GENETIC DIVERSITY OF TEF [*ERAGROSTIES TEF* (ZUCC.) TROTTER]

LANDRACES FROM VARIOUS REGIONS OF ETHIOPIA

A THESIS SUBMITTED TO

THE SCHOOL OF GRADUATE STUDIES OF THE ADDIS ABABA UNIVERISTY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN BIOLOGY (APPLIED GENETICS)

BY:

DAGNACHEW LULE

JULY 2008

ADDIS ABABA UNIVERISTY

SCHOOL OF GRADUATE STUDIES

GENETIC DIVERSITY OF TEF [*ERAGROSTIES TEF* (ZUCC.) TROTTER] LAND RACES FROM VARIOUS REGIONS OF ETHIOPIA

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JULY, 2008

DEDICATION

This thesis is dedicated to my mother Alemi Dhugasa

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ACRONYMS AND ABBREVIATIONS

ARs	Administrative Regions
Alt.	Altitudes
CL	Culm length
cm	centimeter
CV	Coefficient of variations
DAP	Diammonium phosphate
df	degree of freedom
DM	Days to 50% maturity
DPE	Days to 50% panicle emergence
DGF	Days to grain filling period
EV	Environmental Variance
FCD	First culm diameter
FF/SP	Fertile floret per spikelet
GA	Genetic Advance
GCV	Genotypic Coefficient of Variation
g	gram
GCV	Genotypic Coefficient of variation
GV	Genotypic Variance
GY/Plant	Grain yield per plant
Ha	Hectare
H’	Shannon- Weaver Diversity Index
H^2	Broad sense heritability
HI%	Harvest index
HSW	Hundred seed weight
LC	Lemma color
LG	Lodging index
LSD	Least Significant Difference

m.a.s.l	meter above sea level
m^2	meter square
MS	Mean square
NIN	Number of internodes per main culm
NPB	Number of panicle branch per main panicle
PCA	Principal Component Analysis
PCV	Phenotypic Coefficient of Variation
PF	Panicle forms
PLHT	Plant height
PNL	Panicle length
RS	Rust severity
PV	Phenotypic Variance
SC	Seed color
SCD	Second culm diameter
SP/PN	number of spikelet per main panicle
TN	Tiller number per main plant
UPGMA	Unweighted Pair Group Method of Arithmetic Averages

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ABSTRACT: *Seventy nine tef populations collected from ten administrative regions, seven altitude classes were planted with two improved varieties in simple lattice design at Gute sub-site of Bako Agricultural Research Center during 2007/08 cropping season to assess quantitative and qualitative trait diversity among tef populations, within and between regions and altitudes of origin. Loose and very loose panicle forms, gray panicle color and brown seed colors were abundant across all regions and altitude classes. Whereas, compact and semi-compact panicle forms, red and purple panicle color and white seed color were less frequent. Overall population, across all regions and altitude classes, relatively higher mean Shannon diversity index (H') were noted for seed color (0.45) and the lowest for panicle form (0.33). Regionally, East Gojam (0.46), Horro Guduru (0.44) and East Wellega (0.43) were regions with maximum H', but South Wello (0.32) and Bale (0.33) revealed minimum Shannon index. Tef sample collected from 1768-1961m. a.s.l. noted maximum H' (0.42) and samples collected from altitude range of >2544m. a.s.l. attain the lowest H' (0.36). Analysis of variance for quantitative trait showed that highly significant ($P \leq 0.01$) and significant ($P \leq 0.05$) variations between treatments were observed for most of quantitative traits considered. The first five principal components explained about 69.2% of the entire diversity among population of which 33.04% of the variation is explained by the first principal component that originated mainly due to metric character such as plant height, panicle length, culm length, first and second culm diameter. A total of 86.8% and 96.1% of the variation between regions of origin and altitudinal classes were explained by the first four and five PC, respectively. About 48.4% of the total trait association showed significant correlation out of which 83.8% of the correlation coefficient was with positive and significant. Cluster analysis of tested materials for quantitative traits resulted in the formation of 13 clusters ranging from 2-19 population per cluster at 50% similarity level and six populations remain outliers. Relatively, higher GCV (52.54%) and H^2 (73.073%) were observed for grain yield per plant, lower for number of culm internodes (0.625% and 0.183%, respectively). GA (%mean) was minimum for number of culm internodes (0.058%) and maximum for lodging index (84.683%). High and positive genotypic direct effect on grain yield per plant were obtained from first culm diameter (5.29), panicle length (4.26), spikelete per panicle (2.16), second culm diameter (1.65), harvest index (1.03) and days to grain filling period (0.99). However, high but negative direct effect on grain yield was obtained from plant height (-15.71), culm length (-10.5), lodging index (-3.46), days to 50 % panicle emergence (-3.12), days to 50% maturity (-2.74) and number of panicle branch per main panicle (-1.07).*

Key Words and phrases: *Eragrostis tef*, accessions, regional and altitudinal diversity

1. INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is an indigenous cereal to Ethiopia. Tef belongs to the grass family poaceae (Gramineae), sub-family chlorodoideae (Eragrostoidae), tribe Eragrostideae, sub tribe Eragrosteae, and genus *Eragrostis* (Ketema, 1993b). As one of the biggest genera in the grass family, the genus *Eragrostis* includes about 300 species. Within the genus *Eragrostis* 43% of the species seem to have originated in Africa, 18% in South America, 12% in Asia, 10% in Australia, 9% in Central America, 6% in North America, 2% in Europe (Costanza, 1974 as cited in Ketema, 1997).

Tef is adapted to a wide range of environments and is presently cultivated under diverse agro-ecological conditions. It can be grown from sea level up to 2800 m.a.s.l, under various rainfalls, temperatures and soil regimes. However, the most suitable for excellent tef performance is at an altitude of 1800-2100m, annual rainfall of 750 – 850mm, growing season rainfall of 450 – 550mm, and a temperature range of 10^0C - 27^0C. Its special adaptation to diverse biotic and abiotic stresses has made it a "low risk" crop for cultivation (Ketema, 1993a).

The Central Statistical Authority data reveals that about 23% of the country's lands under crops were planted with tef and 14% of the crop production was attributed to this crop with an average yield of about 0.9 tones per hectare (CSA, 2002). The area devoted to tef cultivation and its productivity is increasing from year to year. In 2003-2004, it occupied about 2 million hectares, which accounts for 28.5% of the total cereal crops grown in the country (CSA, 2004). But in 2004/05, 2005/06 and 2006/07 main cropping season, the total land allocated for tef production and the yield obtained per hectare were; 2.14, 2.25 and 2.41 million hectares of land and 0.948, 0.969 and 1.014 ton/ha of grain yield, respectively (CSA, 2007).

When compared with other cereal crops grown in the country, tef is highly valued by farmers and consumers. The area devoted to tef cultivation is also high mainly due to its several quality parameters. Some of the specific merits of tef that make it more important and more preferable compared to other cereals by farmers are, the higher prices for its grain, more nutritious straw for feed and better adaptation under both low and high moisture stress, often it is sown as a rescue crop as it survives and produces grain when planted after other cereals that have failed because of moisture shortage, less susceptibility to disease & insect pests and being more free from storage pest attack (Ketema, 1997; Tefera and Ketema, 2001).

Depending on the location and maturity period of the cultivar, tef is grown during main growing season between July and November, and also during the small rainy season between March and June (Ketema, 1997). It is mainly cultivated as a monocrop, but occasionally intercropped with Safflower (*Carthamus tinctorius*), rapeseed (*Brasicca napus*) sunflower (*Helianthus annuus*) or relay-cropped with maize (*Zea mays)* and sorghum (*sorghum bicolor*). It is also cropped sequentially in crop rotation system after pulse crops and oil seed such as noug (Hundara *et al*., 2001; Ketema, 1997).

Because of its minute seed size, tef requires a very fine, flat and smooth seedbed for sowing. On average, 25-30kg/ha seed rate would be hand broadcasted. Depending on soil type, fertilizer rate ranged from 40kg/ha -60kg/ha N and 26kg/ha P_2O_5. Two to three times weeding is recommended (Hundara *et al*., 2001).

The excised leaf water loss and leaf canopy temperature are potential drought avoidance selection criteria for drought resistance in tef and also sufficient variation exists within tef cultivars to make selection for salt tolerance (Takele *et al.,* 2001).

Assefa *et al*., (2003a) pointed that several studies on tef have demonstrated the existence of broad variation in many of the phenotypic traits studied. However, efficient utilization of the tef genetic resources still requires comprehensive, systematic and intensive evaluation and characterization of the genetic diversity of both old and new collections to enrich tef germplasm data base and to identify landraces for utilization in the breeding programs. Therefore, this study is aimed to contribute towards such pressing needs.

2. OBJECTIVES

Major objective

To evaluate the genetic variation of Ethiopian tef landrace populations collected from ten Administrative regions of Ethiopia.

The specific objectives are:

† To assess the extent and pattern of diversity of landraces with respect to region and altitude of origin.

† To evaluate and characterize the genetic diversity of these landraces

† To estimate heritability and genetic advance for quantitative traits.

† To assess the level of correlation between different traits.

† To identify traits which have an impact directly and/or indirectly on grain yield.

3. LITERATURE REVIEW

3.1 Origin and distribution of tef

The abundance of several species of *Eragrostis* in Ethiopia and also the presence of wider genetic diversity for tef in Ethiopia than the other part of the world indicate that tef originated and domesticated in Ethiopia (Vavilov, 1951). The exact date and location for the domestication of tef is still unresolved. Tef has become known to Europeans through the Portuguese contact in the 16th century (Ebba, 1975). All the morphological, biochemical, cytological and molecular analysis forwarded by different researchers (Jones *et al*., 1978; Costanza *et al.*, 1978; Bekele and Lester, 1981; Bekele, 1986; Tavassoli, 1986; Feyisa, 1999; Ayele *et al.*, 1999; Bai *et al.,* 2000; Amanda and Jeff, 2001; Gugsa *et al.,* 2001) indicate that *E. pilosa* (2n=4x=40) seems to be the closest relative and thus the likely candidate to be considered as the progenitor of tef.

3.2 Taxonomy and morphology

Tef [*Eragrostis tef* (Zucc.) Trotter] belongs to grass family, Poaceae (Gramineae), sub family Eragrostidae, tribe Eragrosteae and genus *Eragrostis*. The species classification of the genus *Eragrostis* exhibits taxonomic complexity; spike morphology, including size of palea and lemma have been found to be the most useful features for classifying the genus in to broad groups of species (Bekele, 1986; Ketema, 1993b). Tef is a C4, self pollinated, chasmogamouse annual cereal (Ponti, 1978, Ketema, 1997). It has a fibrous root system with mostly erect stems, although some cultivars are bending or elbowing types (Ketema, 1997; Tefera and Ketema , 2001).

3.3. Cytology of Tef

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). The genetic study on the inheritance of lemma color, seed color and panicle forms resulted in the disomic inheritance patterns for different characters and hence confirmed that tef is an allotetraploid

(Berhe *et al., 2001*). Meiosis in tef and its hybrids was difficult to observe due to the few pollen mother cells in each anther. However, it was found that tef forms regular meiosis with 20 bivalents (Tavassoli, 1986). The chromosome size of tef ranged between 0.8 - 2.29µm and it was generally said that the chromosome of tef is very small even by the standard of the genus. Most of the tef chromosomes are either metacentric or sub-metacentric (Gugsa *et al*., 2001)

3.4 Distribution and production of tef in Ethiopia

Tef is grown in almost all regions of the country since it is the preferred grain for local consumption and for market since it fetches the highest grain price compared with other cereals (Ketema, 1997). Amhara (778,202 ha) and Oromia (762,119.72 ha) have the largest acreage of tef followed by Southern Nations and Nationalities and Peoples Region (133,882 ha) and Tigray (124,698.64 ha) (CSA, 2003).

3.5 Genetic diversity

Genetic diversity is defined as the extent to which heritable material differs within a group of plants. Diversity is also expressed as genetic differences between species, sub species, varieties, population or individuals (Jarvis *et al*., 2000). Genetic differentiation is the extent to which heritable material differs between groups of plant and it is the result of evolution including domestication and plant breeding. The process of natural evolution resulted in a build up of genetic diversity in natural population where as domestication caused further differentiation of small parts of the diversity of wild species, which became adapted to human requirement. Genetic diversity can be assessed at four levels of organization: among species, among populations, within population and among individuals (Hunter, 1996). Sub dividing the variation into its components may assist in genetic conservation and utilization, and establishment of *in situ* gene conservation (Bekele, 1985)

Species with greater genetic diversity are more likely to be able to evolve in response to a changing environment than those with low genetic diversity. Population that lack genetic diversity may experience low fertility, high mortality among offspring, even in environments that are fairly stable (Hunter, 1996).

Several research results (Bekele, 1983; Tefera *et al.*, 1990; Demeke *et al*., 1992; Demissie and Bjornstrand, 1996; Assefa *et al.,* 2002a and Keneni *et al*., 2007) showed that studying the extent and patterns of distribution of genetic variation of a crop species 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 elucidating the taxonomy, evolution and origin of crop species.

3.6 Marker systems used for diversity study

Morphological, biochemical or molecular markers can be considered to detect variations between and among different genotypes and populations. Bekele (1985) states that the characterization of a given population and its environment in the field and electrophoresis survey of proteins in the laboratory can give: an objective measure of genetic variation between genotypes as well as within and between populations, and a good estimate of genetic difference between closely related cultivars, thus enabling the curator to reduce redundant samples in the gene bank.

3.6.1 Morphological markers

Morphological traits were among the earliest genetic markers used for scientific investigation and are still in use in germplasm management. They are inexpensive, simple and rapid to score (Tsegaye, 1997).

Quantitative morphological traits are influenced by environmental factors, implying that those traits show continuous variation. This results in low heritability and high genotype by environment interaction that makes it difficult to determine genetic variation accurately.

Previous studies on morphological traits of tef germplasm have demonstrated the existence of broad variations in many of the traits studied (Bekele, 1996; Tefera and Ketema, 2001; Assefa *et al.*, 2001a; Assefa *et al.*, 2003a).

The diverse agro-ecology of Ethiopia together with the many millennia of cultivation of the crop under different socio-economic and cultural practices of the country could account for evolution of the highly diverse forms observed.

3.6.2 Isozyme markers

Biochemical markers can be used to reflect genetic differences between plants. These differences are measured in the form of differences in amino acid sequences of proteins (Chamerlain *et al.*, 1998). Those markers are developed to overcome limitations of morphological data although it does not mean that any of the biochemical or molecular techniques or both replace morphological markers.

Isozyme polymorphism has been used for characterizing and identifying genotypes and varieties of crop plants, for studying population genetics and for examining geographical patterns of variation. Isozymes have also been used in genomic analysis of higher plants both to determine phylogenetic and evolutionary relationships among whole genomes and to determine homologous relationships among individual chromosomes (Hart, 1996).

Seed proteins have been used to characterize tef cultivars (Bekele, 1995). However, because of their limited number, protein markers did not allow separation of individual tef accessions into distinct classes. Bekele and Lester (1981) undertook biochemical assessment involving chromatography of leaf phenolics and electrophoresis of seed proteins and found that there was complex pattern of variations among tef cultivars.

3.6.3. Molecular markers

There are numerous DNA- based molecular marker systems that can be used for genetic diversity assessment. Some of the most commonly used marker systems are Restriction

Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) and Simple Sequence Repeat (SSR) markers, each having its own advantages and disadvantages.

The RFLP procedure has been a valuable tool for detecting DNA polymorphism in plants and is highly reproducible. However, it is laborious and few loci are detected per assay, difficult in finding appropriate probes, time consuming and require huge investment (Karp *et al.,* 1997).

AFLP has a high multiplex ratio, offering a distinctive advantage when the genome coverage is a major issue, but limited by the number of steps required to produce results, requirement of additional expenses and the necessity to use probes (Wolf and Liston, 1998).

The RAPD, a PCR based assay, allows a relatively large number of genetic loci to be assayed rapidly and inexpensively. It has been used to study the genetic relationship in many taxonomic groups (Hoey *et al.,* 1996). However, RAPD markers are dominated and may not always show enough variability and are not always necessarily reproducible.

The Inter Simple Sequence Repeat (ISSR) markers are a PCR based markers, which relies on the abundance of simple sequence repeats (SSRs) or micro satellites in the eukaryotic genomes. The method involves PCR amplification of regions between two adjacent and inversely oriented microsatelites using a single primer, usually 16-25 base pair long. It does not require prior sequence information for prior design, and it can overcome some of the technical limitations of RFLP and RAPD (Nagaoka and Ogihara, 1997). The ISSR, in addition to its suitability to genetic diversity study, it is specific as compared to RAPD, highly polymorphic, reproducible, cost effective and requires no prior information of the sequence (Bornet *et al*., 2002)

Molecular diversity analysis studied by means of AFLP (Ayele *et al.,* 1999; Bai *et al.*, 1999) and RAPD (Bai *et al*,. 2000) markers have generally identified a relatively low number of DNA polymorphism in tef as compared to the other cereals like wheat, sorghum, barley, rice and maize. The DNA polymorphism assessed using 8 ISSR primers for 92 selected tef genotypes belonging to 8 origin groups generally indicated that there was considerable variation within and among tef populations of the 8 groups of origin (Assefa *et al.,* 2003b). The present study was initiated to complement the data base of tef genetic diversity for efficient utilization plus conservation of tef genetic resources and to identify genotypes with desirable traits for utilization in the different breeding methods.

4. MATERIALS AND METHODS

4.1. Description of the study area

The study was conducted at Gute research sub-site of the Bako Agricultural Research Center. The site is located at an elevation of 1850 m.a.s.l. and it receives an annual average rainfall of 1011mm. The temperature of this location ranges from 11.1ºC to 26.7ºC with annual mean temperature of 18.9ºC. The dominant soil type is nitosol.

4.2 Experimental material

A total of 79 landrace populations and two improved tef varieties were used in this study. These landraces were collected by the Institute of Biodiversity Conservation from the major tef production areas of western, south western, south eastern and north central part of Ethiopia, particularly, Arsi, Bale, East Gojam, East Wellega, Horro Guduru Wellega, Illuababor, Jimma, South Wello, West Shewa and West Wellega (Table 1). Improved variety DZ-Cr-255 (Gibe) was released by the Debre Zeit Agricultural Research Center in 1993 and is well adapted for mid to high altitude (1500-2200 m.a.s.l.), and improved variety DZ-01-1880 (Guduru) was released by the Bako Agricultural Research Center in 2005 and is well adapted to mid to high altitude region (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:

$$K = 1+3.32\log_{10}n \quad \text{and } W= (L-S)/K$$ (Agrawal, 1996)

where K= number of class interval, W= width of class interval, L= the largest value, S= the smallest value and n= sample size (in this case accession number)

Table 1: List of experimental materials with their respective region of origin, soil type of collection area and altitude

No.	Acc.	Admin. Regions	District	Soil type	Altitude
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 Wellega	Bila Seyo	Clay loam	1600
27	202991	East Wellega	Arjo	Clay	2420
28	237704	East Wellega	Sibu Sire	Clay loam	1760
29	237706	East Wellega	Guto Wayu	Clay loam	1620
30	237707	East Wellega	Gida Kiremu	Clay loam	1450
31	237700	East Wellega	Bila Seyo	Clay loam	2470
32	236364	East Wellega	Diga Leka	Loam	2420
33	236365	East Wellega	Jimma Arjo	Loam	2470
34	55261	East Wellega	Limu	Clay loam	2210
35	239391	East Wellega	Gatama	Loam	2260
36	236359	East Wellega	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

Table 1. continued…

No.	Acc.	Admin. Region	District	Soil type	Altitude
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 Wellega	Gimbi	NI	1900
73	208753	West Wellega	Ayra Guliso	Clay loam	1800
74	202997	West Wellega	Jimma Gidami	Clay loam	2190
75	237712	West Wellega	Gimbi	Clay loam	1800
76	237713	West Wellega	Gimbi	Clay loam	1800
77	55156	West Wellega	Nejo	NI	2750
78	55147	West Wellega	Jarso	NI	2000
79	55154	West Wellega	Nejo	NI	2000
80	DZ-01-1880	Released	-		-
81	DZ-Cr-255	Released	-		-

Key: NI= Not Identified

Table 2. Regional and altitudinal distribution of tef population

		Altitude classes							
No.	**Admin. Region**	≤1563	1564-1767	1768-1961	1962-2155	2156-2349	2350-2543	≥2544	**Sub total**
1	Arsi	1	2	0	1	0	1	3	**8**
2	Bale	1	2	0	1	1	2	2	**9**
3	East Gojam	1	1	2	0	1	1	2	**8**
4	East Wellega	1	3	0	1	2	4	0	**11**
5	Horro Guduru	0	0	0	0	4	4	0	**8**
6	Illubabor	0	2	1	2	0	0	0	**5**
7	Jima	1	1	3	0	0	0	0	**5**
8	South Wello	1	1	0	0	0	4	0	**6**
9	West Shewa	1	3	0	2	2	2	1	**11**
10	West Wellega	0	0	4	2	1	0	1	**8**
Sub total		**7**	**15**	**10**	**9**	**11**	**18**	**9**	**79**
Released Varieties									**2**
Grand total									**81**

4.3 Experimental Procedure

The experiment was laid out in 9 x 9 simple lattices with two replications. The plot size was 0.5m long rows with 0.1m row width (0.05m^2). The spacing was 1m between plots and 2m between adjacent blocks. Based on the recommended seeding rate of 30kg/ha, 0.15gram of seeds was hand-broadcasted along the 0.1m breadth of the row surfaces. The experimental field was fertilized with 100kg/ha DAP and 50kg/ha urea. Eight individual plants were selected randomly per plot, marked before panicle emergence and used as a sample for some quantitative data to be collected. Data were recorded for the following qualitative and quantitative traits:

Qualitative Traits:

Panicle form: visual classification of the panicle's appearance taken after flowering

Lemma color: visual classification of the lemma color taken after flowering

Seed (caryopsis) color: Visual classification of seed color after threshing of all the panicles.

Quantitative Traits:

Days to panicle emergence: counted as number of days from sowing to 50% of the plants in the plot in flower

Days to maturity: Number of days from sowing to 50% of the plants in the plot reaching maturity stage (readiness for harvest)

Days to grain fill period: counted as number of days from 50% panicle emergence to 50% maturity date

Plant height (cm): Mean height of eight plants measured in cm from ground level to tip of the panicle on the main plant per plot

Panicle length (cm): Mean panicle height of eight plants in a plot measured in cm from the first branching of the panicle to the tip of the panicle on the main plant

Culm length (cm): Mean length of eight plants measured in cm from the ground to first branching of the panicle on the main plant per plot

Number of culm internodes per culm: the average number of internodes per culm of the main plant.

Number of panicle branches: Average number of panicle branches from eight main plants per plot

Number of spikelet per panicle: Average number of spikelets from eight main plants per plot

Tiller number: The average number of fertile tillers for eight main plants originated from ground level per plot

Fertile floret per spikelet: Average number of fertile floret taken from eight main panicles per plot in which five spikelet from top, five from middle and five from lower part of the panicle have been considered

Grain yield per plant (g): Average yield of eight plants

Harvest index (HI %): The ratio of grain yield to biological yield per plant times 100

First culm diameter: The average diameters of the first culm internode of 8 main plant per plot

Second culm diameter (cm): The average diameters of the second culm internodes of 8 main plants per plot

Hundred seed weights (g): Weight of 100 seeds

Lodging index: Recorded before harvesting in percent

Severity of rust: Severity of rust were estimated in percentage and the value were standardized by square root transformation for statistical analysis

4.4 Analysis of qualitative and quantitative data

4.4.1 Estimation of diversity index for qualitative traits

Genetic diversity index was estimated to measure the diversity of each qualitative trait employed in this study. The amount of genetic variation was determined 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 percentage proportion of the total entries in the i^{th} class. The diversity index was estimated at population level, regional level and altitudinal level.

4.4.2 Quantitative data analysis

4.4.2.1 Analysis of variance

The relative efficiency of simple 9x9 lattice over the RCBD was tested using MSTATC (Michigan State University, 1991) computer software and found to be less efficient for almost all of the traits considered in the present study (Table 8). Analysis of variance for simple lattice can be done using RCBD provided that the relative efficiency of simple lattice over the RCBD is less than 25% (Bolanos and Edmeadeds, 1996 as cited in Adnew, 2002). In the case where the blocking of incomplete block design is less effective, the use of randomized blocks design (RCBD) analysis will be preferable (Cochran and Cox, 1957). The data collected for all quantitative character were subjected to analysis of variance (ANOVA) using Agrobase (2000) software.

4.4.2.2 Principal component analysis

Principal component analysis was computed by using MINITAB14 (MINITAB, 2003) computer software. Standardized quantitative data were used for the analysis. The analysis were also made using the means of 18 quantitative traits for each region of origin and altitudinal classes in order to study the regional and altitudinal patterns of variation.

4. 4.2.3 Estimation of Correlation coefficient

The Pearson's correlation coefficient between all possible pairs of quantitative traits were tested for their significance using SPSS 12.0 (SPSS Inc., 1999) computer software

4.4.2.4 Cluster analysis

Hierarchal clustering of accessions was performed using the NTSYs ver.2.1software with Euclidian distance measure, SAHN clustering and Unweighted 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 that arise due to differences in measurement scales. Clustering was performed to determine the similarity and difference between populations, between altitude and regions of origin.

4. 4.2.5 Analysis of Phenotypic and Genotypic coefficient of variation

The variability of each quantitative trait was estimated by simple statistical measures such as mean, range, phenotypic and genotypic variances and coefficient of variation. The phenotypic and genotypic variation and coefficient of variation were calculated following the formula suggested by Singh and Chaundhary (1977) as follows;

$\delta^2_p = \delta^2_g + \delta^2_e$ where, δ^2_p = phenotypic variance, δ^2_g = genotypic variance and δ^2_e = environmental variance

$\delta^2_g = (MS_g - MS_e)/r$ where, MS_g = mean square of genotype, MS_e = mean square of error and r = number of replications

$PCV = \frac{\sqrt{\delta^2{}_p}}{\bar{x}} \times 100$ where, PCV = phenotypic coefficient of variation, δ^2_p = phenotypic variance and $\bar{x}$ = population mean for the trait considered

$GCV = \frac{\sqrt{\delta^2 g}}{\bar{x}} \times 100$ where, GCV = genotypic coefficient of variation, δ^2_g = genotypic variance and $\bar{x}$ = population mean for the trait considered

4.4.2.6 Broad sense heritability (H^2) and genetic advance

Broad sense heritability was estimated according to the suggestion of Allard (1960) by dividing genotypic variances by phenotypic variance: $H^2 = (\delta^2_g/\delta^2_p) \times 100$, where δ^2_g = genotypic variance and δ^2_p = phenotypic variance. Expected genetic advance under selection assuming a selection intensity of 5% was computed following the formula developed by Allard (1960) as:

$GA = (K)(\delta_p)(H^2)$, where GA = expected genetic advance

K= selection differential that varies depending up on the selection intensity and stands at 2.056 for selecting 5% of the genotypes.

δ_p = phenotypic standard deviation and

H^2= heritability (in broad sense)

Genetic advance as percent of mean (GA as % mean) = $\left(\frac{GA}{\bar{x}}\right) \times 100\%$: where, GA= genetic advance and $\bar{x}$ = population mean for the trait considered

4.4.2.7 Euclidian distance analysis

Euclidian distances (dissimilarity) between the ten regions of origin and among seven altitude classes for the mean of 18 quantitative traits of tef landraces investigated in the present study were analyzed using SPSS 12.0 (SPSS Inc., 1999) computer software.

4.4.2.8 Path coefficient analysis

Path coefficient analyses at phenotypic and genotypic level were carried out to partition and assess the correlation between dependent variable and independent variables in to direct and indirect effects. In path coefficient analysis, grain yield was considered as dependent variable and the remaining traits were considered as independent variables (Singh and Chaundhary, 1977). The direct and indirect effect of the independent variables on grain yield per plant at genotypic and phenotypic level was analyzed using SPAR1 (Doshi and Gupta, 1991) computer software for 14 quantitative traits.

5. RESULTS

5.1 Results of the analysis of qualitative traits

5.1.1 Regional and altitudinal distribution of qualitative traits

The percentage frequency of qualitative characters distributed over regions and altitude zones has been summarized in Table 3, 4 and Figure 1 below. Five panicle forms (very loose, loose, semi-loose, semi-compact and compact) were observed in tef populations collected from East Gojam, East Wellega, Horro Guduru, Illubabore, Jimma and West Shewa Administrative regions to a varying degree. On the contrary, only loose and semi loose panicle forms were observed in tef population collected from South Wello. Tef populations collected from Arsi lack semi-compact and compact, samples from Bale lack compact and samples from West Wellega lack semi-compact panicle forms. The released varieties studied here were loose (DZ-01-1880) and semi loose (DZ-Cr 255). Overall, semi loose followed by loose panicle form was abundant in tef populations under study across regions and altitudes of origins. Semi compact followed by compact panicle forms were the least abundant. Altitude class between 1962-2155 m.a.s.l.. lack semi-compact panicle forms.

In this particular study, five major lemma colors (gray, purple, red, yellowish-white and variegated) were observed in tef populations studied. Variegated lemma color stands for yellowish purple in this case. The frequency distribution of lemma color showed that gray color is dominant across the seven altitude zones and ten administrative regions. Red colored phenotypic classes of lemma color was less abundant across all altitude classes and region of origin. All types of lemma color were observed in tef population collected from all classes of altitude (except for altitude between 1962-2155 m.a.s.l.) as well as across all regions of origin (except for South Wello and West Shewa) in which red lemma color was lacking. Both released varieties studied here have yellowish-white lemma color.

Four categories of (seed) caryopsis color (white, brown, light brown and grayish-white) have been identified for this study. All types of caryopsis color have been observed across the 10 regions and the seven altitude classes. The distribution of caryopsis color across all regions indicated that, brown colored seed is more dominant followed by light brown with percentage proportion of 41.72% and 29.91%, respectively. Similarly, the frequency distribution of brown seed color is also abundant across all altitude classes followed by light brown. Tef populations from South Wello, West Wellega and Bale consisted of about 54.24%, 51.10% and 49.96% brown seeded type, respectively. These three regions, on the other side, consisted of comparatively least abundant distribution of white seed type (6.45%, 11.89% and 8.73%), respectively. White colored seed was comparatively abundant in landrace populations collected from Arsi (30.27%), followed by Illubabor (23.50%). Both improved varieties (DZ-Cr-255 and DZ-01-1880) are white seeded.

Across all regions of origin, semi loose panicle forms, gray colored lemma and brown seed type comprised more than 35% of the populations studied (Fig. 1).

Table 3. Percentage proportion of three major qualitative traits in 79 tef populations collected from ten major tef growing regions of Ethiopia and two released varieties

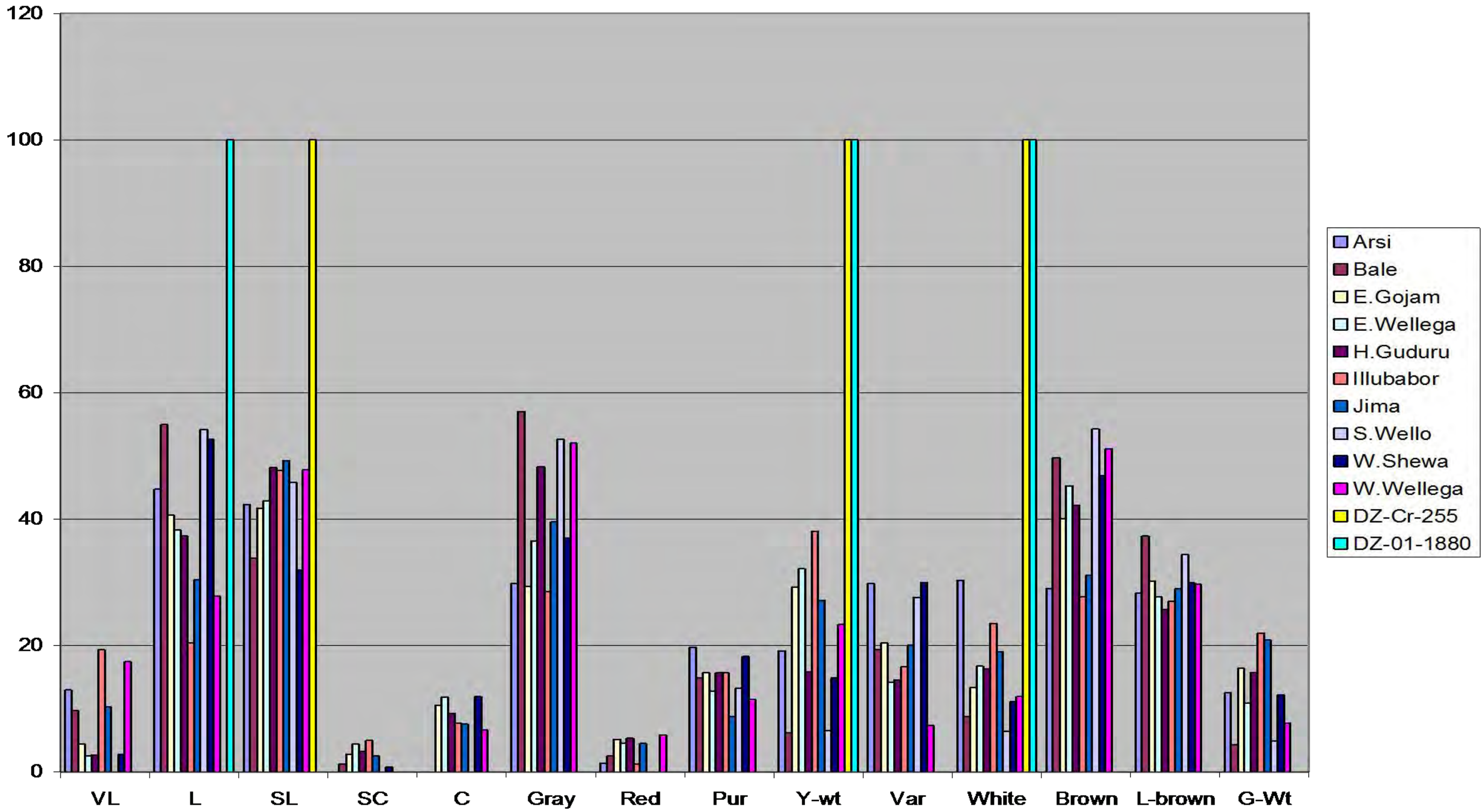
Admin. Region	Panicle forms					Lemma color					Seed Color			
	a	b	C	d	E	1	2	3	4	5	i	ii	iii	iv
Arsi	12.97	44.68	42.35	0.00	0.00	29.81	1.41	19.75	19.18	29.84	30.27	29.02	28.26	12.50
Bale	9.69	54.92	33.79	1.25	0.00	57.00	2.52	14.87	6.17	19.34	8.73	49.66	37.26	4.36
E.Gojam	4.38	40.56	41.71	2.81	10.54	29.42	5.21	15.70	29.26	20.40	13.37	40.06	30.24	16.34
E.Wellega	2.51	38.26	42.91	4.44	11.85	36.50	4.48	12.78	32.14	14.10	16.74	45.29	27.70	10.88
H.Guduru	2.65	37.28	48.14	3.31	9.22	48.29	5.32	15.68	15.83	14.52	16.27	42.21	25.76	15.74
Illubabor	19.28	20.35	47.68	5.00	7.69	28.46	1.17	15.66	38.06	16.65	23.50	27.72	27.00	21.95
Jima	10.27	30.38	49.29	2.50	7.58	39.56	4.50	8.79	27.15	20.00	19.00	31.10	29.00	20.90
S.Wello	0.00	54.15	45.85	0.00	0.00	52.62	0.00	13.19	6.55	27.64	6.45	54.24	34.38	4.93
W.Shewa	2.73	52.61	31.98	0.75	11.93	36.94	0.00	18.25	14.92	29.94	11.12	46.80	29.87	12.19
W.Wellega	17.44	27.79	47.85	0.00	6.63	52.00	5.88	11.51	23.29	7.33	11.89	51.13	29.70	7.79
Mean	**8.19**	**40.09**	**43.15**	**2.01**	**6.54**	**41.06**	**3.04**	**14.61**	**21.25**	**19.97**	**15.73**	**41.72**	**29.91**	**12.75**
DZ-Cr-255	0	0	100	0	0	0	0	0	100	0	100	0	0	0
DZ-01-1880	0	100	0	0	0	0	0	0	100	0	100	0	0	0
mean	**0**	**50**	**50**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**	**0**	**0**	**0**

*Key: **Panicle forms** (a=very loose, b=loose, c=semi-loose, d=semi-compact, e=compact) **Lemma color** (1=gray, 2= red, 3=purple, 4=yellowish- white, 5= variegated) **Seed color** (i= white, ii= brown, iii=light brown, iv= grayish- white*

Table 4. Percentage proportion of three major qualitative traits in tef population collected from seven altitude regions.

Alt range	Panicle forms					Lemma color					Seed Color			
	a	b	c	d	e	1	2	3	4	5	i	Ii	Iii	iv
≤1563	3.59	46.86	38.19	1.75	9.58	34.01	2.01	18.09	29.30	16.57	18.34	35.69	26.89	19.14
1564-1767	19.73	43.65	33.82	0.95	1.85	30.94	2.48	14.94	23.98	27.65	15.68	39.94	33.60	10.78
1768-1961	10.65	32.90	45.50	2.36	8.61	41.35	9.60	11.04	17.97	20.05	13.43	43.49	31.41	11.63
1962-2155	6.39	32.88	56.89	0.00	3.84	32.30	0.00	10.01	33.37	24.37	16.14	38.48	28.88	16.56
2156-2349	2.13	38.46	45.13	2.48	11.78	38.99	2.25	20.77	18.15	19.87	9.52	51.32	27.02	12.10
2350-2543	1.41	44.13	42.35	1.86	10.21	54.33	3.38	14.08	12.65	15.83	15.79	45.19	30.43	8.60
≥ 2544	3.75	56.60	36.21	1.64	1.77	55.49	2.81	12.18	12.06	17.43	17.92	43.13	30.17	8.77
Mean	**6.81**	**42.21**	**42.58**	**1.58**	**6.80**	**41.06**	**3.22**	**14.44**	**21.07**	**20.25**	**15.26**	**42.46**	**29.77**	**12.51**

***Key**: **Panicle forms** (a=very loose, b=loose, c=semi-loose, d=semi-compact, e=compact), **Lemma color** (1=gray, 2= red, 3=purple, 4=yellowish- white, 5= variegated), **Seed color** (i= white, ii= brown, iii=Light- brown, iv= grayish- white)*



Key: Panicle forms (VL=very loose, L=loose; SL=semi-loose; SC=semi-compact; C=compact); **Lemma color**= (Gray, Red, Pur=purple, Y-Wt=yellowish-white, Var= variegated); **Seed color** = (white, Brown, L-brown=light-brown and G-Wt=grayish-white)

Fig. 1 Regional distribution of qualitative traits

5.1.2 Shannon-Weaver diversity index (H') analysis among populations, within and between regions and altitude classes for qualitative traits

An estimate of Shannon-Weaver diversity indices for 79 tef populations, 10 regions of origin and seven altitudinal classes were given in Tables 5, 6 and 7, respectively.

The mean Shannon-Weaver diversity index (H') of tef population determined for three major qualitative traits varied from 0.17 for accession 55253 of Illubabor collected from altitude region of 2000 m.a.s.l.. to 0.60 for accession 55047 of East Gojam collected from 2670 m.a.s.l. In addition, accession 236328 and 239384 (both from Horro Guduru of 2480 and 2500 ma.s.l, respectively) attain H' value of 0.58 each, and accession 236364 (form 2420 m.a.s.l of East Wellega) noted H' indices of 0.55, relatively with higher diversity indices than the rest of the accession. On the contrary, minimum mean diversity index were noted for tef population 55253 (0.17), 236336 (0.19), 229981 (0.19), 212608 (0.21) and 55018 (0.21) collected from Illubabor (2000 m.a.s.l), Horro Guduru (2520 m.a.s.l), Bale (2560 m.a.s.l), and South Wello (2400 m.a.s.l), respectively.

On individual trait basis, diversity index for panicle form ranges from 0 (monomorphic) for accession 55253 of Illubabor and for accession 212597 of South Wello to 0.66 for accession 55047 of East Gojam. For lemma color, accession 239384 (from 2500m.a.s.l. of Horro Guduru) and accession 55047 (from 2670 m.a.s.l. of East Gojam) noted 0.68 and 0.64 H', respectively. On the contrary, six tef populations (236336, 236365, 55147, 236757, 55018 and 229981) were found to be monomorphic for lemma color. Equal (0.59 each) and relatively higher diversity of seed color were observed in accession 55045, 203030, 239391 and 236328 collected from mid to high altitude of East Gojam, Horro Guduru and East Wellega ARS. In general, there were high diversity indices between and within tef populations for seed color and lemma color than were for panicle forms.

For panicle forms, better diversity was observed for tef populations collected from East Wellega (0.41), Horro Guduru (0.40) and Illubabor (0.38), but S. Wello (0.19) exhibited minimum diversity. Similarly, East Gojam (0.49), Horro Guduru (0.45) and East Wellega

(0.44) were the major regions possessing tef populations with comparatively high diversity of lemma color. Bale (0.29) and West Wellega (0.30) were regions with minimum diversity for lemma color. Regarding seed color, East Gojam (0.52), Jimma (0.50), Illubabor (0.49) and East Wellega (0.46) were the highest, but West Wellega (0.40), Bale (0.41) and South Wello (0.41) were among the lowest diversity (Table 6).

Overall, the pooled mean diversity indices for the three traits were comparatively higher for East Gojam (0.46), Horro Guduru (0.44) and East Wellega (0.43), followed by Illubabor and Jimma (H'=0.42 each). However, South Wello (0.32), Bale (0.33) and W. Wellega (0.34) were regions comparatively with lower diversity indices.

Altitudinaly, relatively high mean H' values were noted for tef populations collected from altitude classes between 1768-1961 m. a.s.l. for seed color (0.49), lemma color (0.44), panicle form (0.35). Tef populations collected from altitude region below 1563 m.a.s.l.. also noted H' of 0.49 for seed color. The pooled mean diversity across the three traits was lower for altitude region above 2544 m.a.s.l. and higher for 1768-1961 m.a.s.l. (Table 7).

Table 5. Shannon-Weaver diversity indices (H') and standard error of mean (± SEM) for different qualitative traits of 79 tef populations

No.	**Acc.**	**PF**	**LC**	**SC**	**Mean ± SE**
1	55172	0.30	0.29	0.35	**0.31±0.003**
2	236336	0.27	0.00	0.29	**0.19±0.015**
3	55131	0.25	0.39	0.35	**0.33±0.007**
4	55147	0.18	0.00	0.47	**0.22±0.002**
5	203010	0.56	0.50	0.57	**0.54±0.003**
6	202966	0.30	0.31	0.35	**0.32±0.002**
7	55253	0.00	0.10	0.41	**0.17±0.020**
8	236758	0.30	0.37	0.28	**0.32±0.004**
9	237704	0.29	0.57	0.34	**0.40±0.014**
10	236952	0.30	0.43	0.45	**0.39±0.007**
11	212615	0.28	0.32	0.36	**0.32±0.004**
12	236359	0.29	0.47	0.43	**0.40±0.009**
13	239396	0.39	0.51	0.57	**0.49±0.008**
14	55156	0.28	0.42	0.39	**0.36±0.007**
15	55062	0.30	0.51	0.51	**0.44±0.011**
16	232245	0.30	0.13	0.35	**0.26±0.011**

17	229754	0.49	0.49	0.57	**0.52±0.004**
18	236340	0.24	0.55	0.34	**0.38±0.015**
19	55014	0.33	0.50	0.56	**0.49±0.011**
20	212608	0.17	0.16	0.29	**0.21±0.007**
21	236944	0.27	0.44	0.58	**0.43±0.014**
22	55267	0.30	0.45	0.56	**0.44±0.012**
23	231219	0.24	0.23	0.43	**0.30±0.010**
24	202997	0.29	0.19	0.26	**0.24±0.005**
25	222174	0.36	0.47	0.58	**0.47±0.010**
26	239398	0.30	0.27	0.49	**0.35±0.011**
27	212599	0.21	0.55	0.40	**0.39±0.016**
29	202972	0.54	0.50	0.52	**0.52±0.002**
30	237737	0.18	0.14	0.43	**0.25±0.014**
31	236754	0.29	0.58	0.52	**0.39±0.014**
32	236757	0.20	0.00	0.54	**0.25±0.025**
33	202952	0.47	0.53	0.58	**0.52±0.005**
34	203036	0.45	0.56	0.40	**0.47±0.008**
35	55045	0.27	0.56	0.59	**0.47±0.016**
36	237706	0.30	0.59	0.28	**0.39±0.016**
37	239376	0.50	0.60	0.53	**0.54±0.005**
38	237700	0.41	0.41	0.56	**0.46±0.008**
39	55046	0.25	0.53	0.54	**0.44±0.015**
40	55015	0.38	0.13	0.33	**0.28±0.012**
42	236326	0.28	0.27	0.42	**0.33±0.008**
43	239384	0.55	0.68	0.51	**0.58±0.008**
44	236752	0.27	0.24	0.36	**0.29±0.006**
45	55091	0.42	0.56	0.45	**0.48±0.007**
46	55348	0.34	0.45	0.52	**0.44±0.008**
47	55101	0.25	0.51	0.35	**0.37±0.012**
48	239379	0.30	0.34	0.29	**0.31±0.002**
49	55047	0.66	0.64	0.48	**0.60±0.009**
50	237707	0.40	0.15	0.51	**0.35±0.017**
51	55261	0.53	0.53	0.42	**0.49±0.006**
52	55254	0.43	0.45	0.55	**0.48±0.006**
53	237713	0.55	0.41	0.57	**0.51±0.008**
54	202950	0.27	0.46	0.53	**0.42±0.012**
55	203030	0.33	0.56	0.59	**0.49±0.013**
56	229971	0.40	0.42	0.30	**0.37±0.006**
57	55016	0.32	0.43	0.49	**0.41±0.008**
58	55154	0.51	0.24	0.36	**0.37±0.012**
59	231217	0.35	0.49	0.57	**0.47±0.010**
60	202979	0.58	0.50	0.44	**0.50±0.006**
61	229966	0.15	0.35	0.41	**0.31±0.013**
62	212597	0.00	0.46	0.50	**0.32±0.026**
63	202991	0.45	0.54	0.53	**0.51±0.005**
64	236328	0.54	0.62	0.59	**0.58±0.004**
65	236364	0.56	0.58	0.44	**0.55±0.007**
66	236942	0.29	0.59	0.53	**0.47±0.015**

67	236365	0.29	0.00	0.37	**0.22±0.018**
68	239375	0.37	0.47	0.58	**0.47±0.010**
69	55022	0.28	0.42	0.30	**0.33±0.007**
70	239391	0.38	0.48	0.59	**0.49±0.010**
71	228666	0.24	0.32	0.42	**0.33±0.008**
72	236357	0.44	0.56	0.41	**0.47±0.007**
73	203034	0.30	0.44	0.56	**0.43±0.012**
74	236756	0.30	0.36	0.37	**0.34±0.003**
75	55018	0.25	0.00	0.37	**0.21±0.017**
76	208753	0.18	0.43	0.43	**0.35±0.013**
77	229982	0.30	0.54	0.46	**0.43±0.011**
78	237712	0.22	0.31	0.36	**0.30±0.007**
79	55019	0.21	0.42	0.37	**0.33±0.010**
80	212615	0.21	0.21	0.56	**0.33±0.019**
81	229981	0.29	0.00	0.29	**0.20±0.020**
	mean	**0.33**	**0.39**	**0.45**	**0.39±0.021**

Key: PF= panicle form, LC= lemma color, SC= seed color

Table 6. Shannon-Weaver diversity indices (H') and standard error of mean (± SEM) of tef population from 10 regions of Ethiopia

Region	PF	LC	SC	Mean ± SEM
Arsi	0.29	0.38	0.45	**0.37±0.021**
Bale	0.28	0.29	0.41	**0.33±0.019**
E. Gojam	0.37	0.49	0.52	**0.46±0.021**
E. Wellega	0.41	0.44	0.46	**0.43±0.007**
H. Guduru	0.40	0.45	0.45	**0.44±0.007**
Illubabor	0.38	0.40	0.49	**0.42±0.015**
Jima	0.34	0.42	0.50	**0.42±0.021**
S. Wello	0.19	0.37	0.41	**0.32±0.030**
W. Shewa	0.31	0.40	0.44	**0.38±0.017**
W. Wellega	0.31	0.30	0.40	**0.34±0.014**
Mean	**0.33**	**0.39**	**0.45**	**0.39±0.017**

Key: PF= panicle form, LC= lemma color, SC= seed color

Table 7. Shannon-Weaver diversity index for the seven altitude classes of collection area

Alt. classes	PF	LC	SC	Mean ± SEM
≤ 1563	0.32	0.38	0.49	**0.40±0.027**
1564-1767	0.34	0.42	0.45	**0.40±0.018**
1768-1961	0.35	0.44	0.49	**0.42±0.022**
1962-2155	0.32	0.36	0.44	**0.37±0.019**
2156-2349	0.35	0.44	0.42	**0.40±0.015**
2350-2543	0.32	0.38	0.44	**0.38±0.018**
≥ 2544	0.31	0.32	0.45	**0.36±0.024**
Mean	**0.33**	**0.39**	**0.45**	**0.39±0.020**

Key: PF= panicle form, LC= lemma color, SC= seed color

5.1.3 Regional and altitudinal clustering of qualitative traits

Hierarchal clustering analysis of tef populations collected from 10 administrative regions resulted in the formation of two clusters at 65% similarity level with 4 regions in the first and 6 regions in the second cluster. Tef populations from East Gojam, Horro Guduru and East Wellega were 97.5% similar in overall qualitative traits considered in this study. Tef populations collected from Bale, Arsi, W. Shewa and South Wello fall in the first cluster. Both released varieties were extremely distantly related to tef population from all regions and share similarity at 27% to each other.

Altitudinally, tef populations collected from 1962-2155 m.a.s.l. (C-IV) and 2156-2349 m.a.s.l. (C-V) noted very close similarity. Tef populations from C-I (≤ 1563 m.a.s.l.) were distantly grouped to the rest of six altitude classes, particularly to the high altitude classes. Tef populations from above 2544 m.a.s.l (C-VII) also fall in the extreme group of high altitude classes. In general, proximity in altitude classes and geographic location of the landraces showed more or less similarity in genetic diversity for qualitative traits.

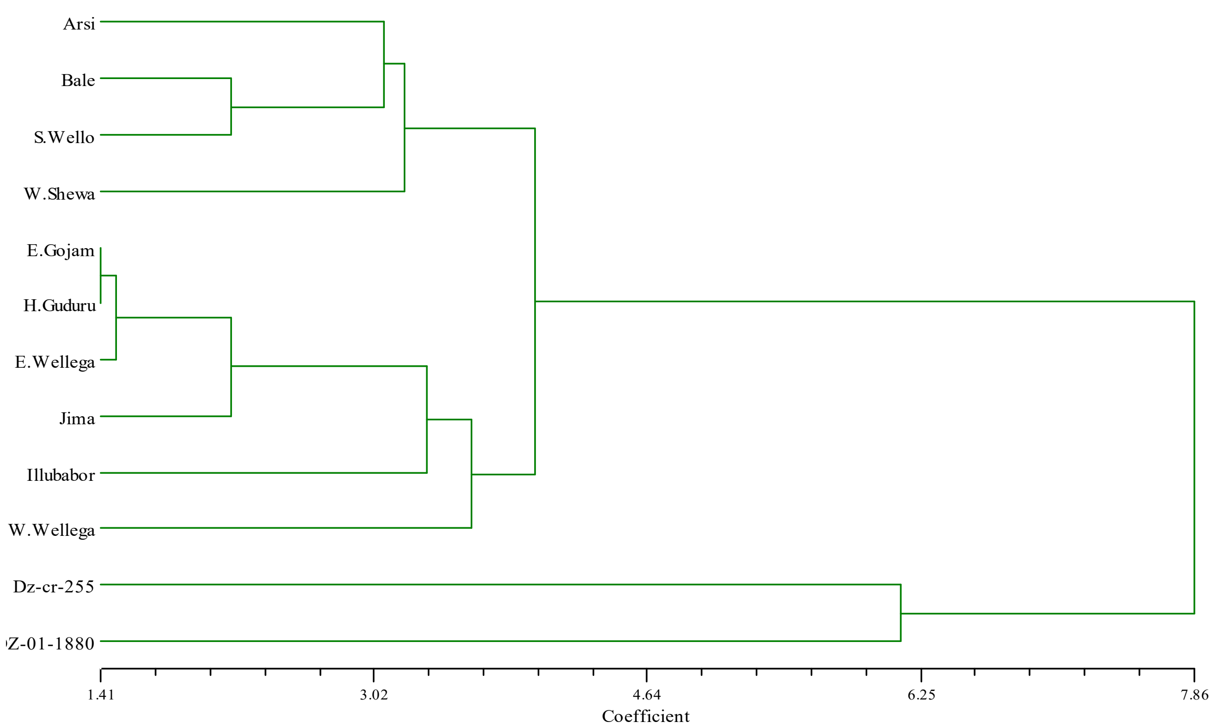


Figure 2. Dendrogram showing similarity between tef population from 10 regions of origin and two released varieties for qualitative traits.

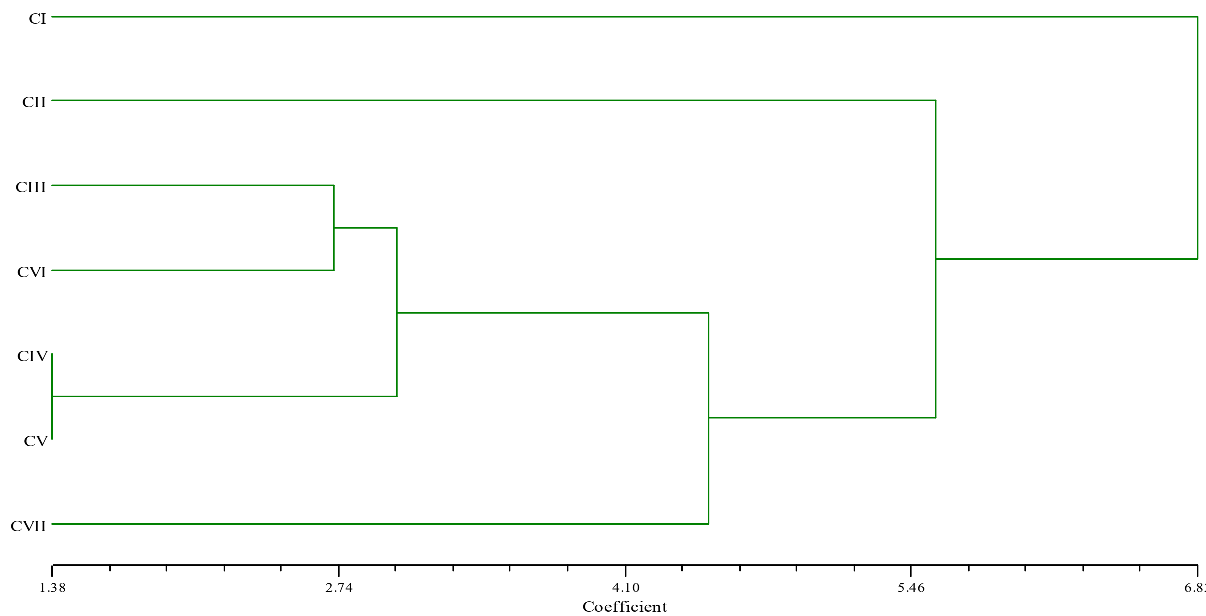


Figure 3. Dendrogram showing similarity between tef populations from seven altitude classes for qualitative traits.
KEY: C-I=≤ 1563 m.a.s.l., C-II= 1564-1767 m.a.s.l., C-III= 1768-1961 m.a.s.l., C-IV=1962-2155m.a.s.l., C-V= 2156-2349 m.a.s.l., C-VI= 2350-2543 m.a.s.l., C-VII= ≥ 2544 m.a.s.l.

5.2 Genetic diversity based on quantitative trait

5.2.1 Analysis of variance

Analysis of variance for quantitative morphological trait for 79 tef populations and two released varieties showed highly significant ($P \leq 0.01$) difference between the tested materials for days to panicle emergence plant height of main plant, culm and panicle length of main panicle, number of panicle branches per main panicle, number of spikelet per main panicle, number of average fertile floret per spikelet of main panicle, grain yield per plant, lodging index, harvest index and first culm diameter of main plant; significant difference ($P \leq 0.05$) between landraces for traits such as days to maturity and severity of rust. However, there is no significant difference for days to grain filling period, average tiller number per plant, second culm diameter, hundred seed weight, and number of internodes per culm (Table 8).

Table 8. Mean squares for quantitative traits of tef landraces as obtained from ANOVA

Source of variation	df	DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	SCD	HSW	GY/PL	HI
Rep	1	164.0*	202.20	94.9	668*	78	373.7**	0.091	4.82	257044**	460**	1.3	285.34*	7.53	0.003	0.009*	0	0.94	27.8*
Genotypes	80	96.7**	74.27*	71.0**	240**	61.7**	79.58**	0.273	17.79**	9427.7**	32.5	1.71	173.36**	5.1*	0.003**	0.003	0	4.48**	61.9**
Error	80	40.3	53.30	25.9	108.0	28.6	50.1	0.273	6.76	4892.84	29.5	0.83	41.74	3.08	0.001	0.002	0	0.697	45.3
CV		7.1	7.10	11.5	15.3	16.4	19.8	15.2	18.2	27.6	38.8	12.27	40.62	39.2	22.7	24.2	24.9	25.4	23.0
RE		8.8	2.1	30.9	0.01	LE	4.07	LE	LE	LE	2	1.6	2.8	13	3.1	21.7	LE	0.2	LE
LSD(0.05)		14.44	14.44	8.43	20.7	10.6	14.09	1.04	5.17	139.1	10.8	1.82	21.24	3.49	0.072	0.079	0.013	1.66	13.4
Mean		57.4	101.70	44.4	68.10	32.70	35.70	3.43	14.26	249.30	13.95	7.5	15.44	4.16	0.161	0.1633	0.025	3.28	17.1

KEY: *df= degree of freedom, DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length, NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelet per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, GY/PL = grain yield per plant and, HI= harvest index (%),Rep=replication, CV=coefficient of variation, RE= relative efficiency, LE=less efficient, LSD=least significant difference at 0.05*

5.2.2 Mean, range and standard deviation for quantitative characters

Mean, range and standard deviation for agronomic traits are widely used to determine variations within and between populations (Bekele, 1996). The mean and range of 79 tef populations and two improved varieties, 10 regions of origin and seven altitude classes are presented in Appendex1, Table 9a and Table 9b, respectively.

5.2.2.1. Population-wise variations

As can be seen from Appendix 1, there were wide ranges of variation between the tested tef materials for most of quantitative traits. Among phenological traits, days to 50% panicle emergence ranges from 45 (for accession 202966, 231219, 55348, 231217, and 55018) to 68 (for accession 229982). Tef 237712 was the first to mature earlier (87 days), but accession 239391 took the highest number of days to mature (112.5). The highest plant height recorded for accession 55261 (100cm) and the lowest for accession 237712 (42.5cm). Extremely high range of variation was noted for number of spikelet per panicle (95 for accession 55018 and 448 for DZ-01-1880). Relatively, the highest lodging index was observed for tef population 202966 (50%), whereas, accession 212597 was resistant (2.5%) to lodging. Accession 212608 was relatively susceptible to rust, but accession 202966 was moderately resistant. In terms of first and second culm diameter, tef accession 239391 attains the highest value (0.24cm) but accession 55348 scores the lowest (0.085cm). Of all tested landraces, the highest grain yield per plant (7.7g) was noted for accession 232245 collected from highland (2550m.a.s.l.) of Arsi, but the lowest (0.88 g) for accession 236756 collected from mid altitude (2100 m.a.s.l..) of West Shewa zone.

5.2.2.2. Regional variation

Generally, there was no wide range of variation observed between the different regions of origin for most quantitative traits of tef population considered in this study (Table 9a). Both improved varieties (DZ-01-1880 and DZ-Cr-255) comparatively score the highest values for the trait such as plant height (90.5cm and 75cm), panicle length (44.5 &36cm), culm length

(46 & 40.5cm), number of panicle branch per panicle (17.9 and 16), spikelet per panicle (448 and 386), hundred seed weight (0.040 and 0.038), grain yield per plant (6.53 and 4.80 g) and harvest index (24.96 and 26.17), respectively. In addition, tef populations from E. Wellega and Illubabor zone were noted higher plant height (75.10 & 73.10cm), panicle length (35.70 & 35.10) and culm length (39.36 and 39.00), respectively. The lowest score in plant height (61.25cm) and panicle length (28.90cm) were recorded for tef population from South Wello; and culm length (31.60cm) for tef population from West Wellega.

In terms of days to maturity, tef populations from West Wellega were comparatively early maturing (98.3 days) and Dz-01-1880 took 111.5 days to mature and hence was late maturing than all the rest. Even though there was no wide variation between regions for average fertile floret per spikelet, Dz-01-1880 (Guduru) attain relatively the highest average fertile floret per spikelet (7.8) and the lowest was noted for tef population from West Wellega (6.5).

Comparatively high lodging index was noted for Jimma collection (21.0%) followed by tef population from West Wellega zone (18.1%) and East Gojam (18.1%). The lowest lodging index was recorded for tef population from Horro Guduru (10%) and South Wello zone (11.70%).

Tef production in South Western Ethiopia, particularly Jimma AR was frequently and severely affected by head smug disease (Amogne *et al.,* 2001, unpublished). However, the expected head smug disease was not observed in this particular trial during the season. Tef populations from Horro Guduru (30.75%) and DZ-Cr-255 (32.5%) were relatively susceptible to rust (from untransformed data). The lowest score for rust severity was recorded for tef population from Jimma (14.3%) and Arsi (16.9%).

The highest hundred seed weight, grain yield and the corresponding harvest index were notably higher for DZ-01-1880 (0.04g, 6.53g and 24.96g), DZ-Cr-255 (0.038g, 4.79g and 26.17g, respectively) and for Arsi collection (0.028g, 4.8g and 22.3g, respectively). However, Illubabor and Horro Guduru collection score low grain yield (2.61 and 2.62g/plant), respectively.

Higher variation for quantitative trait such as days to 50% panicle emergence, plant height, culm length, number of culm internodes, number of spikelet per panicle and hundred seed weight were noted among tef populations from East Wellega. Collection from East Gojam were relatively diverse for number of panicle branch per main panicle and grain yield per plant but least diverse for days to 50% panicle emergence, number of spikelet per panicle and culm length.

Tef population from Illubabor showed relatively higher variation for plant height, panicle length, culm diameters and days to grain filling period, but minimum variation between populations in the region for days to maturity, number of culm internodes and lodging index. Between Jimma populations, relatively wider variation was observed for days to 50% maturity and lodging index; but narrow range of variation between population for tiller number per main plant, average fertile floret per spikelet, second culm diameter and harvest index. Minimum diversity for days to grain filling period, plant height and first culm diameter were observed between tef populations collected from South Wello.

5.2.2.3. Altitudinal variations

The mean, range and standard deviation of 79 tef populations aggregated to seven classes of altitudinal origin are presented in Table 9b. The mean of most quantitative traits (days to 50% flowering, plant height, culm length, number of culm internodes per main plant, number of spikelets per main panicle, severity of rust, first and second culm diameters, hundred seed weight, harvest index and grain yield per plant) were low in tef population collected from 1564-1767 m.a.s.l. As a result of lower culm diameter, maximum lodging index was recorded in this altitude class. Tef population from ≤1563 m. a.. s. l. were relatively late maturing, higher grain filling period, maximum first and second culm diameter, low number of panicle branch per main panicle and minimum tillering capacity.

Tef population collected from above 2544 m.a.s.l. were comparatively categorized as early maturing, higher number of culm internodes and tillers, maximum grain yield and the corresponding harvest index. Tef population from altitude range between 2350-2543 m.a.s.l. were characterized by late panicle emergence, higher number of fertile floret per spikelet and panicle branch per main panicle; low panicle length, lodging and harvest index.

Of the seven altitudinal classes considered in this study, tef populations from the highest altitude class (≥ 2544 m.a.sl.) exhibited minimum range for most quantitative traits (days to 50% flowering, days to 50% maturity, grain filling period, plant height, culm length, number of culm internodes, number of spikelet per main panicle and first culm diameter). Tef population from the lowest altitude class (≤1563 m.a.s.l.) showed low range of variation for tiller number, average fertile floret per spikelet, lodging response, and hundred seed weight; but greater diversity in days to 50% panicle emergence and panicle length. Tef landraces from C-III (1768-1961 m.a.s.l.) display a wide range in some traits, namely; maturity date, lodging index, rust severity, first culm diameter and grain yield. Unlike other major cereal crops whose maturity date decreases with a decrease in altitude level, there was no indicative relationship between days to maturity and altitude level for tef according to the present study. This is an indication for the tremendous level of migration of peoples with their seed from one agro-ecology to another, and the frequent admixture of landraces such that the original landraces are not present in their original form.

Table 9a. Mean, standard deviation and range of 2 improved varieties and 79 tef populations across 10 regions of origin for 18 quantitative traits

Region	Mean	DPE	DM	DGF	PLHT	PAL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RT	FCD	SCD	HSW	GY/PL	HI
Arsi	Mean	53.4	101.3	47.9	64.7	31.3	33.1	3.6	15.0	227.4	14.4	7.3	13.1	3.6	0.146	0.153	0.028	4.825	22.3
	St .dv	5.9	6.7	5.3	7.7	4.2	4.6	0.2	2.7	61.3	3.2	1.4	4.1	1.7	0.046	0.045	0.003	1.715	7.8
	Range	19	21.5	13	24	5	14	0.6	8.7	203	10.3	4.7	12.5	4.6	0.14	0.13	0.01	4.1	25.4
Bale	Mean	55.8	101.2	45.4	66.8	30.7	35.3	3.4	14.0	226.3	13.5	7.7	18	3.9	0.136	0.138	0.026	3.389	15.9
	St .dv	7.6	5.5	6.4	8.4	3.7	4.8	0.4	1.4	56.0	3.8	0.4	9.6	1.6	0.029	0.035	0.005	1.471	9.75
	Range	17	20.5	19.5	27.5	10	18	1.4	4.4	210	10.3	1.2	25	4.47	0.1	0.11	0.015	4.5	32.2
E.Gojam	Mean	61.4	100.6	39.4	66.9	32.3	35.5	3.6	14.4	251.5	15.1	7.7	18.1	4.9	0.161	0.173	0.023	3.694	18.02
	St .dv	4.2	4.5	4.2	5.5	3.1	3.2	0.2	3.8	34.1	3.3	0.5	12.9	1.0	0.034	0.041	0.004	1.319	6.89
	Range	10	16	12	16	11	8	0.7	13.8	98	9	1.51	32.5	3.51	0.12	0.13	0.015	5	26
E.Wellega	Mean	59.1	104.0	44.2	75.1	35.7	39.4	3.5	13.6	265.3	12.2	7.4	15.5	3.8	0.175	0.176	0.026	3.009	18.26
	St .dv	7.2	6.7	5.1	13.8	5.3	9.1	0.5	2.9	77.9	3.5	0.8	8.2	1.1	0.042	0.032	0.005	0.728	8.0
	Range	20	19	19	40	14.5	31	1.6	11.1	261	13.9	2.7	22.5	3.2	0.13	0.12	0.02	2.2	29
H.Guduru	Mean	61.1	101.1	40.0	62.8	31.2	33.1	3.2	14.9	241.3	12.1	7.5	10.0	5.3	0.158	0.145	0.024	2.61	13.67
	St .dv	5.3	3.8	4.9	8.1	4.5	5.2	0.3	2.3	48.7	4.0	1.0	4.7	0.6	0.030	0.028	0.003	0.549	8.7
	Range	13	11.5	16	25	16	14	0.9	7.6	161	13.1	3	15	2	0.1	0.09	0.01	1.5	28.8
Illubabor	Mean	56.0	101.3	45.5	73.1	35.1	38.8	3.3	16.0	259.4	15.0	7.5	13.0	4.7	0.162	0.154	0.024	2.62	14.22
	St .dv	8.2	3.7	7.0	15.6	8.0	7.5	0.2	3.8	83.3	3.4	0.8	5.1	1.4	0.050	0.045	0.004	1.409	6.9
	Range	19	10.5	19.5	41	23.5	20	0.6	11.2	247	9.4	2.4	2	4.17	0.15	0.14	0.01	2.15	19.0
Jimma	Mean	55.0	99.5	45.3	69.6	33.7	35.4	3.3	13.7	240.4	14.2	7.4	21.0	2.8	0.164	0.176	0.025	3.350	20.21
	St .dv	7.7	8.5	5.5	10.7	5.7	5.3	0.2	1.7	54.2	1.6	0.3	14.9	2.3	0.028	0.010	0.003	1.314	9.1
	Range	17	22.5	16.5	33.5	16	15	0.7	4.8	139	4.15	0.75	40	4.74	0.08	0.03	0.01	3.5	22.7
S.Wello	Mean	59.8	103.1	43.5	61.1	28.9	33.5	3.3	14.9	205.0	12.9	7.6	11.7	4.5	0.140	0.148	0.026	2.700	13.9
	St .dv	6.8	5.8	3.1	6.0	2.5	3.9	0.4	3.1	40.3	2.7	0.7	6.6	1.4	0.010	0.028	0.003	0.989	6.9
	Range	17	14	9.5	15.5	7	11	1.4	8.7	116	8.3	1.7	20	4.6	0.03	0.09	0.01	2.7	20.7
W. Shewa	Mean	56.5	103.4	46.6	66.7	32.5	35.8	3.5	13.4	249.9	16.4	7.6	15.3	4.1	0.150	0.157	0.027	2.982	17.1
	St .dv	5.6	5.7	5.4	6.1	4.6	3.8	0.3	3.2	49.5	6.5	0.8	7.8	1.1	0.028	0.034	0.006	1.666	13.2
	Range	17	19	17.5	24	16	13	1.2	10.7	152	20	2.4	25	4.17	0.09	0.12	0.02	4.5	33.2
W.Wellega	Mean	56.6	98.3	43.4	66.0	33.9	31.6	3.5	13.1	262.0	13.5	6.5	18.1	3.7	0.168	0.168	0.023	2.931	15.7
	St .dv	6.7	6.5	5.9	13.2	7.4	7.1	0.4	2.8	65.2	3.5	0.8	13.2	2.2	0.050	0.040	0.005	1.030	5.9
	Range	20	21.5	19.5	27.5	19	24	1.5	7.1	170	12.4	2.57	30	6.09	0.15	0.12	0.01	3.75	19.7
DZ-Cr-255	Mean	64.0	105.0	41.5	75.0	36.0	40.0	3.3	16.0	386.0	18.9	7.7	17.5	5.7	0.220	0.230	0.038	4.800	26.17
	St.dv	1.5	5	6.5	7	6	0.5	0.3	1.65	153	5.61	0.22	12.5	7.5	0.03	0	0.005	0.68	1.24
DZ-01-1880	Mean	57.0	111.5	55.0	90.0	44.5	46.0	3.8	17.9	448.0	12.4	7.8	15.0	4.6	0.240	0.240	0.04	6.500	24.96
	St.dv	8.5	2.5	11.0	1.5	2.5	1.0	0.2	2.4	215.0	4.9	0.83	5.0	7.0	0.0	0.0	0.0	3.2	1.8

The key for this table are provided on page 34 along with Table 9b

Table 9b. Mean standard deviation and range of two improved varieties and 79 tef populations across 7 altitude classes for 18 quantitative traits

Altitude classes (m.a.s.l.)		DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	FCD	HSW	GY/PL	HI
	Mean	58.00	106.63	48.63	69.56	33.64	36.00	3.29	12.60	241.88	12.43	7.53	11.56	3.84	0.17	0.17	0.03	3.52	19.56
	Stdv	8.31	4.08	5.45	12.23	6.27	6.30	0.21	3.16	56.77	2.59	0.48	4.99	1.26	0.04	0.04	0.00	1.16	6.05
≤1563	Range	23	11	14	42	21	21	0.7	10.8	207	7.7	1.50	15	3.46	0.11	0.12	0.005	3.8	20.0
	Mean	52.29	98.71	46.61	62.54	31.07	33.14	3.21	14.43	219.57	13.90	7.31	19.64	3.54	0.14	0.15	0.02	2.65	14.42
	Stdv	6.97	4.98	5.10	9.11	4.89	5.07	0.40	2.35	60.60	2.65	1.03	6.54	1.89	0.04	0.04	0.00	1.23	6.2
1564-1767	Range	19	16	16.5	33.5	15.5	18	1.4	9.5	210	9.9	3.82	20	5.7	0.14	0.16	0.01	4.85	22.6
	Mean.	58.40	99.90	41.85	71.05	35.50	35.50	3.35	13.11	246.50	14.68	7.03	19.25	3.87	0.17	0.17	0.02	3.06	15.46
	Stdv	7.41	6.96	3.70	13.83	7.25	7.32	0.36	2.05	61.21	3.83	0.90	15.29	2.22	0.04	0.03	0.00	1.70	9.4
1768-1961	Range	20	21.5	14	42.5	20.5	25	1.3	8.4	159	11.3	3	45	6.37	0.15	0.12	0.01	5.4	25
	Mean	56.33	100.61	43.94	72.17	35.33	36.67	3.38	14.46	260.44	13.34	7.33	13.61	3.85	0.16	0.16	0.03	2.89	17.8
	St.dv	7.27	4.38	7.26	8.43	3.79	6.20	0.23	3.99	74.88	4.24	0.95	8.75	1.26	0.04	0.03	0.01	1.39	10.4
1962-2155	Range	18	14.5	23.5	26	11	21	0.7	13.7	222	12	3.37	30	3.74	0.13	0.11	0.025	4.7	33.2
	Mean	60.09	103.00	43.05	70.23	32.36	37.45	3.56	14.02	280.55	14.55	7.19	17.05	4.84	0.16	0.16	0.03	3.27	16.1
	Stdv	5.38	4.64	4.92	14.24	6.85	8.53	0.39	3.50	65.39	6.09	0.57	9.76	0.95	0.04	0.04	0.00	1.37	8.1
2156-2349	Range	16	15.5	15	46	20.5	38	1.1	13	211	20.7	2.1	32.5	2.75	0.13	0.13	0.01	4.1	29.5
	Mean	61.00	104.21	43.05	65.37	31.01	34.58	3.52	14.91	236.89	13.54	7.77	10.69	4.75	0.16	0.16	0.03	3.22	17.3
	Stdv	5.11	6.26	6.63	5.76	3.01	4.48	0.41	2.76	51.31	3.89	0.63	6.33	1.04	0.03	0.03	0.00	1.32	11.5
2350-2543	Range	16	21.5	25	23	12	14	1.3	31.1	200	14	2.7	20	5.4	0.12	0.11	0.02	5.35	32
	Mean	55.13	96.50	42.56	66.75	31.44	34.75	3.64	14.83	235.63	15.13	7.77	18.06	3.67	0.15	0.15	0.03	4.13	19.7
	Stdv	1.17	3.31	3.27	6.32	2.71	4.79	0.24	1.27	25.73	4.71	1.08	9.86	1.69	0.04	0.04	0.01	1.47	8.50
≥2544	Range	3	10.5	10	18.5	9	13	0.6	2.2	81	15.2	3.8	15	5.06	0.10	0.012	0.01	5.1	20.4

KEY*: DEP= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length, NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelet per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, GY/PL = grain yield per plant, HI= harvest index (%),St.dv= standard deviation*

5.2.3 Principal component analysis

The principal component was summarized for 79 tef populations and two released varieties, 10 regions of collection and seven altitude classes in Table 10a, 10b and 10c, respectively. The first five principal components having eigen value between 1.293 and 5.65 were extracted from the mean of 18 normalized quantitative traits of 79 tef populations and two released varieties. A variance of about 31.4%, 13.4%, 8.9%, 8.4% and 7.2% were extracted from the first to the fifth components, respectively, and 69.2% of the total variance was explained by these components. A total of 83.6% variation was extracted from the first eight principal components.

Agronomic and phenotypic characters such as plant height, panicle length, culm length, first and second culm diameters, spikelet per panicle and days to 50% maturity were the major contributors for the variation observed in the first principal component. The variation in the second principal component was mainly due to grain yield per plant, days to grain filling period, susceptibility to lodging, harvest index and days to 50% panicle emergency. Likewise, number of panicle branch per main panicle, tiller number per main plant and number of culm internodes and days to grain filling period were among the major contributors to the variation in the third component. Days to 50% maturity, days to grain filling period and hundred seed weight were among the main contributor for the variation observed in the fourth component. The variability in the fifth component was attributed mainly due to the traits such as harvest index and number of panicle branch per main panicle.

When considering regions of origin, 52.1%, 16.3%, 11.0%, and 7.5% of the variances were extracted from the first to the fourth principal components with eigen value greater than one, and 86.5% of the total variance was explained by these components. Spikelet per panicle, first culm diameter, hundred seed weight and plant height were the major contributors for the variation in the first principal component. Days to 50% panicle emergence, severity of rust and days to grain filling period for the second; lodging index, average tiller number and harvest index for the third; and harvest index and lodging index for the fourth were the major traits contributing for the variation observed in the respective principal components. The relative positions of the 2 improved varieties on principal axis were far away from all regions of origin. The close distribution of some regions on the principal axis based on tef populations indicated that the migration of peoples with their seed over short and long distance created relatively similar diversity of tef accessions (Fig. 4).

As regards to the altitude classes, 96.1% of the total variance were observed for the first five principal components; out of which 35.7% is attributed to the first component probably due to the input of first and second culm diameters, days to 50% panicle emergence and maturity, plant height and culm length. Some of the traits contributing for the variance observed in the subsequent components were, number of culm internodes, hundred seed weight and grain yield per plant for the second component; lodging index and average tiller number per plant for the third; harvest index, severity of rust and grain yield per plant for the fourth; and grain yield per plant and number of spikelet per panicle for the fifth principal components.

Table 10a. Principal component analysis for 18 quantitative traits of 79 tef landraces and two released varieties.

PC	DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	SCD	HSW	GY/PL	HI	EV	%VA R	CVAR
1	-0.241	-0.304	0.028	-0.366	-0.367	-0.315	-0.101	-0.012	-0.310	0.023	-0.158	0.165	-0.218	-0.354	-0.327	-0.200	-0.151	-0.001	5.659	31.40	31.40
2	-0.389	-0.115	0.342	0.143	0.060	0.190	0.211	-0.011	0.184	0.082	-0.232	0.389	-0.147	-0.044	0.022	-0.063	0.422	0.403	2.406	13.40	44.80
3	-0.238	0.175	0.441	0.048	0.061	0.008	-0.429	-0.394	0.013	-0.538	-0.084	-0.057	-0.119	0.001	0.020	0.145	-0.156	-0.118	1.599	8.90	53.70
4	-0.016	0.321	0.345	-0.182	-0.243	-0.136	0.039	0.151	-0.227	0.097	0.271	-0.254	0.230	-0.201	-0.143	0.406	0.372	0.163	1.507	8.40	62.10
5	0.012	-0.252	-0.258	-0.093	-0.048	-0.182	-0.395	0.373	0.137	-0.394	0.166	-0.038	-0.075	0.109	0.244	0.070	0.157	0.470	1.293	7.20	69.20

KEY: *PC=principal component, DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length ,NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelete per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, GY/PL = grain yield per plant and, HI= harvest index (%), EV=eigen value, %VAR= percentage variance, CVAR= cumulative variance*

Table 10b. Principal component analysis for 18 quantitative traits of 10 regions of origin

PC	DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	SCD	HSW	GY/PL	HI	EV	%VAR	CVAR
1	-0.056	-0.291	-0.202	-0.300	-0.294	-0.296	-0.176	-0.261	-0.315	-0.051	-0.138	-0.024	-0.112	-0.302	-0.297	-0.302	-0.286	-0.147	9.378	52.1	52.1
2	-0.517	-0.033	0.382	0.083	0.121	-0.015	0.326	-0.129	-0.052	-0.229	-0.224	0.192	-0.507	-0.066	-0.047	-0.058	0.121	0.085	2.928	16.3	68.4
3	0.096	-0.232	-0.214	-0.090	-0.045	-0.137	0.022	-0.218	0.084	0.486	-0.206	0.532	-0.066	0.103	0.207	0.075	0.126	0.409	1.978	11.0	79.4
4	-0.176	0.054	0.156	-0.260	-0.279	-0.204	0.133	0.231	-0.110	0.157	0.211	-0.333	0.116	-0.219	-0.179	0.162	0.296	0.533	1.342	7.5	86.5

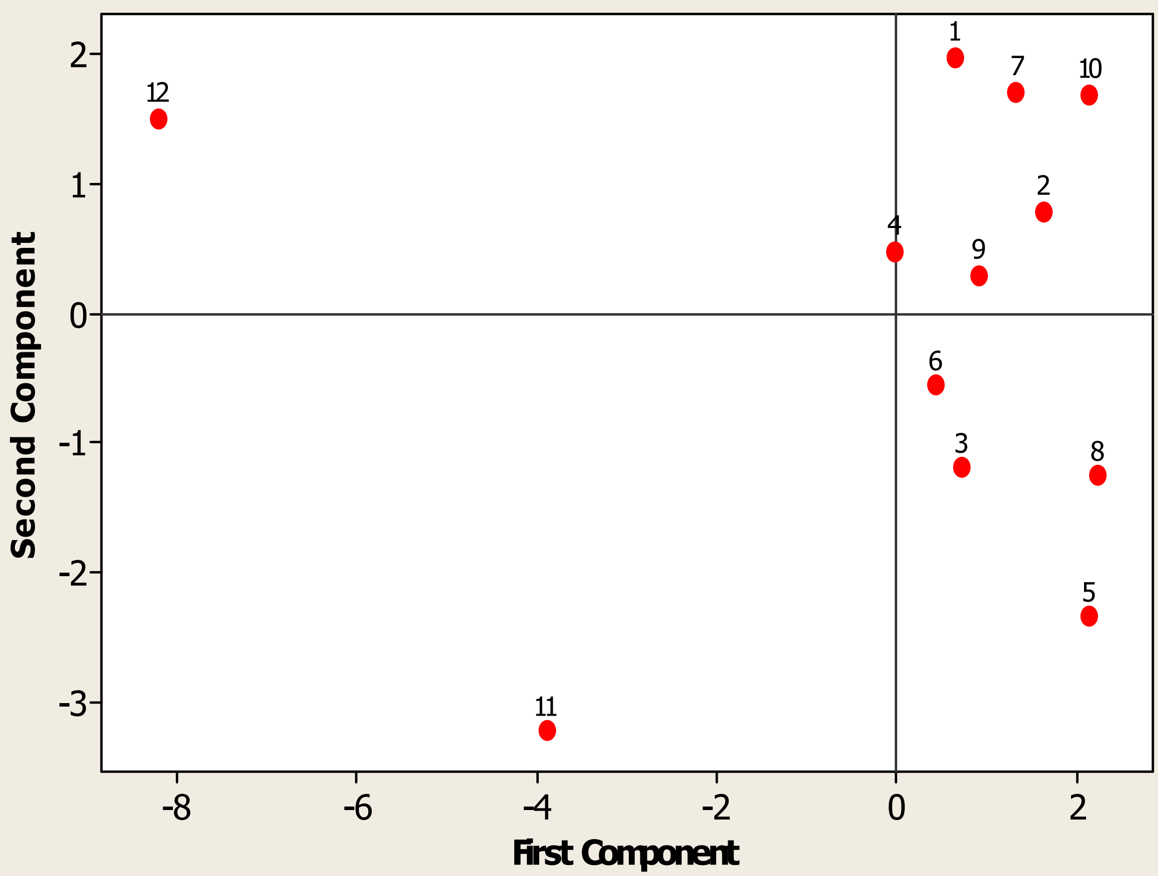
KEY: *PC=principal component, DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length ,NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelete per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, GY/PL = grain yield per plant and, HI= harvest index (%), EV=eigen value, %VAR= percentage variance, CVAR= cumulative variance*

Table 10c. Principal component analysis of 18 quantitative traits for the seven altitudinal classes

PC	DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	SCD	HSW	GY/PL	HI	EV	%VAR	CVAR
1	0.306	0.300	0.006	0.313	0.245	0.320	-0.002	-0.241	0.274	-0.166	-0.121	-0.210	0.196	0.363	0.348	0.142	-0.015	-0.016	6.418	35.7	35.7
2	-0.202	0.030	0.255	-0.025	0.186	-0.139	-0.468	-0.271	-0.170	-0.181	-0.287	0.123	-0.255	0.018	0.153	-0.367	-0.332	-0.232	4.302	23.9	59.5
3	-0.043	-0.331	-0.374	0.251	0.252	0.169	0.110	-0.014	0.237	0.417	-0.369	0.406	-0.052	0.027	0.001	-0.207	-0.035	0.059	3.313	18.4	78.0
4	-0.263	-0.121	0.200	0.242	0.261	0.104	-0.025	-0.203	-0.063	-0.107	0.147	-0.035	-0.461	0.106	0.054	0.182	0.356	0.522	2.128	11.8	89.8
5	-0.245	-0.014	0.188	0.143	0.068	0.311	-0.115	0.307	0.373	-0.242	-0.162	-0.090	0.038	-0.316	-0.315	0.261	-0.405	0.103	1.130	6.3	96.1

KEY: *PC=principal component, DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length ,NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelete per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, GY/PL = grain yield per plant and, HI= harvest index (%), EV=eigen value, %VAR= percentage variance, CVAR= cumulative variance*

Figure 4. The relative position of 10 regions of origin and 2 released varieties on the first and second principal axis.



Key: 1=Arsi, 2=Bale, 3=E. Gojam, 4=E. Wellega, 5=H. Guduru, 6=Illubabor, 7=Jimma, 8= S. Wello, 9= W. Shewa, 10= W. Wellega, 11=DZ-Cr-255, 12=DZ-01-1880

5.2.4 Pearson correlation coefficient analysis of quantitative traits

The Pearson's correlation coefficients of 18 quantitative traits (based on the mean value of the traits) for the 79 tef populations and two improved varieties is given in Table 11. The result of analysis showed that days to 50% panicle emergence were positively and significantly ($p \leq 0.01$) correlated with days to maturity (0.57), first culm diameter (0.495), severity of rust (0.457), second culm diameter (0.399), average fertile floret per spikelet (0.347), panicle length (0.335), plant height (0.310) and spikelet per panicle (0.293). In addition, highly and positively significant correlation coefficient was observed between plant height and culm length (0.900), plant height and panicle length (0.882), first culm diameter and second culm diameter (0.840), panicle length and first culm diameter (0.707), spikelet per panicle and first culm diameter (0.663), plant height and spikelet per panicle (0.662), spikelet per panicle and second culm diameter (0.662), panicle length and culm length (0.640), panicle length and spikelet per panicle (0.578), panicle length and second culm diameter (0.565), internodes number and tiller number (0.383), days to grain filling period and grain yield (0.359), and spikelet per panicle and grain yield per plant (0.354), days to maturity and days to grain filling period (0.347) and, average fertile floret per spikelet with hundred seed weight (0.309).

Days to panicle emergence was significantly and negatively correlated with lodging index (-0.484), days to grain filling period (-0.526) and harvest index (-0.207). Similarly, lodging index was negatively correlated with days to maturity (-0.423), first culm diameter (-0.325), second culm diameter (-0.298) and hundred seed weight (-0.412).

Grain yield per plant has significant positive correlation ($p \leq 0.01$) with days to grain filling period (0.359), number of spikelet per main panicle (0.354), days to 50% maturity (0.284), first cuml diameters (0.297), plant height (0.298) and second culm diameters (0.289). It has also significant correlation ($p \leq 0.05$) with number of internodes per culm (0.332), average fertile floret per spikelet (0.240) and hundred seed weight (0.242).

The only trait which has negative but non-significant correlation with grain yield per plant was days to 50% panicle emergence (-0.048).

Lodging index has highly significant ($P \leq 0.01$) negative correlation with days to panicle emergence (-0.480), days to maturity (-0.440), hundred seed weight (-0.410), first culm diameter (-0.33) and average fertile floret per spikelet (-0.273). But, it has negative and significant ($P \leq 0.05$) correlation with panicle length (-0.240) and plant height (-0.230). Lodging index has highly significant positive correlation ($P \leq 0.01$) only with rust severity (0.335) and significant positive correlation ($P \leq 0.05$) with harvest index (0.255).

Table11. Pearson's correlation coefficient for 18 quantitative traits of 79 tef populations and two improved varieties

Traits	DPE	DM	DGF	PLHT	PNL	CL	NIN	NPB	SP/PN	TN	FF/SP	LOG	RS	FCD	SCD	HSW	GY/PL	HI
DPE	1	0.57**	-0.53**	0.310**	0.335**	0.197	0.073	0.025	0.293**	0.058	0.347**	-0.480**	0.457**	0.495**	0.399**	0.239*	-0.048	-0.229*
DM		1	0.347**	0.489**	0.419**	0.440**	0.107	-0.125	0.368**	-0.062	0.316**	-0.440**	0.509**	0.498**	0.439**	0.436**	0.284**	-0.213
DGF			1	0.129	0.050	0.177	0.020	-0.162	0.051	-0.114	-0.067	0.140	-0.010	-0.046	-0.039	0.132	0.359**	0.098
PLHT				1	0.882**	0.900**	0.239*	-0.005	0.662**	-0.050	0.179	-0.230*	0.331**	0.679**	0.578**	0.313**	0.281**	0.052
PNL					1	0.640**	0.176	-0.034	0.578**	-0.062	0.199	-0.240*	0.255*	0.707**	0.565**	0.280**	0.154	-0.007
CL						1	0.268*	0.026	0.608**	0.034	0.113	-0.080	0.328**	0.515**	0.444**	0.24	0.285**	0.032
NIN							1	0.068	0.202	0.38**	-0.027	0.060	0.084	0.133	0.080	0.032	0.332**	0.037
NPB								1	0.010	0.078	0.196	-0.090	0.102	0.017	-0.005	-0.029	0.16	0.091
SP/PN									1	-0.146	0.084	-0.005	0.276**	0.633**	0.662**	0.202	0.354**	0.143
TN										1	-0.012	0.140	0.032	-0.074	-0.100	-0.058	0.148	0.005
FF/SP											1	-0.273**	0.261*	0.275**	0.273**	0.309**	0.240*	-0.123
LOG												1	0.335**	-0.33**	-0.29**	-0.41**	0.119	0.255*
RS													1	0.310**	0.262*	0.166	0.149	-0.039
FCD														1	0.840**	0.239*	0.297**	-0.057
SCD															1	0.331**	0.287**	0.082
100SW																1	0.242*	0.056
GY/PL																	1	0.59**
HI(%)																		1

@ ***KEY****: DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length, NIN= number of culm internodes per main panicle, NPB= number of panicle branch per main panicle, SP/PN= number of spikelet per main panicle, TN=tiller number, FF/SP= fertile floret per spikelet, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW = 100 seed weight, GY/PL = grain yield per plant, HI= harvest index (%) and; * and ** indicate significant correlation at 0.05 and 0.01 alpha level, respectively.*

5.2.5 Clustering based on quantitative morphological traits

5.2.5.1 Populations-wise clustering

Cluster analysis of 79 tef populations and two improved varieties for 18 quantitative traits resulted in the formation of 13 aggregates and six landraces (55172, 203010, 236340, 232245, 55253 and 55154) remained ungrouped at 50% similarity level. Number of accessions in a cluster ranges from 2 in the smallest class up to 19 in the broadest class.

Three among the six ungrouped landraces, accession 232245, 55253 and 55154 remained solitary even at 30% coefficient of similarity. Accession 232245 is a collected from high altitude area (2550 m.a.s.l.) of Arsi, and is characterized by its comparatively low tiller number, the highest grain yield per plant and a corresponding harvest index. Accession 55253 is a collection from mid altitude (2000 m.a.s.l.) area of Illubabor and characterized by its relatively high number of panicle branch, spikelet per panicle, higher first culm diameter, the least grain yield per plant and minimum lodging index. Accession 55154 is also another solitary genotype collected from mid altitude (2000 m.a.s.l.) area of West Wellega possessing relatively higher lodging and harvest indices and the least hundred seed weight (Appendix 1).

Of the total 81 tested tef materials, 43 fell in the first three clusters (counted from the top of the page to down) and the 3rd cluster comprised of 19 populations (Fig. 4, Table 12)

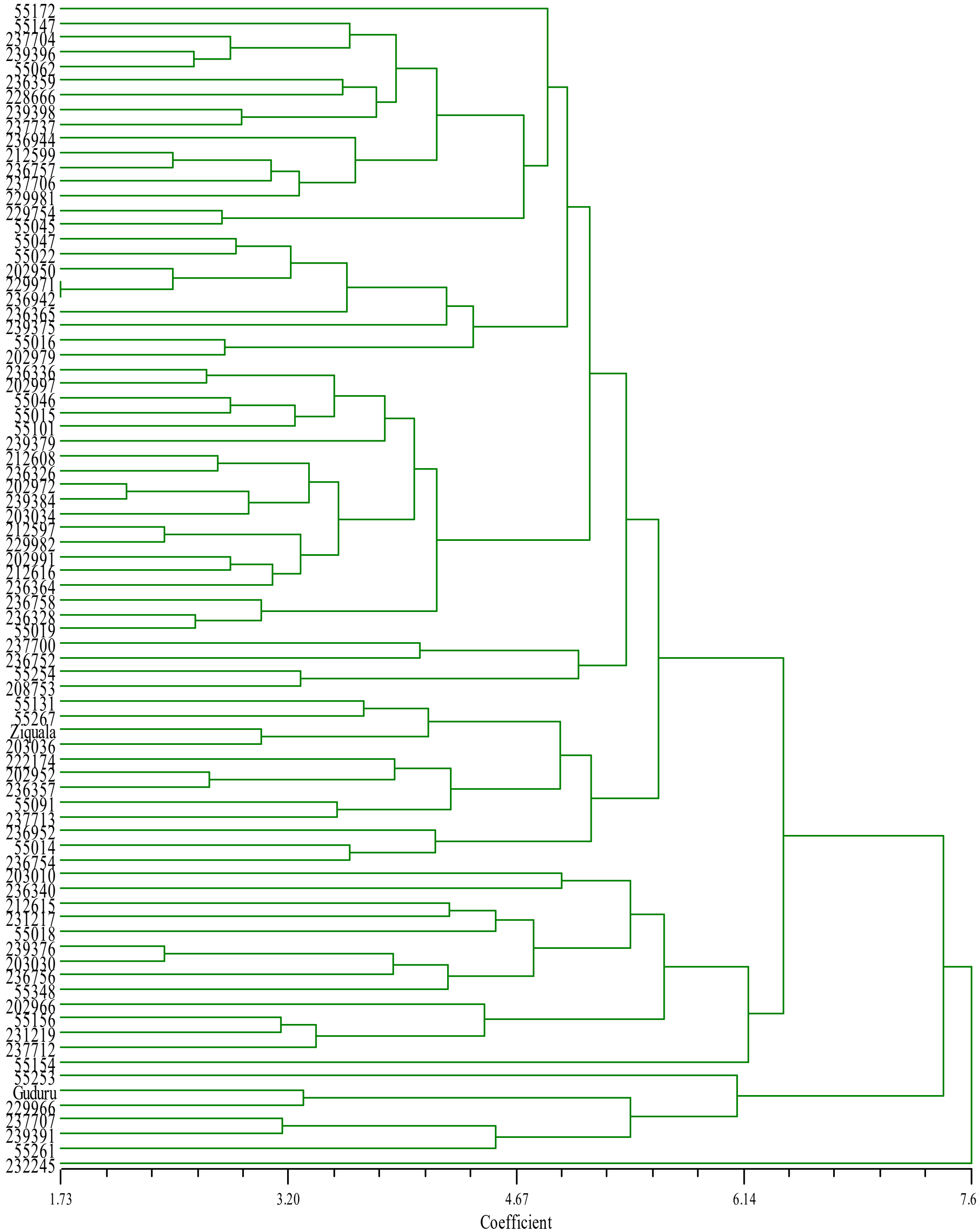


Figure 5. Dendrogram showing similarity between 79 tef populations and two released varieties for quantitative traits.

Key: variety name "Ziquala" in the 5th cluster should corrected to "Gibe"

Table 12. The distribution patterns of 79 tef populations and two released varieties as grouped in to 13 clusters and solitary accessions with a cut-off of 50% similarity by cluster analysis (refer fig.5) with respect to region of origin, altitude and soil types of collection area for 18 quantitative traits

Clus#	T. Acc.	Region of origin										Released varieties		Alt. classes (m.a.s.l.)							Soil type					
		Ar	**Ba**	**EG**	**EW**	**HG**	**IL**	**JM**	**SW**	**WS**	**WW**	**DZcr**	**DZ01**	**CI**	**CII**	**CIII**	**CIV**	**CV**	**CVI**	**CVII**	**i**	**ii**	**iii**	**iv**	**v**	**viii**
1	15	1	2	3	3	0	0	2	1	3	1	0	0	2	3	1	4	1	2	2	0	0	4	6	2	3
2	9	2	2	1	1	0	1	1	0	1	0	0	0	1	2	0	1	1	3	1	1	2	1	2	1	2
3	19	0	3	0	2	5	1	0	4	2	1	0	0	1	2	1	1	4	10	0	0	1	6	5	6	1
4	2	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0
5	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0
6	4	0	0	1	0	0	0	0	0	1	1	1	0	0	0	2	0	0	0	2	0	1	0	0	1	1
7	5	0	0	1	0	1	0	1	0	1	1	0	0	1	2	2	0	0	0	0	0	0	1	2	0	2
8	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	1
9	3	1	1	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0	1	2	0	0
10	4	0	0	0	0	2	1	0	0	1	0	0	0	0	1	0	1	2	0	0	0	0	1	1	1	1
11	4	1	0	0	0	0	0	1	0	0	2	0	0	0	1	1	0	1	0	1	0	0	0	1	1	2
12	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0
13	3	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	2	0	0
Solitary	6	1	0	1	1	0	1	0	0	1	1	0	0	0	2	0	2	0	1	1	0	0	0	4	0	2
Total	**81**	**8**	**9**	**8**	**11**	**8**	**5**	**5**	**6**	**11**	**8**	**1**	**1**	**7**	**15**	**10**	**9**	**11**	**18**	**9**	**1**	**6**	**16**	**28**	**13**	**15**

Key: *Clus# =cluster number, T. Acc= total accessions per cluster*

Region: *Ar= Arsi, Ba=Bale, EG= East Gojam, EW=East Wellega, HG=Horro Guduru, IL=Illubabor, JM=Jima, SW=S. Wello, WS= West Shoa,WW= West Wellega, DZ-Cr-255, DZ-01-1880,*

Altitudes: *C-I=≤ 1563 m.a.s.l., C-II= 1564-1767 m.a.s.l., C-III= 1768-1961 m.a.s.l. m.a.s.l., C-IV=1962-2155 m.a.s.l., C-V= 2156-2349 m.a.s.l., C-VI= 2350-2543 m.a.s.l., C-VII= ≥ 2544 m.a.s.l.*

Soil Types: *i=sand, ii= sandy loam, iii= loam, iv= clay loam, v= clay, viii= not identified*

5.2.5.2 Regional clustering

Tef populations of all regions except Arsi and West Wellega ARs were grouped under one category at 75% similarity level (Fig. 6). The figure shown that both released varieties were extremely distantly related to all regions. This can be due to their higher yielding capacity, long plant height, larger number of spikelet per panicle, highest harvest index and maximum weight for hundred seeds (Appendex 1 and Table 9a). The very high similarity between tef accessions collected from Horro Guduru and South Wello may be due to the high resemblance for the traits such as overall plant height and harvest index, almost equal in culm length, number of panicle branch per main panicle, second culm diameter and grain yield.

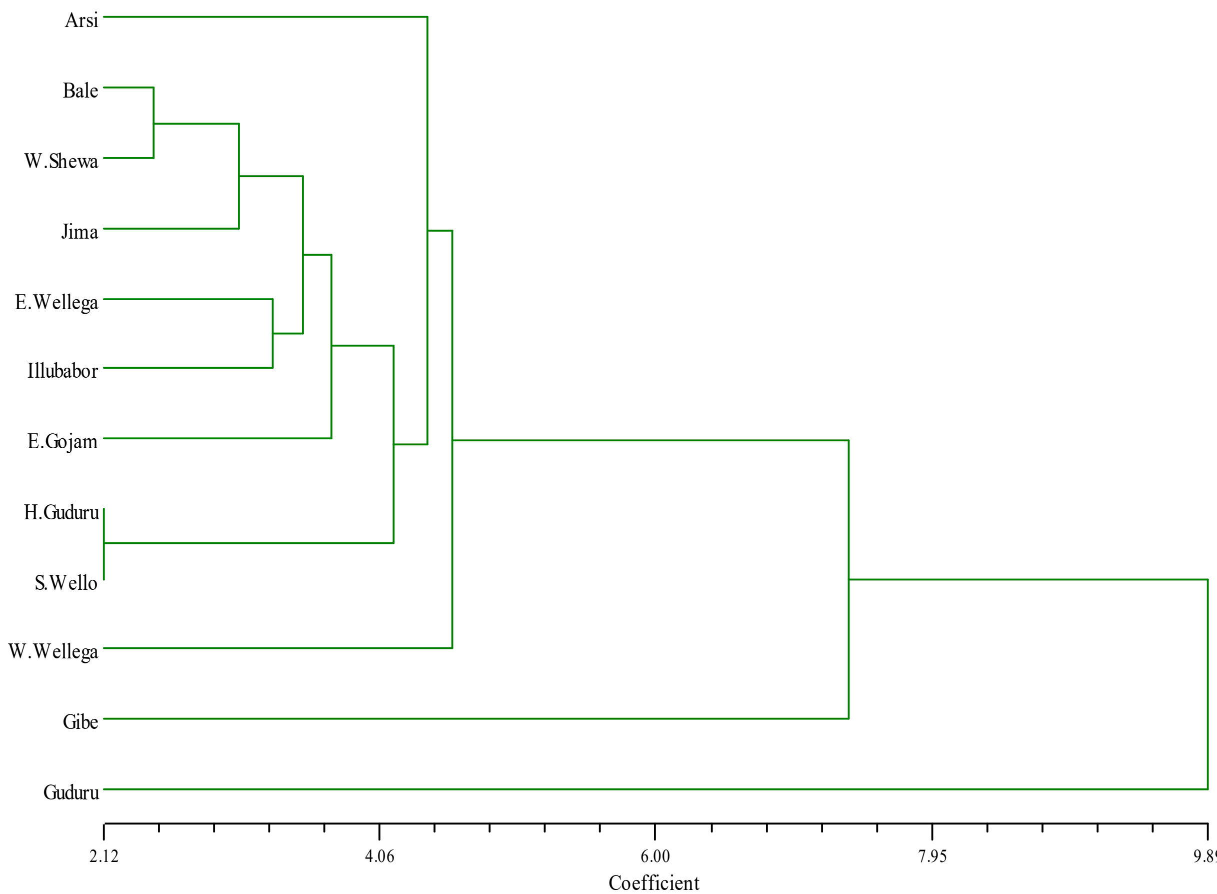


Figure 6. Dendrogram showing similarities of ten regions of origin of 79 tef populations evaluated for 18 quantitative traits.

5.2.5.3 Altitudinal clustering

The seven altitude classes were grouped in to two main clusters (Fig. 7). In the first cluster, five altitude classes were found to share 50% similarity for quantitative traits considered. Altitude C-II (1564-1767 m.a.s.l.) and C-VII (≥ 2544 m.a.s.l.) fall in the second cluster and they share minimum similarity to the rest of altitude classes. The highest similarities for quantitative traits were observed between tef populations collected from C-IV (1962-2155 m.a.s.l) and C-V (C-V= 2156-2349 m.a.s.l.)

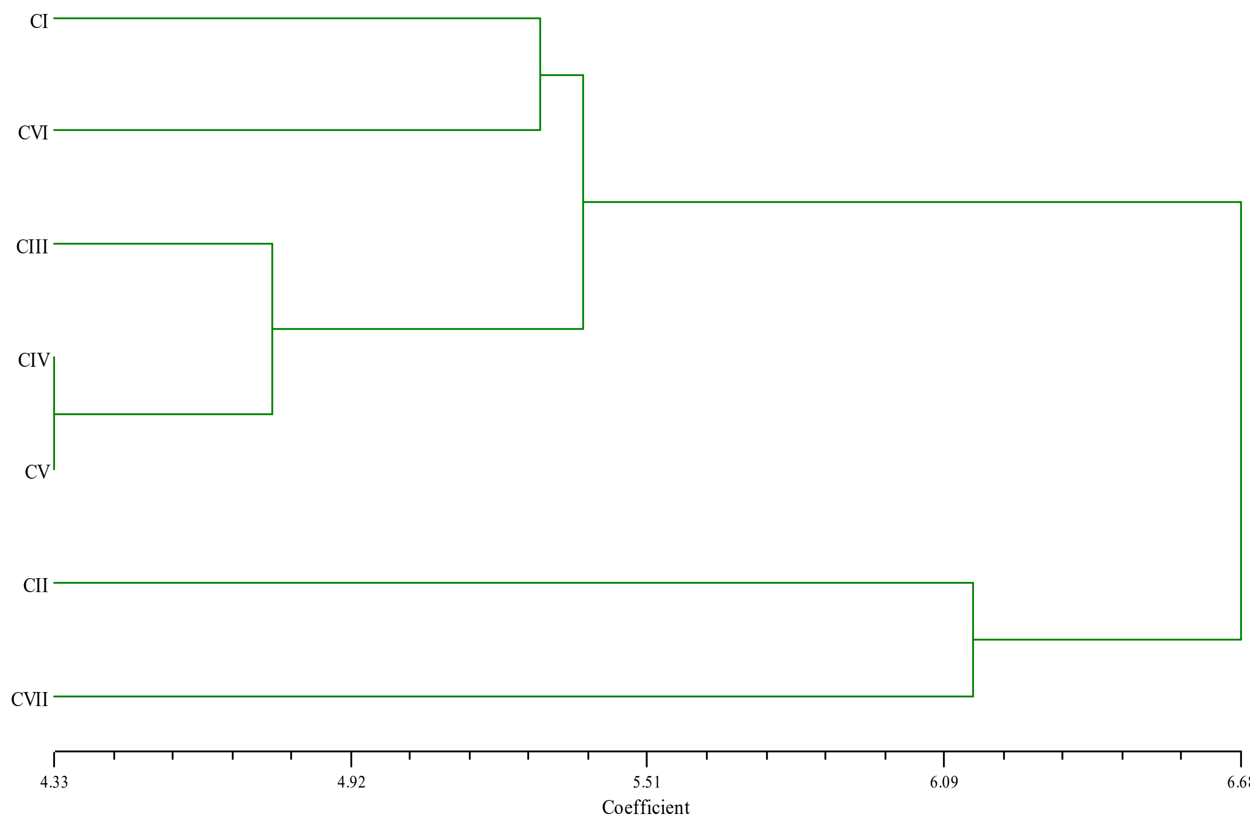


Figure 7. Dendrogram showing similarities of seven altitude classes of 79 tef populations evaluated for 18 quantitative traits.

KEY: C-I=≤ 1563 m.a.s.l., C-II= 1564-1767 m.a.s.l., C-III= 1768-1961 m.a.s.l., C-IV=1962-2155 m.a.s.l., C-V= 2156-2349 m.a.s.l., C-VI= 2350-2543 m.a.s.l., C-VII= ≥ 2544 m.a.s.l.

5.2.6. Phenotypic and Genotypic coefficient of variation

Genotypic coefficient of variation (GCV), genotypic variation (GV), phenotypic coefficient of variation (PCV), phenotypic variation (PV), environmental variation (EV), heritability in broader sense (H^2), genetic advance (as % mean) and genetic advance (GA) values were summarized in Table14.

PCV and GCV values <10%, 10%-20% and >20% are considered to be low, intermediate and higher, respectively (Khorgade *et al.,* 1985). Considering the whole quantitative traits recorded in this study, high phenotypic coefficient of variation were observed for lodging (67.174%), harvest index (51.900%), grain yield per plant (49.050%), severity of rust (48.60%), tiller number (39.900%), spikelet per main panicle (33.900%), second culm diameter (31.25%), first culm diameter (27.90%), number of panicle branch per main panicle (24.60%), culm length (22.450%) and panicle length (20.550%), in order of their importance.

Intermediate PCV were observed for plant height (19.30%), days to grain filling period (15.70%), average fertile floret per spikelet (15.02%), internodes number per culm (15.002%) and days to panicle emergence (14.42%). Across all traits, the PCV was lowest for days to 50% maturity (7.85%).

An estimate of GCV values were lowest for traits such as number of internodes' per culm (0.652%), days to 50% maturity (3.182%), tiller number (8.78%), average fertile floret per spikelet (8.84%) and days to 50% panicle emergence (9.25%). Comparatively higher GCV values were noted for lodging index (52.55%), grain yield per plant (41.16%), severity of rust (24.16%) and harvest index (20.4%). The remaining 10 quantitative gave intermediate GCV value ranging from 10.70% (for days to grain filling period) to 19.70% (for first culm diameter).

Table 13. Genotypic variance (GV), phenotypic variance (PV), environmental variance (EV)

Genotypic coefficient of variation (GCV), phenotypic coefficient variation (PCV), heritability in broader sense(H^2), genetic advance (GA) and genetic advance (as % mean) of 79 tef landraces and 2 improved varieties.

Traits	GV	PV	EV	GCV	PCV	H^2 (%)	GA	GA (% of mean)
Days to 50% panicle emergency	28.200	68.500	40.300	9.252	14.419	41.168	7.019	12.228
Days to 50% maturity	10.485	63.785	53.300	3.184	7.853	16.438	2.704	2.659
Days to grain filling	22.620	48.580	25.960	10.700	15.700	46.560	6.680	15.060
Plant height	66.000	174.000	108.000	11.930	19.370	37.931	10.307	15.135
Panicle length	16.550	45.150	28.600	12.441	20.549	36.656	5.074	15.516
Culm length	14.740	64.840	50.100	10.754	22.556	22.733	3.771	10.563
No.inter node per culm	0.001	0.273	0.272	0.652	15.219	0.183	0.002	0.058
No of panicle branch	5.515	12.275	6.760	16.468	24.569	44.929	3.243	22.740
Spikelet per panicle	2267.430	7160.270	4892.840	19.100	33.942	31.667	55.200	22.142
Tiller number	1.500	31.000	29.500	8.780	39.912	4.839	0.555	3.978
Ave. fertile floret per spikelet	0.440	1.270	0.830	8.844	15.026	34.646	0.804	10.724
Lodging index	65.830	107.570	41.740	52.549	67.174	61.197	13.075	84.683
Severity of rust	1.010	4.090	3.080	24.158	48.615	24.694	1.029	24.731
First culm diameter	0.001	0.002	0.001	19.764	27.951	50.000	0.046	28.789
Second culm diameter	0.001	0.003	0.002	13.975	31.250	20.000	0.021	12.875
Grain yield per plant	1.892	2.589	0.697	41.930	49.051	73.073	2.422	73.837
Harvest Index	8.300	53.600	45.300	20.432	51.923	15.485	2.335	16.563

5.2.7. Heritability (in broader sense) and genetic advance

An estimate of heritability (H^2) varied from 0.183% (for number of culm internode) to 73.07% (for grain yield per main plant) (Table 13). Hence, the highest heritability estimate were observed for grain yield per main plant (73.07%), lodging index (61.2%) and first culm diameter (50%) and, the least heritable traits were number of culm internodes (0.183%) and average tiller number (4.839%)

Lodging index (84.6%) and grain yield per plant (73.07%) were the traits with maximum genetic advance as percent mean. However, number of internodes per culm (0.058%) days to 50% maturity (2.659%) and tiller number (3.978%) were traits with minimum genetic advance.

5.2.8 Euclidian distance

The percentage dissimilarity of all regions of origin and altitude classes for 18 quantitative traits indicated that tef populations collected from South Wello and collections from altitude classV (2156-2349 m.a.s.l.) showed relatively the highest Euclidean distance (dissimilarity) from all the remaining regions and altitude classes, respectively(Table 14a and Table 14b)

Table 14a. Euclidean distance (dissimilarity percentage) between 10 regions of origin for the 79 tef landraces evaluated for regional mean of 18 quantitative traits

Region	Arsi	Bale	E.Gojam	E.Welleag	H. Guduru	Illubabor	Jima	S. Wello	W. Shewa	W.Wellega
Arsi	0.000									
Bale	8.470	0.000								
E. Gojam	28.028	26.640	0.000							
E. Wellega	42.050	41.077	19.035	0.000						
H. Guduru	20.019	19.292	14.134	28.458	0.000					
Illubabor	35.327	34.957	15.258	8.899	22.833	0.000				
Jima	18.173	15.338	15.046	27.432	15.432	21.708	0.000			
S. Wello	25.753	23.913	47.895	62.724	36.866	56.567	38.555	0.000		
W. Shewa	24.512	24.295	10.087	19.196	14.411	13.116	12.603	45.993	0.000	
W. Wellega	36.112	36.259	13.456	15.207	23.738	13.536	22.733	58.257	15.032	0.000

Table 14b. Euclidean distance (dissimilarity percentage) between seven classes of altitude range for the 79 tef landraces evaluated for altitudinal mean of 18 quantitative traits

Alt. classes (m.a.s.l.)	≤ 1563	1564-1767	1768-1961	1962-2155	2156-2349	2350-2543	≥2544
≤ 1563	0.000						
1564-1767	27.090	0.000					
1768-1961	13.670	29.796	0.000				
1962-2155	20.676	43.185	15.940	0.000			
2156-2349	39.845	62.445	34.565	21.483	0.000		
2350-2543	10.450	22.631	15.862	26.118	44.556	0.000	
≥ 2544	16.885	18.844	15.310	26.876	46.401	14.461	0.000

5.2.9 Path coefficient analysis

Path coefficient analysis showing direct and indirect effect of some morphological traits on grain yield per plant on the basis of genotypic and phenotypic level were given in Table 15a and Table 15b, respectively. High and positive genotypic direct effect on grain yield per plant were obtained from first culm diameter (5.29), panicle length (4.26), spikelete per panicle (2.16), second culm diameter (1.65), harvest index (1.03) and days to grain filling period (0.99). However, high but negative direct effect on grain yield was obtained from plant height (-15.71), culm length (-10.5), lodging index (-3.46), days to 50 % panicle emergence (-3.12), days to 50% maturity (-2.74) and number of panicle branch per main panicle (-1.07).

All traits have high but negative indirect effect on grain yield per plant through plant height (except for number of panicle branch and lodging index). In addition, majority of the traits considered have relatively high but negative indirect effect on grain yield through days to 50% panicle emergence, days to 50% maturity and harvest index. In contrary, majority of the traits shown high and positive indirect effect on grain yield per plant through spikelet per main panicle, panicle length and culm length (except for number of panicle branch and lodging index) and; through first and second culm diameter (except for days to grain filling period, number of panicle branch and lodging index).

Phenotypicaly, only plant height showed relatively high and positive direct effect on grain yield per plant. Days to 50% panicle emergence, panicle length and culm length had negative direct effect on grain yield. The remaining 9 traits have positive but very low direct effect on grain yield. Moreover, majority of the traits have lower indirect effect on grain yield through each other. Panicle length (0.483), culm length (0.496) and first culm diameter (0.302) shown relatively high and positive indirect effect on grain yield through plant height. Days to panicle emergence shown no indirect effect on grain yield through number of panicle branch per main panicle and vice verse. Similarly, days to grain filling period, number of panicle branch per main panicle and severity of rust have no indirect effect on grain yield through hundred seed weight.

Table 15a. Estimate of direct (bold and diagonal) and indirect effect of 14 quantitative traits on grain yield per plant on the basis of genotypic correlation.

Traits	**DPE**	**DM**	**DGF**	**PLHT**	**PNL**	**CL**	**NPB**	**SP/PN**	**LOG**	**RS**	**FCD**	**SCD**	**100sw**	**HI**
DPE	**-3.12**	-3.58	-0.46	-12.32	2.59	6.58	-0.03	1.39	1.91	-0.42	4.61	1.22	-0.16	-0.06
DM	-4.08	**-2.74**	0.18	-20.15	5.14	13.58	0.13	1.89	1.93	-0.07	5.57	1.78	-0.56	-0.95
DGF	1.46	-0.48	**0.99**	-3.14	0.42	2.38	0.26	0.07	-0.67	0.17	-0.43	0.08	-0.15	-0.64
PLHT	-1.95	-3.49	0.16	**-15.71**	4.01	10.46	0.08	2.55	1.26	-0.31	5.75	1.58	-0.33	-0.76
PNL	-1.90	-3.31	0.09	-15.03	**4.26**	9.59	0.07	2.32	1.27	-0.24	5.77	1.67	-0.36	-0.54
CL	-1.95	-3.53	0.22	-15.55	3.87	**-10.5**	0.08	2.87	0.98	-0.36	5.55	1.29	-0.26	-0.87
NPB	-0.08	0.35	-0.34	1.42	-0.3	-0.84	**-1.07**	0.02	0.45	-0.07	0.25	0.01	0.05	-0.19
SP/PN	-2.00	-2.39	0.03	-19.23	4.56	14.01	0.01	**2.16**	-0.39	-0.08	5.28	2.11	-0.18	-0.99
LOG	1.72	1.52	0.19	7.16	-1.6	-2.97	0.14	0.24	**-3.46**	0.14	-2.31	-0.30	0.32	-0.17
RS	-5.29	-0.76	-0.68	-19.62	4.15	15.03	-0.29	0.67	2.01	**-0.25**	4.64	1.94	-0.71	-0.99
FCD	-2.71	-2.88	-0.08	-17.38	4.64	11.05	-0.05	2.16	1.51	-0.22	**5.29**	1.73	-0.28	-0.59
SCD	-2.31	-2.96	-0.05	-16.86	4.29	8.25	-0.07	2.65	0.64	-0.29	5.57	**1.65**	-0.36	-0.64
HSW	-1.41	-4.35	0.42	-16.39	4.32	7.98	0.144	1.09	3.12	-0.05	4.25	1.44	**-0.35**	-1.13
HI	0.18	-2.52	0.61	-12.41	2.22	8.83	-0.20	2.07	-0.56	-0.24	3.01	1.02	-0.38	**1.03**

Table 15b. Estimate of direct (bold and diagonal) and indirect effect of 14 quantitative traits on grain yield per plant on the basis of phenotypic correlation.

Traits	**DPE**	**DM**	**DGF**	**PLHT**	**PNL**	**CL**	**NPB**	**SP/P**	**LOG**	**RS**	**FCD**	**SCD**	**HSW**	**HI**
DPE	**-0.092**	0.031	-0.058	0.112	-0.084	0.251-	0.000	0.015	-0.044	0.013	0.027	0.022	0.001	0.012
DM	-0.036	**0.081**	0.046	0.170	-0.094	-0.075	-0.022	0.024	-0.033	0.024	0.031	0.022	0.001	0.085
DGF	0.049	0.035	**0.108**	0.070	-0.023	-0.046	-0.017	0.007	0.016	0.004	-0.002	-0.003	0.000	0.119
PLHT	-0.018	0.025	0.014	**0.559**	-0.306	-0.251	0.001	0.042	-0.004	0.009	0.042	0.034	0.001	0.107
PNL	-0.022	0.022	0.007	0.483	**-0.355**	-0.169	-0.003	-0.003	-0.012	0.006	0.043	0.032	0.001	0.109
CL	-0.008	0.021	0.018	0.496	-0.212	**-0.283**	0.003	0.036	0.003	0.007	0.031	0.027	0.001	0.079
NPB	0.000	-0.014	-0.013	0.006	0.007	-0.007	**0.133**	0.000	-0.010	0.008	0.001	-0.002	0.000	-0.004
SP/PN	-0.016	0.022	0.009	0.271	-0.149	-0.118	0.000	**0.086**	0.006	0.015	0.041	0.037	0.001	0.123
LOG	0.037	-0.025	0.016	-0.023	0.039	-0.008	-0.013	0.005	**0.108**	-0.012	-0.019	-0.007	-0.001	0.015
RS	-0.018	0.030	0.007	0.077	-0.031	-0.031	0.016	0.020	-0.020	**0.066**	0.013	0.008	0.000	0.027
FCD	-0.033	0.033	-0.003	0.302	-0.200	-0.113	0.002	0.046	-0.026	0.012	**0.077**	0.061	0.001	0.058
SCD	-0.026	0.023	-0.005	0.251	-0.152	-0.101	-0.003	0.042	-0.010	0.007	0.062	**0.075**	0.001	0.091
HSW	-0.021	0.023	0.008	0.113	-0.061	-0.042	-0.005	0.018	-0.019	0.008	0.013	0.019	**0.004**	0.131
HI %)	-0.002	0.013	0.024	0.112	-0.072	-0.042	-0.001	0.020	0.003	0.003	0.008	0.013	0.001	**0.05**

KEY: *DPE= days to panicle emergence, DM= days to maturity, DGF= days to grain filling period, PLHT= plant height, PNL= panicle length, CL= culm length, NPB= number of panicle branch per main panicle, SP/PN= number of spikelet per main panicle, LOG= lodging index, RS= rust severity(%), FCD= first culm diameter, SCD= second culm diameter, HSW= 100 seed weight, HI= harvest index (%)*

6. DISCUSSION

6.1 Qualitative traits

6.1.1 Percentage frequency distribution of qualitative traits

Over all regions and across all altitudes, semi-compact panicle forms are less frequent followed by compact panicle forms. The probable reason for this may be, human selection was against the compact and semi-compact panicle forms since they generally gave lower grain yield and comparatively, thick and stronger culm so that less palatable for animals.

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The frequency distribution of lemma color (Table 3 & 4) showed that gray color is dominant across the seven altitude zones and in most administrative region. In this study, it was observed that most of the red and purple colored lemma's were compact panicle forms which have been assumed to give lower yield than other types, so that the selection pressure was against them and limited their abundance.

Overall, less frequent lemma color was observed for red type followed by purple color. All administrative regions and altitude classes considered in this study posses tef populations with four phenotypic classes of seed color, five phenotypic classes of lemma color except South Wello, West Shewa and altitude range between 1962-2155 m.a.s.l. (lack red colored lemma), five phenotypic classes of panicle forms except for Arsi, Bale, South Wello and West Wellega. This implies that there is a diversity of tef landraces in almost all regions of origin and across all altitude classes.

When pooled mean of all phenotypic classes in a given traits are considered, variations were observed between altitude classes for the three qualitative traits, but this variation is not as high as the variation observed within altitude class. This can give a hint that different tef landraces can adapt to the different agro-climatic zones and the variability in terms of tef diversity between the different altitude classes are much less than the variation within a given altitude class.

The result for the percentage proportion of caryopsis color indicates that there is variability within and among tef populations across regions and altitude zones. The four seed color groups were reasonably distributed in the samples of populations studied, which strengthen the notion that farmers in Ethiopia grow different seed color groups for different purpose and for the different merits they have. Eventhough the white and grayish-white seed types are highly preferable for their higher market price and consumer preference; the abundance of brown seed type across all regions and altitude zones indicates that farmers often grow the brown seeded type than the rest type. The probable reason for this might be the wider adaptability, greater productivity and higher straw quality of brown seeded type than the white seed. Beside this, farmers claim that white seeded types have longer length of growing period and difficult to maintain the seed purity even for few years in order to attain maximum market price.

Similarly, Assefa *et al.,* (2002b) noted that the greater proportion of brown seeded type than white seeded type over all collections from Shewa, Wellega, Illubabor, Kefa, Arsi and Bale, and across altitude zones. Further more, the author indicated that farmers' preference for brown seeded type due to its performance under less favorable field conditions and cultural practices plus its market price is not affected by the mechanical mixture.

6.1.2 Shannon–Weaver diversity indices (H')

Shannon-Weaver diversity index for this study depicted that there are substantial levels of diversity in tef populations for all traits and hence enable to suggest emphasis for future collection and germplasm conservation should focus on regions and altitude classes that showed comparatively high level of diversity. Therefore, according to this study, *in situ* conservation, germplasm collection for *ex situ* conservation and utilization for future breeding is preferable if done in East Gojam, East Wellega and Horro Guduru Administrative regions.

Some of the possible reasons for the similarity in genetic diversity of tef among these three regions (Table 3, 5 and Fig. 2) can be the frequent inter-regional migration of farmers (because of their close neighboring) enhanced seed exchange, they may have tef populations initially originated from the same point of origin or they may have agro-ecological similarity, or the combination of these and others.

Shannon-Weaver diversity index across all tef populations, all regions of origin and all altitude classes showed that comparatively higher diversity index was observed for seed color (0.45) followed by lemma color (0.39). Panicle forms displayed the lowest Shannon-Weaver diversity index (0.33).

Similarly, in assessment made on 3600 tef lines representing 36 populations collected from central and northern regions of Ethiopia, significant regional patterns of Shannon-Weaver's diversity indices were only observed for seed color from the rest of qualitative traits but no trait showed detectable clinal variation (Kefyalew *et al*., 2000). Thirteen Durum wheat landraces collected from different ARs of Shewa showed that seed color was highly diverse (H'= 0.97) than other qualitative traits (Tamiru, 1999).

Generally, tef populations from below 1961 m.a.s.l. attain maximum diversity (≥0.40), but population from altitude ≥2544 m.a.s.l. noted the least mean diversity (0.36). Eventhough there were no wider range for pooled mean of diversity indices between the seven altitudinal classes, altitude range between 1768-1961 m.a.s.l. should be given great focus for collection and conservation of tef germplasms.

Similarly, Assefa *et al*., (2002b) reported that the highest mean H' value over all eight traits among 6 regions (Arsi, Bale, Illubabor, Keffa, Shewa and Wellega) was recorded in Illubabor (0.65) and the least mean H' value observed in Bale (0.40). He also noted that, tef population from low land (<1800 m.a.s.l.) score the highest mean diversity (0.60), but population from above 2400 m a.s.l. noted the lowest mean diversity (0.46).

Bekele (1996) also 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 peoples from the diverse central and northern part of the country into the southern and south west carrying their seed stocks with them.

The regional Shannon-Weaver diversity index for pooled mean across the three qualitative traits in this study ranged form 0.32 (for South Wello) to 0.46 (for East Gojam) and the grand mean was 0.39 with deviation from the mean value of 0.0475. Altitudinaly, the range of H' was from 0.36 (for altitude ≥2544 m.a.s.l.) to 0.42 (for altitude between 1768-1961 m.a.s.l.) with grand mean 0.39. Hence, inline with the result of traits frequency distribution within and among population, 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.

Similarly, Kefyalew *et al.,* (2000) reported as there was no significant difference altitudinaly in mean H' value of six qualitative traits in tef population collected from northern and central part of Ethiopia. Bekele (1984) reported that the contribution to the total variation of Ethiopian tetraploid and hexaploid wheat varied among character and that the total phenotypic variation was highest at the lowest level (within localities), followed by difference among populations within a region, and the least among regions.

On the contrary, Belay (1997) noted as there was significant variation for spike density of tetraploid wheat landraces between regions and between altitude groups. Tessema *et al.,(*1991*)* indicated that most of the variation observed between wheat landraces were due to difference among district rather than among population within district and hence suggested that future collection would better cover more different areas than having more samples from similar area.

6.1.3 Cluster analyses of qualitative traits

Dendrogram generated from the standardized morphological data on Euclidian distance matrix with UPGMA cluster analysis classified tef populations collected from 10 admintrative regions into two clusters at 70% similarity level. At this level, samples from relatively neighboring regions were grouped together. There is an indication for the regional and altitudinal patterns in the grouping of the tested tef populations for qualitative traits which may be due to the high tendency of seed exchange and inter-regional migration of farmers. Due to their monomorphic nature to panicle form, lemma color and seed color, the improved varieties could share similarity with none of the regions. Tef populations of Arsi and West Wellega showed highest distance/dissimilarity from each other. Such result has higher importance in choosing population for improvement activities since distantly related accessions are expected to result in wide range of segregation upon crossing. East Gojam, East Wellega and Horro Guduru ARs were clustered together at almost 98% similarity level. This implies that tef populations in these three regions have strong relationships or similarity. The same possible reasons can be forwarded as to the case of their similarity in Shannon-Weaver diversity index.

6.2 Quantitative morphological traits

6.2.1. Analysis of variance

There were highly significant ($P \leq 0.01$) and significant ($P \leq 0.05$) variations between tested tef landraces for most quantitative traits as revealed from the analysis of variance (Table 8). The highest coefficient of variation were recorded for rust severity, tiller number and lodging index, but minimum coefficient of variation for days to panicle emergency and days to 50% maturity. Thus the wider coefficient of variation also indicates the presence of high genetic diversity among studied tef populations. Similarly, Assefa *et al.,* (2002a), Tefera (1988) and Bekele (1996) found that the variation among tef lines within population of both regions and altitude zones was significant in most of the traits.

6.2.2 Mean and range of quantitative characters

The range value of quantitative traits showed the existence of a wide range of variation among tef populations, within and between regions of origin and altitude classes. The wide range in the extreme values of each of the traits studied offers broad opportunities for using landraces with desirable agronomic characters in the breeding program to develop varieties suitable for different agro-ecologies of the country and for different purposes.

The broad range of variation for phenologies such as days to 50% panicle emergency, days to maturity 50% and days to grain filling period (Appendix 1, Table 9 and 10) offer great flexibility for developing improved varieties suitable for various agro-ecologies of the country which have variable length of growing period and also to use in various cropping systems. The overall earliness in maturity of tef population of some region (for instance West Wellega) can also guide breeder to develop a variety which escape late season drought by improving traits which correlate to days to maturity in the required direction.

Moreover, the variability for disease reaction gives the chance to develop resistant/tolerant varieties through crossing. The variation in culm length, culm diameter and number of internodes indicates the possibility to combat lodging problem. Variation in number of panicle branches, number of spikelet per panicle and average number of fertile floret per spikelet implies that the possibility to create a variety with higher grain yield and/or other biological yields. The wider range in tillering capacity would also provide opportunity to raise biomass yield.

The ranges for all quantitative traits are wider among tef populations than within and between region & altitude classes. The range within regions and altitudes of origin also exceeds the variation between the different regions and altitude classes. This leads to suggest that taking more samples within a locality or population would be a better approach to capture the range of variation in tef landrace population and hence, future collection would better focus on taking more samples from a given region having highly diversified tef population than covering many regions.

Both improved varieties (DZ-01-1880 and DZ-Cr-255) relatively score the highest mean values for the trait such as plant height, panicle length, culm length, number of panicle branch per panicle, spikelet per panicle, hundred seed weight and grain yield per plant than regional mean of all the ten regions of origin.

Altitude range between 1564-1767 m.a.s.l noted minimum mean for most quantitative traits such as days to 50% flowering, plant height, culm length, number of culm internodes per main plant, number of spikelets per main panicle, severity of rust, first and second culm diameters, hundred seed weight and grain yield per plant. This indicates that either this class is less favorable for tef production or, the samples collected from the range were inferior to tef populations of other altitude classes, or the micro-environment of trial site could not be suitable for these samples, or the combination of those and other factors.

Overall, the variations observed among tef populations for quantitative trait in this study were supported by previous findings (Tadesse, 1993; Ketema, 1993b; Tefera, 1988 and Assefa, 2001a).

6.2.3 Principal component analysis

The first five principal components accounted for 69.2% and a total of 83.6% variation accounted for the first eight principal components. About 31.4% of the total variance was explained by the first principal component alone, and this was mainly due to variation in metric traits such as plant height, panicle length, culm length, first and second culm diameters. Lodging index, days to grain filling period, grain yield per plant and harvest index were the major contributor for the 12.4% variance observed in the second principal component. A total of 86.8% of the variation observed between regions of origin in the first four principal components where mainly due to great contribution of the traits such as harvest index, plant height, hundred seed weight, culm diameters, and days to panicle emergence, tiller number, severity of rust and number of spikelet per panicle. Altitudinaly, 96.1% of the cumulative variance observed in the first five principal components was due to the contribution of many traits considered in this study in a varying degree in the different components. In the first principal components, the major contributing traits for the overall variation observed among tef populations (31.4%), among regions (52.1%) and among altitude classes (35.7%) were plant height, first culm diameter, second culm diameter, culm length and partly panicle length and days to 50% panicle emergence. In general, the principal component analysis indicated that all quantitative characters considered in this study have contribution to a varying degree for the overall morphological variability among tested tef materials, among regions and altitude classes of origin.

In his study on morphological analysis of *E. tef* for more than 1000 accessions collected from 14 major regions, Bekele (1996) found that 52.32 % of the total variation is associated with the first five principal components and 88.5% with the first eight principal components, out of which 21.79 % of the variance is mainly associated with the first principal axis (PC1).

Assefa *et al*., (1999) reported that about 34% of the total variance of 320 tef germplasm lines evaluated for 20 different characters were mainly due to variability in total plant height, culm and panicle length, diameters of the two basal main shoot culm internodes, main shoot panicle total phytomass and grain yield, counts of primary shoot panicle branches and spikelet, and days to panicle emergence and maturity.

Ayana and Bekele (1999) found that, about 79% of the total variation in 15 quantitative traits of 415 Ethiopian sorghum germplasm accessions were explained on the base of five principal components and the first of these contributed about 37% of the total variance was mainly due to plant height and days to flowering.

Assefa *et al.*, (2001b) observed that four principal components having eigenvalue between 1.13 and 4.67, which contribute about 67% of the total phenotypic diversity noted among 116 tef germplasm lines. About 28% of the total variance was explained by the first principal component, and this was mainly due to variation in diameter of the first and second culm, number of internodes and panicle length.

In the study conducted on morphological variation of 56 accession of linseed collected from 10 different regions of Ethiopia, Negash *et al*., (2005) reported that the first 3 principal component accounted for 73.86% of the total variation, in which seed number per plant contributed about 19.32% of the variation for the first principal factor and days to maturity contributed 19.95% variation for the second principal component.

6.2.4 Correlation coefficient analysis of quantitative traits

Correlations among traits are useful for selecting genotypes/populations having multiple desired characters. However, the correlation coefficient can be affected by the test genotypes and environment. From this study, even though it is a one year trial in single location, there is an implication to combat lower yielding landraces through breeding program by improving spikelet per panicle, plant height, days to grain filling period, days to 50% maturity, culm length, first and second culm diameter, fertile floret per spikelet and hundred seed weight since these traits have significant positive correlation with grain yield.

Phenological traits such as days to panicle emergence, days to maturity and days to grain filling period have generally high and significant positive correlation with each other. Metric characters such as plant height, culm length and panicle length also show highly significant positive correlation with one another. In general, about 48.4% of the total traits association showed significant, out of which 83.8% associated positively. This positive correlation could be resulted from the presence of common genetic elements or micro environment (or both) that controls the characters to the same direction. Positive significant correlation due to effect of genes can be the result of the presence of strong coupling linkage between their genes or the characters may be the result of pleiotropic genes that control these characters in the same direction (Kearsey and Pooni, 1996)

The susceptibility to lodging was significantly ($P \leq 0.01$) but negatively correlated with traits such as the first and second culm diameters, average fertile floret per spikelet, days to 50% maturity, days to 50% panicle emergence; negative but significant ($P \leq 0.05$) correlation with plant height, panicle length and hundred seed weight. It has also positive and significance ($P \leq 0.01$) correlation with severity of rust, where as positive but non significant correlation ($P \leq 0.05$) with grain yield. This implies that there is a possibility to overcome lodging problem in tef by identifying the consistency of association among traits and combining these traits in a given desired genotype through crossing program.

The negative correlation of hundred seed weight with number of panicle branch, lodging index and tiller number, and also the negative association between days to 50% panicle emergence and grain yield per plant can probably be explained as the available resources were used up in the production of profuse vegetative growth for longer time at the expense of material production that should be stored in the seeds. In addition, the different genes or pleiotrophic genes that have dominance on the character may control the character in different directions (Kearsey and Pooni, 1996).

In line with this, majority of the correlation coefficients of 15 quantitative characters of 415 sorghum accessions collected from 11 regions of origin showed positive and highly significant (Ayana, 2001). Most metric characters (plant height, panicle length, culm length, peduncle length, first and second culm internodes diameter) for the tested tef landraces were positively and significantly ($P \leq 0.01$) correlated with each other (Assefa *et al.,* 2002a). He also indicated that lodging resistance was positively correlated ($P \leq 0.05$) with culms diameter, plant height, panicle and peduncle length. Significant positive correlations were noted between plant height, days to 50% maturity and days to 50% flowering in linseed accessions (Negash, 2005).

Contrary to this findings, Assefa *et al.,* (2002a) observed that negative correlation coefficient ($P \leq 0.05$) between days to maturity and plant height, days to maturity and culm length, grain filling period and culm length. The author found that grain yield per plant was correlated negatively with days to maturity, days to grain filling period, harvest index and number of primary branches. Tefera (1988) noted as grain yield per plant of the 35 tef cultivars has insignificant positive correlation with plant height, spikelet per main panicle, days to heading, hundred seed weight and grain yield per main panicle but significant negative correlation with days to maturity and insignificant negative correlation with panicle length and days to heading.

Bekele (1996) noted that grain yield per plant has no significant correlation ($P \leq 0.05$) with all traits for tef accessions collected from Gamugofa; significant correlation ($P \leq 0.05$) with biomass weight, number of primary branch per plant, average number of spikelets of the 1^{st} and 2^{nd} top branches and length of spikelet for tef accessions collected from Hararghe; and significant correlation with all traits except length of flag leaf, breadth of flag leaf and average number of spikelets of the 1^{st} and 2^{nd} top branches for tef accessions collected from Shoa. He indicated that grouping of significantly correlated characters do not show consistency over regions perhaps due to significant difference in selection pressure operating at each site.

6.2.5 Cluster analysis for quantitative traits

6.2.5.1 Population-wise clustering

Except for tef accessions of West Wellega, Horro Guduru and Illubabor region, and the released varieties, accessions collected from all administrative regions, all altitude classes and all soil types contributed to the first cluster in varying degrees.

There is no cluster formed solely either from tef populations of a given region, tef populations collected form similar agro-ecological zones or populations collected from areas with similar soil type stated in this study except some clusters with few number of accessions per cluster such as cluster 5, which was made of two accessions having similar soil type and altitude class and, cluster 13 possessing a total of three accessions all originated from East Wellega (Fig. 5 and Table 12)

Overall, there is an implication for the presence of high genetic diversity within region than between regions. Several possible reasons could be given for the genetic similarity among a few accessions from different corners of the country. It could be due to informal seed exchange among farmers in the different eco-geographic regions of the country or a few materials might have originally been introduced from the same sources. There could also be a tendency of selecting for the same traits of interest like yield, resistance to biotic and abiotic stress and low input demanding. Some regions took a greater share of contribution for the formation of some of the clusters mentioned. The soil type and altitude similarities too. Hence, regional and altitudinal patterns of clustering were manifested but in a lesser extent in case of clustering population using quantitative traits.

Overall, the aggregation of 79 tef populations and two released varieties in to 13 clusters at 50% similarity level having 2-19 landraces per cluster and six landraces remained ungrouped indicated that there is morphological diversity between the tested tef populations.

Similarly, the dendrogram obtained from the hierarchical cluster analysis grouped 42 finger millet populations sampled from 8 major growing regions in to seven clusters, in which no clusters were solely constructed from finger millet populations of the same region of origin (Tsehaye and Kebebew, 2002). Negash (2005) noted that 56 accessions of linseed collected from 10 different regions of Ethiopia were grouped in to five clusters and all regions contributed to the formation of each cluster at varying degree. However, 75% of accessions from Tigray grouped in the 5^{th} cluster.

Assefa *et al.,* (2001b) reported that 120 tef genotypes were clustered in to 13 major groups comprising 2-36 genotypes, and four of the test genotypes remained with out grouping. The authors conclude that as there were no clearly indicated regional and altitudinal patterns in the grouping of the test genotypes. In addition, 320 tef germplasm lines were clustered in to 14 groups based on 20 phenomorphic and agronomic traits (Assefa *et al.,* 1999). On the bases of variation in prolamine fraction of seed protein (Bekele, 1995) stated that the formation of seven distinct clusters of 37 tef cultivars. Workey (2002) noted that 50 Chick pea genotypes collected from 10 administrative regions were grouped in the same cluster and these from the same region of origin grouped under different cluster.

In contrast to this study, Ayana (2001) reported the grouping of 415 Ethiopian sorghum germplasm accessions evaluated for 15 quantitative traits in to ten clusters and many of the accessions from similar adaptation zones or those originating from regions of similar agro-climatic conditions tended to cluster together. The cluster analysis made on 32 landraces of tetraploid wheat collected from Wello and Bale resulted in grouping of landraces from both regions separately (Eticha, 2001)

6.2.5.2 Regional-based clustering of quantitative traits

All regions except Arsi and W. Wellega show relatively close relationship for quantitative traits considered. The two improved varieties were distantly related to each other and extremely distantly related to tef populations of all regions. Some neighboring regions show very close relationship. This indicates that there are extensive informal seed exchanges or inter-regional migration of farmers with their seed, or combination of these and other reasons. Some other regions show strong similarity for most quantitative traits while they are far away from each other (for instance, Horro Guduru with South Wello, Bale with Jimma and West Wellega ARs). This indicates that migration was not limited by distance, the primary seed source for these regions can be the same, or the impact of settlement or, the combination of those and other factors. The finding of Ayana (2001) indicated that sorghum accessions collected from more neighboring regions were grouped together. This report partly resembles and partly contrasting to the present result.

6.2.5.3. Altitude class-based clustering of quantitative traits

Two distantly related clusters were formed in which the first cluster comprised of tef populations from five altitude classes and the second cluster formed of altitude class II and VII. Altitude classes that partially or fully fall in the range of the most favorable tef growing agro-climate (Ketema, 1997) were clustered at very high (about 80%) similarity level. This indicates that the frequency of informal seed exchange was high in those altitude regions. Other possible reasons can be, tef populations having similar characters were well-adapted and well-accepted by farmers in those agro-climatic regions.

6.2.6. Phenotypic and genotypic coefficient of variation

Genetic parameters including genotypic coefficient of variation, heritability and genetic advance are a pre- requisite for genetic improvement of crops (Khorgade *et al.,* 1985). The higher the genetic coefficient of variation, the more the genetic variability between genotypes. Most of the quantitative traits considered in this study had medium to high GCV values. This implies that there is genetic variability among tef populations. On the contrary, the lower GCV values for number of internodes per culm, days to 50% maturity, average fertile floret per spikelet and days to 50% panicle emergence indicates that selection is not effective for such traits because of the narrower genetic variability. In general, PCV values were higher than the corresponding GCV value for all traits in this study. This implies that, beside the genetic factors, other factors such as environments have great contribution for the variations observed.

Among previous findings, the study on variation, heritability and genetic advance in phenomorphic and agronomic traits of 120 tef germplasm lines (Assefa *et al*., 2001b) indicated that PCV was lowest for days to maturity, higher for grain yield per panicle and per plant, and intermediate (10-20%) for first and second basal culm length and diameter, panicle length, number of panicle branches, fertile floret per spikelet and harvest index. Relatively high GCV was observed for grain yield per plant and lower GCV were noted for days to 50% maturity, days to 50 % panicle emergency, culm length, number of internodes, second basal internodes diameter and shoot phytomass per plant. He forwarded that higher values of PCV and GCV can be obtained in mono-environment than in multi-environment due to high genotype-environment interaction effect noted for most of the traits evaluated in multiple environment.

Mengesha *et al.,* (1965) reported that very high GCV for days to flowering (99.4%), plant height (96.1%) and grain yield per plant (76%). Assefa *et al.,* (1999) reported comparatively higher PCV (40.23%) and GCV (21.95%) for grain yield per plant. Hundara *et al.,* (1999) noted relatively lower (<10%) PCV and GCV for major traits such as days to 50% panicle emergence, days to 50% maturity, plant height, lodging index and harvest index.

Tefera *et al.,* (1990) found relatively higher PCV (22.4) and GCV (18.71%) for grain yield per plant than for days to panicle emergency, days to maturity, plant height and lodging index. Most of those authors also found that PCV values were higher than GCV values for all quantitative traits considered in their study. The inconsistence of PCV and GCV result obtained at different time and regions by the different authors indicated that either due to genetic erosion, or due to the size and type of the sample.

6.2.7. Heritability (in broad sense) and genetic advance

Heritability and genetic advance are an important factor to determine the importance of selection in breeding program. Pandey and Tawari (1983) indicated the importance of estimating heritability to know the inheritance of quantitative traits as it indicate the genetic gains that may be gained through selection. For this particular study, grain yield per plant, lodging index, first culm diameter, days to grain filling period, number of panicle branch per main panicle and days to 50% panicle emergence had relatively better heritability, indicating that improvement of these traits through selection are better than for the remaining traits.

Genetic advance provides a prior quantitative estimate of the magnitude of the progress that could be achieved through selection. Hence, the higher genetic advance followed by higher heritability recorded for grain yield per plant, lodging index and first culm diameter indicated that the ease of phenotype based selection. This also implies the possibility to improve the crop for its yielding capacity and its ability to resist lodging through selection method. High heritability coupled with high expected genetic gain may result due to high additive gene effect and thus selection applied on such traits lead to yield improvement (Arora, 1991).

On the other side, the lower heritability value and genetic advance for number of culm internodes per main plant, number of tiller per main plant, days to 50% maturity and harvest index implies that most of the variation for those traits were environmental and thus leading to low heritability and low expected genetic gains from selection and eventually result in low progress of selection.

Overall, the result for heritability and genetic advance of the current study provide information for the existence of wider genetic diversity in tef populations and this offers high chances for improving several traits of the crop through selection method and the need for hybridization to improve the character with low heritability.

From previous work, Assefa *et al*., (2001b) noted that low heritability (< 35%) for traits such as days to maturity, first basal culm internodes length, grain yield per plant and harvest index; intermediate heritability (35-54%) culm length, diameter of the first and the second basal culm, peduncle length, grain yield per panicle and number of fertile tiller per plants; and comparatively higher heritability for days to panicle emergence, panicle length, average number of fertile floret per spikelet and number of panicle branch. Overall, his finding was supportive for the current study for most of the traits and contrasted for some traits.

Tefera (1988) noted the high GCV, heritability and genetic advance as percent mean for spikelet per main panicle, 100 kernel weight, grain yield per main panicle, panicle length and kernel weight per main panicle and productive tiller per main plant indicated the possibility to improve those characters through single plant selection.

Assefa *et al*., (2001b) found that relatively high GA (% of mean) for number of fertile tiller per plant, number of fertile floret per spikelet, length and grain yield of main shoot panicle (GA>17%); low GA (<10%) for harvest index, first and second basal internodes diameter, culm and peduncle length; and intermediate GA (10-17%) for days to panicle emergence, length of the second and diameter of the first basal culm internodes, number of culm nodes, number of panicle branch and grain yield per plant.

Tefera and Ketema (2001) summarized the result of narrow sense heritability (h^2) from three different studies as high h^2 value for days to grain filling period (48-74%), days to maturity (32-69%) and panicle length (40-68%); intermediate for grain yield per panicle (23%) with variation across studies suggesting that this trait could be reliable guide for selection. Low heritability values have been reported for kernel weight (0.09), tiller number (0.15-0.52) and plant height (0.11-0.56). The fluctuation in heritability across experiments and environment made the utility of these traits for selection dependent on the crosses and the environmental condition.

6.2.8 Euclidian distance

Tef landraces of different regions as a whole, showed a range of pair-wise population dissimilarities, and in particular, population from South Wello noted the highest Euclidian distance from landraces of most regions. Tef population sampled from 2156-2349 m.a.s.l. also showed the highest dissimilarity to the rest of altitude classes. Such results have importance in choosing populations for improvement activities since distantly related populations are expected to be more heterotic. Relatively higher dissimilarity was observed between regions of origin than between altitude classes. This also implies the presence of high genetic diversity of tef between regions than between altitude classes.

6.2.9 Path coefficient analysis

Breeder frequently used to determine the relationships of yield and yield component using simple correlation coefficient. But this does not provide an exact picture of the relative importance of direct and indirect influence of each of the traits towards grain yield (Tefera, 1988). Hence, the high and positive genotypic direct effect of traits such as panicle length of main plant, spikelete per main panicle, days to grain filling period, harvest index, first and second culm diameter in the present study indicated that keeping the other traits constant an increase for those traits can increase grain yield per plant. It also implies that those traits are the most important component of grain yield per plant.

The negative direct effect on grain yield observed from days to 50 % panicle emergence and days to 50% maturity could gave a clue that improvement for grain can be attained if breeder use tef accessions that have early panicle emergence and maturity characters. Harvest index has positive direct effect on grain yield per plant confirming that an increase in yield per plant can increase harvest index. In other words, maximum nutrients are utilized by the plant to produce the grain than vegetative part or the heritable traits are responsible to increase the grain part of the plants than the vegetative part.

Lodging index was negatively and significantly correlated to plant height (Table 12). This trait has also high but negative direct effect on grain yield. Environmental factors which result in an increase of plant height have positive effect for lodging resistance and grain yield increments. In other words, tef accessions which are resistant to lodging would have higher grain yield per plant. Lodging index has also negative indirect effect on grain yield through first and second culm diameter. This implies that accessions with thick culm diameter resist lodging and hence give good grain yield per plant.

The positive insignificant correlation coefficient observed between grain yield per plant with number of panicle branch per main panicle and lodging index; and the positive significant correlation of grain yield per plant with days to maturity and plant height could be either raised from pheno-agronomic characters or a misleading impression that an increase of those traits through manipulation of heritable factors of the plants could decrease grain yield per plant as confirmed form genotypic path analysis.

All traits have high but negative indirect effect on grain yield per plant through plant height (except for number of panicle branch and lodging index). This implies that in addition to the negative direct effect of plant height, several traits influence grain yield per plant indirectly through plant height. Panicle length has positive significant effect on grain yield directly and indirectly through culm length, spikelet per panicle, lodging, first and second culm diameter. This indicates that the positive effect of panicle length is not exclusive due to its direct effect but also due to its indirect effect through those traits.

Phenotypicaly, environmental factors and agronomic practices that improve the growing conditions of tef populations and hence plant height of that population slightly affect/increase grain yield per plant. Days to 50% panicle emergence, panicle length and culm length had negative direct effect on grain yield. This implies that an improvement through non-heritable components of tef accessions for those traits would decrease grain yield per plant. Majority of the traits have positive but very low direct effect and also lower indirect effect on grain yield per plant through each other.

Days to 50% panicle emergence shown no indirect effect on grain yield through number of panicle branch per main panicle and vice verse. This indicates that a decrease or an increase of the phenotypic components of days to panicle emergence of those traits has no value for grain yield indirectly through each other. Similarly, an increase or a decrease in non heritable traits of tef populations for days to grain filling period, number of panicle branch per main panicle and severity of rust have no indirect effect on grain yield through hundred seed weight.

Overall, the present study implies that the genetic manipulations of tef accessions for several quantitative characters are more advisable to improve the productivity of tef landraces than pheno-agronomic and environmental manipulations.

In line with the present finding, Adnew (2002) noted that high and positive genotypic direct effect on grain yield of tef landraces were obtained from spikelet per panicle and harvest index, high but negative direct effect were observed from days to panicle emergence, number of panicle branch and thousand grain weights. In contrary, he found that days to maturity and plant height have high and positive direct effect on grain yield but, panicle length and number of fertile tiller per main plant had high and negative direct effect on grain yield. Majority of the traits he considered had negative indirect effect on grain yield through days to panicle emergence, days to grain filling period and panicle length but positive indirect effect through days to maturity.

Tefera (1988) found that positive direct effect of hundred kernel weights, grain yield per main panicle and productive tiller on grain yield per plant for the 35 tef cultivars investigated. Hundred kernel weights had negative indirect effect on grain yield per plant through grain per main panicle and productive tillers but positive indirect effect through spikelet per main panicle. Spikelet per main panicle had negative indirect effect on grain yield per plant via hundred kernel weight and productive tiller; but positive indirect effect through grain yield per main panicle. Mengesha (1965) reported panicle length has positive and significant direct effect on grain yield, but it has insignificant indirect effect through plant height and days to maturity. He also found insignificant direct effect of plant height and days to maturity on grain yield. Chanyalew *et al*., (2006) also indicated as panicle length, harvest index and shoot biomass have positive direct effect on grain yield.

7. CONCLUSIONS

The higher frequency of brown seeded color than white seed color in the population of the current study across all regions may be indicating that the selection pressure due to its greater productivity, high straw quality, reasonable demand for external input and wider adaptability are in favor of brown seeded color.

The result from Shannon-Weaver diversity index depicted that there are substantial levels of diversity in tef population for all traits and hence enable to suggest greater emphasis should be given for collection and germplasm conservation particularly to regions with relatively high diversity (East Gojam, East Wellega and Horro Guduru) administrative regions.

Relatively, higher Shannon-Weaver diversity index (H') and wider range of variation for quantitative traits were observed among population, within region and within altitude classes, in order of their importance, than do between regions and between altitude classes. This urges that collection to capture maximum diversity could be most effective if it is made by taking more samples within region and within altitude class than increasing the number of regions and altitude classes.

The significant variation ($P \leq 0.05$ and $P \leq 0.01$) between landraces for most quantitative traits as revealed from analysis of variance and coefficient of variation; the contribution of each traits to the variations as revealed from principal component analysis and the positive significant correlation coefficient between the major traits indicated that the existence of great diversity among population, the possibility to improve traits such as yielding ability, resistant/tolerant to lodging, rust resistance and other important characters through selection breeding and through inter and intra-population crossing.

The cluster analysis that resulted from entire population based on quantitative traits implies that the material collected either from the same regions of origin, or from the same altitude classes (agro-ecology) or from the same soil type were rarely grouped fully under a given cluster. This also gave a hint that diverse tef populations are grown within region, within altitude class and even on the same soil type.

Most of the quantitative traits had medium to high GCV values. This implies that there is genetic variability among tef population and selection is effective for such traits. The overall higher PCV than GCV implies that environmental factors have also great contribution for the variation observed.

The high and positive genotypic direct effect of traits such as panicle length of main plant, spikelete per main panicle, days to grain filling period, harvest index, first and second culm diameter on grain yield per plant in the present study as obtained from path analysis indicated that keeping the other traits constant an increase for those traits can increase grain yield per plant. The minimum value of direct and indirect phenotypic effect of majority of the traits on grain yield per plant observed in this study indicates that genetic manipulations of tef accessions for several quantitative characters are more advisable to improve the productivity of tef landraces than pheno-agronomic and environmental manipulations

8. RECOMMENDATIONS

Susceptibility to lodging is the major bottleneck to increase the productivity of tef. In the present study, it has significant negative correlation with some lodging tackling traits such as culm diameters, plant height, culm and panicle length. There are implications how to overcome/minimize lodging problems through selection and crossing techniques if the consistency of associations among these traits will be further identified and confirmed.

This study indicated as there is maximum tef population diversity within region and within agro-ecologies. Therefore, every spot in a district of each region in the country should possibly be addressed; appropriate management and frequent maintenance breeding of each landraces should be considered; and greater emphasis of collecting more landraces per district and strategic conservations should be made in those regions with greater genetic diversity to capture diversified tef genetic resources.

The present study only addresses tef landraces from 10 major tef growing Administrative Regions. In order to overcome the problem of genetic erosion, the micro center of origin/diversity for tef should be known to conserve, collect and utilize the genetic resource available. Hence, the regional and altitudinal distribution of the closer progenitor of tef should be known and tef population from all tef growing region and agro-climates should be sampled proportionally and tested under multi-environment to predict the probable/reasonably primary center of origins and diversity. From breeding point of view, those characters having genetically positive direct effect on grain yield should be given due attention when collection, conservation and selection of landraces targeted for yield improvement will be planned

Genetic information for tef especially at the molecular level is limited as compared to other cereal crops. Efficient utilization of the tef genetic resource and identification of superior landraces for future breeding still urges morphological diversity study supported by molecular marker system.

9. REFERENCE

Adnew, T. (2002). Genetic diversity and association among quantitative traits in tef germplasm. MSc. thesis. Alemaya University.

Agrawal, B.L (1996). *Basic statistics*, 3rd ed. New Age International (P) Limited, New Delhi, pp.713.

Agronomix Software, Inc., and Agrobase 1998 Addendum, 2000. Agrobase TM, 71 Waterloo St. Winnipeg, Manitoba R3NNOS4, Canada.

Allard, R.W. (1960). *Principle of plant breeding.* 2nd ed. John Wiley and Sons, New York.

Amanda, L. I. and Jeff, D. J. (2003). The origin and evolution of *Eragrostis tef* (Poaceae) and related polyploidy: Evidence from nuclear waxy and plastid rps 16. *Amer. J. Bot.* **90**(1): 116-122.

Amogne, S., Hundera, F., Kassaye, Z. and Abebe, F. (2001). Tef disease survey in the Western Shewa and some part of East Wellega (unpublished).

Ayana, A. (2001). Genetic diversity in sorghum [*Sorghum bicolor* (L.) Moench] germplasm from Ethiopia and Eritrea. Ph.D thesis, Addis Ababa University.

Ayana, A. and Bekele, E. (1998). Geographical patterns of morphological variation in sorghum [*Sorghum bicolor* (L.) Moench] germplasm from Ethiopia and Eritrea: Qualitative characters. *Hereditas* **129**:195-205.

Assefa, K., Arnulf, M. and Tefera, H. (2003a). Multivariate analysis of diversity of tef (*Eragrostis tef* (Zucc.) Trotter) germplasm from western and south western Ethiopia. *Hereditas* **138**: 228-236.

Assefa, K., Arnulf, M. and Tefera, H. (2003b). Inter Simple Sequence Repeate (ISSR) analysis of diversity in tef (*Eragrostis tef* (Zucc.) Trotter). *Heredites* **139**: 174-183.

Assefa, K., Tefera, H.and Arnulf, M. (2002a). Variation and interrelationship of quantitative trait in tef (*Eragrostis tef* (Zucc.) Trotter) germplasm from western and south western Ethiopia. *Hereditas* **136**: 116-125.

Assefa, K., Arnulf, M. and Tefera, H. (2002b). Qualitative trait variation in tef (*Eragrostis tef* (Zucc.) Trotter) germplasm from western & southern Ethiopia. *Euphytica* **127**: 399-410.

Assefa, K., Tefera, H., Arnulf, M., Kefyalew, T. and Hundera, F. (2001a). Quantitative trait diversity in tef [*Eragrostis tef* (Zucc.) Trotter] germplasm from central and northern Ethiopia. *Genet. Reso. Crop. Evol. **48***: 53-61.

Assefa, K., Tefera, H., Arnulf, M., Kefyalew, T. and Hundera, F. (2001b). Variability, heritability and genetic advance in phenomorphic and agronomic traits of tef [*Eragrostis tef* (Zucc.) Trotter] germplasm from eight regions of Ethiopia. *Hereditas **134***: 103-113.

Assefa, K., Ketema, S.,Tefera, Nguyen, H., Blum, A., Ayele, M., Bai, G., Simane, B. and Kefyalew, T. (1999). Diversity among germplasm lines of the Ethiopian cereal tef [*Eragrostis tef* (Zucc.) Trotter]. *Euphytica* **106**: 87-97.

Ayele, M., Tefera, H., Assefa, K. and Nguyen, H. (1999). Genetic characterization of two *Eragrostis* spicies using AFLP and morphological traits. *Hereditas* **130**: 33-40.

Belay, G. (1997). Genetic variation, breeding potential and cytogenetic profile of Ethiopian tetraploid wheat landraces. Doctoral thesis, Swedish University of Agricultural Sciences. Uppsala.

Bekele, E. (1996). Morphological analysis of *Eragrostis tef*: detection for regional patterns of variation. *SINET: Ethiop. J.Sci.* **19:** 117-140.

Bekele, E. (1995). Variation in basic amino acids including lysine and total protein in *Eragrostis tef (Zucc*.) Trotter. *SINET: Ethiop. J. Sci*. **18(2):** 175-194.

Bekele, E. (1986). The relationship between wild and cultivated species of *Eragrostis* (Poaceae) using flavonoid patterns, caryopsis and pollen morphology as markers. *SINET: Ethiop. J. Sci.,* **9** (suppl.).

Bekele, E., (1985). The biology of cereal landrace populations. Problem of gene conservation, plant breeding schemes and sample size requirement. *Hereditas* **103**: 119-134.

Bekele, E. (1984). Analysis of regional patterns of phenotypic diversity in the Ethiopian tetraploid and hexaploid wheats. *Hereditas* **100**: 131-154.

Bekele, E. (1983). Some measures of genetic diversity analysis on landrace population of Ethiopian Barley. *Hereditas* **98:** 127-143.

Bekele, E. and Lester, R. N. (1981). Biochemical assessment of the relationship of *Eragrostis tef (Zucc*.) Trotter with some wild *Eragrostis* species (Gramineae). *Ann. Bot.* **48:** 717-725.

Berhe, T. (1981). Inheritance of Lemma color, seed color and panicle form among four cultivars of *Eragorstis tef* (Zucc.) Trotter. Ph.D. thesis, University of Nebraska, Lincoln, USA.

Bornet, B.C., Muller, F.P., and Branchared, M. (2002). Highely informative nature of Inter Simple Sequence Repeat (ISSR) sequence amplified using tri, and tetra-nucleotide primer form DNA of cauliflower (Brasica oleracea var. ‘ botrytus’ L.). *Genome* **45**: 890-896.

Central Statistical Authority (2007). Federal Democratic Republic of Ethiopia Central Statistical Agency, Statistical Abstract.

Central Statistical Authority (2004). Agricultural sample survey. Part III. Report on the preliminary results of area, production and yield of temporary crops, (Meher season, private peasant holding), Addis Ababa.

Central Statistical Authority (2003). Agricultural sample survey. Part II. Report on the preliminary results of area, production and yield of temporary crops, (Meher season, private peasant holding), Addis Ababa.

Central Statistical Authority (2002). Agricultural sample survey. Part I. Report on the preliminary results of area, production and yield of temporary crops, (Meher season, private peasant holding), Addis Ababa.

Chamberlain, J.R.(1998). Systematic and population genetics laboratory for isozyme analysis. University of oxiford, UK.

Chanyalew, S., Tefera, H., Zelleke, H. and Singh, H. (2006). Correlation and path coefficient analysis of yield related traits in recombinant inbred lines of tef (*Eragrostis tef*). *J. Genet. & Breed.* **60**:1-8

Cochran, W.G. and Cox, G. M.(1957). *Experimental designs*. 2nd ed., John Wiley and Sons, Inc., New York.

Costanza, S.H., deWet, J.M and Harlan, J.R. (1978). Literature review and numerical taxonomy of *Eragrostis tef* (t’ef). *Econ. Bot*. **33**: 413-424.

Demeke, T.,Adams, R.P. and Chibbar, R.(1992). Potential taxonomic uses of random amplified polymorphic DNA (RAPD): a case study in Brasica. *Theo. App. Gen*. **84:** 990-994.

Demissie, A. and Bjonstrand, A. (1996). Phenotypic diversity of Ethiopian barley in relation to geographic regions, altitudinal range and agro ecological zones: as an aid to germplasm collection and conservation strategy. *Hereditas* **124:** 17-29.

Doshi, S. R. and Gupta, K. C. (1991). SPAR (Statistical Package for Agricultural Research). ICRA, New Delhi, 110012.

Ebba, T. (1975). T'ef (*Eragrostis tef*) cultivars: Morphology and classification. Part II, Agricultural Experimental station Bulletin, 66, Addis Ababa University, college of Agriculture, DireDawa.

Eticha, F. (2001). Phenotypic and Isozymic diversity in tetraploid wheats (Triticum spp.) in Bale and Wello regions of Ethiopia. M.Sc. thesis. Addis Ababa University.

Feyisa, T. (1999). The sequence variation of chloroplast DNA intergenic spacer regions between trnT (UGU) and trnL (UAA) 5' exon of *Eragrostis tef* (Zucc.) Trotter and *E. pilosa*. The requirement for the degree of Masters of Science in biology (Applied Genetics).

Gugsa, L., Belay, G. and Ketema, S. (2001). Cytogenetics of tef. **In:** *Narrowing the Rift: Research and Development in Tef: Workshop Proceedings,* pp. 49-57, (Tefera, H., Belay, G. and Mark, S. eds). Ethiopian Agricultural Research Institute, Addis Ababa.

Guihua Bai, Ayele, M., Tefera, H. and Nguyen, H. (2000). Genetic diversity in Tef [*Eragrostis tef* (Zucc.) Trotter] and its relative as revealed by RAPD. *Euphytica* **112**: 15-22.

Guihua Bai, Ayele, M., Tefera H.and Nguyen, H. (1999). Amplified fragment length polymorphism analysis of tef [*Eragrostis tef* (Zucc.) Trotter]. *Crop Sci.* **39**:819-824.

Hart, E.G. (1996). Genom analysis in Triticeae using Isozymes. **In:** *Methods of genome analysis in plants*. pp. 195-204, (Jauhar, P.P.eds), CRS press. Inc. USA.

Hoey, B.K., Crowe, K.R, Jones, V.M and Polans, N.O. (1996). A phylogenetic analysis of pisum based on morphological characters, allozymes and RAPD markers, *Theo. App. Gene*. **92:** 92-100.

Hundara, F., Tefera, H., Assefa, K., Tefera, T. and Kefyalew, T. (1999). Genetic variability and correlation of morpho-agronomic characters in tef landraces. *Trop. Sci*. **39**: 140-146.

Hundara, F., Bogale, T., Tefera, H., Assefa, K., Debelo, A. and Ketema S. (2001). Agronomy research in tef. **In:** *Narrowing the Rift: Research and Development in Tef: Workshop Proceedings,* pp. 167-175, (Tefera, H., Belay, G. and Mark, S. eds). Ethiopian Agricultural Research Institute, Addis Ababa.

Hunter, M. (1996). *Fundamentals of conservation biology*. Blackwell Science, Inc., USA.

Jain, K.S., Quaset, C.O., Bhatt, G.M. and Wu, K.K. (1975). Geographical patterns of phenotypic diversity in a world collection of Durum wheat. *Crop Sci*. **15:** 700-704.

Jarvis, D.I., Myer, L.K, Klemick, H., Guarino, L., Smale, M., Brown, A., Sadiki, M. and Hodgkin, K. (2000). A training guide for *insitu* conservation, Version 1, pp. 75-92, International plant genetic resources Institute, Rome, Italy .

Jones, B.M., Ponti, J.A., Tavassoli, A. and Dixon, P. A. (1978). Relationships of the Ethiopian cereal *Eragrostis tef* (Zucc.) Trotter: Evidence from morphology and chromosome number. *Ann. Bot*. **4**: 1369-1373.

Karp, A., Kresovich, S., Bhatt, K.V., Ayad, W.G. and Hodgkin, T. (1997). Molecular Tools in Plant Genetic Resources Conservation: A Guide to the Technologies. IPGRI Technical Bulletin No.2. International Plant Genetic Resources Institute (IPGRI), Rome, Italy.

Kearsey, M.J. and Pooni, H.S. (1996). *The genetical analysis of quantitative traits.* Chapman and Hall, London, Weinhein, New York, pp. 381.

Kefyalew, T., Tefera, H., Assefa, K. and Ayele, M. (2000). Phenotypic diversity for qualitative and phenologic characters in germplasm collection of tef (*Eragrostis tef*). *Genet. Reso. Crop Evol. **47***: 73-80.

Kefyalew, T. (1999). Assessment of genotype x environment interaction for grain yield and related traits in tef [(*Eragrostis tef* (Zucc.) Trotter]. M.Sc. thesis, Alemaya University, Ethiopia.

Keneni, G., Jarso, M. and Wolabu, T. (2007). Eco-geographical and microcenters of genetic diversity in faba bean (*Vicia Faba* (L) and field pea (*Pisum Sativum* (L.) germplasm collection from Ethiopia. *East Afri. J. Sci* **1(1)**:10-24.

Ketema, S. (1993a). Tef *(Eragrostis tef): Breeding, Genetic Resources, Agronomy, Utilization and Role in Ethiopian Agriculture*. Ethiopian Agricultural Research Institute, Addis Ababa.

Ketema, S. (1993b). Phenotypic variation in tef *(Eragrostis tef*) germplasm, morphological and agronomic traits. A catalog. Technical manual No. 6, Institute of Agricultural Research, Addis Ababa, Ethiopia.

Ketema, S. (1997). Tef. *Eragrosties tef (Zucc.)* Trotter. Promoting the conservation and use of underutilized and neglected crops, bulletin no.12. Institute of Plant Genetics and Crop Plant Research, Gatersleben (International Plant Genetic Resources Institute). Rome, Italy.

Khorgade, P., Narkhede, W. and Raut, S.K. (1985). Genetic variability in chickpea. International chickpea newsletter, no. 5, pp.3-4.

Mengesha, M.H., Picket, R.C. and Davis, R.I.(1965). Genetic variability and interrelationships of characters in tef [*E. tef* (Zucc.) Trotter]. *Crop Sci.* **5**:155-157.

Michigan State University (MSU), 1991. Users Guide to MSTAT-C. Michigan State University, East Lansing, U.S.A.

MINITAB (2003). MINITAB statistical software, version 14.13.0.0, Minitab Inc.

Nagaoka, T., and Ogihara, Y. (1997). Applicability of inter-simple sequence repeat polymorphism in wheat for use as DNA markers in comparison to RFLP and RAPD markers. *Theor. Appl. Genet*. **94**: 597-602.

Negash, W., Asfaw, Z. and Yibra, H. (2005). Variation and association analysis on morphological characters of Linseed (*Linum usitatissimum* (L.) in Ethiopia. *SINET: Ethiop. J.Sci*., **28(2):**129-140.

Noirot, M., Hamon, S. and Anthony, F. (1996). The principal component scoring; a new method of constituting a core collection using quantitative data. *Genet. Reso. Crop. Evol.* **43(1):** 1-6.

Pandey, R.L. and Tawari, A.S. (1983). Heritability and genetic gain in chickpea. International chickpea newsletter, no. 9, pp. 5-6.

Pejic, I., Ajmone-Marsan, P., Morgante, M., Kozumplick, V., Castigilioni, P., Tarmino, G. and Motto, M. (1998). Comparative analysis of genetic similarity among maize inbredlines detected by RFLPs, RAPDs and AFLPs. *Theor. App. Genet.* **97**:1248-1255.

Ponti, J.A. (1978). The systematic of *Eragrostis tef* (Gramineae) and related species. Ph.D. thesis, University of London, U.K.

Rohlf, F. J. (2004). NTSYSpc, Numerical Taxonomy and Multivariate Analysis System. Version 2.11T. Distribution by Exter software, Setauket, NewYork.

Singh, K.B. and Singh, S. (1991). Evolution of exotic germplasm in lentil. *J. Agri. Res*. **6(2)**: 304-306.

Singh, R.K and Chaundhary, B. D. (1977*). Biometrical Methods in Quantitative Genetic Analysis*. Kalyani publishers, New Delhi, p 304.

Singh, S.B. (2002). *Plant Breeding: Principle and Methods.* Kalyani Publishers, New Delhi, Ludhiana, India.

SPSS Inc. (1999). SPSS Base 12.0 for Windows User's Guide. SPSS Inc. Chicago IL, U.S.A.

Tadesse, D. (1993). Study on genetic variation of landraces of tef [*Eragrostis tef (Zucc*.) Trotter]. in Ethiopia. *Genet. Resour. Crop Evol*. **40**:101-104.

Takele, A., Kebede, H. and Simane, B. (2001). Physiological research in tef. **In:** *Narrowing the Rift: Research and Development in Tef: Workshop Proceedings,* pp.177-189, (Tefera, H., Belay, G. and Mark, S. eds). Ethiopian Agricultural Research Institute, Addis Ababa.

Tamiru, M. (1999). Morphological and molecular diversity in Durum wheat (*Tritcum durum* Desf.) landraces of Shewa. M.Sc. thesis, Addis Ababa University.

Tavassoli, A. (1986). The cytology of *Eragrostis* with special reference to *E. tef* and its relatives. Ph.D. Thesis, University of London, U.K.

Tefera, H. (1988). Variability and association of characters in tef [*Eragrostis tef* (Zucc.) Trotter] cultivars. MSc. thesis. Alemaya University, Ethiopia.

Tefera, H. and Ketema, S. (2001). Production and importance of tef in Ethiopian agriculture. **In:** *Narrowing the Rift: Research and Development in Tef: Workshop Proceedings,* pp. 3-7, (Tefera, H., Belay, G. and Mark, S. eds). Ethiopian Agricultural Research Institute, Addis Ababa.

Tefera, H., Ketema., S. and Tessema, T. (1990). Variability, heritability and genetic advance in tef [*Eragrostis tef* (Zucc.) Trotter] cultivars. *Trop. Agric*. **67**: 317-320.

Tessema, T., Belay, G. and Werede, M. (1991). Morphological diversity in wheat landrace populations from central highlands of Ethiopia. *Hereditas* **114:** 172-176.

Tsegaye, T. (1997). Genetic diversity and sturucture of tetraploid wheat landraces of the central highlands of Ethiopia. Doctoral thesis, Swedish University of Agricultural Sciences.

Tsehaye, Y. and Kebebew, F. (2002). Morphological diversity and geaographical distribution of adaptive traits in finger millet (*Eleusine corracana* (L.) Gaertn. Subsp. Coracana (poaceae) population from Ethiopia. *Ethio. J. Biol. Sci.* **1(1):**37-62.

Vavilov, N. (1951). The origin, variation, immunity and breeding of cultivated plants, pp. 37-38. Ronald Press, NewYork, U.S.A. [Translated from the Rusian by K. Starrchester].

Wolf, A.D. and Liston A. (1998). Contributions of PCR based methods to plant systematics and evolution biology. **In**: *Plant molecular systematic*, 2nd ed., pp. 43-86; (Soltis, D.E., Solitis, P. and Doyl, J.J.,eds.), Kluwer Acadamic Publishers, Boston, U.S.A..

Workeye, F. (2002). Morphological and biochemical diversity analysis in chick pea landraces of Ethiopia. MSc. thesis, Addiss Ababa University.

10. APPENDIX

Appendix 1. Mean of 18 morphological traits of 81 tef landraces

Trt	Acc.#	DPE	DM	DGF	PLH	PAL	CL	N gIN	PAB	SP/PN	TN	FF/SP	LOG	RT(adj)	FCD	FCD	100sw	GY/PL	HI
1	55172	59	92	33	58	26	32	3.6	18	227	14.8	7.7	15	5.1	0.16	0.19	0.015	3.40	14.7
2	236336	65	97	32	57	30	27	3.6	14	196	13.1	7.7	7.5	6.17	0.16	0.12	0.025	1.65	7.3
3	55131	57	98.5	42	76	40	36	2.6	17	341	11.7	7.67	10	5.22	0.22	0.21	0.025	2.55	13.9
4	55147	65	98.5	33	69.5	41	29	3.4	16	189	14.5	6.72	10	2.9	0.18	0.17	0.03	2.45	18.2
5	203010	51	93	42	60	33	27	2.4	15	249	13.9	8.7	10	2.2	0.13	0.16	0.03	1.85	15.7
6	202966	45	88.5	38	51.5	23	29	2.9	12	191	13	7.1	50	0.00	0.11	0.18	0.02	1.3	7.9
7	55253	62	99	37	82.5	41	41	3.6	22	411	11.8	7.0	5	2.23	0.24	0.22	0.025	1.13	7.5
8	236758	62	100	38	54	26	28	4	12	234	22.2	7.8	7.5	3.6	0.16	0.14	0.025	1.2	4.3
9	237704	59	99.5	40	64	31	33	3.4	13.6	201	14.9	6.8	22.5	2.44	0.13	0.15	0.02	2.65	12.2
10	236952	57	99	42	72	34	38	3.9	15	231	14.7	10.1	10	4.54	0.21	0.23	0.03	3.4	11.8
11	212615	47	95.5	49	51.5	25	31	2.6	10.3	182	12.1	6.5	17.5	4.67	0.14	0.16	0.03	1.9	14.1
12	236359	47	93	38	75	36	39	3.6	13.8	237	10	6.6	10	1.73	0.16	0.16	0.03	2.1	9.4
13	239396	64	97	42	72	38	31	3.5	14	190	16.4	7.8	17.5	2.23	0.17	0.17	0.025	2.33	11.9
14	55156	54	91	46	54	26	27	3.4	12.4	269	13.4	6.2	27.5	0.71	0.11	0.12	0.02	2.97	16.5
15	55062	57	96	39	66.5	32	34	3.8	14.6	242	16.9	7.5	7.5	2.96	0.16	0.17	0.02	3.75	14.2
16	232245	54	96	42	59.5	29	28	3.3	16.6	225	10.7	7.1	10	1.58	0.13	0.15	0.03	7.7	28.3
17	229754	64	103	39	64	32	33	3.4	13.8	286	17.5	7.6	35	4.47	0.16	0.17	0.02	6.4	30.4
18	236340	47	95	49	60.5	39	32	3.5	15	165	19.9	8.7	25	2.23	0.12	0.10	0.02	0.9	5.4
19	55014	55	100	45	72.5	35	33	3.3	13.4	268	11.6	8.4	20	5.52	0.19	0.21	0.035	4.75	19.8
20	212608	64	105	41	64.5	30	34	3.1	16.9	269	13.7	8.25	12	6.51	0.14	0.16	0.025	2.9	11.9
21	236944	55	98	43	63.5	33	31	3.7	12	193	18.9	6.1	15	5.15	0.11	0.13	0.025	4.2	25.6
22	55267	64	101	37	73	34	39	3.4	19.8	281	12.9	8.4	10	6.47	0.23	0.24	0.025	3.1	22.3
23	231219	45	90	45	53	26	26	3.4	12.9	149	12.9	5.4	20	0.71	0.11	0.11	0.025	1.85	8.3
24	202997	62	100	38	60.5	30	29	4.1	15.7	251	13.5	7.4	12	6.09	0.13	0.14	0.025	3.45	16.1
25	222174	67	108	41	74	37	37	3.1	6	284	10.25	8.1	10	4.43	0.19	0.22	0.025	3.2	14.4
26	239398	47	93.5	47	69.5	33	38	3.6	13.3	276	15.75	7.0	20	0.87	0.17	0.16	0.025	4.0	28.0
27	212599	55	94.5	39.5	67	32	38	4	17.5	225	18.5	6.9	17.5	4.48	0.12	0.10	0.025	3.75	16.0
28	DZ-Cr- 255	64	105	41.5	75	36	40	3.3	16	386	18.8	7.6	18.5	5.66	0.22	0.23	0.015	4.8	26.2
29	202972	64	106	42.5	65	34.5	30	3.2	10.8	259	15.6	8.7	19	5.58	0.17	0.16	0.025	1.45	7.7

Appendix 1. Continued…….

30	237737	51	90.5	40	65.5	28.5	38	4	13.6	247	17.0	7.2	22.5	1.12	0.12	0.13	0.02	2.8	12.3
31	236754	64	106.5	43	78	37.5	40	3.3	17.6	306	9.6	9.46	15	4.54	0.14	0.19	0.04	4.4	38.0
32	236757	55	93	38	67	32	40	3.8	15.7	249	25.3	7.25	25.5	4.4	0.12	0.13	0.02	2.8	10.5
33	202952	62	107.5	45	85	39	44	3.2	12.3	329	12.3	7.51	15.5	6.1	0.19	0.19	0.03	4.8	31.5
34	203036	61	105.5	45	67	33	36	3.3	14.1	299	15.7	6.9	20	3.87	0.20	0.18	0.02	4.7	10.7
35	55045	61	102.5	42	60	32	31	3.8	13.4	279	19.3	6.8	40	5.12	0.14	0.15	0.025	4.4	23.0
36	237706	52	98	46	69	32	37	3.8	16.5	219	13.7	6	27.5	4.17	0.12	0.12	0.015	2.84	18.0
37	239376	52	97	45	69	30.5	36	3.1	18.5	253	9.9	6.8	20	5.8	0.11	0.12	0.02	2.86	15.6
38	237700	67	108.5	42	73	33	40	3.9	16	242	20.95	7.6	25	5.1	0.21	0.19	0.03	3.49	26.9
39	55046	65	101	36	70	35	39	3.7	14.5	225	10.7	8.1	12.5	4.74	0.14	0.13	0.025	1.48	6.1
40	55015	64	101	37	62	29	34	3.1	15.5	264	9.1	7.9	7.5	4.93	0.09	0.10	0.025	1.31	5.2
41	Dz-01-1880	57	111.5	55	90	44.5	46	3.8	17.9	448	12.35	7.8	15	4.63	0.24	0.24	0.035	6.5	25.0
42	236326	62	100	38	70	29.5	41	2.7	15.3	190	14.6	7.9	7.5	5.12	0.18	0.16	0.025	2.8	14.4
43	239384	65	108.5	43	63	33.5	29	3.2	13.3	250	9.2	8.8	5	5.39	0.18	0.16	0.025	1.5	5.0
44	236752	64	106.5	43	62	23	39	3.6	16.5	220	28.5	7.6	7.5	3.81	0.17	0.16	0.03	5.3	15.5
45	55091	57	112	55.5	72	36.5	36	3.8	6.9	317	12.1	7.05	7.5	5.0	0.18	0.17	0.03	4.6	47.6
46	55348	45	95.5	50.5	46	20.5	31	3	16.6	164	10.7	6.3	15	4.17	0.09	0.08	0.02	2.1	16.0
47	55101	64	107.5	44	66	28	38	3.6	19	169	10.2	8.2	10	5.23	0.14	0.13	0.02	2.06	6.7
48	239379	64	98.5	35	57	26	31	3	17.8	251	12.4	6.13	7.5	5.64	0.13	0.16	0.02	2.03	7.6
49	55047	54	101.5	48	70	30.5	39	3.8	15.2	188	18.3	7.37	12	5.76	0.11	0.11	0.03	3.3	19.3
50	237707	65	109.5	44.5	98	45.5	52	3.2	12	362	9.5	8.2	10	4.97	0.25	0.22	0.025	2.7	23.1
51	55261	67	110	43.5	100	42.5	58	3.8	5.4	427	10.9	6.9	25	4.08	0.20	0.19	0.03	2.8	12.2
52	55254	62	103	41	85	43.5	42	3.5	13.3	209	20.1	7.2	10	6.37	0.18	0.17	0.02	3.3	13.6
53	237713	55	105	50	82	39.5	43	3.9	8.6	318	12.4	6.1	5	5.39	0.24	0.23	0.025	4.85	25.1
54	202950	57	111	54.5	70	35.5	35	3.4	16.8	216	13.5	7.4	10	4.74	0.18	0.18	0.025	4.3	21.8
55	203030	52	100	48	63	28	34	3	15.3	242	7.8	7.4	15	4.17	0.14	0.11	0.02	2.06	7.1
56	229971	52	106.5	54	68	33.5	35	3.6	16	246	17.2	6.7	15	5.39	0.14	0.15	0.025	5.7	23.3
57	55016	48	102	54	79	36	44	3.5	15.9	305	16.4	7.4	30	4.67	0.15	0.17	0.025	5.05	20.8
58	55154	50	97.5	52.5	61	30	31	3.4	9.8	352	16.4	7.36	35	5.47	0.17	0.19	0.015	3.65	21.3
59	231217	45	100	55	56	24.5	31	3.5	11.3	155	16.5	7.4	17.5	2.23	0.09	0.10	0.03	3.9	23.8
60	202979	47	103	56.5	87	36	50	3	17.1	254	10.5	7.5	20	4.97	0.13	0.14	0.03	5.02	26.3
61	229966	64	111.5	48	77	38	40	3.9	20	352	10.35	9.8	10	4.73	0.23	0.22	0.035	6.52	33.7
62	212597	67	108.5	42	54	27	27	3.0	12.5	153	10.4	7.3	2.5	4.43	0.15	0.19	0.03	1.21	7.6
63	202991	67	108	41	64	32.5	32	3.1	14.8	250	17.3	8.3	5	4.17	0.15	0.17	0.035	4.0	36.2

Appendix 1. Continued…….

64	236328	65	104	39	57.5	30	27	3.6	13.9	197	11.6	9.1	7.5	4.73	0.15	0.13	0.025	3.0	10.7
65	236364	62	104	42	69.5	35	34	2.9	13.5	166	14.1	5.7	5	3.81	0.17	0.16	0.025	2.65	7.3
66	236942	55	109	54	68.5	32	36	3.8	16.3	268	12.7	8	7.5	4.08	0.15	0.13	0.025	5.16	23.9
67	236365	51	108	57	62.5	29	33	4	14	203	14.7	8.1	10	5.1	0.17	0.18	0.025	3.99	21.0
68	239375	55	110.5	50	71	29.7	41	4	12.2	316	11.7	5.8	35	5.0	0.11	0.22	0.035	4.35	20.9
69	55022	51	102	51	74	32.5	38	3.7	13.6	216	15.8	7.5	25	5.59	0.13	0.12	0.025	5.68	22.7
70	239391	62	112.5	50	91	43.5	48	3.9	15.1	362	10.5	8.1	20	3.52	0.24	0.24	0.025	4.07	18.9
71	228666	48	100	52	69.5	36	33	3.3	14.4	208	10.9	7.6	20	2.70	0.17	0.17	0.025	2.31	14.9
72	236357	64	104	40	82	42	40	3.2	10.9	351	9.2	6.5	10	5.77	0.21	0.20	0.03	5.03	33.8
73	203034	57	106	49	66.5	33	34	3.2	15	230	10.1	7.6	12.5	6.41	0.16	0.16	0.03	1.32	15.3
74	236756	52	102.5	50	66.5	31.5	35	3	8.3	205	8.4	7.1	12.5	3.52	0.12	0.11	0.02	0.88	4.8
75	55018	45	101.5	56.5	51	25	26	2.6	13.15	95	10	7.8	30	1.12	0.10	0.10	0.02	2.92	7.7
76	208753	65	108.5	43.5	82.5	43	39	3.5	12	194	21.9	6.1	5	4.17	0.20	0.17	0.025	1.1	5.4
77	229982	68	110.5	42.5	57.5	25.5	32	2.9	11.3	232	10.8	7.2	5	4.32	0.15	0.14	0.03	1.9	8.0
78	237712	45	87	42	42.5	22	19	3.3	13.6	182	10.7	5.1	35	0.0	0.09	0.11	0.015	2.4	9.0
79	55019	65	107.5	42.5	66.5	32	34	3.4	13.5	197	20.4	7.9	5	4.17	0.16	0.16	0.03	2.2	9.0
80	212616	62	107.5	45.5	63.5	31.6	33	3.3	13.0	232	11.6	7.8	7.5	1.93	0.15	0.15	0.025	4.18	27.4
81	229981	55	95.5	40.5	72.5	33	39	3.8	15.7	213	10.1	8.1	17.5	3.87	0.13	0.11	0.02	4.4	37.7

DECLARATION

I, the undersigned, declared that this thesis is my own original work. All relevant sources used for the thesis are duly acknowledged.

Name	Signature	Date
Dagnachew Lule	…………………	…………………

The work has been done under my supervision and hence submitted for examination with my approval as advisor.

Name	Signature	Date
Prof. Endashaw Bekele	…………………	………………………