966), Wricke's ecovalence stability index(Wi2;Wricke 1962), Shukla's stability variance(σi2;Shukla 1972), environmental coefficient of variance (CVi;Francis and Kannenberg 1978), Peterson's mean variance component (θi;Plaisted and Peterson ,1959), Plaisted's GE variance component (θi;Plaisted 1960), yield stability index(YSi; Kang 1991), AMMI stability value(ASV; Purchase et al. (2000) and GGE biplot (Yan et al.2010 and Mohammedi et al. 2010). The stability evaluation method grouped in to two concept of stability based on the discrimination and correlation analysis. These groups were static and dynamic stability (Mohammedi et al. 2010).

Crossing of tef parent to produce recombinant inbred lines and evaluation of tef genotypes their yield performance and stability in multi-location trial (MET) is an important phenomenon. Due to the climatic fluctuation providing tef variety that has higher yielding and stable over the tested location per season is more necessary. Higher yielding and stable tef varieties increases the production and productivity of tef in the nation. The purpose of this study was to evaluate tef genotypes their yield performance, stability and parametric stability statistics for select the most independent and informative statistics method

## 2. Materials and Methods

### *2.1 Description of the Study Areas*

Tef genotypes were selected for evaluation of their stability at Axum and Maytsebri Agricultural Research Center during the 2017/18 and 2018/19 cropping season at stations of these centers. The list of locations their names, coordination point, altitude and soil texture (Table 1). Except Selekhlekha all tested location were ranged in similar altitudes.

Table 1. Lists of locations, their geographical coordination of each location and soil texture

| s.on | Locations | Longitude | Latitude | Altitude(masl) | Soil texture |
|---|---|---|---|---|---|
| 1 | Hatsebo | $38^0$ 46'17.403'' | $14^0$ 6'28.051'' | 2100 | Clay loam |
| 2 | Maysiye | $38^0$ 36'41'' | $14^0$ 6'43'' | 2200 | Sandclay loam |
| 3 | N/adet(adeyselam) | $38^0$ 38'18.366'' | $13^0$ 52'16.302'' | 2100 | Slit loam |
| 4 | Selekhlekha | $38^0$ 16'45.768'' | $14^0$ 4'9.084'' | 1961 | Loam |

### *2.2 Experimental Design and Materials*

The trial was conducted having nineteen recombinant inbred lines with two checks, standard and local. These recombinant lines were obtained from the national tef research program of preliminary yield trial (PVT) tested at our site (Hatsebo 2015/16). Consequently, lines which were higher in yield than the standard checks selected for regional variety trial. The experiment was layout using RCBD design with three replication and plot size of 2mx2m=4m$^2$ with ten number of rows per plot and the net harvestable plot size 3.2 m$^2$, 0.2m between rows,0.5m between plots and 1m between replication were spaced. The seed were sown by drilling in a row with hand. Type of fertilizer used and their application was: - blended fertilizer had applied per the blanket recommendation of the tested locations with rate of 100kg/ha while urea was applied 100kg/ha for all locations with split application. The first phase at early two weeks later after germination the second phase also applied near to heading of the crop. All recommended agronomic management practice was applied.

Table 2. List of the pedigree for the tested genotypes and their source

| Pedigree | Source | Code | Pedigree | Source | code |
|---|---|---|---|---|---|
| DZ-Cr-387 X Rosea(RIL-9) | DZARC | G1 | DZ-Cr-387 X Rosea(RIL-80) | DZARC | G12 |
| DZ-Cr-387 X Rosea(RIL-13) | DZARC | G2 | DZ-Cr-387 X Rosea(RIL-107 ) | DZARC | G13 |
| DZ-Cr-387 X Rosea(RIL-18) | DZARC | G3 | DZ-Cr-387 X Rosea(RIL-114 ) | DZARC | G14 |
| DZ-Cr-387 X Rosea(RIL-23) | DZARC | G4 | DZ-Cr-387 X Rosea(RIL-116) | DZARC | G15 |
| DZ-Cr-387 X Rosea(RIL-24) | DZARC | G5 | DZ-Cr-387 X Rosea(RIL-117 ) | DZARC | G16 |
| DZ-Cr-387 X Rosea(RIL-30) | DZARC | G6 | DZ-Cr-387 X Rosea(RIL-133 ) | DZARC | G17 |
| Dz-cr-387xkey-murri(RIL.133B)Kora | DZARC | G7 | DZ-Cr-387 X Alba(RIL-60) | DZARC | G18 |
| DZ-Cr-387 X Rosea(RIL-40) | DZARC | G8 | DZ-Cr-387 X Alba(RIL-7) | DZARC | G19 |
| DZ-Cr-387 X Rosea(RIL-106) | DZARC | G9 | DZ-Cr-387 X Rosea(RIL-44) | DZARC | G20 |
| DZ-Cr-387 X Rosea(RIL-48) | DZARC | G10 | Local check | AxARC | G21 |
| DZ-Cr-387 X R\osea(RIL-71) | DZARC | G11 | | | |

DZARC=Debre Ziet Agricultural research center, AxARC= Axum Agricultural research Center G1=genotype 1 etc….

### *2.3 Data Collection and Analysis of Variance*

Data collected on grain yield and was estimated in kg ha$^{-1}$ by converting the grain harvested per net harvestable plot to hectare. Combined analysis of variance for 21 tef genotypes in seven environments was computed to determine the effect of environment (E), genotypes (G) and their interaction for grain yield at the probability alpha level of 0.05 and the comparison mean difference was subjected by least significance difference (LSD). Analysis of variance assumptions normality was tested by Shapiro using the R software. Homogeneity of residual variance (MSE) was computed according to Cruz et al. (2004), when the ratio between the highest and lowest MSE was less than 7.

Therefore, the data was subjected to Analysis of variance (ANOVA) to compute significance difference of the source of variance in model by R software. The significance of G, E, and GEI effect was determined by probability value ($P<0.001$). Moreover, stability and adaptability of 21 tef genotypes were tested by GGE- biplot (Yan et al. 2000) and nine parametric stability statistics. The model for the GGE bioplot was linear mixed model effect the genotype was considered as random effect while the environment was fixed effect. This model used a package to run was lme4 package (Chambers, John M. 2016). As Yan and Tinker, (2006) described the GGE biplot and stability analyze was R functions (commands) of the GGEBiplotGUI package. From the Biplot tools menu bar, select tester-center (G+GE), without any scaling and row metric preservation for mean performance and stability of genotypes was used. At mean Vs stability GGE biplot graph the projection vector length shows the magnitude of the stability (Yan et al., 2006) when the projection of the vector is perpendicular to the straight line of the average longer regardless of the direction this implies there is greater tendency of GEI and lower genotype stability (Bornhofen et al. 2017). The GGE biplot shows the first two principal components (PC1 and PC2) derived from subjecting environment centered yield data to singular- value decomposition (Asio et al. 2007: Gabriel et al., 1971 and Yan et al. 2000). The factor explained (%) for the genotypes by environment interaction was calculated, subtracting the sum square of residual from the total and sum square of the remained source of variation to divided by the total sum square multiplied by 100. The parametric stability statistics was analyzed by online tool http://mohsenyousefian.com/stability/ (Pour Aboughadareh et al. 2019). All the statistic parameter was detailed described see at appendix 1. The program calculates patterns of genotypes, based on each index and the result would present on excel of two separate sheets with naming of statistics and ranks including average grain yield, parametric and ranking of the genotypes per each statistic along and also Standard deviation (Aboughadareh et al. 2019). The Pearson's correlation was analyzed by SPSS software (SPSS In.2009).

## 3. Results and Discussions

### *3.1 Analysis of Variance*

The analysis of variance for the combined mean of grain yield showed that there was significance difference (P<-0.001) between genotypes, environments and genotype by environment interaction (GEI)(Table 3). The statistical significance difference of genotypes and environments shows that there was variance in response of genotypes for grain yield performance whereas, the different environment also differently influencing the genotypes for their yield performance. Therefore, the variance performance of genotypes leads for plant breeders to select superior genotypes differently responding. However, environmental variance indicates assorting of tef genotypes through their stability and for specific adaptation. GEI reveal that, the performance of genotypes was not parallel over all testing environments. This indicates the substantial contribution of GEI in influencing the grain yield of tef genotypes (Kefyalew 1999). Then, the significance of GEI makes difficulty in selection of superior genotypes across environments (Hagos and Abay 2013; Bornhofen et al.,2017). Mohammedi et al. (2007) and Eberhart and Russel (1966) suggested for the minimization of GEI in selection of genotypes, creating homogeneous environment and development of stable genotypes. The presence of significance difference for genotypes, environments and GEI on tef was reported by (Jifar et al.,2019). The occurrence of significance difference on GEI helps to proceed for estimating phenotypic stability (Farshdar and Sutka 2006). Kassa et al. (2013) also reported that a significance difference between tef genotypes and genotype by interaction. The result was combined from the seven environments which missed from Maysiye at 2017/18 of cropping season due to the waterlogging problem at the site.

The environmental effect was responsible for the total sum of squares (SS) of grain yield about (48.71%). While, the effect of genotypic was 13.60% and GEI was 37.68% of the total sum of square explained. The present finding shows a significant change on grain yield due to both environment and GEI effect. This implies that selection of genotypes on their performance of grain yield depends on environment and GEI. The larger variance of on the total sum square obtained from the environment and GEI might be; environment is combination of location and season. While, location is combination of different weather conditions effect, biotic and abiotic factors of the event. Mainly the climatic and soil fertility depletion might be causes to vary the responds of tef genotypes for yield. Moreover, phenotypic performance is not only influenced by environment rather the combination of both genotypic and phenotypic effect. Therefore, in addition to the environmental factors the genotypic by environment interaction causes differently responding tef genotypes for yield. This source of variance is expected when genotypes were conducted in multi-environmental trails (MET) through more seasons (Yan and Kang, 2003).

The GEI mean of grain yield varied from 820.94kg/ha to 2438.96kg/ha(Table 5) while the genotype mean yield was varied from 1382.432 and 1989.697kg/ha(Table 4) with grand mean of 1698.20kg/ha. In the present study higher variance of grain yield in GEI shows that alteration of climatic factors mainly in rain fall, a black soil (Hatsebo) that causes low germination due to un appropriate compaction and moisture limitation. Whereas, the genotype mean variance might be due to the genetic makeup of the tef genotypes. Then, selection of tef genotypes with higher yielding and stable performance are important per the tested locations. Jifar et al. (2019) reported that the variability in grain yield performance is due to a large changeability in climatic and soil condition. Out of the 21 tef genotypes three genotypes G19, G17 and G6 were identified with high grain yield performance across four locations.

The first two principal components of the GGE biplot in this study explained 82.58% (Axis1=44.23% and Axis2=38.35%) of the total variance (Fig. 2). The GEI is stronger with presence of the crossover interaction (Yan and Tinker, 2006). There was a larger obtuse angle between selekhliha and Adet it is negatively correlated (Fig 2.) each other and causes to occur a crossover GEI (Fig 1). Association of the angle between genotypes and location with larger angle indicates there was interaction between the genotypes and locations. In addition to this alignment of genotypes on the bioplot: tef genotypes failed near the origins are well stable than the far apart one. The maximum numbers of genotypes were failed near the origin. The single arrowed line is the AEC abscissa; it points to higher mean yield across environments (Fig 3). As Yan et al. (2006) stated the performance genotypes with individual location, in the present finding shows G19 was the highest yielding genotype and also its angle and the locations shows less than 90° which implies genotype 19 and the location has positive correlation. Whereas, G8 and G11 had an angle greater than 90° it indicates these genotypes were below the average. While the angle between G2 and the locations Hatsebo(Table 1) was about 90° meaning it was near the grand mean(fig 2).

*3.2 Stability Analysis*

The parametric stability statistics such as ASV, YSI, Wi, σi2, bi, θi and θ(i) indicated that G19 was the most stable genotype however, the CVi and $S^2$di parameter resulted a genotype stability for G17 and G7 respectively(Table 4.). Genotypes G19, G17, G12, G2, and G4 had the best static stability, however, G6, G9 and G11 were dynamic stability over the tested locations (fig.1.). This shown that, G19 was consistently performing across different environments. It also confirmed by the ranking of stability methods except the $s^2d_i$, CVi, and $\theta_i$(Table 4.). Lin et al. (1986) and Lin and binns (1991) reported that $S^2$di and CVi statistics are grouped under the same stability method. Therefore, G19 was evaluated its stability in Multi-location trail that is best strategy in the development of the variety. Hence, this genotypes was constantly achieved its grain yield in different environments it is so stable as stated by (Romagosa & Fox 1993). In general, genotypes categorized by dynamic stability are very important for the addition of the inputs (fertilizer and chemical ….. etc applications). While the static stability is useful for areas with erratic rain fall and affected by different edaphic factors (Annicchiarico 2002). This consistence stability of tef genotype performance might be due to the inheritance of the traits for stability.

However, G8 and G11 were the lower yielding tef genotypes. Whereas, G20 was highly stable but, with low yield (Fig 3). Farmers under inadequate inputs and erratic rain fall prefer yield stability than increment (Bantayehu 2009). Therefore, selection of genotypes within higher yielding and stable is important for environment faced with moisture stressed areas of Tigray. Stable genotypes explained by parametric stability statistics when AMMI stability value (ASV), Yield stability index(YSI), mean variance component( θi) Shuklas' stability variance( σi2), and GE variance component θ (i) were shown lower value and regression coefficient (bi) near a unit (Table 4.)The average rank values in table 4 indicated that G19 was scored lower value which means this method confirmed that genotype 19 is higher yielding and stable one. A genotype with lower Average Ranking value is selected as superior and stable genotypes (Pour Aboughadareh et al. 2019). The G19 shows that first ranked by five parametric stability methods, while the G7, G17 and G9 were ranked by $s^2d_i$, CVi, and $\theta_i$, respectively.

G19 was stable and high yielder following G17 in mean vs stability analysis of GGE bioplt(Fig 3). The single-arrowed line is the AEC abscissa (or AEA); it points to higher mean yield across environments (GGE biolpot).The tef genotype which is at point and shorter projection from the AEC abscissa indicated the higher yielding and stable genotype (Yan and Tinker 2006; Frutos et al. 2014).Whereas, G9 shows that a longer projection and it was unstable genotype. In this study the GGE bio plot of stability was taken the genotype by location rather than the genotypes by environment. In agreement with Chandra et al.(1974) report the stability of genotypes was evaluated that the GE interaction with location is more important than GE interaction with years. There was a crossover performance of tef genotype over four locations and two seasons (Fig. 1). The crossover ranking implies that the GEI causes to vary in yield performance of the genotype in magnitude and direction (Bnrnn 1988). Mainly that showed the yield of the GxE interaction mean of the genotypes and G9 was the higher yield but the G8 was the lower yielding from the tested genotypes (Fig.3). Genotypes measured their stability on the static were the G19 and G17 this implies that these tef genotypes were recommended for the unfavorable growing environments. However, G6 and G9 had dynamic stability this variety/genotype would be better to the favorable growing environment (Mohammadi et al. 2010).

*3.3 Association between Mean Yield and Parametric Stability*

Mean yield was not shown positively and statistically significance difference with all parametric stability statistics except the yield stability index ((YSI, r=-0.75**) which shown a statistically significance difference having a negative correlation (Table 7). Presence of association among parametric stability used to defines the discriminating ability among genotypes for stability (Duarte and Zimmermann, 2014). However, the finding indicated that all parametric stability did not have shown positive and significant correlation with mean yield. Parametric stability methods which are not significantly and positively correlated with yield belongs to the static stability while, methods correlated with mean yield also grouped with dynamic stability (Bornhofen et al. 2017). Therefore, As Bornhofen et al., reported these methods were recommended for use in selection of tef genotypes for static stable tef varieties. However, Khalili and Pour-Aboughadareh (2016) reported in double haploid of barley lines non-significant methods were not used for stability selection.

The following parametric stability statistics shows a correlation with each other; ASV was positively and significantly with strong correlation of $Wi^2$(r=0.829**), $\sigma i^2$(r=0.829**), and θi r=0.829**). Whereas, the $Wi^2$, also associated with $\sigma i^2$(r=1.000**), CVi(r=0.73**) and θi(r=1.000**); $\sigma i^2$ was significantly correlated with CVi(r=0.73**) and θi(r=1.000**); bi was correlated with CVi(r=0.843**) and CVi was also correlated with θi(r=0.73**). Significant and high magnitude correlation coefficients indicate similarity in the ranking of genotypes (Sabaghnia et al. 2006). The Mean variance component (θi) was highly correlated with all parametric stability except the yield stability index (YSI) and GE variance component {θ(i)}. Therefore, evaluating tef genotypes with this parametric stability is important including GGE biplot. The import of GGE biplot is uses for mixed models (Yang et al. 2099).

Table 3. Combined analysis of variance for mean grain yield of 21 tef genotypes in two year and for four locations

| Sources | DF | Sum of square | Mean square | F-value | P>F | Explained SS (%) | Coefficient of variance % |
|---|---|---|---|---|---|---|---|
| Genotypes | 20 | 8683673 | 434184 | 3.599 | 0.000 | 13.60 | 18.05 |
| Environment | 6 | 31101186 | 5183531 | 42.976 | 0.000 | 48.71 | |
| GxE | 120 | 24059613 | 200497 | 1.666 | 0.0029 | 37.68 | |
| Residuals | 294 | 35460062 | 120612 | | | | |
| Total | | 99304534 | | | | | |
| Grand mean(kg/ha) | | 1698.2 | | | | | |

NB- the DF =degree of freedom, the environment showed the 6 was one year data was missed

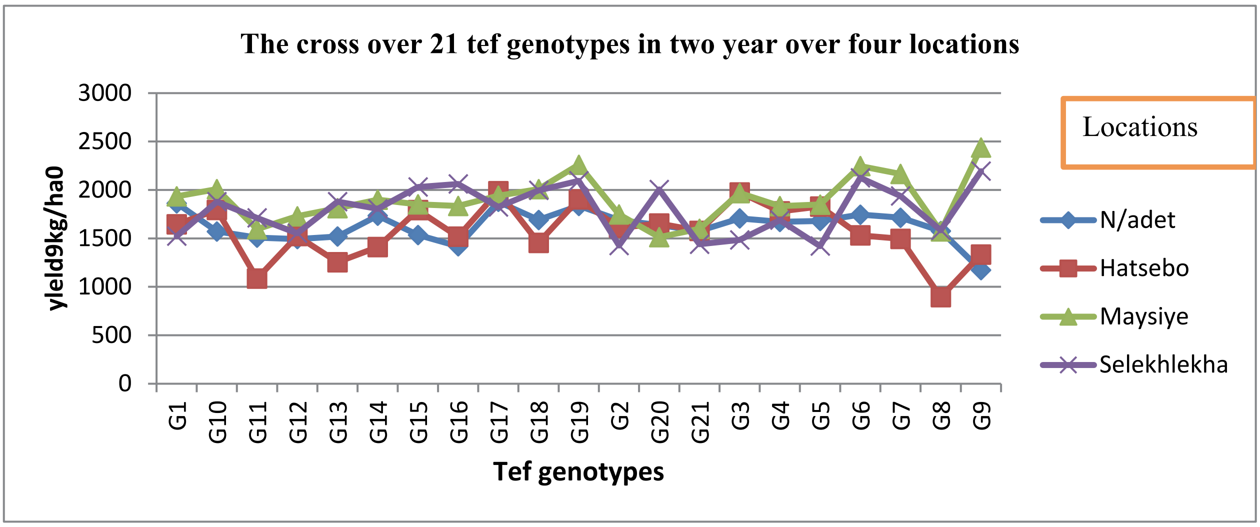


Figure 1. Grain yield performances of tween one tef genotypes across four locations Ha=hatsebo,MY=Maysiye, N/ade=Naeder adet, Sel=Selekhelekha,) and two years showing the existence of relative changes in ranks (cross-overs) due to genotype by environment interaction

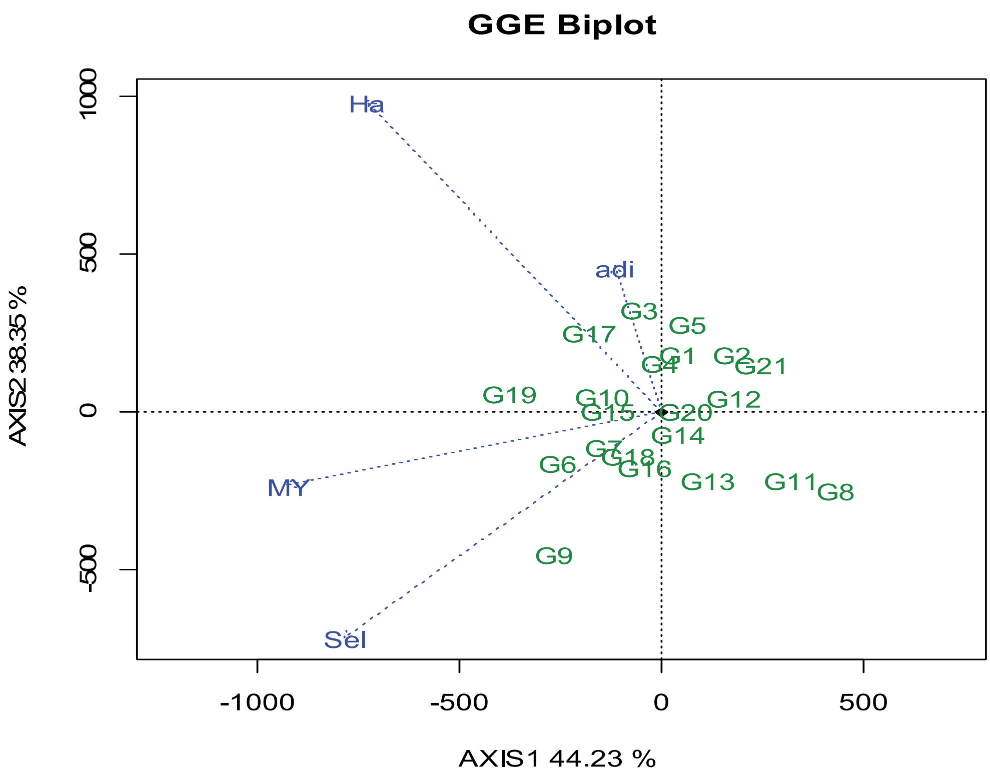


Figure 2. The GGE bioplot of the 21 tef genotypes describes the presence of GEI and relationship of genotype and locations for grain yield performance

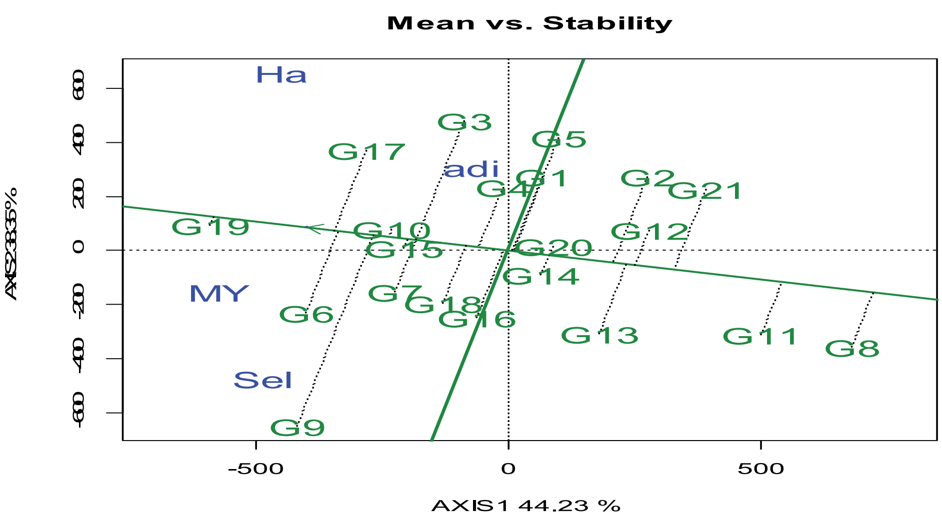


Figure 3. The average-environment coordination (AEC) view to show the mean grain yield performance and stability of the tef genotypes

Table 4. Mean grain yield and ten parametric stability statistics measures for: 21 tef genotypes across seven environments

| Genotypes | Codes | Yield mean(kg/ha) | ASV | YSI | $W_i^2$ | $\sigma^2_i$ | $s^2d_i$ | $b_i$ | CVi | $\theta_{(i)}$ | $\theta_i$ | AR | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DZ-Cr-387 X Rosea(RIL-9) | G1 | 1713.59cdefgh | 23.44 | 25.00 | 132781.99 | 46457.04 | 14594.77 | 0.32 | 10.94 | 46806.88 | 47863.28 | 11.8 | 11 |
| DZ-Cr-387 X Rosea(RIL-13) | G2 | 1599.53efghi | 26.39 | 34.00 | 117475.15 | 40817.68 | 8346.91 | 0.05 | 8.64 | 47088.84 | 45184.58 | 13.9 | 16 |
| DZ-Cr-387 X Rosea(RIL-18) | G3 | 1756.92bcdef | 37.22 | 29.00 | 253487.03 | 90927.31 | 23540.69 | -0.16 | 13.21 | 44583.36 | 68986.66 | 14.25 | 7 |
| DZ-Cr-387 X Rosea(RIL-23) | G4 | 1729.57bcdefg | 18.62 | 20.00 | 57313.77 | 18652.95 | 2155.70 | 0.20 | 4.41 | 48197.08 | 34656.34 | 5.88 | 9 |
| DZ-Cr-387 X Rosea(RIL-24) | G5 | 1672.84defgh | 35.01 | 34.00 | 205416.35 | 73217.06 | 16419.46 | -0.17 | 11.65 | 45468.87 | 60574.29 | 15.81 | 15 |
| DZ-Cr-387 X Rosea(RIL-30) | G6 | 1863.97abc | 25.19 | 19.00 | 105696.05 | 36478.01 | 1397.24 | 2.21 | 17.36 | 47305.83 | 43123.24 | 7.94 | 3 |
| Kora | G7 | 1779.92bcde | 16.00 | 11.00 | 62839.35 | 20688.70 | 1009.37 | 1.92 | 15.79 | 48095.29 | 35623.32 | 7.25 | 6 |
| DZ-Cr-387 X Rosea(RIL-40) | G8 | 1382.43j | 21.77 | 34.00 | 213144.30 | 76064.20 | 27634.06 | 1.55 | 24.33 | 45326.52 | 61926.68 | 16.31 | 21 |
| DZ-Cr-387 X Rosea(RIL-106) | G9 | 1691.55cdefgh | 60.98 | 29.00 | 706676.04 | 257891.69 | 13642.69 | 4.05 | 35.04 | 36235.14 | 148294.74 | 17.75 | 12 |
| DZ-Cr-387 X Rosea(RIL-48) | G10 | 1785.12bcde | 7.14 | 9.00 | 39564.93 | 12113.91 | 5644.12 | 0.97 | 10.15 | 48524.03 | 31550.29 | 6.63 | 5 |
| DZ-Cr-387 X R\osea(RIL-71) | G11 | 1457.27ij | 18.34 | 29.00 | 104255.44 | 35947.25 | 13353.40 | 1.40 | 18.51 | 47332.37 | 42871.13 | 14.38 | 20 |
| DZ-Cr-387 X Rosea(RIL-80) | G12 | 1552.51ghij | 10.74 | 24.00 | 18996.58 | 4536.10 | 1271.38 | 0.61 | 6.69 | 48902.92 | 27950.83 | 6.56 | 18 |
| DZ-Cr-387 X Rosea(RIL-107 ) | G13 | 1587.98fghi | 21.76 | 29.00 | 82793.72 | 28040.31 | 6478.35 | 1.75 | 17.79 | 47727.71 | 39115.33 | 12.25 | 17 |
| DZ-Cr-387 X Rosea(RIL-114 ) | G14 | 1685.45cdefgh | 8.36 | 17.00 | 37336.86 | 11293.04 | 4781.49 | 1.24 | 12.39 | 48565.08 | 31160.38 | 8.31 | 14 |
| DZ-Cr-387 X Rosea(RIL-116) | G15 | 1795.26bcd | 5.88 | 9.00 | 89432.06 | 30486.01 | 12300.41 | 0.78 | 11.36 | 47605.43 | 40277.04 | 10.31 | 4 |
| DZ-Cr-387 X Rosea(RIL-117 ) | G16 | 1690.08cdefgh | 21.29 | 24.00 | 122407.72 | 42634.94 | 14604.23 | 1.55 | 17.27 | 46997.98 | 46047.78 | 14.94 | 13 |
| DZ-Cr-387 X Rosea(RIL-133 ) | G17 | 1903.28ab | 24.85 | 19.00 | 99894.50 | 34340.60 | 1987.54 | -0.14 | 3.74 | 47412.70 | 42107.97 | 8.19 | 2 |
| DZ-Cr-387 X Alba(RIL-60) | G18 | 1755.22bcdef | 17.97 | 15.00 | 55113.61 | 17842.37 | 3312.95 | 1.70 | 14.90 | 48237.61 | 34271.31 | 6.88 | 8 |
| DZ-Cr-387 X Alba(RIL-7) | G19 | 1989.69a | 4.89 | 2.00 | 13919.53 | 2665.60 | 1465.82 | 1.24 | 9.50 | 48996.45 | 27062.35 | 3.69 | 1 |
| DZ-Cr-387 X Rosea(RIL-44) | G20 | 1729.04bcdefg | 5.46 | 16.00 | 195002.62 | 69380.43 | 19081.67 | 0.03 | 12.40 | 45660.71 | 58751.89 | 14.56 | 10 |
| Local check | G21 | 1541.061hij | 24.78 | 34.00 | 93865.45 | 32119.36 | 2216.30 | -0.09 | 4.73 | 47523.76 | 41052.88 | 11.88 | 19 |

ASV=AMMI stability value, YSI=yield stability index, Wi=Wricke's ecovalence stability index, $\sigma^2$i=Shukla's stability variance $S^2$di=deviation for the regression, bi=regression coefficient, CVi=environmental coefficient of variance, θ(i)=GE variance, θi=mean variance component AR=average rank

Table 5. The mean yield performance of tween one tef genotypes across seven environments

| Genotypes | Code | N/Adet | | Hatsebo | | Maysiye | Selekhilekha | |
|---|---|---|---|---|---|---|---|---|
| | | 2010 | 2011 | 2010 | 2011 | 2010 | 2010 | 2011 |
| DZ-Cr-387 X Rosea(RIL-9) | G1 | 1815.73 | 1909.06 | 1640.94 | 1649.69 | 1934.17 | 1789.44 | 1256.15 |
| DZ-Cr-387 X Rosea(RIL-13) | G2 | 1593.75 | 1785.73 | 1467.5 | 1749.9 | 1747.08 | 1806.2 | 1046.56 |
| DZ-Cr-387 X Rosea(RIL-18) | G3 | 1747.4 | 1665.42 | 2050.52 | 1899.38 | 1968.12 | 1750.46 | 1217.19 |
| DZ-Cr-387 X Rosea(RIL-23) | G4 | 1830 | 1511.25 | 1530.83 | 2026.56 | 1833.12 | 2414.54 | 960.73 |
| DZ-Cr-387 X Rosea(RIL-24) | G5 | 1900.1 | 1459.38 | 1604.79 | 2054.17 | 1848.85 | 1794.81 | 1047.81 |
| DZ-Cr-387 X Rosea(RIL-30) | G6 | 1889.17 | 1600.52 | 1413.12 | 1648.33 | 2246.15 | 2634.91 | 1615.62 |
| Kora | G7 | 1681.67 | 1745.83 | 1959.06 | 1031.56 | 2165.73 | 2232.59 | 1643.02 |
| DZ-Cr-387 X Rosea(RIL-40) | G8 | 1530.62 | 1621.77 | **820.94** | 965.31 | 1572.29 | 2082.13 | 1083.96 |
| DZ-Cr-387 X Rosea(RIL-106) | G9 | 936.35 | 1409.38 | 1285.21 | 1382.19 | **2438.96** | 2323.52 | 2065.31 |
| DZ-Cr-387 X Rosea(RIL-48) | G10 | 1689.79 | 1452.4 | 1821.25 | 1766.77 | 2008.96 | 2551.3 | 1205.42 |
| DZ-Cr-387 X R\osea(RIL-71) | G11 | 1375.52 | 1639.9 | 1057.92 | 1111.35 | 1594.48 | 2406.85 | 1014.9 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DZ-Cr-387 X Rosea(RIL-80) | G12 | 1344.27 | 1641.04 | 1650 | 1399.58 | 1728.12 | 1992.31 | 1112.29 |
| DZ-Cr-387 X Rosea(RIL-107 ) | G13 | 1509.79 | 1529.06 | 1170.73 | 1336.98 | 1812.19 | 2517.59 | 1239.58 |
| DZ-Cr-387 X Rosea(RIL-114 ) | G14 | 1841.77 | 1627.08 | 1435.94 | 1384.9 | 1899.17 | 2386.3 | 1223.02 |
| DZ-Cr-387 X Rosea(RIL-116) | G15 | 1590.52 | 1480.42 | 1986.15 | 1597.92 | 1851.46 | 2425.37 | 1635 |
| DZ-Cr-387 X Rosea(RIL-117 ) | G16 | 1312.4 | 1524.9 | 1501.15 | 1534.06 | 1834.69 | 2502.87 | 1620.52 |
| DZ-Cr-387 X Rosea(RIL-133 ) | G17 | 1983.65 | 1774.48 | 2048.85 | 1926.46 | 1940.83 | 2504.44 | 1144.27 |
| DZ-Cr-387 X Alba(RIL-60) | G18 | 1697.71 | 1682.71 | 1629.17 | 1278.54 | 2008.33 | 2511.02 | 1479.06 |
| DZ-Cr-387 X Alba(RIL-7) | G19 | 1673.44 | 1997.5 | 1996.98 | 1810.73 | 2260.31 | 2356.11 | 1832.81 |
| DZ-Cr-387 X Rosea(RIL-44) | G20 | 1619.27 | 1654.58 | 1794.69 | 1511.35 | 1513.96 | 2498.24 | 1511.25 |
| Local check | G21 | 1581.25 | 1572.92 | 1703.23 | 1451.98 | 1598.85 | 1506.59 | 1372.6 |

Table 6. Ranks of genotypes for mean yield and phenotypic stability measures in 21 tef genotypes

| Genotype | Code | $W_i^2$ | $\sigma^2_i$ | $s^2d_i$ | CVi | $\theta_{(i)}$ | $\theta_i$ | rASV | rYSI |
|---|---|---|---|---|---|---|---|---|---|
| DZ-Cr-387 X Rosea(RIL-9) | G1 | 16 | 16 | 16 | 8 | 16 | 6 | 14 | 11 |
| DZ-Cr-387 X Rosea(RIL-13) | G2 | 14 | 14 | 12 | 5 | 14 | 8 | 18 | 16 |
| DZ-Cr-387 X Rosea(RIL-18) | G3 | 20 | 20 | 20 | 13 | 20 | 2 | 20 | 9 |
| DZ-Cr-387 X Rosea(RIL-23) | G4 | 6 | 6 | 6 | 2 | 6 | 16 | 10 | 10 |
| DZ-Cr-387 X Rosea(RIL-24) | G5 | 18 | 18 | 18 | 10 | 18 | 4 | 19 | 15 |
| DZ-Cr-387 X Rosea(RIL-30) | G6 | 13 | 13 | 3 | 17 | 13 | 9 | 17 | 2 |
| Kora | G7 | 7 | 7 | 1 | 15 | 7 | 15 | 7 | 4 |
| DZ-Cr-387 X Rosea(RIL-40) | G8 | 19 | 19 | 21 | 20 | 19 | 3 | 13 | 21 |
| DZ-Cr-387 X Rosea(RIL-106) | G9 | 21 | 21 | 15 | 21 | 21 | 1 | 21 | 8 |
| DZ-Cr-387 X Rosea(RIL-48) | G10 | 4 | 4 | 10 | 7 | 4 | 18 | 4 | 5 |
| DZ-Cr-387 X R\osea(RIL-71) | G11 | 12 | 12 | 14 | 19 | 12 | 10 | 9 | 20 |
| DZ-Cr-387 X Rosea(RIL-80) | G12 | 2 | 2 | 2 | 4 | 2 | 20 | 6 | 18 |
| DZ-Cr-387 X Rosea(RIL-107 ) | G13 | 8 | 8 | 11 | 18 | 8 | 14 | 12 | 17 |
| DZ-Cr-387 X Rosea(RIL-114 ) | G14 | 3 | 3 | 9 | 11 | 3 | 19 | 5 | 12 |
| DZ-Cr-387 X Rosea(RIL-116) | G15 | 9 | 9 | 13 | 9 | 9 | 13 | 3 | 6 |
| DZ-Cr-387 X Rosea(RIL-117 ) | G16 | 15 | 15 | 17 | 16 | 15 | 7 | 11 | 13 |
| DZ-Cr-387 X Rosea(RIL-133 ) | G17 | 11 | 11 | 5 | 1 | 11 | 11 | 16 | 3 |
| DZ-Cr-387 X Alba(RIL-60) | G18 | 5 | 5 | 8 | 14 | 5 | 17 | 8 | 7 |
| DZ-Cr-387 X Alba(RIL-7) | G19 | 1 | 1 | 4 | 6 | 1 | 21 | 1 | 1 |
| DZ-Cr-387 X Rosea(RIL-44) | G20 | 17 | 17 | 19 | 12 | 17 | 5 | 2 | 14 |
| Local check | G21 | 10 | 10 | 7 | 3 | 10 | 12 | 15 | 19 |

$Wi^2$=Wricke's stability index, $\sigma^2_i$ =Shula's ecovalence stability index, $s^2d_i$=deviation from the regression, CVi=environmental coefficient of variance, $\theta_{(i)}$=GE mean variance, $\theta_i$ =mean variance component, SD=standard deviation, rASV=rank of AMMI stability value, rYSI=rank of yield stability index and RS=rank sum

Table 7. Pearsons correlation coefficient among grain yield, stability parameters for 21 tef genotypes across seven environments at Tigray regional state

| | yield | ASV | YSI | $W_i^2$ | $\sigma^2_i$ | $s^2d_i$ | $b_i$ | CVi | $\theta_{(i)}$ | $\theta_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield | 1 | -0.156 | -.750$^{**}$ | -0.13 | -0.13 | -0.41 | -0.012 | -0.266 | 0.13 | -0.13 |
| ASV | | 1 | .640$^{**}$ | .829$^{**}$ | .829$^{**}$ | 0.3 | 0.323 | .532$^{*}$ | -.829$^{**}$ | .829$^{**}$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| YSI | 1 | 0.403 | 0.403 | .451* | -0.116 | 0.228 | -0.403 | 0.403 |
| $W_i^2$ | | 1 | 1.000** | .495* | .477* | .732** | -1.000** | 1.000** |
| $\sigma^2_i$ | | | 1 | .495* | .477* | .732** | -1.000** | 1.000** |
| $s^2d_i$ | | | | 1 | -0.067 | .454* | -.495* | .495* |
| $b_i$ | | | | | 1 | .843** | -.477* | .477* |
| CVi | | | | | | 1 | -.732** | .732** |
| $\theta_{(i)}$ | | | | | | | 1 | -1.00** |
| $\theta_i$ | | | | | | | | 1 |

ASV= AMMI stability value, YSI= yield stability index, $Wi^2$=Wricke's stability index, $\sigma^2_i$ =Shula's ecovalence stability index, $s^2d_i$=deviation from the regression, CVi=environmental coefficient of variance, $\theta_{(i)}$=GE mean variance and $\theta_i$ =mean variance component

## 4. Conclusion

The combined analysis of multi-environmental trail shows significance difference within the genotypes, environments and genotypes by environments interaction. Yield was varied due to the higher source of variation of environment and the interaction of genotype by environment. The GEI also shows there is inconsistence of genotype performance across the tested environments. In addition to this stability of tef genotypes were evaluated through the static and dynamic stability. Therefore, G19 and G17 were the best static stable tef genotypes and these are suited for the unfavorable environments. This is fitting for the testing areas, which is faced to fluctuation of climatic condition and fertility depletion. But, G6 was the dynamic stable and better to grow in the favorable environments. The association of mean yield and parametric stability statistics do not shown a statistically significance difference except for YSI with negatively correlated. According to the GGE bioplot G19 was stable and selected for the national variety releasing committee. The Mean variance component (θi) was highly correlated with all parametric stability except the yield stability index (YSI) and GE variance component {θ(i)}.Therefore, this method combined with GGE bioplot is good for development of tef variety.

Finally, this research finding recommended that G19 was the most stable followed by G17 and these were the promising tef genotype with high yield performance. Moreover, use of the evaluation method GGE bio plot is better for the evaluation of tef genotypes for the development of cultivar. However, the higher yielding and dynamic stable tef was G6; this genotype could be grows in the potential tef growing area of Ethiopia. To increase the effectiveness of the plant breeders during selection of the genotype and reducing cost as well as to increase or decrease testing year and location the following situation should fulfill. That is identifying meg-environments, discriminant locations, representativeness of location and ideal testing location and genotype are the important criteria for plant breeding program.

### Acknowledgments

We wish to thank Tigray Agricultural Research Institute Axum and Maytsebri centers allocating the budget to accomplish this activity and the staff of both centers of Axum and Maytsebri center as well as the tef national coordinators debre Zeit Agricultural research Center providing the recombinant tef lines.

### References

Annicchiarico, P. (2002). Genotype × environment interaction: challenges and opportunities for plant breeding and cultivar recommendation. *FAO Plant Production and Protection* (Paper No. 174). Rome: FAO.

Assefa, K., Cannarozzi, G., Girma, D., Kamies, R., Chanyalew, S., Plaza-Wüthrich, S., … Tadele, Z. (2015). Genetic Diversity in Tef [*Eragrostis Tef* (Zucc.) Trotter]. *Frontiers in Plant Science, 6*, 177.

Bnrnn, R. J. (1988). Tests for crossover genotype-environmental interactions. *Can. J. Plant Sci., 68*, 405-410.

Lin, C. S., Binns, M. R., & Lefkovitch, L. P. (1985). Stability Analysis: Where Do We Stand? Research scientists, Engineering and Statistical Res. *Centre, Agric. Canada*.

Lin, C. S., Binns, M. R., &. Lefkovitch, L. P. (1985). Stability Analysis: Where Do We Stand? *Res. Branch, Agric.* Canada, Ottawa, Canada.

Lin, C. S., & Binns, M. R. (1991). Assessment of a method for cultivar selection based on regional trial data. *Theor*

*Appl Genet*, *82*, 379-388.

Chandra, S., Sohoo, M. S., & Singh, K. P. (1974). Genotypeenvironment interaction for yield in ram. *Journal of Research*, *8*,165-168

Cruz, C. D., Regazzi, A. J., & Carneiro, P. C. S. (2004). Modelos biométricos aplicados ao melhoramento genético. v. 1(3rd ed). Viçosa: Editora da UFV.

CSA. (2018). The Federal Democratic Republic of Ethiopia Central Statistical Agency Agricultural Sample Survey. Volume I Report on Area and Production Of Major Crops. 586 Statistical Bulletin 586, Addis Ababa April, 2018.

Ebba, T. (1969). Tef (Eragrostistef): The Cultivation, Usage, And Some of The Known Disease and Insect Pests. Part I. Experiment Station Bulletin 60. Haile Sellassie I University, College of Agriculture.

Eberhart, S., & Russel, W. A. (1966). Stability Parameters For Comparing Variaaties. *Crop Science, 6*, 36-40.

Elesandro, B., Giovani, B., Lindolfo, S., Leomar, G. W., Thiago, D., Matheus, G. S., & Sergio, V. M. (2017). Statistical methods to study adaptability and stability of wheat genotypes. Basic Area. *Bragantia Campinas, 76*(1), 1-10.

Elisa, F. M., Purificacio, G., & Victor, L. (2014). An interactive biplot implementation in R for modeling genotype-by-environment interaction. *Stoch Environ Res Risk Assess, 28,* 1629–1641. https://doi.org/10.1007/s00477-013-0821-z

Ezatollah, F., Nasrin, M., Anita, Y. (2011). AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.) *Aisterialn journal of crop science*, *5*(13), 1837-1844.

Farshadfar, E., & Sutka, J. (2006). Biplot analysis of genotype environment interaction in durum wheat using the AMMI model. *Acta Agronomica Hungarica, 54,* 459-467.

Finlay, K. W., & Wilkinson, G. N. (1963). The analysis of adaptation in a plant-breeding programme. *Aust. J. Agric. Res.*, *14,* 742-754.

Francis, T. R., & Kannenberg, L. W. (1978). Yield stability studied in short-season maize. I. A descriptive method for grouping genotypes. *Can. J. Plant Sci., 58,* 1029-1034.

Habte, J., Kebebew, A., Kassahun, T., Kifle, D., & Zerihun, T. (2015). Genotype-by-Environment Interaction and Stability Analysis in Grain Yield of Improved Tef (*Eragrostis tef*) Varieties Evaluated in Ethiopia. *Journal of Experimental Agriculture International, 35*(5), 1-1.

Hagos, H. G., & Abay, F. (2013). AMMI and GGE biplot analysis of bread wheat genotypes in the northern part of Ethiopia. *Journal of Plant Breeding and Genetics*, *1,* 12-18.

Heinrich, G. M., Francis C. A., & Eastin J. D. (1983). Stability of Grain Sorghum Yield Components Across Diverse Environments. *Crop Sci., 23,* 209–212.

Joâo batista Duarte & Maria Jose de O. Zimmermann. (1995). Correlation among yield stability parameters in common bean. *Crop science, 35*(3).

John M. C. (2016). Extending R. Chapman and Hall/CRC Press, 364 pp., ISBN 9781498775717, GBP 44.99 (print), GBP 31.49 (eBook).

Gabriel, K. R. (1971). The biplot graphic display of matrices with application to principal component analysis. *Biometrika, 58,* 453e467.

Kang, M. S., & Pham, H. N. (1991). Simultaneous selection for high yielding and stable crop genotypes. *Agron. J.*, *83*, 161-165.

Kassa, L. D., Smith, M. F., & Fufa, H. (2006). Stability Analysis Of Grain Yield Of Tef (Eragrostis Tef) Using The Mixed Model Approach. *South African Journal Of Plant And Soil, 23*(1), 38-42.

Kebebew, A., Getachew, B., Hailu, T., Ju-Kyung, Y., & Mark, E. S. (2009). Breeding Tef: Conventional and Molecular Approaches. Pp 21-25. In Zerihun Tadele (Ed.), *New Approaches to Plant Breeding of Orphan Crops In Africa: Proceedings Of An International Conference* (pp. 19-21). September 2007, Bern, Switzerland.

Kebebew, A., Yu, J. K., Zeid, M., Gelay, G., Tefera, H., & Sorrells, M. E. (2011). Breeding tef [Eragrostis tef (Zucc.) trotter]: conventional and molecular approaches. *Plant Breeding, 130*, 1-9.

Lin, C. S., Binns, M. R., & Lefkovitch, L. P. (1986). Stability analysis: Where do we stand? *Crop Sci., 26,* 894-

900.

ÜLker, M., Sönmez, F., Çiftçi, V., Yilmaz, N., & Apak, R. (2006). Adaptation and Stability Analysis in The Selected Lines of Tir Wheat. *Pak. J. Bot., 38*(4), 1177-1183.

Asio, M. T., Osiru, D. S. O., & Adipala, E. (2007). Multilocational evaluation of selected local and improved cowpea lines in Uganda. Afr. *Crop Sci. J.*, 13(4).

MoALR. (2017). Ministry of agriculture and livestock resource, plant variety release, protection and seed quality control directorate, crop variety Rehister, Issue No. 20, Addis Ababa, Ethiopia.

Mohammadi, R., Abdulahi, A., Haghparast, R., & Armion, M. (2007). Interpreting genotype x environment interactions for durum wheat grain yields using nonparametric methods. *Euphytica*, *157,* 239-251. http://dx.doi.org/10.1007r/s10681-007-9417-3

Mohammadi, R., Mozaffar, R. M., Yousef, A., Mostafa, A., & Amri, A. (2010). Relationships of phenotypic stability measures for genotypes of three cereal crops. *Canadian Journal Plant Science*, *90*, 819-830.

Muluken, B. (2009). Analysis and Correlation of Stability Parameters in Malting Barley. *African Crop Science Journal*, *17*(3), 145-153.

Plaisted, R. I., & Peterson. L. C. (1959). A technique for evaluating the ability of selection to yield consistently in different locations or seasons. *American Potato Journal, 36*, 381–385.

Plaisted, R. L. (1960). A shorter method for evaluating the ability of selections to yield consistently over locations. *American Potato Journal, 37,* 166–172.

Pour-Aboughadareh, A., Yousefian, M., Moradkhani, H., Poczai, P., & Siddique, K. H. M. (2019). STABILITYSOFT: A new online program to calculate parametric and non-parametric stability statistics for crop traits. *Applications in Plant Sciences, 7*(1), e1211. http://dx.doi.org/10.1002/aps3.1211

Purchase, J. L., Hatting, H., &Vandeventer, C. S. (2000). Genotype × environment interaction of winter wheat (*Triticum aestivum L.*) in South Africa: П. Stability analysis of yield performance. *South Afric J Plant Soil, 17,* 101-107.

Romagosa, I., & Fox, P. N. (1993). Genotype x environment interaction and adaptation. p. 374-390. In Hayward, M.D., N.O. Bosemark, and I. Romagosa (eds.) Plant breeding, principles and prospects. Chapman & Hall, London, UK.

Roostaei, M., Mohammadi, R., & Amri, A. (2014). Rank correlation among different statistical models in ranking of winter wheat genotypes. *The Crop Journal*, *2*, 154-163. http://dx.doi.org/10.1016/j.cj.2014.02.002

Sabaghnia, N., Dehghani, H., & Sabaghpour, S. H. (2006). Nonparametric methods for interpreting genotype × environment interaction of lentil genotypes. *Crop Science*, *46,* 1100-1106. http://dx.doi.org/10.2135/cropsci2005.06-0122

Seyfu, K. (1993). Tef, (*Eragrostis Tef*): Breeding, Genetic Resources, Agronomy, Utilization and Role In Ethiopian Agriculture. Institute of Agricultural Research, Addis Ababa, Ethiopia.

Shukla, G. K. (1972). Some statistical aspects of partitioning genotypeenvironmental components of variability. *Heredity, 29,* 237–245

Silva, W. C. J., & Duarte, J. B. (2006). Métodos estatísticos para estudo de adaptabilidade e estabilidade fenotípica em soja. *Pesquisa Agropecuária Brasileira*, *41,* 23-30. http://dx.doi.org/10.1590/S0100-204X2006000100004

Spaenij-Dekking, L., Kooy-Winkelaar, Y., & Frits, K. (2005). The Ethiopian Cereal Tef In Celiac Disease. *The New England Journal of Medicine*, *353*, 1748-1749.

SPSS Inc. (2009). *Statistical Package for Social Scientists.* SPSS for Windows. Release 18.0. SPSS Inc. Chicago, IL.

Tiruneh K. (1999). Assessment of Genotype xEnvironment Interaction for Yield and Yield Related Traits in Tef [Eragrostis Tef (Zucc.) Trotter] Genotypes. Msc Thesis, Alemaya University of Agriculture, Ethiopia.

Wricke, G. (1962). U ber eine Methode zur Erfassung dero¨ kologischen Streubreite in Feldversuchen. Z. Pflanzenzu¨ chtg47, 9296.

Y ali, Z., Hussian, F., & Shakur, A. (2004). Genotypes by environment interaction in cowpea for yield and disease resistance. *Int J. environ Sci Technolog, 1*(2), 119-123.

Yan, W., & Tinker, N. A. (2006). Biplot Analysis of Multi-Environment Trial Data: Principles and Applications. *Can J Plant Sci., 86,* 623–645.

Yan, W., & Kang, M. S. (2003). GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. *CRC Press, Boca Raton, FL.*

Yan, W., & Tinker, N. A. (2006). Biplot analysis of multi-environment trial data: Principles and applications. *Can. J. Plant Sci*., *86*, 623–645.

Yan, W., Hunt, L. A., Sheng, Q., & Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on GGE biplot. *Crop Sci., 40,* 596–605.

Yang, R. C., Crossa, J., Cornelius, P. L., & Burgueño, J. (2009). Biplot analysis of genotype × environment interaction: proceed with caution. *Crop Science, 49,* 1564-1576. http://dx.doi.org/10.2135/cropsci2008.11.0665