Phenotypic Diversity in Tef [*Eragrostis Tef* (Zucc.) Trotter] Accessions from Different Regions of Ethiopia

Dagnachew Lule[1], Endashaw Bekele[2] and Amsalu Ayana[3]
[1]Bako Agricultural Research Center, PO. Box: 03, Bako, Ethiopia
[2]Addis Ababa University, Department of Biology, Addis Ababa
[3]Oromia Agricultural Research Institute, P.O.Box 81265, Addis Ababa

Abstract

Seventy nine tef landraces collected from ten administrative zones and seven altitude classes were planted with two improved varieties in simple lattice design at Gute and Bako in 2007 and 2008, respectively to assess the patterns of genetic variation for quantitative and qualitative traits. Loose and fairly loose panicle forms; gray lemma color and brown seed color were abundant across all regions and altitude classes while compact and semi-compact panicles, red and purple lemma color and white seed color were less frequent. Higher Shannon diversity indices were observed for East Gojam, East Wollega, Horro Guduru Wollega, Illubabor and Jimma collections. Mean squares due to genotypes were significantly different for all traits except number of culm internodes, number of spikelet per panicle and number of fertile floret/spikelet at top of the panicle. Genotypes and environments interacted highly significantly (P≤0.01) for number of panicle branches, lodging index, above ground biomass weight, grain yield per plant and harvest index. About 73% of the entire diversity among population was explained by the first six principal components (PCs), of which the first PC explained about 31% of the variation. This originated mainly due plant height, panicle length, culm length, first and second culm internode diameters, days to panicle emergency and days to maturity. Similarly, about 91% and 90% of the variations among regions of origin and altitude classes were explained by the first five and three PCs, respectively. At 50% similarity level, 11 clusters were formed, containing 2-33 landrace populations per cluster, while six tef landraces remain solitary. There is no cluster formed solely either from tef populations of a given region, tef populations collected from similar agro-ecological zones or populations collected from areas with similar soil type. Some neighboring regions were grouped together in one cluster, implying that there are extensive informal seed exchanges or inter-regional migration of farmers with their seed. Some other regions show strong similarity while they are geographically very far away from each other (for instance, South Wello and Horro Guduru Wollega). Six altitude classes were grouped in to two main clusters at about 50% similarity level. However, tef landraces collected from altitude class below 1576 m.a.s.l (class I) remain un-grouped.

Key Words: Accessions, clustering, *Eragrostis tef*, germplasm, diversity pattern, principal component

Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is an indigenous cereal to Ethiopia. It belongs to the grass family Poaceae (Gramineae) and genus *Eragrostis* (Seyfu, 1993). Ethiopia is the center of both origin and diversity of tef (Vavilov, 1951). Tef is an allotetraploid plant with a chromosome number of 2n= 40 and the basic chromosome number of the genus *Eragrostis* is X=10 (Tavassoli, 1986). It is the major Ethiopian cereal grown on about 2.5 million hectares annually (CSA, 2008), and serving as staple food grain for over 50 million people. The area devoted to tef cultivation is on the increase because both the grain and straw fetch high domestic market prices. It is also a resilient crop adapted to diverse agro-ecologies with reasonable tolerance to both low (especially terminal drought) and high (water logging) moisture. Tef, therefore, is useful as a low-risk crop to farmers due to its high potential of adaption to climate change and fluctuating environmental conditions.

Variety development is a continuous process, and in tef it is largely an Ethiopian undertaking. Breeding depends heavily upon the existence and if not already there on the creation of variability on which selection can be exercised. Indigenous crops like tef with no germplasm or breeding materials stock to receive from other national or international institutions have no choice but to depend on the existing natural variation, or create variation with conventional breeding techniques. Accordingly, studying the genetic variation of a crop is essential for effective utilization of germplasm in plant breeding programs, devising appropriate sampling procedures for germplasm collection and conservation, obtaining some collections for efficient germplasm management and explicating the taxonomy, evolution and origin of crop species (Endashaw 1985; Hailu *et al.*, 1990; Abebe and Bjornstrand, 1996; Kebebew *et al.,* 2002, and Gemechu *et al.*, 2007).

The existence of broad genetic variations has been identified in tef germplasms for morphological traits (Melak-Hail *et al.*, 1965; Tadesse, 1975; Endashaw, 1996; Hailu and Seyfu, 2001; Kebebew *et al.*, 2003). Nevertheless, efficient utilization of tef genetic resources still requires comprehensive, systematic and intensive evaluation and characterization of the genetic diversity to enrich tef germplasm database, to devise appropriate sampling procedures for germplasm collection and conservation, and to identify genotypes for utilization in the breeding programs. In an attempt to contributing to this end, the current study was carried out to assess the genetic variability among tef accessions originating from different regions and altitudinal ranges of Ethiopia.

Materials and Methods

A total of 79 landrace populations and two improved tef varieties were evaluated at Gute (sub-site of Bako Agricultural Research Center) and Bako during the main cropping seasons of 2007 and 2008, respectively. These landraces were collected by the Institute of Biodiversity Conservation (IBC) from 10 major tef producing administrative zones (Arsi, Bale, East Gojam, East Wollega, Horro Guduru Wollega, Illuababor, Jimma, South Wello, West Shewa and West Wollega) (Table 1). The improved varieties included were DZ-Cr-255 (Gibe) released by the Debre Zeit Agricultural Research Center in 1993 and adapted to mid to high altitudes (1500-2200 m.a.s.l.), and DZ-01-1880 (Guduru) released by the Bako Agricultural Research Center in 2005 and adapted to mid to high altitude regions (1800-2450 m.a.s.l.).

Seven altitude classes were used to group tef population with relative resemblance of agro-climatic origin using the formula: $K = 1+3.32\log_{10}n$ and $W= (L-S)/K$ (Agrawal, 1996) where: K= number of class intervals, W= width of class interval, L= the largest value,, S= the smallest value and n=sample size (in this case accession member).

The experiment was laid out in 9 x 9 simple lattices with two replications. Seed and fertilizer rate was used as per the recommendation. Data were recorded for qualitative traits such as panicle form, lemma color, and seed color. The quantitative parameters assessed included days to 50% panicle emergence, days to 50% maturity, plant height (cm), panicle length (cm), culm length (cm), number of culm internodes, number of panicle branches, number of spikelet per panicle, lodging index, first basal culm internodes diameter (cm), second basal culm internodes diameter (cm), number of fertile floret per spikelet (at top, middle and base of the panicle), above ground weight per plant (g), biomass weight per plant (g), grain yield per plant (g) and harvest index (HI%) were recorded following tef descriptors (IBC, 1995) and procedures of previous research (Tadesse, 1975; Tareke, 1981; Kebebew, 2001).

The frequency distribution of qualitative traits across regions and altitude classes were computed using the EXCEL computer program. Genetic diversity index (amount of genetic variation) within tef population, region and altitude classes were estimated using the Shannon-Weaver diversity index, which is calculated by the formula described by Jain *et al*., (1975):

$$H' = -\sum_{i=1}^{n} Pi \log ePi$$

where; n is the number of phenotypic classes for a character and P_i is the genotypic frequency as the proportion (%) of the total entries in the i^{th} class.

The analysis of variance and the relative efficiency of simple lattice over the RCBD were tested using Agrobase (2000) software. The design used was less efficient for all quantitative traits except for days to panicle emergence, number of culm internodes and second basal culm internode diameter. In cases where the blocking of incomplete block design was less effective, the randomized complete block design (RCBD) was used for the analysis as suggested by Cochran and Cox (1957). Principal component analysis was computed by using MINITAB14 (MINITAB, 2003) computer software for entire population, regions and altitudes of origin separately. Clustering was performed to determine the relatedness and differences among populations, altitude classes and regions of origin using the NTSYs ver.2.1 software with Euclidian distance measure, SAHN clustering and Un-weighted Pair Group Methods based on Arithmetic averages (UPGMA) (Rohlf, 2004). Data on all quantitative traits were standardized to a mean of zero and a variance of one before clustering to avoid bias arising due to differences in measurement scales.

Table 1. Accession number, region, district, soil type & altitude of the tef germplasm accessions studied

No.	Acc.	Admin. Regions	District	Soil type	Altitude (m.a.s.l.)
1	229966	Arsi	Sherka	Sandy-loam	2550
2	229971	Arsi	Ziway Dugda	Sand	1730
3	231217	Arsi	Chole	Clay loam	1540
4	231219	Arsi	Jeju	NI	1600
5	236952	Arsi	Dodotana Sire	Sandy-loam	2710
6	232245	Arsi	Sherka	Clay loam	2550
7	236942	Arsi	Gedeb	Sandy-loam	2350
8	236944	Arsi	Tiyo	Loam	2000
9	55014	Bale	Sinanana Dinisho	NI	2565
10	55015	Bale	Agarfa	Clay	2500
11	55016	Bale	Goro	NI	1710
12	237737	Bale	Adaba	Clay loam	2400
13	229981	Bale	Sinanana Dinisho	Clay	2560
14	229982	Bale	Mennana Herena Bulu	Loam	1440
15	55018	Bale	Ginir	Loam	1630
16	55019	Bale	Gaserana Gololcha	Clay	1980
17	55022	Bale	Gaserana Gololcha	NI	2300
18	55045	East Gojam	Hulet Ej Enese	Clay	2260
19	55046	East Gojam	Hulet Ej Enese	NI	1920
20	55047	East Gojam	Goncha Siso Enese	Clay	2670
21	222174	East Gojam	Dejen	NI	1500
22	229754	East Gojam	Hulet Eju Enese	Loam	1790
23	55172	East Gojam	Machakel	NI	2440
24	55267	East Gojam	Dejen	Sandy-loam	1570
25	55062	East Gojam	Enemay	Clay	2560
26	203010	East Wollega	Bila Seyo	Clay loam	1600
27	202991	East Wollega	Arjo	Clay	2420
28	237704	East Wollega	Sibu Sire	Clay loam	1760

Table 1. Continued

No.	Acc.	Admin. Regions	District	Soil type	Altitude (m.a.s.l.)
29	237706	East Wollega	Guto Wayu	Clay loam	1620
30	237707	East Wollega	Gida Kiremu	Clay loam	1450
31	237700	East Wollega	Bila Seyo	Clay loam	2470
32	236364	East Wollega	Diga Leka	Loam	2420
33	236365	East Wollega	Jimma Arjo	Loam	2470
34	55261	East Wollega	Limu	Clay loam	2210
35	239391	East Wollega	Gatama	Loam	2260
36	236359	East Wollega	Guto Wayu	Loam	2100
37	239384	Horro Guduru	Jimma Horo	Sandy-loam	2500
38	203030	Horro Guduru	Jimma Horo	Clay	2210
39	236357	Horro Guduru	Guduru	Loam	2200
40	239376	Horro Guduru	Guduru	Loam	2300
41	236326	Horro Guduru	Abay Chomen	Loam	2420
42	236336	Horro Guduru	Jimma Horo	Clay	2520
43	236328	Horro Guduru	Jimma Horo	Loam	2480
44	239379	Horro Guduru	Abay Chomen	Loam	2300
45	55253	Illubabor	Bedele	Clay loam	2000
46	55254	Illubabor	Bedele	Clay loam	1910
47	55248	Illubabor	Yayu	NI	1750
48	202979	Illubabor	Gechi	Clay loam	2140
49	202972	Illubabor	Bedele	Clay loam	1710
50	202952	Jimma	Sokoru	Clay loam	1920
51	202966	Jimma	Kersa	Clay	1770
52	202950	Jimma	Sokoru	Clay loam	1390
53	239396	Jimma	Kersa	Clay loam	1790
54	239398	Jimma	-	NI	1750
55	212597	South Wello	Legambo	Clay	2360
56	212599	South Wello	Legambo	Clay loam	2450
57	212608	South Wello	Kutaber	Clay loam	2400
58	212615	South Wello	Tehuledere	Clay loam	1690
59	212616	South Wello	Ambasel	Clay	1460
60	55101	South Wello	Dessie Zuria	NI	2500
61	203034	West Shewa	Bako Tibe	Clay loam	1610
62	203036	West Shewa	Cheliya	Clay	1680
63	228666	West Shewa	Ambo	NI	1500
64	55091	West Shewa	Jeldu	NI	2470
65	239375	West Shewa	Cheliya	Sandy-loam	2410
66	236752	West Shewa	Dendi	Clay	2160
67	236756	West Shewa	Cheliya	Clay loam	2100
68	236757	West Shewa	Adda Berga	Loam	2600
69	236758	West Shewa	Wonchi	Loam	2280
70	236340	West Shewa	Bako Tibe	Clay loam	1710
71	236754	West Shewa	Ambo	Clay loam	2150
72	55131	West Wollega	Gimbi	NI	1900
73	208753	West Wollega	Ayra Guliso	Clay loam	1800
74	202997	West Wollega	Jimma Gidami	Clay loam	2190
75	237712	West Wollega	Gimbi	Clay loam	1800
76	237713	West Wollega	Gimbi	Clay loam	1800
77	55156	West Wollega	Nejo	NI	2750
78	55147	West Wollega	Jarso	NI	2000
79	55154	West Wollega	Nejo	NI	2000
80	DZ-01-1880	Released	-		-
81	DZ-Cr-255	Released	-		-

NI = Not identified

Results and Discussion

Frequency distribution of qualitative traits at regional and altitudinal level

Five panicle forms (very loose, loose, fairly loose, semi-compact and compact) were observed in tef populations collected from East Gojam, East Wollega, Horro Guduru, Illubabor, Jimma and West Shewa administrative regions to a varying degree (Table 2). Tef populations collected from South Wello and Arsi lacked compact panicle forms. Overall, loose followed by fairly loose panicle form were abundant in tef populations across regions and altitudes of origins. Semi-compact and compact panicle forms were the least abundant. Five major lemma colors (gray, red, purple, yellowish-white and yellowish purple) were observed in the tef populations studied. The frequency distribution of lemma color showed that gray color is dominant across the seven altitude zones and ten administrative regions; whereas red colored lemma was less abundant. All types of lemma colors were observed in tef population collected from all altitude classes as well as across all regions of origin (except for South Wello) in which red lemma color was lacking. Both of the released varieties studied here have yellowish-white lemma color. Four categories of caryopsis color (white, brown, light brown and grayish-white) have been identified in this study.

All types of caryopsis colors have been observed across the 10 regions and the seven altitude classes, where brown colored seed is more dominant followed by light brown. Tef populations from South Wello, West Wollega and Bale consisted of about 52%, 49% and 47% brown seeded types, respectively, and these three regions, on the other hand, had few accessions with white seeds. White colored seed was comparatively abundant in populations collected from Arsi (33%), followed by Illubabor (23%). Both improved varieties are white seeded. In general, the higher frequency of open panicle form, gray colored lemma and brown seed color than other phenotypic classes of those traits in tef landraces considered in the current study across all altitude classes and regions of origin implies that selection was in favor of those phenotypes, probably due to greater productivity, high straw quality, reasonable requirement for external input and wider adaptability.

Shannon-Weaver diversity index (H’) analysis for qualitative traits

The mean Shannon-Weaver diversity index (H’) of tef populations determined for the three qualitative traits considered in the current study varied from 0.21 for accession 55147 of West Wollega

Table 2. Proportion (%) of three qualitative traits in 79 tef populations collected from ten major tef growing regions of Ethiopia and two released varieties

Traits	Phenotypic classes	Administrative zones: Arsi	Bale	East Gojam	East Wollega	H/Guduru Wollega	Illubabor	Jimma	South Wollo	West Shewa	West Wollega	Mean
panicle form	Very Loose	19.45	14.85	11.72	7.19	8.70	10.64	7.64	3.96	4.89	20.55	10.96
	Loose	46.40	50.98	41.06	41.18	42.70	40.01	37.94	53.74	49.60	32.00	43.56
	Fairly Loose	33.83	29.67	34.92	37.80	37.37	39.00	45.63	41.26	32.12	37.00	36.86
	Semi Compact	0.32	1.08	1.72	3.36	2.28	4.75	2.50	1.04	1.97	1.82	2.08
	Compact	0.00	3.42	10.58	10.47	8.95	5.60	6.29	0.00	11.42	8.63	6.54
panicle color	Gray	35.06	55.58	34.87	35.64	41.96	34.73	38.52	50.27	37.30	49.44	41.34
	Red	1.80	2.30	6.04	2.47	4.08	0.59	8.25	0.00	0.91	6.68	3.31
	Purple	13.00	12.00	11.60	10.59	9.87	9.33	5.40	12.43	11.06	7.01	10.23
	Yellowish-white	22.72	11.70	29.63	35.73	30.42	39.53	28.58	15.15	22.46	27.58	26.35
	yellowish purple	27.42	18.42	17.86	15.57	13.67	15.82	19.25	22.15	28.27	9.29	18.77
	White	33.23	12.23	16.95	20.17	19.78	23.25	19.67	9.95	14.30	14.21	18.41
seed color	Brown	26.89	47.15	37.45	42.48	39.70	30.30	30.74	51.74	44.43	48.91	39.95
	Light brown	26.39	35.26	28.16	25.87	23.78	24.50	28.32	32.38	28.05	27.98	28.07
	Grayish white	13.49	5.36	17.44	11.48	16.74	21.95	21.27	5.93	13.22	8.80	13.57

collected from altitude region of 2000 m.a.s.l. to 0.52 for accession 236328 of Horro Guduru Wollega collected from 2480 m.a.s.l

In addition, accession s 239375 (from 2410 m.a.s.l of West Shewa) and 203010 (from 1760 m.a.s.l of East Wollega) noted H′ indices of 0.50 each, relatively with higher diversity indices than the rest of the accession (data not shown).

Region wise, greater diversity in panicle forms were observed for tef populations collected from Illubabor (0.332), Horro Guduru (0.279) and East Wollega (0.277); but populations from South Wello (0.195) exhibited minimum diversity. Similarly, East Gojam (0.510), West Shewa (0.461), Arsi (0.458) and East Wollega (0.457) were the major regions possessing tef populations with comparatively high diversity of lemma color, and West Wollega (0.367) and Bale (0.377) were regions with minimum diversity for lemma color. Regarding seed color, East Gojam (0.543), Jimma (0.522) and Illubabor (0.504) were among the highest, but West Wollega (0.439) and Bale (0.448) were among the lowest diversity (Table 3).

Table 3. Shannon-Weaver diversity indices (H') of tef population from 10 regions of Ethiopia

Region	Panicle form	Lemma color	Seed color	Mean
Arsi	0.214	0.458	0.463	0.378
Bale	0.259	0.377	0.448	0.362
East. Gojam	0.262	0.510	0.543	0.438
East Wollega	0.277	0.457	0.487	0.407
Horro Guduru Wollega	0.279	0.447	0.478	0.401
Illubabor	0.332	0.413	0.504	0.416
Jima	0.258	0.443	0.522	0.407
South Wello	0.195	0.448	0.456	0.366
West Shewa	0.231	0.461	0.469	0.387
West Wollega	0.247	0.367	0.439	0.351
Mean	**0.255**	**0.438**	**0.481**	**0.391**

In terms of altitude, relatively high mean H′ values were noted for tef populations collected from altitude classes between 1763-1948 m. a.s.l. for panicle forms (0.297) and lemma color (0.495). Comparatively, diversified seed color (0.535) was observed in tef population collected below altitudes range of 1576m.a.s.l followed by H′ of 0.514 in altitude range of 1763-1948 m.a.s.l (Table 4).

Table 4. Shannon diversity index for the seven altitude classes of the tef germplasm collection areas

Altitude range (m.a.s.l.)	Panicle form	Lemma color	Seed color	Mean
≤1576	0.235	0.445	0.535	0.405
1577-1762	0.250	0.488	0.456	0.398
1763-1948	0.297	0.495	0.514	0.435
1949-2134	0.215	0.345	0.461	0.340
2135-2320	0.288	0.485	0.461	0.411
2321-2506	0.255	0.445	0.476	0.392
≥ 2507	0.244	0.361	0.465	0.357
Mean	**0.255**	**0.438**	**0.481**	**0.391**

The mean diversity across the three traits were lower for altitude region of 1949-2134 m.a.s.l (0.340) and higher for 1763-1948m a.s.l (0.435) (Table 4). The pooled mean for the three qualitative traits ranged from 0.351 (West Wollega) to 0.438 (East Gojam) and the grand mean was 0.39.

Altitudinaly, the range of H′ was from 0.34 (for altitude between 1949 - 2134 m.a.s.l.) to 0.435 (for altitude between 1763-1948 m.a.s.l.) with grand mean of 0.39. Hence, in line with the result of traits frequency distribution within and among populations, regions and altitudes; it can be said that the diversity between regions and between altitude classes were less important than the diversity within populations, among population within a region and among population within a given altitude class.

Overall, pooled mean diversity indices for the three traits were comparatively higher for East Gojam (0.438), Illubabor (0.416), Jimma (0.407), East Wollega (0.407) and Horro Guduru (0.401). Some of the possible reasons can be the frequent inter-regional migration of farmers (because of their close proximity) enhanced seed exchange, they may have tef population initially originated from the same point of origin or they may have agro-ecological similarity, or the combination of these and others. Such result also enable us to suggest that emphasis for future collection and germplasm conservation should focus on regions and altitude classes that showed comparatively high level of diversity.

Similarly, Endashaw (1996) noted that the increase in tef diversity in southern and south western part of the country was as a consequence of the migration effect of Ethiopian people's from the diverse central and northern part of the country into the southern and south west carrying their seed stocks with them.

Supportive results were reported by Tiruneh *et al*. (2000) and Tamiru, (1999).

Analysis of variance

The analysis of variance showed that the mean square due to locations failed to approach significance only for number of spikelet per panicle; while it was significant for panicle length; and highly significant for all the remaining traits (Table 5). This implies as there is difference between the two environments. Similarly results were reported by Temesgen, (2002) and Kebebew *et al.,* (1999). The mean squares for genotypes showed no significant for number of culm internodes, number of spikelet per panicle and number of fertile floret per spikelet at top of the panicle; while it was significant (P≤0.05) for number of fertile floret per spikelet at base of the panicle and biomass weight per plant, but highly significant (P≤0.01) for the remaining traits. Genotypes and locations (environments) interacted highly significantly (P≤0.01) on the number of panicle branches, lodging index, above ground biomass weight, grain yield per plant and harvest index, and significantly (P≤0.05) on the number of spikelet/panicle. This implies that for these traits the tef populations responded differently over the two locations, and hence specific recommendations would be advisable for the two locations as regards these traits (Table 5).

Table 5. Mean squares from the combined analysis of variance over locations of data for 18 quantitative traits of tef landraces as obtained from combined data over location

Traits	Mean squares				CV (%)	Mean
	Location (df =1)	Genotype (df =80)	G X E interaction (df=80)	Error (df=160)		
Days to panicle emergence	25724.6**	102.23**	33.14	25.13	10.34	48.49
Days to mature	43033**	66.81**	26.51	29.80	6.04	90.30
Plant height (cm)	22478**	301.8**	76.90	79.61	11.67	76.45
Panicle length (cm)	113.80*	88.7**	22.14	25.52	15.18	33.28
Culm length (cm)	18626**	100.51**	42.14	41.35	15.02	43.28
Number of culm internodes	37.96**	0.334	0.331	0.28	14.13	3.77
Number of panicle branches	3925.0**	47.83**	16.24**	9.78	17.63	17.74
No. spikelet/panicle	8100.00	7115.84	9303.67*	6037.27	31.8	244.30
Lodging index	6302.60**	258.96**	128.30**	38.52	30.88	20.10
First basal culm internode diameter (mm)	0.086**	0.003**	0.001	0.001	22.16	0.15
Second basal culm internode diameter (mm)	0.078**	0.003**	0.001	0.001	22.35	0.15
No. fertile florets/spikelet (top)	1159.02**	2.50	2.18	2.16	29.48	5.06
No. fertile florets/spikelet (middle)	1247.30**	1.84**	1.38	1.12	19.18	5.52
No. fertile florets/spikelet (bottom)	967.60**	2.90*	2.70	2.08	23.34	6.18
Shoot phytomass/plant (g)	2479.48**	84.83**	71.37**	41.55	34.18	18.86
Biomass weight/plant (g)	644.88**	57.31*	32.59	32.41	42.52	11.51
Grain yield per plant (g)	31.79**	5.13**	3.77**	0.77	24.46	3.59
Harvest index (%)	4848.88**	137.73**	115.58**	22.42	22.54	21.05

Principal components analysis

On the basis of the whole test materials for the 19 quantitative traits, the first six principal components having eigenvalue greater than unity together explained about 73.3% of the gross variation among the tef accessions (Table 6). A variance of about 31.2%, 12.3%, 9.1%, 7.7%, 7.2% and 5.9% were explained by the 1st to the 6th components, respectively. Plant height, panicle length, culm length, first and second basal culm internode diameter, days to 50% maturity and days to panicle emergency were the major contributors for the variation explained by the first principal component. Different authors reported in agreement with the present study (Endashaw, 1996; Kebebew *et al.*, 1999; Kebebew *et al.*, 2001). Much of the variations contributed to the second component were due to variations in aboveground shoot weight/plant, biomass weight/plant and number of spikelet/panicle. Likewise, the major contributors to the third principal component were grain yield per plant, harvest index, number of fertile florets/spikelet at the middle of the panicle, biomass weight/plant and above ground shoot weight/plant.

Region wise, about 91% of the gross variance was explained by the first five principal components (PCs) having eigenvalues greater than one, and variance of 48%, 20%, 9%, 7% and 6% were extracted by these components, respectively (Table 6). Plant height, number of spikelet/panicle, days to maturity, panicle length, culm length, first and second basal culm internodes diameter were the major contributors to the first PC; above-ground shoot weight/plant, hundred kernel weight, and number of culm internodes for the second PC; and number of fertile florets per spikelet at the top and middle of the panicle for the third PC were the major contributors for the observed variations.

With regard to altitude classes, about 90% of the total observed variance was extracted by the first three principal components having eigen values greater than unity. Variance of 54%, 27% and 9% of were extracted from the 1st to 3rd, respectively (Table 6). The major traits contributing to the first PC were grain yield/plant, culm length, plant height and second basal culm internode diameter. In general, the principal component analysis indicated that all quantitative characters considered in this study have contribution to a varying degree to the overall morphological variability observed among tested tef populations, and among regions and altitude classes of origin.

Cluster analysis

Populations-wise clustering

The cluster analysis of 79 tef populations and two improved varieties for 19 quantitative traits resulted in the formation of 11 aggregates, and 6 of the populations (i.e. Accessions 55172, 222174, 208753, 55253, 55261 and 229966) remained ungrouped at 50% similarity level (Figure 1). Apart from the solitary (un-clustered) populations, the number of accessions/cluster ranged from two in the smallest class up to 33 in the broadest class. Among the outliers, accession 229966 is a collection from high altitude (2500 m.a.s.l.) of Arsi, and it is characterized by the highest grain yield/plant, maximum number of fertile florets/spikelet at the middle of the panicle and lateness in panicle emergence and maturity.

Accession 222174 is collected from altitude of 1500 m a.s.l of East Gojam, and this accession has got the least number of panicle branches. Accessions 208753 is collected from mid-altitude (1800 m.a.s.l) area of West Wollega; and attain the least grain yield/plant and harvest index.

Of the total 81 tested tef genotypes, about 41% (33 populations) fell in one cluster (Figure 1). Cluster numbering was made from top to bottom of the page at 50% similarity level. There is no cluster formed solely either from tef populations of a given region, tef populations collected from similar agro-ecological zones or populations collected from areas with similar soil types (Figure 1). This implies that diverse tef populations are grown within regions, within altitude classes and even on the same soil type. Similarly, Kebebew *et al.*, (2001) reported that 120 tef genotypes were clustered into 13 major groups comprising 2-36 genotypes, without clear indication regional and altitudinal patterns in the grouping of the test genotypes. Other supportive results were noted by Endashaw (1995) and Kebebew *et al*. (1999) for tef crop; Firdissa (2001) for bread wheat; Feaven (2002) for chick pea; Yemane and Fassil (2002) for finger millet.

Regional and altitudinal clustering

Region wise, tef population from West Shoa and South Wello showed closer similarity than the population from the rest of the regions. At 75% similarity level, one major cluster was formed in which eight regions fell. Population from West Wollega, East Gojam and both released varieties were solitary (Figure 2).

Tef populations collected from altitude below 1576 m.a.s.l. were outliers (Figure 3). This could be due to the highest in grain yield, prolonged days to maturity, minimum number of panicle branches/plant, and taller plant height and culm length. The highest similarities for quantitative traits were observed between tef populations collected from altitude class II (1577-1762 m.a.s.l) and class IV (1949-2134 masl).

Table 6. Principal component analysis for 19 quantitative traits for entire tef population, regional and altitude level

Quantitative traits	**Population level**						**Regional level**					**Altitudinal level**		
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC1	PC1	PC2
Days to panicle emergence	-0.30	0.15	0.14	0.07	0.25	-0.06	-0.20	0.22	-0.04	0.37	0.21	-0.21	-0.30	0.15
Days to maturity	-0.33	0.02	0.04	-0.05	0.28	0.16	-0.32	0.00	0.10	0.06	0.19	-0.30	-0.33	0.02
Plant height	-0.36	-0.21	0.00	-0.10	-0.03	-0.03	-0.32	-0.10	-0.07	-0.14	0.10	-0.30	-0.36	-0.21
Panicle length	-0.33	-0.14	0.09	0.00	-0.04	-0.24	-0.30	-0.08	-0.05	-0.29	0.02	-0.28	-0.33	-0.14
Culm internod length	-0.30	-0.24	-0.07	-0.22	-0.04	0.15	-0.31	-0.09	-0.08	0.07	0.21	-0.30	-0.30	-0.24
Number of internodes	-0.13	-0.10	-0.25	-0.53	0.02	0.38	-0.12	-0.40	0.00	0.14	-0.24	-0.17	-0.13	-0.10
Number of panicle branch	-0.12	0.13	0.13	-0.06	-0.47	0.08	-0.23	-0.16	0.01	-0.21	0.25	-0.26	-0.12	0.13
Spikelet per panicle	-0.24	-0.28	-0.16	0.04	-0.16	-0.01	-0.32	0.12	0.01	-0.03	-0.06	-0.29	-0.24	-0.28
Lodging index	0.18	-0.25	-0.23	-0.31	-0.34	-0.19	0.09	0.02	-0.29	-0.69	-0.12	0.15	0.18	-0.25
First culm internodes diameter	-0.34	-0.02	0.00	0.20	-0.02	-0.28	-0.30	-0.12	-0.06	-0.11	-0.21	-0.29	-0.34	-0.02
Second culm internodes diameter	-0.31	-0.01	-0.01	0.30	-0.11	-0.22	-0.31	0.09	-0.08	-0.06	-0.10	-0.30	-0.31	-0.01
No. fertile florets/spikelet (top)	-0.03	0.27	0.28	0.05	-0.49	0.22	-0.02	0.11	-0.65	0.32	-0.02	-0.01	-0.03	0.27
No. fertile florets/spikelet (middle)	-0.16	0.27	0.34	-0.12	-0.30	0.12	0.02	-0.25	-0.49	-0.04	0.43	0.00	-0.16	0.27
No. fertile florets/spikelet (bottom)	-0.22	-0.07	0.16	-0.18	0.03	-0.07	-0.22	-0.29	0.15	0.08	0.28	-0.24	-0.22	-0.07
Shoot phytomass/plant (g)	-0.11	0.50	-0.30	-0.18	0.06	-0.16	0.00	-0.44	-0.15	0.18	-0.30	-0.04	-0.11	0.50
Biomass weight/plant (g)	-0.08	0.50	-0.32	-0.17	0.07	-0.24	0.21	-0.30	-0.24	0.10	-0.22	0.18	-0.08	0.50
Hundred seed weight (g)	-0.08	0.10	0.10	0.18	0.28	0.56	-0.07	-0.44	0.28	-0.02	-0.15	-0.09	-0.08	0.10
Grain yield per plant (g)	-0.22	0.14	-0.46	0.14	-0.19	0.28	-0.28	-0.02	-0.18	-0.02	-0.35	-0.30	-0.22	0.14
Harvest index (%)	0.01	-0.09	-0.42	0.51	-0.19	0.18	-0.20	0.28	-0.03	0.08	-0.41	-0.20	0.01	-0.09
Eigen value	5.93	2.34	1.73	1.46	1.36	1.12	9.09	3.86	1.75	1.39	1.10	10.32	5.93	2.34
Percent variance	31.20	12.30	9.10	7.70	7.20	5.90	47.80	20.30	9.20	7.30	5.80	54.30	31.20	12.30
Cumulative variance	31.20	43.50	52.60	60.30	67.50	73.30	47.80	68.10	77.30	84.70	90.50	54.30	31.20	43.50

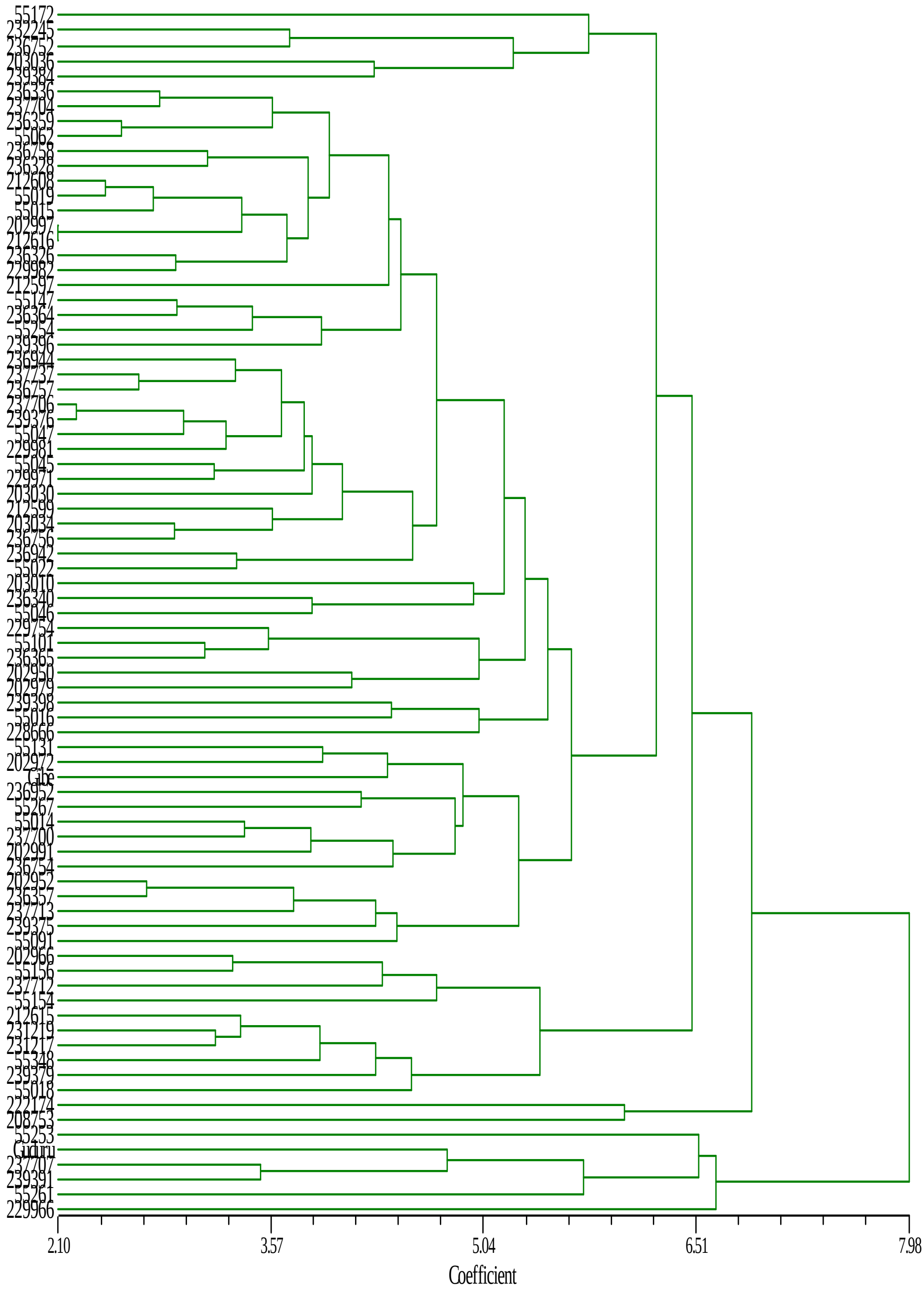


Figure 1. Dendrogram showing similarity between 79 tef population and two released varieties for 19 quantitative traits

Some neighboring regions and proximity in altitudinal classes shared strong similarity (Figures 2 and 3). The similarity could be either due to the fact that farmer's selection criteria for a given traits might be similar particularly based on the adaptive role of traits for the environment, the primary seed source can be the same, or high tendency of seed exchange. The finding of Amsalu (2001) indicated that sorghum accessions collected from more neighboring regions were grouped together.

Other supportive results were also reported by different authors (Kebere *et al.*, 2006; Yemane and Fassil, 2002). On the other hand, few distantly located regions and none proximity altitude classes share close similarity.

The most probable reasons can be, migration and gene flow was not limited by distance, the primary seed source can be the same, eco-geographic similarity for the adaptation of similar populations, the combination of those and other factors.

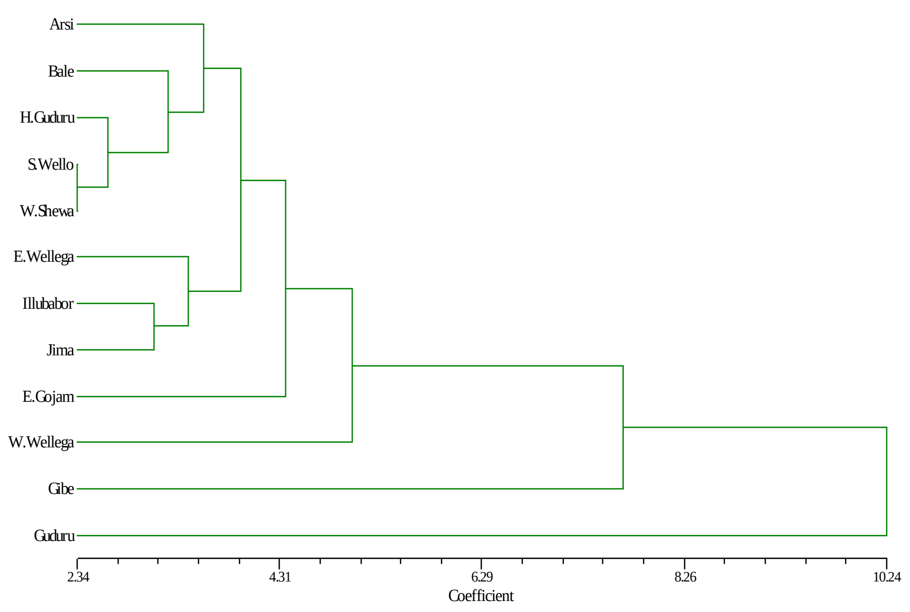
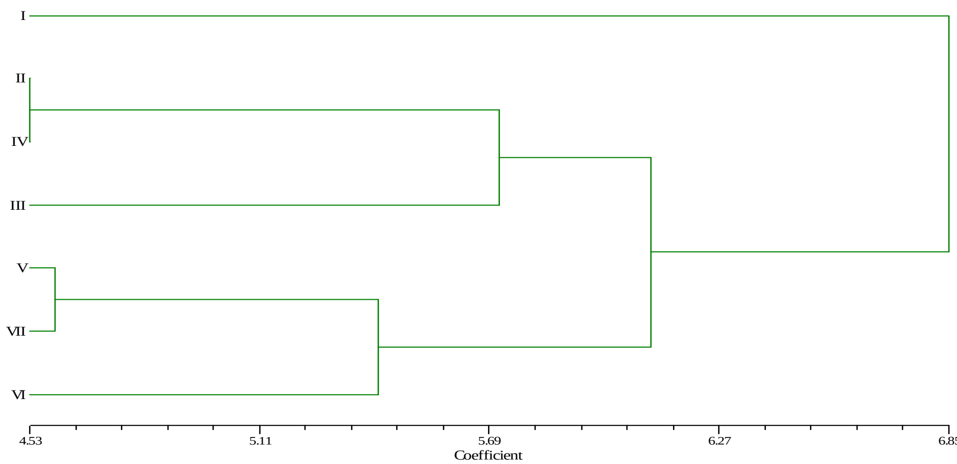


Figure 3. Dendrogram showing similarities of ten regions of origin for 79 tef populations and two released variety evaluated for 19 quantitative traits.



Key: Altitude classes (I= ≤1576m.a.s.l, II=1577-1762, III=1763-1948, IV=1949-2134, V=2135-2320; VI= 2321-2506, VII = ≥ 2507 m.a.s.l)

Figure 4. Dendrogram showing similarities of seven altitude classes of 79 tef populations evaluated for 19 quantitative traits

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