Journal of Scientific Agriculture 2022, 6: 25-31
doi: 10.25081/jsa.2022.v6.7595
https://updatepublishing.com/journal/index.php/jsa

Research Article

ISSN: 2184-0261

Genetic divergence analyses in tef (*Eragrostis tef* (Zucc.) Trotter) landraces based on morpho-agronomic traits

Siraye Ashagrie[1], Fisseha Worede[2]*, Wossen Tarekegne[3]

[1]Ethiopian Commodity Exchange, Genda Wuha office, Metema, Ethiopia, [2]Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center, Bahir Dar, Ethiopia, [3]Bahir Dar University, College of Agriculture and Environmental Sciences, Bahir Dar, Ethiopia

ABSTRACT

Tef (*Eragrostis tef* (Zucc.) Trotter) is a gluten-free cereal crop mainly grown in Ethiopia. Knowledge of the nature and magnitude of variation that exists in breeding materials is of great importance for effective breeding. This study was designed to assess the genetic divergence of tef landrace collections using quantitative and qualitative traits and to investigate the important trait in discriminating the tef landraces. The experiment was carried out at Adet Agricultural Research Center during the rainy season in 2019. Sixty-two landraces and two improved varieties were laid out in an 8×8 simple lattice design. Data were collected on 12 quantitative and three qualitative traits. The analysis of variance detected significant ($P \leq 0.05$) variation for panicle length and biomass yield, and highly significant ($P \leq 0.01$) differences among the tef landraces for the rest 10 traits, indicating the existence of appreciable genetic diversity that can be exploited in future tef breeding programs. Cluster analysis using the average linkage method grouped the 64 tef genotypes into four clusters. The highest inter-cluster distance was recorded between clusters III and IV; as a result, the tef genotypes from these clusters could be used as parents for future crossing programs. Principal components analysis revealed that the first four principal component axes accounted for 75.12% of the total variation among landraces, indicating that the traits considered were appropriate to detect the variation. The finding also demonstrated that grain yield, harvest index, days to heading, culm length and lodging index are higher contributors to the diversity of the tef landraces. These traits were most important in the discrimination of the landraces. Overall, the present study confirmed the presence of substantial diversity among the tef landraces.

Received: March 16, 2022
Revised: October 04, 2022
Accepted: October 06, 2022
Published: October 27, 2022

***Corresponding author:**
Fisseha Worede,
fisseha1@yahoo.com

KEYWORDS: Cluster analysis, Eigenvalue, Genetic distance, Genetic divergence, Principal Component

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is the most important cereal crop cultivated in Ethiopia. Ethiopia is the center of both origin and diversity for tef (Vavilov, 1951); thus, sheltering a wide range of phenotypic diversity in landraces and related wild species. It is a minute seeded, fine stemmed, annual grass characterized by a shallow root system (Lacey & Llewellyn, 2005).

Tef grows in a wide range of environmental conditions and is most tolerant to drought, water logging and disease. Tef needs rainfall of 450–550 mm, and temperature range of 10–27°C (Ketema, 1997). Although the crop is mainly grown under rain-fed conditions, it can be grown under an irrigation production system (Worede *et al*., 2007; Ben-Zeev *et al*., 2018; Fikre *et al*., 2020).

In Ethiopia, tef serves as a staple food, and most of the people prefer it for making *injera*, porridge, unraised bread and local beverage (Ketema, 1997). Grain of tef is known for its higher mineral contents than other major cereals (Mengesha & Guard, 1966). Nowadays, because of its nutritional balance, tef is becoming popular in Europe and North America as a healthy food for persons with gluten intolerance (Spaenij-Dekking *et al*., 2005; Hopman *et al*., 2008). Tef seeds can be stored for a long time, even under local storage conditions. Furthermore, diseases and pests are not serious problems in the major tef-growing areas of Ethiopia (Ketema, 1997).

Each year, a large area of land is devoted to tef production as compared to other cereal crops in Ethiopia. Tef was grown on 3 million ha of land and 5.4 million tons were harvested with average productivity of 1.76 t ha^{-1} in 2018 in Ethiopia (Central Statistical Authority, 2019).

Estimation of inter- and intra-cluster genetic distances allows identification of genetically dissimilar parents for crossing.

The hybridization of divergent parents leads to transgressive segregants. A great deal of diversity has been reported in the tef landrace collections using various quantitative traits (Assefa *et al*., 2000, 2002, 2003; Ayalew *et al*., 2011; Worede, 2017). However, characterization and evaluation of tef landraces collected from different agro-ecological zones should be continuous to come up with better varieties through hybridization. This calls for study of the genetic divergence of tef landraces to identify better parents for crossing. The objectives of the study, therefore, were to assess the extent of genetic divergence present in tef landraces collected from different parts of Ethiopia; and to determine the contribution of traits to the overall genetic diversity of tef landraces.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Adet Agriculture Research Center (AARC) in 2019 main cropping season. The location represents the major tef producing agro-ecologies of Northwest Ethiopia. The experimental site was located at a latitude of 11° 16' 32" N and a longitude of 37° 29' 30" E at about 2240 m above sea level. The average minimum and maximum temperatures are 7.3°C and 31.3°C, respectively. The total annual rainfall of the experimental site is 921.3 mm. The soil type of the site is red light soil, with a pH of 5.43.

Experimental Materials

Totally, sixty-four genotypes were used in this experiment of which 62 were landraces and two of them were check varieties. Originally, the landraces were populations or accessions collected from different parts of Ethiopia by the Ethiopian Biodiversity Institute (EBI). Pure lines which were developed from those accessions were used in the study (Table 1). The lines were obtained from Adet Agricultural Research Center.

Experimental Design and Management

The experiment was conducted using an 8×8 simple lattice design. Landraces were assigned randomly to the plots within a block. Each experimental plot had five rows of 2 m length and 1 m width. The spacing between rows, plots and replications were 0.2 m, 0.6 m and 1.5 m, respectively. The experimental field was ploughed three times with oxen, harrowed and levelled manually to have a fine bed for proper seedling establishment. Seeds were sown by drilling in rows at the seed rate of 10 kg ha^{-1} and fertilizer was applied at a rate of 150 kg NPS and 75 kg Urea per ha. NPS was applied at planting while urea was applied in two splits; half at first weeding (15 days after planting) and the remaining half at second weeding (35 days after planting).

Data Collection

Twelve quantitative traits and three qualitative traits were collected. From the quantitative traits, plant height (cm), panicle length (cm) and culm length (cm) were measured by randomly taking five plants from the central three rows of each plot; the mean values of the five samples were used for analysis. The number of total-tillers, effective -tillers and unproductive-tillers were recorded as the number of tillers produced per 0.5 m row assessed as the mean of three randomly selected central rows per plot. Days to heading, days to maturity, biomass yield (kg ha^{-1}), grain yield (kg ha^{-1}), harvest index (%) and lodging index (%) were measured on a plot basis. The lodging index was recorded using the method of Caldicott and Nuttall (1979), who defined the lodging index as the sum of the product of each degree of lodging (0-5 scale) and their respective percentage divided by five.

The three qualitative traits data were recorded based on visual observation and classification on a plot basis from the central three rows in each plot. Seed color: the seed coat color was recorded after threshing all the panicles as white and brown. Panicle form: the panicle appearance taken after flowering was recorded as very loose, loose, semi-compact and compact. Lemma color: classification of the lemma color was taken after flowering and was recorded as yellowish white, purple-brown, brown, dark brown, red and variegated.

Data Analyses

Analysis of Variance (ANOVA) was computed to test the presence of significant differences among landraces for the traits considered. The data collected for each quantitative trait was subjected to analysis following the Proc lattice command of SAS version 9.2 (SAS Institute, 2002).

The trait means data were standardized to a mean of zero and variance of one before computing cluster and principal component (PC) analyses. Squared distances (D^2) for each pair of genotype combinations were computed using the following formula of Mahalanobis (1936):

$$D^2_{ij} = (X_i - X_j)\, S^{-1}\, (X_i - X_j)$$

Where D^2_{ij} = the square distance between any two landraces i and j, X_i and X_j = the vectors for the values for ith and jth landraces, and S^{-1} = the inverse of pooled variance-covariance matrix.

Based on the D^2 values, cluster analysis was done by the average linkage method and the number of clusters was determined based on pseudo F and pseudo t^2 values. Average intra- and inter-cluster distances were estimated using the formula $\frac{\sum Di^2}{n}$, where $\sum D_i^2$ is the sum of the distance between all possible combinations, (n)= the number of the landraces included in a cluster. The principal component analysis was based on correlation matrix. As suggested by Iezzoni and Pritts (1991), principal components with eigenvalues less than 1 were ignored. Estimation of D^2, intra- and inter-cluster distances were done by using the SAS statistical package (SAS Institute, 2002). The dendrogram construction and the PC analysis were performed using the JMP SAS program.

Table 1: Description of the 62 tef landrace lines and two varieties tested at Adet in 2019

No.	Landraces	Collection region	District	No.	Landraces	Collection region	District
1	225921-1	Amhara	Este	33	228668-3	Oromia	Cheliya
2	242199-1	Amhara	Tach Gayint	34	237690-4	Oromia	Dendi
3	222062-4	Amhara	Ambasel	35	55090-1	Oromia	Jeldu
4	225898-1	Amhara	Debresina	36	222123-1	Oromia	Walisona Goro
5	225907-2	Amhara	Kelala	37	222123-3	Oromia	Walisona Goro
6	212591-2	Amhara	Were Ilu	38	236761-3	Oromia	Wonchi
7	242138-2	Amhara	Adet	39	55151-1	Oromia	Kombolcha
8	242150-3	Amhara	Bure Wemberma	40	238606-1	Oromia	Ada'a Chukala
9	238221-4	Amhara	Baso Liben	41	238606-6	Oromia	Ada'a Chukala
10	234776-2	Amhara	Dejen	42	237573-2	Oromia	Arsi Negele
11	229772-1	Amhara	Enarj Enawga	43	237573-3	Oromia	Arsi Negele
12	229759-1	Amhara	Enebise Sar Midir	44	236262-2	Oromia	Boset
13	234742-2	Amhara	Enemay	45	238618-2	Oromia	Lome
14	238223-4	Amhara	Guzamn	56	237575-1	Oromia	Seraro
15	238220-1	Amhara	Machakel	47	237574-2	Oromia	Shashemene
16	238220-2	Amhara	Machakel	48	237700-C	Oromia	Bila Seyo
17	229767-1	Amhara	Shebel Berenta	49	236361-2	Oromia	Diga Leka
18	202377-4	Amhara	Chefe Golana Dewera	50	237699-3	Oromia	Guduru
19	214214-1	Amhara	Addi Arkay	51	237709-4	Oromia	Guto Wayu
20	235758-1	Amhara	Alefa	52	236360-2	Oromia	Sasiga
21	242186-1	Amhara	Belesa	53	236535-2	Oromia	Degem
22	234701-1	Amhara	Dembia	54	236748-2	Oromia	Hidabu Abote
23	212489-1	Amhara	Lay Betna Tach Bet	55	237730-2	SNNP	Limo
24	229749-1	Benishangul-Gumuz	Dibate	56	244793-1	SNNP	Kacha Bira
25	230773-2	Oromia	Moyale	57	237576-2	SNNP	Angacha
26	230772-3	Oromia	Moyale	58	230802-1	Somali	Jigjiga
27	244887-1	Oromia	Gechi	59	230802-2	Somali	Jigjiga
28	244882-2	Oromia	Gechi	60	234360-1	Tigray	Enderta
29	237695-4	Oromia	Ambo	61	234357-1	Tigray	Hintalo Wajirat
30	237722-1	Oromia	Becho	62	219850-2	Tigray	Adwa
31	237722-2	Oromia	Becho	63	Flagot	Standard Check	-
32	239373-1	Oromia	Cheliya	64	Washera	Standard Check	-

SNNP = Southern Nation, Nationalities and Peoples

RESULTS AND DISCUSSION

Analysis of Variance

The result of the analysis of variance (ANOVA) for the 12 traits considered is presented in Table 2. The result showed that the mean squares due to landraces were significant ($P \leq 0.05$) for panicle length and biomass yield, and they were highly significant ($P < 0.01$) for the other 10 traits. This result revealed the existence of adequate variations which can be exploited through selection. The result agrees with that of Abraha *et al.* (2017), Worede and Tefera (2020), and Tesfa *et al.* (2021). The coefficient of determination (R^2) ranged from 0.67 for panicle length to 0.99 for days to maturity indicating that from 67% to 99% of the variation in the tef landraces was explained by the traits measured.

Table 2: Mean squares of the 12 traits of the 64 tef landraces evaluated at Adet in 2019

Trait	Source of variation			CV (%)	R^2
	Replications (df=1)	Landraces (df=63)	Error (df=49)		
Days to heading	3.12	35.99**	9.62	7.32	0.81
Days to maturity	25.38	315.86**	4.00	3.01	0.99
Plant height (cm)	207.82	246.16**	104.49	7.88	0.77
Panicle length (cm)	51.51	42.03*	26.79	12.96	0.67
Culm length (cm)	7.31	294.26**	152.87	14.32	0.71
Effective tillers	254.53	1255.2**	237.66	15.04	0.85
Unproductive tillers	147.05	705.2**	132.96	14.9	0.86
Total tillers	787.03	3841.6**	727.96	15.1	0.85
Biomass yield (kg ha^{-1})	537166.12	136261.86*	78151	3.137	0.70
Grain yield (kg ha^{-1})	296363.38	784130.42**	145113	16.01	0.85
Harvest index (%)	14.53	78.92**	15.01	15.05	0.85
Lodging index (%)	741.12	925.89**	163.58	20.78	0.87

df = Degrees of freedom, *, **= Significant at $P < 0.05$ and $P < 0.01$, CV (%) = Coefficient of Variation, R^2 = Coefficient of determinant

Cluster Analyses

Clustering of landraces

Using the mean values of the 12 traits, all possible pairwise squared distances (D^2) were computed for all the 64 tef landraces. Hierarchical cluster analysis was employed by using the average linkage method. The 64 landraces considered in the present study were grouped into four clusters (Table 3 and Figure 1) based on quantitative traits, which is an indication of genetic variation among the landraces. The result is in line with that of Ayalew *et al.* (2011) who grouped 37 tef lines collected from the Amhara Region into five clusters. The first cluster had the highest number of landraces with 46 members including the two checks (*Flagot* and *Washera*), the second cluster

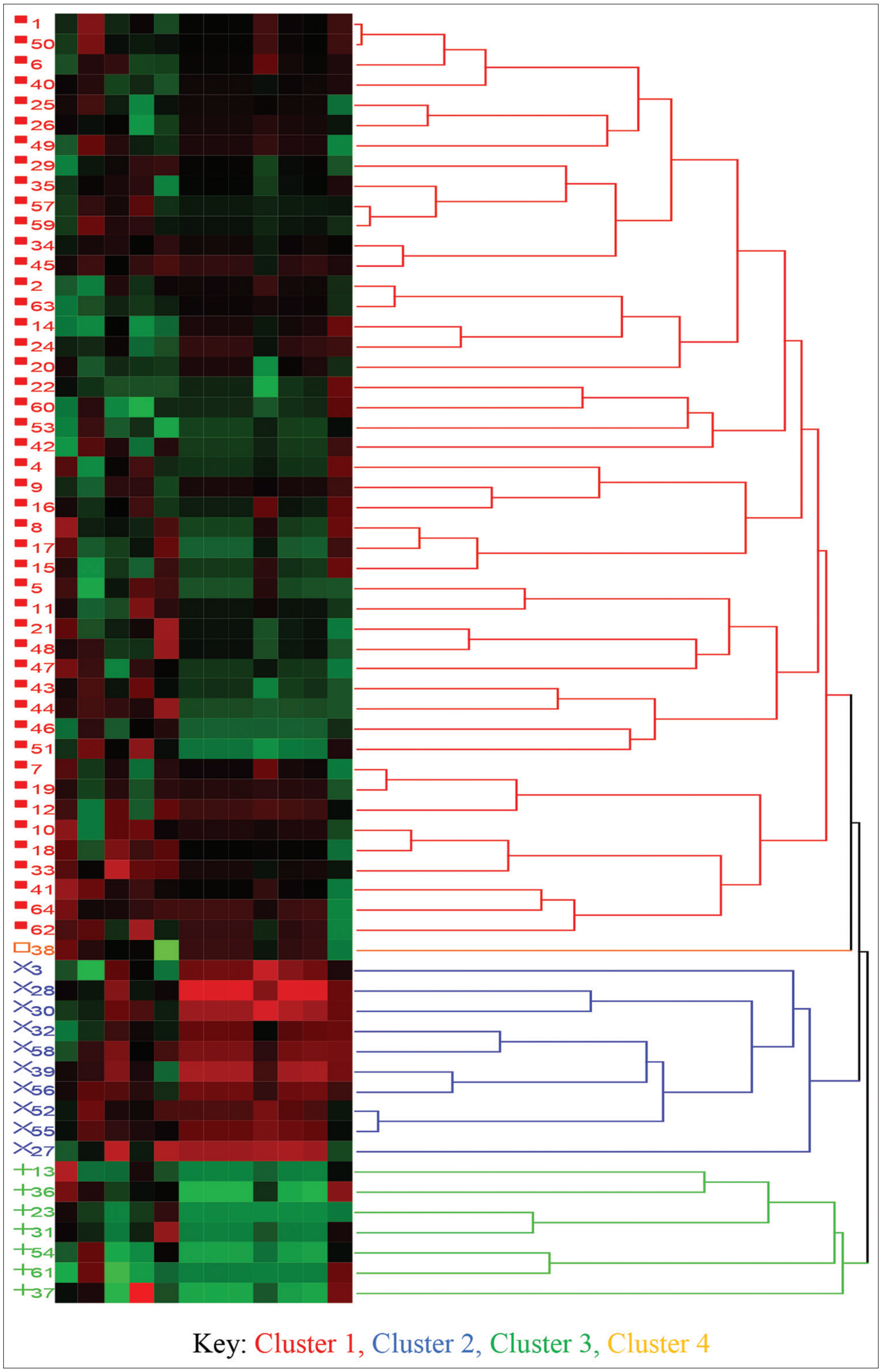

Figure 1: Dendrogram showing relationships among the 64 tef landraces based on 12 traits. The numbers indicate identification of the landraces as presented in Table 1

had 10 landraces and the third cluster was comprised of seven tef landraces. On the other hand, the fourth cluster was comprised of only one tef genotype. This genotype was collected from the Wonchi district of the Oromia region.

Cluster means of traits

The trait means for each cluster are presented in Table 4. The first cluster showed an average performance for most of the traits studied. This cluster had a higher mean value for panicle length.

Cluster II, which consisted of ten landraces, was characterized by the lowest mean for plant height; grain yield; number of total-, effective-, and unproductive-tillers; biomass yield and harvest index. This cluster is the least important in terms of the traits considered. Cluster III that contained seven landraces was characterized by the longest plant height, high value of number of tillers (effective, unproductive, and total), biomass yield, grain yield, harvest index and lodging index. Compared to the other clusters, this cluster generally showed the highest performance for most of the desirable traits. Hence, direct selection might be a good approach for accumulating the desirable traits in a genotype.

Cluster IV was consisted of tef landraces with the highest mean for days to heading, days to maturity and panicle length; intermediate mean for plant height, and longest culm length. Comparatively late-maturing landraces could be selected from this custer.

Intra- and inter-cluster distances

The standardized D^2 statistics showed the existence of genetic difference between pairs of clusters, and the divergences between all pairs of clusters were highly significant ($p<0.01$) except for cluster I-cluster II pairwise distance which was significant ($p<0.05$); while intra-cluster divergences showed non-significant differences (Table 5).

Regarding the inter-cluster distance, the maximum distance was found between clusters III and IV ($D^2=64.4$) followed by clusters II and III ($D^2=61.6$) and clusters II and IV ($D^2=57.02$). These higher and significant inter-cluster distances indicated the presence of wider genetic diversity among the tef landraces. The extent of diversity present in the studied landraces implied the opportunity of tef improvement through selection and hybridization depending on the nature of gene action governing the desired traits. Based on these variations, crossing involving members of cluster III with cluster II and cluster IV may exhibit high heterotic expression in the F_1 and broad-spectrum of variability in the succeeding segregating population.

The minimum distance was found between clusters I and II ($D^2=20$). Crossing of parents from these clusters may not be effective.

Table 3: Clustering of the 62 tef landraces and two varieties into four groups using mean of 12 morphological traits

Cluster	Number of landraces	Landraces included in the cluster
I	46	225921-1, 242199-1, 225898-1, 225907-2, 212591-2, 242138-2, 242150-3 238221-4, 234776-2, 229772-1, 229759-1, 238223-4, 238220-1, 238220-2 229767-1, 202377-4, 214214-1, 235758-1, 242186-1, 234701-1, 229749-1 230773-2, 230772-3, 237695-4, 228668-3, 237690-4, 55090-1, 238606-1 238606-6, 237573-2, 237573-3, 236262-2, 238618-2, 237575-1, 237574-2 237700-c, 236361-2, 237699-3, 237709-4, 236360-2, 236535-2, 237576-2 230802-2, 234360-1, 219850-2, Flagot, Washera
II	7	234742-2, 212489-1, 237722-2, 222123-1, 222123-3, 236748-2, 234357-1
III	10	222062-4, 244887-1, 244882-2, 237722-1, 239373-1, 55151-1, 236360-2 237730-2, 244793-1, 230802-1
IV	1	236761-3

Table 4: Cluster means for 12 quantitative traits of the 64 tef landraces

Traits	Cluster I	Cluster II	Cluster III	Cluster IV
Days to heading	43.22	43.43	40.95	48.5
Days to maturity	68.93	71.43	71.55	76.5
Plant height (cm)	127.53	108.48	141.68	127.35
Panicle length (cm)	38.59	37.81	39.64	39.1
Culm length (cm)	82.48	80.56	82.2	93
Effective tillers	108.61	66.68	152.15	130.75
Unproductive tillers	81.43	49.92	114.05	92.25
Total tillers	190.04	116.61	266.21	229
Biomass yield (kg ha^{-1})	9022.3	8724.1	9426.9	8990.5
Grain yield (kg ha^{-1})	2461.7	1457.9	3598.4	2947.9
Harvest index (%)	27.23	16.7	38.15	32.79
Lodging index (%)	57.74	71.02	76.55	30

Principal Component Analysis

In the present study, the principal component (PC) analysis revealed that four principal components with eigenvalues greater than one were retained (Table 6). The first four PCs accounted for 76% of the total variation, from which PC1 contributed for 41.95% of the variation, and PC2, PC3 and PC4 explained 16.31%, 9.28% and 8.46% of the variations among the 64 tef landraces, respectively (Table 6). In agreement with the present finding, Worede (2017) explained 74% of the total variation of 166 tef landraces by three PCs. Wuthrich *et al.* (2013) explained 80% of the variation of tef landraces grown under greenhouse conditions with four PCs using 13 traits. In addition, the work of Assefa *et al.* (2003) with 17 traits of 60 tef pure lines showed similarity in variations explained in PC1. However, the first PC in the studies of Adnew *et al.* (2005) and Jifar *et al.* (2015) explained a relatively high proportion of the variation as compared to this study. The variation explained by the second PC in the present study is in line with the results of Assefa *et al.* (2000).

Traits that contributed relatively more to the first PC were grain yield, harvest index, plant height, tiller-related traits and biomass yield. Similarly, days to heading culm length and lodging index had a high contribution to the second PC. The third principal component accounted for 9.28% of the total variation mainly contributed by days to maturity. The fourth

Table 5: Pair-wise generalized intra-cluster (bold diagonal) and inter-cluster (off diagonal) distances (D^2) between four clusters

Clusters	I	II	III	IV
I	6.62	19.95*	25.98**	30.41**
II		12.06	61.6**	57.02**
III			7.75	64.41**
IV				5.06

$\chi^2=24.72$ at 1% probability level and $\chi^2=19.67$ at 5% probability level.

Table 6: Eigenvectors, explained variance and eigenvalues of 12 traits by quantitative traits

Trait	Eigenvectors			
	PC1	PC2	PC3	PC4
Days to heading	-0.036	**0.543**	-0.185	0.295
Days to maturity	-0.039	-0.151	**0.852**	-0.164
Plant height (cm)	**0.371**	0.155	0.025	0.078
Panicle length (cm)	0.015	0.322	0.402	**0.716**
Culm length (cm)	0.019	**0.502**	-0.032	-0.414
Effective tillers	**0.356**	-0.202	-0.005	0.002
Unproductive tillers	**0.332**	0.139	0.026	-0.140
Total tillers	**0.380**	-0.054	0.048	-0.023
Biomass yield (kg ha^{-1})	**0.365**	0.009	-0.132	0.072
Grain yield (kg ha^{-1})	**0.420**	-0.002	0.040	-0.008
Harvest index (%)	**0.410**	0.000	0.059	-0.019
Lodging index (%)	0.028	**-0.489**	-0.225	0.413
Eigenvalue	5.034	1.957	1.114	1.015
Variance explained (%)	41.95	16.31	9.28	8.46
Cumulative variance explained (%)	41.95	58.26	67.54	76.00

principal component accounted for 8.46% of the total variation with a relatively high contribution of panicle length, culm length and lodging index.

From the present results, it can be concluded that grain yield, harvest index, days to heading, culm length and lodging index are the higher contributors to the diversity of the tef landraces. These traits were most important in the discrimination of the landraces into clusters; therefore, selection efforts based on these traits could be more effective for improving the genotypic value of the new populations. The fact that the entire variation cannot be explained in terms of a few PCs reflects the presence of sizable phenotypic diversity among the tef landraces.

The first two principal components which accounted for 58.26% of the variance were plotted to observe relationships between the traits and the 64 tef landraces (Figure 2). The most prominent relationships are the strong positive association of yield (both grain and biomass) with harvest index, number of tillers and plant height (Figure 2).

The biplot also helps to envision the trait profiles of genotypes, which is important for parents as well as variety selection (Yan & Kang, 2003). Based on the present results, the landraces situated on the very right side of the biplot like 244887-1, 244882-2 and 237722-1 are better in terms of grain and biomass yield, harvest index, tiller number and plant height. As a result, these landraces could be directly selected for grain and biomass yield improvement. However, landrace lines 222123-3, 222123-1 and 236748-2 which are located on the very left side of the biplot are poor in most of the yield and yield-related traits like grain- and biomass-yield, harvest index, tiller number and plant height. The cluster analysis also confirmed that these landraces are grouped in cluster II, a cluster with minimum mean values for most of the agronomically important traits.

Qualitative Trait of tef

In the present study three qualitative traits were observed among tef landraces. The 64 tef landraces were grouped visually into two categories as white (56.25%) and brown (43.75%) based on seed color. Similarly, for lemma color, six categories, variegated (57.81%) brown (9.37%), yellowish white (25%), purple-brown (3.12%), red (1.56%) and dark brown (1.56%) were obtained. This shows that most of the populations are from the variegated lemma color group.

Table 7: Frequency occurrence of some qualitative traits of the 64 tef landraces

Trait	Characters	Number of occurrences	Frequency of occurrence (%)
Seed color	White	36	56.25
	Brown	28	43.75
Panicle forms	Very lose	24	37.5
	Lose	36	56.25
	Semi-compact	1	1.56
	Compact	3	4.68
Lemma color	Variegated	37	57.81
	Yellowish white	16	25
	Brown	6	9.37
	Purple-brown	2	3.12
	Red	1	1.56
	Dark brown	1	1.56

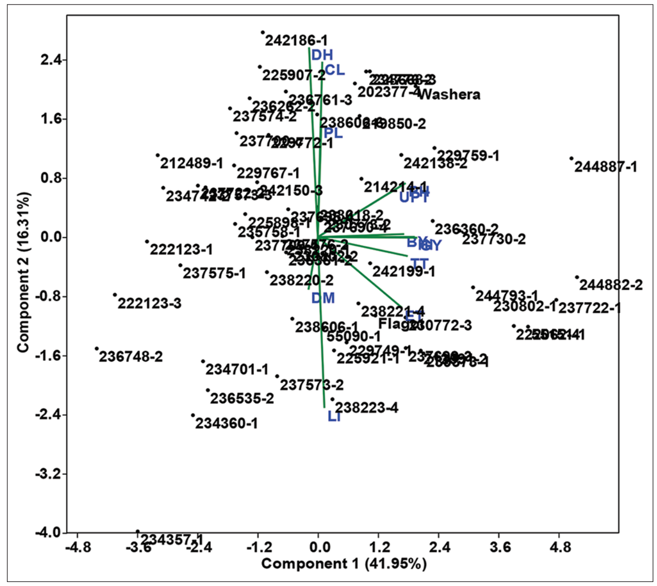

Figure 2: Biplot of PC1 and PC2 showing the relationship of the 64 tef landraces by 12 traits. PH=plant height, PL=panicle length, CL=culm length, TT=total-tillers, ET= effective-tillers, UPT=unproductive-tillers, DH=days to heading, DM=days to maturity, BY=biomass yield, GY=grain yield, HI=harvest index and LI=lodging index.

With respect to panicle form, the 64 tef landraces were grouped into four categories which include very loose (37.5%), loose (56.25%), semi-compact (1.56%) and compact (4.68%) (Table 7). Almost all of the landraces in this study are from very loose and loose panicle form. This agrees with what has been reported by Assefa *et al.* (2002). Differences in panicle form, seed and lemma color are other indicators of variation existing in tef landraces. Generally, frequency of occurrence data of panicle form, the color of lemma and seed coat showed the presence of variation among the tef landraces studied.

CONCLUSIONS

The results of the analysis of variance showed the presence of sufficient genetic variability among the tef landraces and that could be utilized for improvement through direct selection. Through cluster analysis, the maximum genetic distance was found between clusters III and IV followed by clusters II and III. Therefore, to exploit heterosis at F_1 generation, it will be better to use parents for crossing from clusters III and IV, and clusters II and III. The principal component analysis revealed the presence of enough variability within the 64 landraces of tef and traits like grain yield, harvest index, culm length, days to heading and lodging index were more important in explaining the gross variability and differentiating the tef landraces. The frequency occurrence of qualitative traits shows that most of the landraces had variegated lemma color, loose panicle form and white seed color.

Keeping in view of the present findings, promising landraces, mostly grouped in cluster III like 244887-1, 244882-2 and 237722-1, could be considered for improvement of tef to enhance tef production. Genetic diversity analysis through molecular markers and over season study of these landraces is recommended for better reliability and utility of the present results.

ACKNOWLEDGEMENT

A special appreciation goes to Mr. Misganaw Ferede and the tef breeding staff of Adet Agricultural Research Center for providing the experimental materials and for technical support during the research work.

REFERENCES

Abraha, M. T., Hussein, S., Laing, M., & Assefa, K. (2017). Genetic variation and trait association of tef [*Eragrostis tef* (Zucc.) Trotter] evaluated under optimal and moisture stressed environments. *Australian Journal of Crop Science, 11*(3), 241-247.

Adnew, T., Ketema, S., Tefera, H., & Sridhara, H. (2005). Genetic diversity in tef [Eragrostis tef (Zucc.) Trotter] germplasm. Genetic Resources and Crop Evolution, 52, 891-902. https://doi.org/10.1007/s10722-003-6099-0

Assefa K., Merker, A., & Tefera, H. (2002). Qualitative trait variation in Tef [*Eragrostis tef* (Zucc.) Trotter] germplasm from Western and Southern Ethiopia. *Euphytica, 127*, 399-410. https://doi.org/10.1023/A:1020318903145

Assefa, K., Ketema, S., Tefera, H., Kefyalew, T., & Hundera, F. (2000). Trait diversity, heritability and genetic advance in selected germplasm lines of tef [*Eragrostis tef* (Zucc.) Trotter]. *Hereditas, 133*(1), 29-37. https://doi.org/10.1111/j.1601-5223.2000.t01-1-00029.x

Assefa, K., Merker, A., & Tefera, H. (2003). Multivariate analysis of diversity of tef (*Eragrostis tef* (Zucc.) Trotter) germplasm from western and southern Ethiopia. *Hereditas, 138*(3), 228-236. https://doi.org/10.1034/j.1601-5223.2003.01638.x

Ayalew, H., Genet, T., Dessalegn, T., & Wondale, L. (2011). Multivariate diversity, heritability and genetic advance in tef landraces in Ethiopia. *African Crop Science Journal, 19*(3), 201-212.

Ben-Zeev, S., Bimro, J., Barak, V., & Saranga, Y. (2018). Phenotypic diversity and heritability in *Eragrostis tef* under irrigated Mediterranean conditions. *Israel Journal of Plant Sciences, 65*(3-4), 222-231. https://doi.org/10.1163/22238980-00001061

Caldicott, J. J. B., & Nuttall, A. M. (1979). A method for the assessment of lodging in cereal crops. *Journal of the National Institute of Agricultural Botany, 15*, 88-91.

Central Statistical Authority. (2019). *Agricultural Sample Survey 2018/19, Volume I: Report on area and production for major crops*. Statistical bulletin 589. Addis Ababa, Ethiopia.

Fikre, T., Genet, Y., Kebede, W., Tolossa, K., Chanyalew, S., Demissie, M., Assefa, K., Fentahun, A., Demis, E., Bayisa, T., & Tadele, Z. (2020). Yield and agronomic performance of selected semi-dwarf tef (*Eragrostis tef* (Zucc.) Trotter) genotypes under irrigation farming system in Ethiopia. *American Journal of Plant Biology, 5*(4), 110-119. https://doi.org/10.11648/j.ajpb.20200504.16

Hopman, E., Dekking, L., Blokland, M. L., Wuisman, M., Zuijderduin, W., Koning, F., & Schweizer, J. (2008). Tef in the diet of celiac patients in the Netherlands. *Scandinavian Journal of Gastroenterology, 43*(3), 277-282. https://doi.org/10.1080/00365520701714871

Iezzoni, A. F., & Pritts, M. P. (1991). Applications of Principal Component Analysis to Horticultural Research. *HortScience, 26*(4), 334-338. https://doi.org/10.21273/HORTSCI.26.4.334

Jifar, H., Assefa K., & Tadele, Z. (2015). Grain yield variation and association of major traits in brown-seeded genotypes of tef [*Eragrostis tef (Zucc.)* Trotter]. *Agriculture and Food Security, 4*, 7. https://doi.org/10.1186/s40066-015-0027-3

Ketema, S. (1997). *Tef: [Eragrostis tef (Zucc.) Trotter]: Promoting the Conservation and Use of Underutilized and Neglected crops. 12.* Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy.

Lacey, T., & Llewellyn, C. (2005). *Eragrostis tef as a specialized niche crop*. Farm Note 42/2005. State of Western Australia.

Mahalanobis, P. C. (1936). On the generalized distance in statistics. *Proceedings of the National Institute of Science of India, 2*, 49-55.

Mengesha, M. H., & Guard, A. T. (1966). Development of the embryo sac and embryo of teff, *Eragrostis tef. Canadian Journal of Botany, 44*(8), 1071-1075. https://doi.org/10.1139/b66-114

SAS Institute. (2002). *SAS/STAT Guide for Personal Computers.* Version 9.2 editions. Cary, N.C., SAS Institute Inc.

Spaenij-Dekking, L., Kooy-Winkelaar, Y., & Koning, F. (2005). The Ethiopian cereal tef in celiac disease. *The New England Journal of Medicine, 353*(16), 1748-1749.

Tesfa, E. W., Abebe, T. D., & Worede, F. (2021). Variance components in recombinant inbred lines of Tef [*Eragrostis tef* (Zucc.) Trotter]: Estimation and their implications in selection. *Cogent Food and Agriculture, 7*(1), 2005896. https://doi.org/10.1080/23311932.2021.2005896

Vavilov, N. I. (1951). *The Origin, Variation, Immunity and Breeding of Cultivated Plants* (translated from Russian by K. Star Chester) (pp. 37-38) Waltham, Massachusetts: Chronica Botanica.

Worede, F. (2017). Multivariate analyses of phenotypic diversity in Northeast Ethiopian tef [*Eragrostis tef* (Zucc.) Trotter] landrace collections. *Abyssinia Journal of Science and Technology, 2*(1), 17-24. https://doi.org/10.20372/ajst.2017.2.1.67

Worede, F., & Tefera, H. (2020). Selection for yield and its component traits in inter specific recombinant inbred lines of tef. *Journal of Scientific Agriculture, 4*, 77-82. https://doi.org/10.25081/jsa.2020.v4.6263

Worede, F., Wondimu, S., & Shewayirga, H. (2007). Performance of tef varieties in moisture stress areas of Welo, Northeast Ethiopia. In E. Abate, A. Teshome, A. A. Gebeyaneh, M. Wale, T. Desalegn & T. Tadesse (Eds.), Proceedings of the 1st Annual Regional Conference on Completed Crop Research Activities (pp. 178-182), 14-17 August 2006. ARARI. Bahir Dar, Ethiopia.

Wuthrich, S. P., Cannarozzi, G. M., & Tadele, Z. (2013). Genetic and phenotypic diversity in selected genotypes of tef [*Eragrostis tef* (Zucc.) Trotter]. *African Journal of Agricultural Research, 8*(12), 1042-1049. https://doi.org/10.5897/AJAR2012.6682

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