European Online Journal of Natural and Social Sciences 2023; www.european-science.com
Vol.12, No 1 pp. 121-139
ISSN 1805-3602

Assessment of Improved Tef (*Eragrostis tef* L.) Varieties for Yield and Yield Related Traits at Nono Benja and Cheliya Districts, Oromia, Ethiopia

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Received for publication: 24 July 2022.
Accepted for publication: 01 September 2022.

Abstract

Tef (*Eragrostis tef*) is one of the most important and strategic cereal crop grown in drought-prone areas of Ethiopia. Genetic variability, genotypic correlations, and yield components are prerequisites for the selection of crop breeding, cultivation of improved varieties that provide optimum seed yield is one of the major constraints of the crop. The present study aimed to investigate the adaptive and best-performing tef varieties based on their yield and related traits under rain-fed conditions at Nono Benja and Celia districts in Ethiopia. The experiment was conducted by using a split-plot design with three replications, sixteen improved varieties, and one local landrace. The combined analysis of variance revealed that varieties were significantly different for studied characters except for panicle length, total tiller number, and spikelet length. The mean yields of nine improved varieties (Dukem, Asgori, Tesfa, Negus, Quncho, Kora, Koye, Boset, and key tena) were relatively higher than the local check compared with mean values of grain yield ranged from Welkomi (372.08 kg/ ha) to Dukem (1315.41 kg/ ha). Grain yields were studied high in four varieties across two locations were (Dukem (1315.4 kg/ ha), asgori (1279.6 kg/ ha), Tesfa (1206.02 kg/ ha), Negus (1072.61 kg/ ha) with 72.8%, 68.2%, 58.5 %, and 41% over the local check. The genotypic coefficient variation was observed from 4.6% to 82.9% for the loading index and the phenotypic coefficient variation ranged from 5.8% to 91.0% for the loading index at Cheliya, respectively, the fertilizer application (0, 60/40 P/N kg ha-1) showed highly differences among all traits except in GFP, PH, and TGW traits. The varieties Gibe, Koye, Boset, Gimbichu, Enat, and Kora were observed highly strong association with the environment, similarly, Asgori and Gedo varieties showed a highly significant and strong connection with the environment Nono Benja with fertilization. Results reveal that correlation studies provide a better understanding of yield components during the selection of tef genotypes.

Keywords: AMMI, Coefficient of Variations, Grain yield, Genotypic and Phenotypic, Heritability, Tef varieties,

Introduction

Tef (*Eragrostis tef*) Trotter] belongs to the Poaceae family and humans using for eating purpose, the genus Eragrostis were cultivated (Watson & Dallwitz, 1992). Ethiopia is not only the center of origin but also the center of diversity of Tef (Vavilove, 1951). Tef contains more lysine than barley, millet, and wheat and slightly less than rice and oats. Tef is superior in minerals such as calcium, iron, magnesium, phosphorus, and potassium and it is also rich in essential amino acids; particularly in alanine, methionine, threonine, and tyrosine and it is an excellent source of fiber too (USDA, 2018; Ketema, 1997).

The Tef cultivation in Ethiopia more than 3 million ha out of the total 10,232,582.23 ha (80.71%) area under cereals production in 2017/18 E.C Meher season production, tef took the 1st place among cereals in the production area with 3,023,283.50 ha (23.85%) by preceding maize 16.79%, sorghum 14.79% and wheat 13.38%., production, out of the 267,789,764.02 quintals or 87.48% cereals production, tef ranked 2nd, 52,834,011.56 quintals (17.26%) following maize 27.43%. The average national and regional (Oromia) productivity in the 2017/18 production season was 17.48 quintals ha^{-1} and 17.88 quintals ha^{-1} respectively (CSA, 2017/18).

Tef [*Eragrostis tef* (Zucc.) Trotter] is Ethiopians' most ancient indigenous staple food. It is one of the most important crops, which serves as a source of farm income, food, and nutrition security in Ethiopia. Tef is considered a cultural heritage and national identity, being labeled as one of the latest super foods of the 21st century, like the ancient Andean grain quinoa, tef's international popularity is rapidly growing (Collyns, 2013).

Based on the maturity, the tef grows main growing seasons between July-November and March-June. It is mainly cultivated as a single crop (Ketema, 1997). The bioavailability of minerals like Fe and Zn is reduced in the presence of phytic acid and phosphates. Tef grains contain less than one percent of these inhibitory components (528-842mg/100g) (Blandino et al., 2003). One more study revealed that the amount of phytates in enjera is remarkably reduced due to the fermentation process and its acidity, which is supposed to increase the absorbability of different minerals (Blandino et al., 2003).

According to Singh (2015), if the heritability of a trait is very high around 80% or more, selection for such a trait would be easy since there is a close correspondence between genotype and phenotype due to the relatively small influence of the environment on the phenotype. The characters with low heritability are less than 40%, the selection may be considered very hard and impractical because of environmental effects. The information on the most adaptive and productive tef varieties in Ethiopia is very poor. Consequently, it is necessary to provide information on phenotypic and genotypic variances as well as heritability and interrelationships of yield and yield-related traits among Tef genotypes. Therefore, the present investigation aimed to determine the association with seed yield and yield contributing traits in improved Ethiopian tef genotypes under fertilizer management.

Materials and Methods

Procedure

The experiment was conducted during the 2018/2019 primary cropping season at Nono Benja and Cheliya Districts. The following table shows the agro-ecological aspects of the two experimental sites (**Table.1**). Sixteen nationally released Tef varieties were obtained from the national tef coordinating center based at Debre Zeyit Agricultural Research Centre and one local variety was used as planting materials for this study. Descriptions of the sixteen varieties used in this study are presented in **Table.2.**

Table 1. **Description of study area**

Location	Alt (m.a.s.l)	Coordinates	Soil type	Distance from Addis	Mean annual Rf(mm)	Mean annual temp(^{o}C)
Cheliya	2900	9° 00'N 37° 29'E	Andosols	178	1,350	17
Nono Benja	1981	29°38'N 29°46' E	Nitosoil	252	1800	22

Table 2. List of study genotypes with their altitudinal ranges and rainfall requirements

Entry	Variety Name	Common Name	Year of release	Altitude(m.a.s.l)	Rain Fall (mm)	Source
1	Dz 01-196	Moga/magna	1970	1800-2400	300-700	DZARC
2	Dz Cr 457	Tesfa	NA	NA	NA	NA
3	Dz-Cr-385	Simada	2009	Low to mid	300-700	ADETARC
4	DZ-01-787	Welkomi	1978	1800-2500	400-700	DZARC
5	DZ-Cr-82	Melko	1982	1700-2000	300-700	DZARC
6	DZ-Cr-438	Kora	2014	1700-2400	400-700	DZARC
7	DZ-01-974	Dukem	1995	1500-2200	500-700	DZARC
8	DZ-Cr-255	Gibe	1993	1520-1750	550-850	DZARC
9	Dz-01-1285	Koye	2002	NA	NA	DZARC
10	Cr 427	Negus	NA	NA	NA	DZARC
11	DZ-01-99	Asgori	1970	1400-2400	300-700	DZARC
12	DZ-Cr-387	Quncho	2006	1800-2500	500-700	DZARC
13	DZ-Cr-409	Boset	2012	NA	NA	DZARC
14	DZ-01-354	Enatit	1970	1600-2400	300-700	DZARC
15	DZ-01-1881	Key tena	2002	1600-1900	300-500	DZARC
16	DZ-01-899	Gimbichu	2005	2000-2500	NA	NA
17	Local	Landrace	NA	NA	NA	NA

Note: NA = Not available

The experiment was laid out in a split-plot design with three replications where treatments, fertilizer (0, 60/40 kg ha-1), and varieties, were assigned as the main plot factor and sub-plot factor respectively. Fine seedbed suited for tef cultivation was prepared before sowing using three times ploughing, similar to the farmers' practices. Experimental plots were designed to have a 2m length and a 1.2m width to have 2.4 m^2 plot areas. Spacing between plots and blocks was 0.5m and 1m, respectively. Rows were prepared in 20cm separation to have six rows in each plot. Varieties were assigned to experimental plots using the randomization technique. Each variety was sown by hand drilling at a 25 kg ha-1 seed rate. Fertilizers were applied at the rate of (0/0, 60/40 kg ha^{-1}) P_2O_5/N in the form of DAP and Urea, respectively. The total DAPS and half of the Urea fertilizers were applied at planting and the remaining half of the Urea was applied during tillering stage. Weeding was done before the second application of Urea fertilizer. Other agronomic practices like harvesting were done as per the farmers' practices in the areas.

1. Days to heading (DTH): Days to heading were recorded as the number of days from the sowing date to the date when 50% of the plants in the plot had bearing their spikes fully emerged.

2. Days to maturity (DTM): Days to maturity was recorded as the number of days from sowing to the date when 90% of the plants in a plot reached physiological maturity (as evidenced by eyeball judgment of the plant stands when the color of the vegetative parts changed from green to yellow color).

3. Grain filling period (GFP): Number of days from 50% heading to 90% maturity of the stands in each plot, obtained by subtracting the former from the latter.

4. Plant height (PH): Plant height was measured as the average height of five randomly selected plants from each plot, measured from the base of the ground to the top of the panicle in centimeters at maturity.

5. Panicle length (PL): Was measured as the length of the panicle in centimeters from the node where the first panicle branch starts to the tip of the panicle at maturity, recorded as the average of five randomly taken plants from each experimental unit.

6. Culm length (CL): The length of the main shoot culm in centimeters was measured from five randomly selected main shoots from the base of the plant to the point of start of panicle branching at maturity and averaged.

7. Internode length (IL): Each average of three internodes length of randomly selected five main shoots culm were recorded to give the average internode length of the plot in centimeters.

8. Spikelet length (SL): The spikelet length of each plot was recorded in millimeters by averaging the length of the five-spikelet length of five randomly selected plants.

9. Number of Total Tillers per Plant (NTT): Average numbers of tillers per plant were recorded by counting and averaging tillers of five randomly selected plants of each experimental unit.

10. Grain yield (GY): Grain yield is a complicated trait affected by the growing environment, the genotype, and their interactions, for any crop management interventions to boost productivity in a given environment is highly relying on the genetic yield potential of the cultivars used (Muluken Bayable et al., (2021). Grain yield was harvested from the central four rows of each plot, threshed, weighed, and adjusted to 12.5% moisture content in kilograms per hectare.

11. Biomass Yield (BY): Biomass yield was measured as the weight in kilograms of sun-dried for 10 days above-ground parts of the plants harvested from the central four rows of each plot before the grain had been removed. This result is in line with Asaye Birhanu et al., (2020) studied that, among tasted tef genotypes biomass yield ranged from 7.2 to 12.57 tons per hectare at Dembia, Northwestern, Ethiopia under irrigation season and significant difference among tested genotypes.

12. Thousand Seeds Weight (TGW): A thousand seeds were counted from harvested grains of each plot by seed counter and weighed in grams.

13. Lodging index (LI): It is the value measured from the whole plot according to the method of Caldicott and Nuttall, (1979). The value was taken as the product sum of the lodging degree taken on a 0-5 scale (0 being erect plant and 5 completely lodged) and the lodging severity as a percent of the stand.

$$\text{Lodging index} = \frac{\text{Sum (Lodging degree X the respective percentage area lodged)}}{5}$$

14. Harvest index (HI): It was calculated as the ratio of grain yield divided by above-ground biomass on plot bases and multiplied by 100.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Above ground biomass}} * 100$$

Analysis of variance

Analysis of variance (ANOVA) from individual locations and combined ANOVA was conducted for all traits according to Gomez and Gomez (1984). Bartlett's (1937) test was used to assess the homogeneity of variance between environments (Manoukian et al., 1986). Analysis of variance of grain yield and related traits of each location, Tukey's HSD - test mean comparison, Combined Analysis of variance over locations, and principal component analysis were performed using R- statistical software Version R i386 3.6.0. Estimates of variance components and broad sense heritability were computed using Microsoft excels software 2007 and Genotypic and phenotypic correlation coefficients were computed using SAS software version 9.

Estimation of the magnitude of variation

The phenotypic and genotypic variances at each location were estimated according to the method suggested by Burton and De Vane (1953).

$$\sigma_g^2 = \frac{ms_g - m_e}{r}$$

Where, σ_g^2 = genetic variance, ms_g = Mean square due to genotypes,

m_e = Environmental variance (error mean square),

$\sigma_p^2 = \sigma_g^2 + \sigma_e^2$, σ_p^2 =phenotypic variance, r= Number of replication,

Coefficients of variations at phenotypic and genotypic levels were estimated using the following formulae

$$PCV = \frac{\sqrt{phenotypic\ variance}}{population\ mean\ for\ the\ character} \times 100$$

$$GCV = \frac{\sqrt{genotypic\ variance}}{population\ mean\ for\ the\ character} \times 100$$

Estimation of genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV) was done according to the formula given by Burton and De Vane (1953).

Heritability in broad sense (h2b) was calculated according to the formula suggested by Hanson et al. (1956).

$$h^2b = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

δg^2=genotypic variance and $\delta^2 p$= phenotypic variance

Estimation of phenotypic and genotypic correlations

Phenotypic correlation is the observable correlation between two variables, which includes both genotypic and environmental effects, and genotypic correlation is the inherent association between two variables. The simple correlation coefficients were computed to determine the degree of association between yield and yield attributes.

Principal component, Genotype by environment interaction, and stability analysis

The combined principal component analysis was computed using Minitab statistical software. To compute the genotype by environment interaction stability analysis location combined with fertilizer condition is considered as an environment. In this case, by combining the two locations with the two fertilizer conditions, four environments were considered for the analysis. These are Gedo with fertilization, Gedo without fertilization, Nono with fertilization, and Nono without fertilization. AMMI biplot analysis was computed using R statistical software to compute the AMMI1 biplot and AMMI2 biplot.

Results and Discussion

Analysis of variance results at Cheliya reveals fertilizer response of all the traits under examination except TGW and TTN showed significant differences. Similarly, all traits except TGW, which non-significantly responded, showed highly significant differences on varietal differences at Cheliya. All the traits other than SL, TGW, and TTN have a significant response for the interaction effect in the same location of which all, except LP, showed highly consequential differences. In this experimental site grain yield responded highly significantly to all three parameters: fertilizer, genotype, and their interaction (**Table 3).**

Table 3. **Mean squares values for different characters evaluated at Cheliya in 2018**

Traits/Df	**Rep (2)**	**Fer (1)**	**Ea (2)**	**Var (16)**	**Fer:Var (16)**	**Eb (64)**	**CV(b) (%)**
BM	311217	15527215**	274222	2233535**	1799066**	35598	8.9
CIL	0.4	68.68*	2.942	2.614**	2.312**	0.42	9.2
CL	17.2	3667.2**	33.6	121.2**	87.7**	27.3	14.3
GFP	10.9	189.4**	1.7	243.6**	96.5**	4.8	3.8
DM	28.5	1468.3*	22.2	349.1**	37.1**	13.7	2.9
GY	709	19185760**	7674	447777**	520851**	6697	9.6
DH	23.6	602.9*	23.2	348.8**	75.8**	13.2	5.2
HI	70.7	6723*	152.1	282.7**	352.34**	43.88	12.0
LP	0.3	20.67*	0.2396	0.94**	0.31*	0.16	65.0
PH	21	8183**	25.4	214.1**	83.3**	27.3	8.9
PL	1.3	8944.16**	2.02	25.87**	11.41**	3.98	8.9
SL	4.1	16.6416*	0.4	4.34**	1.0139	0.69	10.1
TGW	3.60E-05	0.0003	4.80E-05	0.0055	0.0034	0.004	17.5
TTN	6.2	406.4	29.9	10.05**	4.4	4	15.0

DF=degree freedom, BM=biomass yield, CIL=culm internode length, CL=culm length, DM=days to maturation DH=days to heading, GFP=grain filling period, HI=harvest index, LP=lodging percentage, PH=plant height, PL=panicle length, SL=spikelet length, TGW=thousand grain weight, TTN= total tiller number. Rep=replication, fer=fertilizer, Ea=error main plot, var=variety, Eb=error sub plot.

Analysis of variance result of Nono Benja depicts that traits BM, CIL, GY, PL, SL, and TTN showed highly significant differences. While traits CL, LP, and PH showed notable differences in the response of fertilizer. With regard to the variety factor, all the traits except HD and HI have shown highly significant differences, though HI resulted in a significant difference at a 0.05 probability level. All traits recorded significant differences for the interaction effect, among which BM, CIL, CL, GFP, DM, GY, PH, PL, and TGW revealed highly remarkable differences (**Table 4**).

Table 4. **Mean squares and CV values for different characters evaluated at NonoBenjain 2018**

Traits/Df	**Rep (2)**	**Fer (1)**	**Ea (2)**	**Var (16)**	**Fer.Var (16)**	**Eb (64)**	**CV(b) (%)**
BM	86834	169864127.0**	3387	4717269**	1583867**	190438	17.0
CIL	1.1	118.6**	0.9	3.502**	3.669**	0.9	8.7
CL	164	3571.9*	187.1	315.1**	118.1**	45.4	13.8
GFP	2.5	290	20.7	246.3**	308.1**	14	10.0
DM	13.4	92.2	46.8	102.6**	206.3**	39.4	6.3
GY	9006	17046306.0**	4156	640483**	244433**	7405	9.7
HD	8.9	709.4	5.4	267.5	48.71*	24.2	7.8
HI	20.7	292.4	61.5	107.1*	159.1*	78.4	22.2
LP	0.1	24.7*	0.3	1.17**	0.3181*	0.2	43.7

Traits/Df	Rep (2)	Fer (1)	Ea (2)	Var (16)	Fer.Var (16)	Eb (64)	CV(b) (%)
PH	186.7	8655.4*	243	418.1**	129**	44.3	8.3
PL	1.07	1106.8**	3.7	34.1**	51.0**	10.4	7.3
SL	3.6	19.8**	0.1	2.96**	1.02*	0.5	8.2
TGW	0.001	0.006	0.0002	0.02**	0.007**	0.0003	4.7
TTN	1.9	1473.7**	4.17	36.2**	11.0**	4.5	12.1

DF=degree freedom, BM=biomass yield, CIL=culm internode length, CL=culm length, DM=days to maturation DH=days to heading, GFP=grain filling period, HI=harvest index, LP=lodging percentage, PH=plant height, PL=panicle length, SL=spikelet length, TGW=thousand grain weight, TTN= total tiller number.Rep=replication,fer=fertilizer, Ea=error main plot, var=variety,Eb=error sub plot.

Mean values of genotypes for different characters

The mean values of tested genotypes at Cheliya and Nono Benja are presented in Tables 8 and 9. Turkey's HSD mean comparison test was conducted for all the traits that showed significant differences between varieties in the ANOVA result, except for TGW. Variety Dukem was observed to be superior for the twelve traits' mean performance out of the fourteen traits examined at Cheliya followed by Kora and Koye, which is at par with Welkomi and Enatit, which showed superior mean performance on ten and nine traits respectively. Varieties Gimbichu, Melko, Tesfa, Moga, Key-tena, and Quncho also showed superior mean performance on half of the studied traits at Cheliya. Variety Dukem showed inferior performance for LP trait. Variety Kora showed lower mean performance for DM, GFP, and HI. The least superior mean performances were recorded for Gibe and Simada and Asgori varieties that were better only for two (GFP and LP), three (BM, CIL, and HI), and four (GFP, GY, LP, and TN) traits respectively. The highest mean performances of grain yield were observed on five varieties: Asgori (1366.3), Quncho (1199.7), Kora (1065.4), Koye (1040.7), and Tesfa (1137.0) at Cheliya (**Table 5**)

At Nono Benja, all the fourteen traits under study were subjected to Tukey's HSD mean comparison test. The highest mean performance of traits was recorded for varieties Kora and Boset on twelve traits, followed by varieties Koye, Gimbichu, Tesfa, Dukem, Quncho, and Enatit on ten traits and then by variety Welkomi on nine traits. Melko and Moga's varieties showed the highest mean performance for eight traits. Variety Asgori also recorded the highest mean performance for half of the studied traits. Variety Kora showed the lowest mean performance on traits HD and TGW similarly variety Bose showed the lowest mean performance on traits HD and LP. Gibe and Negus's varieties showed the lowest high mean performance for four traits (DM, GFP, HI, and LP) and (GFP, GY, HI, and LP) respectively at Nono Benja. Varieties Dukem (1639.16), Negus (1282.5), Tesfa (1275), and Asgori (1192.83) showed the highest mean performance for grain yield (**Table. 6**).

Among the tested tef materials Negus, Gibe, and Asgori were the early heading (in days) genotypes at both Cheliya and Nono Benja (52.2 and 52.2),(55.5 and 50.6) and (57.8 and 51.6), respectively. Simada (54.3) and Boset (59.5) Genotypes also showed early heading character at Nono Benja. This study's findings of significant variability on DM, PH, PL, DH, and GY traits at both locations were similar to the findings of Fetie et. al. (2012): Mathewos Ashamo and Getachew Belay (2012) experimented on tef varieties.

Both Tesfa (45.8 and 28.1) and local check (47.17 and 32.5) showed the shortest grain filling period at both Cheliya and Nono Benja locations, respectively, while Kora (49) at Cheliya and K/Tena (29.7), Moga (29.8), Gimbichu (30), Welkomi (32.8) and Quncho (33) at Nono Benja was the additional varieties which showed early grain filling period. Early maturing genotypes recorded at Cheliya were Negus (114.8), Gibe (116.8), Simada (118.3), Asgori (119.2), Kora (120.5), and Tesfa (121.5), while the remarkable variability observed at Nono Benja with respect to maturity time was narrow margined.

Table 5. Mean values of 17 Tef varieties for 13 traits tested at Cheliya

Varieties	DH	GFP	DM	CIL	CL	PH	PL	TN	BM	SL	LP	GY	HI
Kora	71.5^{a-d}	49^{fg}	120.5^{efg}	7.61^{a-c}	42.86^{ab}	66.70^{ab}	23.8^{a-c}	15.8^{a}	2804.86^{ab}	9.75^{a}	0.17^{cd}	1065.4^{b-d}	33.6^{b-d}
Simada	66.5^{cd}	51.83^{ef}	118.3^{fg}	7.25^{a-d}	26.28^{d}	46.32^{e}	20.0^{cd}	11.8^{cd}	2799.16^{ab}	7.9^{c-e}	0.8^{a-c}	679.3^{h-j}	38.6^{a-d}
Asgori	57.8^{e}	61.3^{bc}	119.17^{fg}	6.28^{c-e}	32.10^{b-d}	54.20^{c-e}	22.1^{b-d}	13.8^{a-d}	1510.86^{e-g}	7.4^{de}	0.25^{cd}	1366.3^{a}	26.2^{d}
Koye	68.7^{bcd}	68.17^{a}	136.8^{a}	6.5^{b-e}	38.16^{a-c}	60.80^{bc}	22.6^{b-d}	13.5^{a-d}	1685.38^{d-f}	9.3^{a-c}	0.7^{a-d}	1040.7^{b-d}	39.5^{a-d}
Gibe	55.5^{e}	61.3^{bc}	116.8^{g}	6.45^{c-e}	30.13^{cd}	49.80^{de}	19.6^{d}	11.5^{cd}	1287.16^{g}	7.9^{b-e}	0^{d}	516.0^{j-l}	29.7^{cd}
Gimbich	71.1^{a-d}	60.17^{c}	131.3^{a-c}	7.00^{b-e}	38.2^{a-c}	62.10^{a-c}	23.9^{a-c}	12.4^{b-d}	2370.93^{c}	7.9^{b-e}	0.8^{a-c}	675.7^{h-j}	47.8^{a}
Melko	76.6^{a}	58.5^{cd}	135.17^{ab}	7.28^{a-d}	34.76^{c-e}	54.80^{cd}	20.0^{cd}	13.4^{a-d}	1305.57^{fg}	9.2^{a-c}	0.6^{a-d}	478.5^{kl}	38.4^{a-d}
Tesfa	75.6^{ab}	45.8^{g}	121.5^{d-g}	7.05^{b-e}	34.87^{a-d}	56.40^{b-e}	21.5^{b-d}	11.1^{d}	2599.93^{bc}	9.6^{ab}	0.5^{a-d}	1137.0^{bc}	44.45^{ab}
Moga	74^{a-c}	58.17^{cd}	132.17^{a-c}	6.17^{de}	41.90^{ab}	62.50^{a-c}	20.6^{cd}	12.9^{a-d}	1917.83^{d}	8.05^{a-e}	0.6^{a-d}	619.4^{i-k}	33.7^{a-d}
Boset	68.5^{a-d}	59^{cd}	127.5^{b-e}	7.38^{a-d}	34.97^{a-d}	56.40^{b-e}	21.5^{b-d}	12.9^{b-d}	2722.33^{abc}	8.3^{a-e}	0.8^{a-c}	930.25^{d-g}	43.9^{ab}
K/Tena	66^{d}	65.3^{ab}	131.3^{a-c}	5.83^{e}	35.80^{a-d}	58.90^{b-d}	23.1^{b-d}	13.8^{a-d}	1676.67^{d-g}	7.1^{e}	0.17^{cd}	973.4^{c-f}	27.4^{cd}
Welkomi	74.1^{ab}	62.6^{bc}	136.8^{a}	6.95^{b-e}	37.60^{a-c}	62.70^{a-c}	25.1^{ab}	15.1^{ab}	1656.28^{d-g}	8.2^{a-e}	0.25^{cd}	369.1^{l}	32.6^{b-d}
Dukem	71.5^{a-d}	62.3^{bc}	133.8^{ab}	8.55^{a}	43.77^{a}	71.70^{a}	27.9^{a}	14.1^{a-c}	2871.25^{ab}	8.8^{a-d}	1.28^{a}	991.6^{c-e}	39.9^{a-d}
Negus	52.16^{e}	62.7^{bc}	114.8^{g}	7.21^{a-d}	38.30^{a-c}	60.40^{b-d}	22.1^{b-d}	15.1^{ab}	1598.07^{d-g}	7.3^{de}	0.4^{b-d}	862.7^{e-g}	30.7^{b-d}
Quncho	73.8^{a-c}	54.8^{de}	128.7^{b-d}	7.3^{a-d}	34.30^{a-d}	58.00^{b-d}	23.7^{b-d}	12.9^{a-d}	3101.27^{a}	7.8^{c-e}	1.19^{ab}	1199.7^{ab}	31.7^{b-d}
Enatit	76^{ab}	60.8^{bc}	136.8^{a}	7.8^{ab}	37.67^{a-c}	60.40^{b-d}	22.7^{b-d}	14.1^{a-c}	2332.51^{c}	7.05^{e}	0.35^{cd}	819.1^{f-h}	30.6^{b-d}
Local	78^{a}	47.17^{g}	125.17^{c-f}	7.06^{b-e}	39.87^{a-c}	61.60^{a-c}	21.7^{b-d}	15.6^{ab}	$1725.2d^{e}$	8.3^{a-e}	1.23^{ab}	787.7^{g-i}	40.75^{a-c}
Mean	69.3	58.2	127.5	7.05	36.6	59.1	22.5	13.5	2115.6	8.3	0.6	878.5	35.9
MSE	13.2	4.8	13.7	0.4	27.3	27.3	4.0	2.0	35597.5	0.7	0.2	16425.7	45.9
LSD(5%)	7.6	4.6	7.7	1.4	10.9	10.9	4.2	2.9	392.3	1.7	0.83	266.5	14.1

DH=days to heading, GFP=grain filling period, DM=days to maturity, CIL= culm internode length, CL= culm length, PH=plant height, PL=panicle length, TN= total tiller number, BM= biomass yield, SL= spikelet length, LP=lodging percentage, GY=grain yield, HI=harvest index, MSE=mean square error, LSD=least significance difference.

The highest plant height (in cm) recorded genotypes at both Cheliya and Nono Benja was Dukem (71.7 and 94.5), Kora (66.7 and 91), Welkomi (62.7 and 89.3), Moga (62.5 and 81.3) and Gimbichu (62.1 and 91), while Local (61.6) at Cheliya and Enatit (83.8) and Boset (82.7) at Nono Benja showed single location highest plant height response. Quncho (3101.3 and 3745), Dukem (2871.3 and 4283.3) and Kora (2804.9 and 3937.5) genotypes showed higher biomass production (in Kg) at both Cheliya and Nono Benja locations respectively, while Simada (2799.2) and Boset (2722.3) were among the higher biomass producers at Cheliya. The highest grain yield (in kg/ha) at both Cheliya and Nono Benja locations were recorded by Asgori (1366.3 and 1192.8) and Tesfa (1137 and 1275) genotypes respectively. However, genotypes Quncho (1199.7), Kora (1065.4), and Koye (1040.7) at Cheliya and Dukem (1639.2) and Negus (1282.5) at Nono Benja have also recorded the highest grain yield production. The significant difference observed among varieties LP and TTN was similar to the finding of Kedir et al. (2016).BM variation among the tested genotypes of this experiment is also in agreement with the findings of Sebsib Muanenda et al. (2019), Bogale and Wondmu (2017), and Lema et al. (2017).

Similarly, the notable variability observed among the varieties of HI, CL, PL, and GFP coincide with Bogale and Wondmu (2017) and a significant variation was observed among varieties for CIL in agreement with Bedane et al., (2015) report.

Table 6. Mean values of 17 Tef varieties for 14 traits tested at Nono Benja

Varieties	DH	GFP	DM	CIL	CL	PH	PL	TN	BM	SL	LP	GY	TGW	HI
Kora	64.8^{lb}	39^{b-e}	103.83^{abc}	11.16^{a-d}	57.15^{abc}	90.98^{ab}	33.83^{ab}	19.56^{bc}	3937.5^{ab}	9.66^{a}	0.83^{a-e}	966.66^{cd}	0.36^{fg}	30.53^{b}
Simada	54.3^{cd}	41.16^{a-d}	95.5^{c}	10.5^{a-d}	35.43^{f}	65.96^{f}	30.53^{a-f}	14.63^{c-f}	2777.21^{c}	7.83^{d}	1.63^{a}	690.0^{fg}	0.37^{efg}	42.78^{ab}
Asgori	51.6^{d}	46.33^{a-c}	98.0^{abc}	11.0^{a-d}	43.6^{e-f}	70.93^{def}	27.33^{ef}	15.53^{c-f}	1179.05^{f}	8.0^{cd}	0.75^{b-e}	1192.83^{b}	0.37^{efg}	34.08^{ab}
Koye	62.6^{a-c}	46.5^{ab}	109.16^{a}	11.16^{a-d}	43.01^{def}	74.96^{def}	31.95^{a-e}	18.66^{bc}	2765.33^{c}	9.66^{a}	0.71^{b-e}	915.0^{cde}	0.29^{i}	39.26^{ab}
Gibe	50.6^{d}	48.0^{ab}	98.66^{abc}	10.16^{bed}	45.26^{c-f}	71.96^{def}	26.7^{f}	14.216^{f}	1047.55^{f}	8.16^{bcd}	0.67^{cde}	537.5^{gh}	0.35^{fgh}	42.65^{ab}
Gimbich	67.5^{ab}	30.0^{fg}	97.50^{abc}	12.16^{a}	60.36^{ab}	91.0^{a}	30.63^{a-f}	17.51^{b-e}	2299.16^{cde}	8.33^{abc}	0.88^{a-d}	760.0^{ef}	0.38^{def}	33.48^{ab}
Melko	70.0^{l}	38.83^{b-e}	108.83^{ab}	9.66^{d}	46.6^{b-f}	79.16^{b-f}	32.56^{abc}	16.76^{b-c}	1572.50^{ef}	9.33^{ab}	0.0^{e}	995.0^{c}	0.35^{fgh}	40.13^{ab}
Tesfa	70.5^{l}	28.1^{6g}	98.66^{abc}	10.83^{a-d}	50.48^{a-e}	79.86^{b-e}	29.38^{b-e}	17.66^{b-e}	2708.33^{cd}	9.5^{ab}	0.84^{a-d}	1275.0^{b}	0.35ghi	49.78^{a}
Moga	66.16^{ab}	29.83^{fg}	96.0^{be}	11.66^{abc}	51.83^{a-e}	81.26^{a-d}	29.43^{b-f}	17.01^{b-e}	2645.28^{cd}	8.0^{cd}	0.79^{a-e}	421.66^{h}	0.42^{bcd}	43.15^{ab}
Boset	68.5^{b-d}	41.16^{a-d}	100.66^{abc}	12.00^{ab}	51.48^{a-e}	82.66^{a-d}	31.18^{a-f}	20.75$^{a b}$	3079.16^{bc}	8.66^{abc}	1.44^{a-c}	916.66^{cde}	0.44^{b}	41.98^{ab}
K/Tena	66^{lb}	29.66^{g}	98.16^{abc}	10.66^{a-d}	41.86^{ef}	76.66^{c-f}	34.8^{a}	17.03^{b-e}	2195.0^{cde}	7.83^{d}	0.86^{a-d}	792.5^{def}	0.32^{hij}	37.4^{ab}
Welkomi	67.33^{ab}	32.83^{e-g}	100.16^{abc}	10.0^{cd}	56.03^{a-d}	89.3^{abc}	33.26^{abc}	16.6^{b-e}	2495.83^{cd}	8.33^{abc}	0.54^{de}	375.0^{h}	0.44^{b}	40.35^{ab}
Dukem	65.0^{lb}	37.5^{d-f}	102.5^{abc}	10.0^{cd}	61.53^{a}	94.5^{a}	32.96^{abc}	19.23^{bcd}	4283.33^{a}	9.0^{abc}	1.48^{abc}	1639.16^{a}	0.35^{fgh}	32.25^{ab}
Negus	52.16^{d}	42.5^{a-d}	94.66^{c}	9.5^{d}	39.5^{ef}	67.16^{ef}	27.66^{def}	15.08^{def}	1853.66^{def}	7.66^{d}	0.52^{de}	1282.50^{fg}	0.31^{ij}	42.53^{ab}
Quncho	64.66^{ab}	33.0^{efg}	97.66^{abc}	11^{a-d}	47.1^{b-e}	79.45^{b-e}	32.35^{a-d}	24.0^{a}	3745.0^{ab}	8.5^{abc}	1.52^{ab}	941.0^{cd}	0.5^{a}	45.48^{ab}
Enatit	62.5^{a-c}	38.66^{cde}	101.16^{abc}	10.83^{a-d}	51.83^{a-d}	83.83^{a-d}	32.0^{a-e}	17.6^{b-e}	2625.0^{cd}	7.66^{d}	0.79^{a-c}	702.50^{fg}	0.4^{cde}	46.61^{ab}
Local	68.83^{ab}	32.5^{efg}	101.33^{abc}	10.33^{a-d}	48.43^{a-e}	77.2^{b-f}	28.76^{c-f}	15.36$^{e f}$	2356.16^{cde}	8.0^{cd}	1.47^{abc}	743.33^{ef}	0.35^{fgh}	36.2^{ab}
Mean	62.8	37.4	100.1	10.8	48.9	79.8	30.9	17.5	2562.7	8.5	0.93	964.8	0.4	39.9
MSE	24.2	14	39.4	0.9	45.4	44.3	5.1	4.5	190437.5	0.5	0.17	11799.3	0.0003	78.4
LSD (5%)	10.2	7.8	13.1	2.0	14.0	13.8	4.7	4.4	907.5	1.4	0.8	225.9	0.04	18.4

DH=days to heading, GFP=grain filling period, DM=days to maturity, CIL=culm internode length, CL=culm length, PH=plant height, PL=panicle length, TN=tiller number, BM=biomass yield, SL=spikelet length, LP=lodging percentage, GY=grain yield, TGW=thousand grain weight, HI=harvest index, MSE=mean square error, LSD=least significance difference.

Genotypic and phenotypic coefficient variation and heritability

The genotypic, environmental, and phenotypic variances; genotypic and phenotypic coefficient of variability; broad sense heritability, genetic advance, and genetic advance as percent of mean values for the fourteen traits studied at Cheliya are presented in (**Table 7**). At Cheliya, the highest values of phenotypic, genotypic, and environmental variances were recorded for BM (744511.7, 732645.7, and 11866) and GY (149259, 147026.7, and 2232.3). While the lowest values of phenotypic, genotypic, and environmental variances were recorded for TGW (0.0018, 0.0006, and 0.0012), followed by LP (0.31, 0.26, and 0.05), CIL (0.9, 0.7 and 0.1), SL (1.5, 1.2 and 0.2), TN (3.6, 2.9 and 0.7) and PL (8.6, 7.3 and 1.3). LP had the highest PCV and GCV (91 and 82.9) at Cheliya, followed by GY (45.3 and 44.9), BM (40.8 and 40.5), HI (24.9 and 22.4) and CL (17.4 and 15.3). However, these coefficients of variability were very low for DM (8.5 and 8.3). The highest broad sense heritability value was recorded for GY (98.5), followed by BM (98.4), GFP (98), DH (96.2), DM (96.1), and PH (87.3). While the lowest broad sense heritability value was noted for TGW (31.3).

Table 7. Genotypic, environmental and phenotypic variance, genotypic and phenotypic Coefficient of variation and heritability values for traits studied at Cheliya

Traits	GV	GE	PV	GCV	PCV	H^2
DH	111.9	4.4	116.3	15.3	15.6	96.2
GFP	79.6	1.6	81.2	15.3	15.5	98
DM	111.8	4.6	116.4	8.3	8.5	96.1
CIL	0.7	0.1	0.9	12.1	13.2	83.9
CL	31.3	9.1	40.4	15.3	17.4	77.5
PH	62.3	9.1	71.4	13.4	14.3	87.3
PL	7.3	1.3	8.6	12	13.1	84.6
TTN	2.9	0.7	3.6	12.6	14	81.3
BM	732646	11866	7444512	40.5	40.8	98.4
SL	1.2	0.2	1.5	13.3	14.6	84
LP	0.26	0.05	0.31	82.9	91	83
GY	147027	2232	149259	44.9	45.3	98.5
TGW	0.0006	0.001	0.0018	6.8	12.2	31.3
HI	64.4	15.3	79.7	22.4	24.9	80.8

DH=days to heading, GFP=grain filling period, DM=days to maturity, CIL=culm internode length, CL=culm length, PH=plant height, PL=panicle length, TTN=Total tiller number, BM=biomass yield, SL=spikelet length, LP=lodging percentage, GY=grain yield, TGW=thousand grain weight, HI=harvest index, GV=genotypic variance, EV=environmental variance, PV=phenotypic variance, GCV=genotypic coefficient of variation, PCV= phenotypic coefficient of variation, H^2=broad sense heritability

On the other hand, at Nono Benja (**Table 8**), the superior values of phenotypic, genotypic and environmental variability were observed for BM (1572423, 1508944 and 63479) and GY (213494.3, 211026 and 2468.3) traits. Conversely, the inferior values of these parameters were recorded for TGW (0.005, 0.0053 and 0.0001), LP (0.4, 0.0053 and 0.0001), SL (1, 0.8 and 0.2) and CIL (1.2, 0.9 and 0.3) traits.

Highest PCV and PCV were noted at Nono Benja for LP (67.1 and 62.2), followed by GY (51.9 and 51.6) and BM (48.9 and 47.9). While lowest of these variability values were recorded for DM (5.8 and 4.6) and CIL (10.1 and 8.7). Similarly highest broad sense heritability values were observed for LP (98.8), GY (98.1) and BM (96). However lowest broad sense heritability were recorded for HI (53.9) and DM (61.6).

Table 8. Genotypic, environmental and phenotypic variance, genotypic and phenotypic Coefficient of variation and heritability values for traits studied at Nono Benja in 2018

Traits	GV	GE	PV	GCV	PCV	H^2
DH	81.1	8.1	89.2	14.4	15.1	91
GFP	77.4	4.7	82.1	23.5	24.2	94.3
DM	21.1	13.1	34.2	4.6	5.8	6`1.6
CIL	0.9	0.3	1.2	8.7	10.1	75
CL	89.9	15.1	105	19.4	21	85.6
PH	124.6	14.8	139.4	14	14.8	89.4

Traits	GV	GE	PV	GCV	PCV	H^2
PL	9.7	1.7	11.4	10.1	10.9	85
TTN	10.6	1.5	12.1	18.6	19.9	87.6
BM	1508944	63479.3	1572423	47.9	48.9	96
SL	0.8	0.2	1	10.7	11.7	83.8
LP	0.3	0.1	0.4	62.2	67.1	85.9
GY	211026	2468.3	213494.3	51.6	51.9	98.8
TGW	0.0053	0.0001	0.005	19.3	19.5	98.1
HI	30.6	26.1	56.7	13.9	18.9	53.9

DH=days to heading, GFP=grain filling period, DM=days to maturity, CIL= culm internode length, CL= culm length, PH=plant height, PL=panicle length, TTN= total tiller number, BM= biomass yield, SL= spike-let length, LP=lodging percentage, GY=grain yield, TGW= thousand grain weight, HI=harvest index, GV=genotypic variance, EV=environmental variance, PV=phenotypic variance, GCV=genotypic coefficient of variation, PCV= phenotypic coefficient of variation, H^2=broad sense heritability.

Phenotypic and genotypic correlations among traits

Positive highly significant phenotypic correlation of GY was observed with PH (0.57), PL (0.60), CL (0.47), CIL (0.38), TTN (0.47), LP (0.38), and BM (0.70) traits at Cheliya (**Table 9**). At the phenotypic level, GY also showed a negative and greatly significant association with DM (0.42) and HI (0.51), while it showed a remarkable negative association with DH (0.24). In addition to GY, BM had shown a positive more considerable phenotypic correlation with PH (0.67), PL (0.69), CL (0.56), CIL (0.62), and TTN (0.44). Both PH and PL besides each other (0.75), they had shown a positive and exceptionally significant phenotypic correlation with CL (0.96 and 0.53), CIL (0.56 and 0.47), TTN (0.65and 0.60), LP (0.55 and 0.55) and BM (0.67 and 0.69) at Cheliya. Similarly, CL and CIL in addition to each other (0.519) had outstanding phenotypic correlation with TTN (058 and 0.47), LP (0.46 and 0.47), and BM (0.56 and 0.62).

GY showed positive and negative high significant genotypic correlation with BM and HI re-spectively studied at Cheliya. The more important genotypic correlation at Cheliya was observed in PH and CL (0.96). Positive significant genotypic correlations were recorded among TTN with PH (0.63), PL (0.49), and CL (0.61); PL with PH (0.80) and CL (0.60) BM with CIL (0.62) and LP (0.49) and TGW with LP (0.53) **(Table 9)**.

Table 9. **Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of traits studied at Cheliya**

Trait	DH	DM	GFP	PH	PL	CL	CIL	SL	TTN	LP	GY	BM	HI	TGW
DH		0.670*	-0.424	0.356	0.214	0.374	0.32	0.419	-0.047	0.441	-0.14	0.359	-0.161	0.127
DM	0.572**		0.388	0.495	0.429	0.46	0.145	0.119	0.128	0.234	-0.25	0.017	-0.176	0.27
GFP	-0.458**	0.467**		0.162	0.257	0.096	-0.221	-0.375	0.215	-0.263	-0.131	-0.424	-0.014	0.172
PH	-0.104	-0.098	0.006		0.798*	0.961**	0.394	0.247	0.631*	0.25	0.135	0.216	-0.295	0.391
PL	-0.092	-0.138	-0.05	0.754**		0.599*	0.479	0.088	0.492*	0.268	0.254	0.386	-0.181	0.456
CL	-0.093	-0.065	0.03	0.956**	0.529*		0.303	0.288	0.612*	0.209	0.062	0.109	-0.308	0.31
CIL	-0.07	-0.142	-0.078	0.564**	0.471**	0.519**		0.29	0.116	0.449	0.049	0.615*	-0.385	0.247
SL	-0.1	-0.001	-0.109	0.327*	0.187	0.339*	0.369*		-0.096	0.183	0.073	0.214	0.139	-0.099
TTN	-0.174	0.001	-0.043	0.651**	0.595**	0.576**	0.469**	0.159*		-0.194	-0.01	-0.163	-0.345	-0.135
LP	-0.01	-0.126	-0.147	0.546**	0.553**	0.459**	0.482**	0.262*	0.301*		0.142	0.493*	-0.384	0.535*

Trait	DH	DM	GFP	PH	PL	CL	CIL	SL	TTN	LP	GY	BM	HI	TGW
GY	-0.243*	-0.098	-0.192	0.567**	0.600**	0.466**	0.380**	0.157	0.474**	0.494**		0.387	-0.269	0.233
BM	-0.066	-0.418**	-0.297*	0.672**	0.692**	0.560**	0.624**	0.333*	0.444**	0.659**	0.699**		-0.338	0.383
HI	0.041	0.222*	0.197*	-0.487**	0.001	-0.418**	-0.383**	-0.196*	-0.522**	-0.418**	-0.514**	-0.572**		-0.316
TGW	0.042	0.134	0.099	0.187	0.124	0.186	0.049	-0.043	-0.023	0.143	-0.004	0.065	-0.034	

DH=days to heading, DM=days to maturity, GFP=grain filling period, PH=plant height, PL=panicle length, CL= culm length, CIL= culm internode length, SL=spikelet length, TTN=total tiller number, LP=lodging percentage, GY=grain yield, BM=biomass yield, TGW=thousand grain weight, HI=harvest index.

The phenotypic correlation coefficient analysis at Nono Benja revealed that GY had an effective and highly significant association with PH (0.70), PL (0.62), CL (0.59), CIL (0.74), SL (0.47), TTN (0.79), LP (0.69) and BM (0.85) traits. However, it had negative and remarkable and considerable phenotypic associations with DH (0.44) and HI (0.23) traits respectively. PH, in addition to GY, had shown positive and outstanding phenotypic correlations with PL (0.71), CL (0.93), CIL (0.61), SL (0.45), TNN (0.66), LP (0.66), and BM (0.73) traits. Similar to GY, it had negative and highly significant and significant phenotypic associations with DH (0.41) and HI (0.23) traits, respectively. In addition, GY with Both Cl and IL as mentioned above and each other (0.52) had shown a constructive highly crucial association with SL (0.41 and 0.42), TTN (0.536 and 0.667), LP (0.535 and 0.606), and BM (0.61 and 0.686). Moreover, they also showed effective significant (0.404) and productive significant (0.529) phenotypic correlation with PL respectively at Nono Benja. For the same reason, PL and SL had shown great significant phenotypic association (0.322) with each other and efficacious significant phenotypic association with TTN (0.62 and 4.10), LP (0.616 and 0.456) and BM (0.643 and 0.425) (**Table 10).**

Table 10. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of traits studied at Nono Benja.

Trait	DH	DM	GFP	PH	PL	CL	CIL	SL	TTN	LP	GY	BM	HI
DH		0.420	-0.744*	0.620*	0.692**	0.504*	0.139	0.11	0.359	-0.060	-0.056	0.379	-0.113
DM	-0.043		0.269	0.327	0.392	0.257	-0.078	0.622*	0.232	-0.269	0.045	0.223	-0.229
GFP	-0.579**	0.790**		-0.361	-0.399	-295	-0.170	0.071	-0.184	-0.128	0.099	-0.170	-0.138
PH	-0.414**	-0.086	0.212*		0.666*	0.967**	0.286	0.399	0.571	0.049	0.058	0.591	-0.442
PL	-0.3003*	0.0964	0.287*	0.707**		0.454	0.030	0.315	0.490*	-0.087	-0.016	0.520*	-0.286
CL	-0.382*	-0.161	0.128	0.933**	0.404*		0.332	0.369	0.514*	0.088	0.075	0.528*	-0.430
CIL	-0.298*	-0.041	0.171	0.613**	0.529**	0.522**		0.103	0.355	0.291	-0.222	0.243	0.006
SL	-0.264*	0.007	0.167	0.447**	0.322*	0.414**	0.416**		0.442	-0.160	0.376	0.408	-0.167
TTN	-0.417**	-0.073	0.202	0.660**	0.62**	0.536**	0.667**	0.410**		0.371	0.363	0.756*	-0.075
LP	-0.326*	-0.078	0.155	0.657**	0.616**	0.535**	0.606**	0.456**	0.674**		0.118	0.586*	-0.014
GY	-0.443**	-0.098	0.193	0.705**	0.616**	0.597**	0.737**	0.470**	0.790**	0.687**		0.281	-0.305
BM	-0.500**	-0.165	0.204	0.725**	0.643**	0.610**	0.686**	0.425**	0.769**	0.067	0.848**		-0.221
HI	0.218*	0.096	-0.044	-231*	-0.152	-0.221*	-160	-0.133	-0.170	-0.159	-0.225*	-399	
TGW	-0.095	0.031	0.042	0.071	-0.052	0.118	0.094	0.013	0.144	0.030	0.156	0.164	-0.031

DH=days to heading, DM=days to maturity, GFP=grain filling period, PH=plant height, PL=panicle length, CL= culm length, CIL= culm internode length, SL=spikelet length, TN=tiller number, LP=lodging percentage, GY=grain yield, BM=biomass yield, TGW=thousand grain weight, HI=harvest index.

BM and HI have a high significant association with GY positively and negatively respectively at Nono Benja. However, HD with PL (0.692) and PH with CL (0.967) had shown positive and highly significant correlation, and HD with PH (0.62) and CL (0.504), DM with SL (0.622), PH with PL (0.666), TTN with PL (0.49), CL (0.514) and BM (0.756), BM with PL (0.52), CL (0.528) and LP (0.586) had also shown positive outstanding correlation and negative significant genotypic correlation was recorded between HD and GFP (0.744) (**Table 11**).

Table 11. Mean square values of combined analysis of variance for the fourteen studied traits across two locations in 2018/19

SV	DF	HD	DM	GFP	PH	PL	CL	CIL	SL	TTN	LP	GY	BM	HI
Rep	2	25.46	67.2	5.5	165.5	6.8	122.6	0.5	5.7	3.5	0.4	7384	72534.5	100.8
Fertilizer	1	1310.2**	979.5**	49	16835	1965.4**	7296.1**	182.8**	36.4**	1815.1**	45.3**	36200000**	3.108E+08**	5160.2**
Variety	16	571.4	350.1**	321.1**	543.1**	47.9**	333.1**	2.5**	7.0**	25.1**	1.7**	886587**	6220448**	217.4**
location	1	2167.8**	39231.6**	22323.3**	21956.6**	3647.4**	7705.9**	692.7**	2.3	903.4**	5.1**	70948**	10190000**	16002.6**
Fer X var	16	59.6**	119.3**	182.9	112.3	28.2**	83.7**	2.6**	1.6**	5.04	0.2**	562619**	2448810**	167.2**
Var X loc	16	45.0**	97.1**	152.2**	89*	12.3	81.0**	3.7**	0.3	27.2**	0.4**	201673**	730356**	1946.8**
Fer X var X loc	16	64.9	110.1**	179.8**	100*	9.4	98.3**	3.4**	0.5	9.1	0.5**	202666**	934122**	200.1**
Error	134	18.4	51.4	49.6	38.9	7.5	38	0.7	0.6	6.7	0.2	6946.5	116959	304.1
Mean		66	113.7	47.8	69.4	26.7	42.7	8.9	8.4	15.5	0.8	872.3	2339.1	47.57
CV		6.5	4.7	14.72	9	10.2	14.4	9.33	9.23	16.6	52.4	9.6	14.62	17.82
R2		0.71	0.83	0.64	0.82	0.78	0.69	0.79	0.58	0.64	0.68	0.75	0.84	0.53

BM= biomass yield, CL= culm length, CIL= culm internode length, DH=days to heading, DM=days to maturity, GFP=grain filling period, GY=grain yield, HI=harvest index, PH=plant height, PL=panicle length, LP=lodging percentage s= spikelet length, TTN= total tiller number TGW= thousand grain weight.

Combined analysis of variance & mean performance evaluation

The combined analysis of variance of both locations, Cheliya and Nono Benja, on the 14 studied traits revealed that location had shown highly significant differences among the tested tef genotypes for all traits except for SL which shows that there are differences between the two environments to examine the genetic performance of tef genotypes **(Table 11)**

The mean square due to variety also showed more constructive differences among the tested tef genotypes for all traits except for HD. Similarly, fertilizer application too showed highly significant differences for all but GFP, PH, and TGW traits. The interaction effect between fertilizer and variety exposed highly productive differences among tef genotypes for the studied traits except for GFP, PH, and TTN. With regard to the interaction effect between variety and location, traits: HD, DM, GFP, CIL, GY, HI, and TGW had shown highly significant differences among tested genotypes. While traits PH, CL, and LP had shown effective differences among the tested tef genotypes for the same source of variation. The interaction effect among the three factors: fertilizer, variety, and location of the combined analysis of variance had shown more important tef varietal differences for traits: DM, GFP, CL, CIL, LP, BM, and HI. However, this interaction effect depicted significant differences among the tested tef genotypes for PH and TGW traits.

Principal components analyses

By using Minitab software and eigenvalue greater than one as a measure of the significance of a principal component analysis (PCA), four PCs extracted about 75.4 percent of the total variance of the 17-tef varieties, and thus, the first three PCs explained about 92% of the gross population variance. About 63.7% of the total variation accounted by the first PC alone was mainly due to variations in plant height, panicle length, culm length, internode length, and total tiller number. Likewise, the second PC accounting for about 17.7% of the total variance of the populations originated mainly from variations in days to maturation, grain filling period, and grain yield and Biomass yield. Variations in days to heading and spikelet length constituted a large part of the total variance explained by the third PC about 10.6% **(Table12).**

Table 12. Eigenvectors and eigenvalues of the first four principal components analysis (PCA) of 14 quantitative traits of 17 Tef varieties across two locations

Characters	**Eigenvectors**			
	PC1	**PC2**	**PC3**	**PC4**
Days To Heading (No)	0.124	0.08	0.784	0.145
Days To Maturation (No)	0.239	0.468	0.215	-0.139
Grain Filling Period(No)	0.183	0.486	-0.256	-0.244
Plant Height(Cm)	-0.341	-0.054	0.131	-0.054
Panicle Length(Cm)	-0.316	-0.091	0.034	-0.001
Culm Length(Cm)	-0.309	-0.028	0.165	-0.074
Internode Length(Cm)	-0.31	-0.206	-0.004	0.016
Spikelet Length(Mm)	-0.146	0.251	0.33	0.358
Total Tiller Number(No)	-0.302	0.083	-0.01	-0.089
Lodging Index (%)	-0.252	0.23	0.011	-0.15
Grain Yield(Kg/Ha)	-0.226	0.366	-0.222	0.114
Biomass Yield(Kg/Ha)	-0.293	0.328	0.032	-0.041
Harvest Index (%)	0.265	0.146	0.071	-0.19
Thousand Grain Weight(G)	-0.099	-0.141	0.245	-0.826
Eigenvalue	5.6584	1.7251	1.5928	1.0297
Standard deviation	2.666	1.407	1.087	1.015
Proportion of Variance	0.474	0.132	0.079	0.069
Cumulative Proportion	0.474	0.606	0.685	0.753

Mean of grain yield across locations

The mean values of varieties across two locations are presented **(Table 13).** The mean value of varieties ranged from 369.2 kg ha-1 for Welkomi at Cheliya to 1639.2 kg ha-1 for Dukem at Nono Benjawith a grand mean value of 872.3kg ha^{-1}. Genotype Dukem revealed the highest yield performance across locations followed by genotypes Asgori, Tesfa, Negus, and Quncho.

Table13. Mean grain yield (Kg ha-1) of Tef varieties Evaluated at two environments

Genotype	**Cheliya**	**Nono Benja**	**Combined**	
Dukem	991.6^{c-e}	1639.16^{a}	1315.4	a
Asgori	1366.3^{a}	1192.83^{b}	1279.6	a

Genotype	Cheliya	Nono Benja	Combined	
Tesfa	1137.0^{bc}	1275.0^{b}	1206.0	a
Negus	862.7^{e-g}	1282.50^{b}	1072.6	b
Quncho	1199.7^{ab}	941.0^{cd}	1070.4	b
Kora	1065.4^{b-d}	966.66^{cd}	1016.0	bc
Koye	1040.7^{b-d}	915.0^{cde}	977.9	bd
Boset	930.25^{d-g}	916.66^{cde}	923.5	cd
K/Tena	973.4^{c-f}	792.5^{def}	883.0	d
Local	787.7^{g-i}	743.33^{ef}	765.5	e
Enatit	819.1^{f-h}	702.50^{fg}	760.8	e
Melko	478.5^{kl}	995.0^{c}	736.7	e
Gimbichu	675.7^{h-j}	760.0^{ef}	717.8	e
Simada	679.3^{h-j}	690.0^{fg}	684.6	e
Gibe	516.0 $^{j-l}$	537.5^{gh}	526.8	f
Moga	619.4^{i-k}	421.66^{h}	520.1	f
Welkomi	369.1^{l}	375.0^{h}	372.1	g
Mean	853.6	890.96	872.3	
LSD CV (%)	266.5 9.6	225.9 9.6	173.3 9.6	

Genotype by environment interaction and stability analysis of grain yield

To illustrate the effect of each genotype and environment, the AMMI1 (PC1 vs. grain yield means) (**Fig.1**) and AMMI2 (PC2 vs. PC1) (**Fig. 2**) biplot were plotted. In Fig1, the x-coordinate indicates the main effects (grain yield means) and the y-coordinate indicates the effects of the interaction (PC1).

Stability analysis

Environments Nono Benja with fertilization and Nono Benja without fertilization showed an intermediate contribution to the interaction, and environments Cheliya with fertilization and Cheliya without fertilization had a high contribution (**Fig. 1**). Only in environments Cheliya with fertilization and Nono Benja with fertilization averages were recorded above the overall averages (863.3 kg/ha), indicating that these were favorable environments to obtain high means.

Varieties Simada, Koye, Keytena, Gimbichu, Boset, and Melko have shown less variability across environments while varieties Local, Welkomi, Asgori, Kora, and Negus showed high variability across environments. On the other hand environments, Nono without fertilization and Gedo without fertilization showed a strong correlation as environment Nono with fertilization and Gedo with fertilization do.

In AMMI 1 biplot, genotypes Koye, Gibe, Gimbichu, Boset, Key tena, Welkomi, Quncho, and Local form one cluster; Simada, Tesfa, Moga, Dukem, and Enatit form another cluster; similarly genotypes Kora, Asgori, Melko, and Negus form an additional cluster. Cheliya with fertilizer application and Noon Benja with fertilizer application form one environmental cluster, while Cheliya without fertilizer application and Noon Benja without fertilizer application form another one. Genotypes Simada, Koye, Gimbichu, Tesfa, Moga, Boset, Key tena, Dukem, and Quncho are closer to the origin of the biplot while genotypes Kora, Asgori, and Local are far from the origin. Environment Noon Benja vector showed relatively closer to the origin than environment Cheliya **Figure 1**.

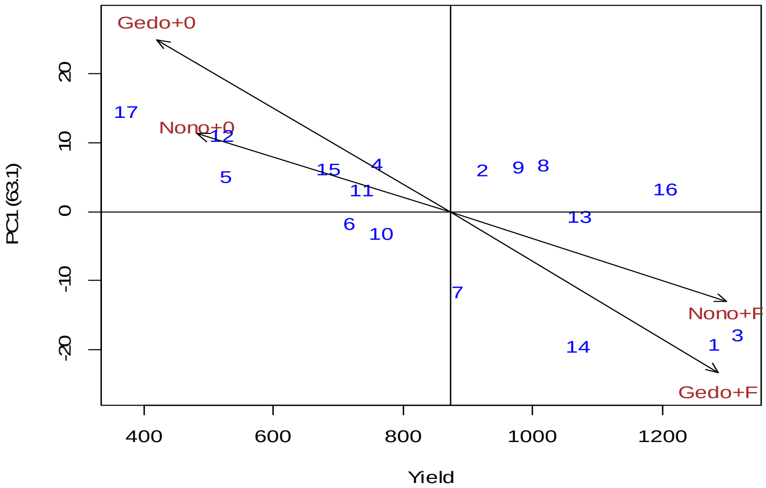

Figure 1. AMMI 1 Biplot for grain yield (kgha-1) of 17 tef genotypes (G) and two environments (E) using genotypic and environmental scores

Gedo+F=Cheliya with fertilizer application,Gedo+0=Cheliya without fertilizer application, Nono=Nono Benja with fertilizer application, Nono+0=Nono Benja without fertilizer application, 1=Kora, 2=Simada, 3=Asgori, 4=Koye , 5=Gibe, 6=Gimbichu, 7=Melko, 8=Tesfa, 9=Moga, 10=Boset, 11=Key tena, 12=Welkomi, 13=Dukem, 14=Negus, 15=Quncho, 16=Enatit, 17=Local

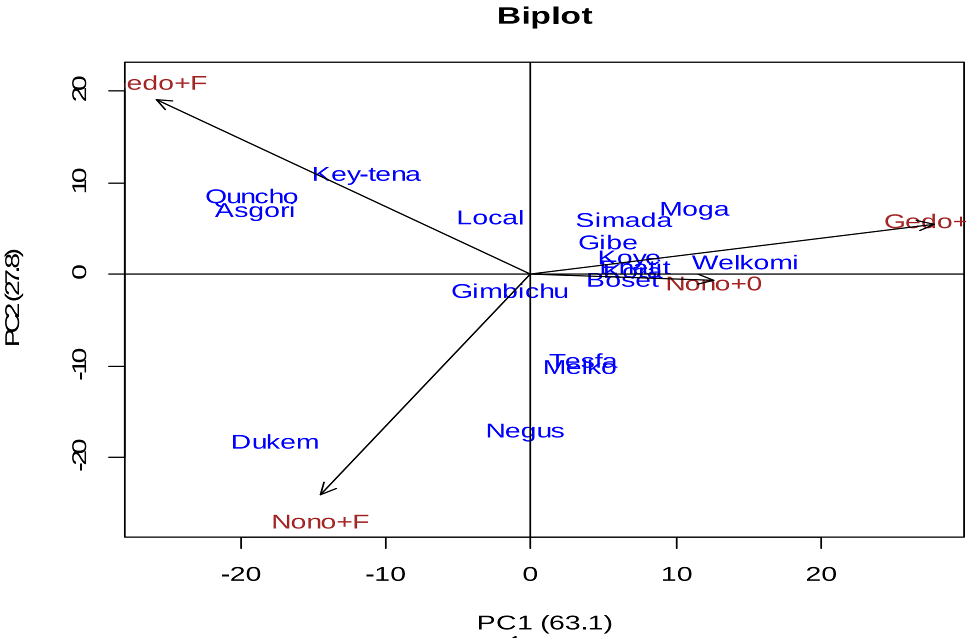

Figure 2. **AMMI 2 Biplot for grain yield (Kgha^{-1}) showing the interaction of IPCA2 against IPCA1 scores of 17 tef genotypes (G) in two environments (E).**

Gedo+F=Cheliya with fertilizer application, Gedo+0=Cheliya without fertilizer application, Nono=Noon Benja with fertilizer application, Nono +0=Nono Benja without fertilizer application.

Genotype by environment interaction

In AMMI biplot 2, genotype Gimbichu was positioned the most closer to the origin, followed by Boset, Koye, Kora, Enatit, and Gibe. Other genotypes like Local, Simada, Moga, Welkomi, Tesfa, and Melko are moderately closer to the origin of the plot. Whereas, genotypes Negus, Dukem, Quncho, Asgori, and Key tena are relatively far from the origin. Environment Nono Benja without fertilizer vector was recorded to be the closest one to the AMMI 2 biplot origin, while Cheliya with fertilizer application plotted the distant environment.

Variety Gibe, Koye, Boset, Gimbichu, Enat, and Kora showed a highly strong association with the environment Gedo with fertilization, similarly, variety Asgori showed a highly positive strong association with the environment Nono with fertilization (**Figure 3**).

Figure 3. **A.Tef (*Eragrostis tef* L.) Variety Gibe, Koye, Boset, Gimbichu, Enat and Kora observed a highly strong association with fertilization. B. Tef variety Asgori showed a highly positive strong association with the environment Nono with fertilization. C. Grain filling period in Tef genotypes D. Harvesting stage of Tef genotypes Koye, Gibe, Gimbichu, Boset, Key tena, Welkomi, Quncho and Local Simada, Tesfa, Moga, Dukem.**

Conclusion

Substantial differences were observed among tef genotypes at the individual locations and combined analysis of variance with regard to considered traits indicates that there is a need to choose better performing tef genotype for the particular location. Asgori, Quncho, Tesfa, Kora, and Koye at Cheliya and Dukem, Asgori, Tesfa, and Negus at Nono Benja were the best performing varieties in individual location analysis. Though there were genotypes relatively performing consistently across locations, some variety's performance was inconsistent across two locations. This may be due to environmental factors. The varieties Dukem, Asgori, Tesfa, Negus, Quncho, Kora, koye, Boset, and key Tena showed relatively consistent performance over the local variety across the tested location and they were greater than the grand mean (872.3kg/ha).

The significant variability among varieties was largely due to genetics, i.e., the genotypic variance was not only greater than the environmental variance but also closer to phenotypic variances, which indicated that most differences among varieties were genetically governed. Besides this, the broad sense heritability of almost all studied traits showed higher heritability values. Therefore, selecting genotypes for specific locations would be feasible.

Acknowledgments

The authors are grateful to the DebreZeit Agricultural Research Center (DZARC), DebreZeit and Farmers Training Centre (FTC), Nono Benja, and Cheliya agriculture office for providing the research materials and laboratory facilities.

References

Asaye Birhanu, Yismaw Degenet, Zeyinu Tahir. (2020) Yield and agronomic performance of released Tef [Eragrostis tef (Zucc.) Trotter] varieties under irrigation at Dembia, Northwestern, Ethiopia. *Cogent Food & Agriculture,* 6:1

Bartlett, M.S. (1937) Properties of Sufficiency and Statistical Test. Proceedings of the Royal Society A, 160, 268-282. https://doi.org/10.1098/rspa.1937.0109

Bedane, G. M., Saukuru, A. M., George, D. L., Gupta, M. L. (2015).Evaluation of Tef (*'Eragrostis tef'*[Zucc.] Trotter) lines for agronomic traits in Australia. *Australian Journal of Crop Science, 9* (3), 242.

Blandino A, Al-Aseeri ME, Padilla SS, Cantero D and C Webb (2003). Review: Cereal-based fermented foods and beverages. *Food Res. Int. 36*:527–543.

Bogale, A., and Wondmu, W. (2017).Evaluation and Selection of Some Improved Tef (*Eragrostis tef* (Zucc.)Trotter) Varieties in Three Districts of Bench Maji Zone, Ethiopia. *Asian Journal of Agricultural Research, 11*, 98-102.

Burton, G.W., and Devane, E. H. (1953). Estimating heritability in tall fescue (Festucaarundinacea) from replicated clonal material. *Agronomy Journal, 45* (10), 478-481.

Caldicott, J. J. B., Nuttall, A. M. (1979). A method for the assessment of lodging in cereal crops. *Journal of the National Institute of Agricultural Botany, 15*(1): 88-91.

Collyns, D. (2013). Quinoa brings riches to the Andes. The Guardian, 15

CSA. Agricultural Sample Survey 2018 (2010 E.C.) Report on Area and Production of Major Crops (private peasant holdings, Meher season), vol. I. Addis Ababa: *Central Statistical Agency*; 2013.

Fetie, M., Nigus Demelash,N., and Jemberu T.,(2012). Participatory on farm performance evaluation of improved Tef (*Eragrostis tef* L.) varieties in East Belessa, North western Ethiopia. *International Research Journal of Plant Science. 3*(7): 137-140.

Gomez, K. A., and Gomez, A. A. (1984). Statistical procedures for agricultural research. John Willey and Sons. Inc. New York, 641.

Hanson G., Robinson HF., Comstock RE (1956). Biometrical studies on yield in segregating population of Korean Lespedeza. *Agron. J.*, 48: 268-274.

Kedir, A.,O.Chimdesa,S.Alemu and Y.Tesfaye (2016). Adaptability study of tef varieties at mid and agro-ecologies of Guji Zone, southern Oromia *.J .Natural sci,Res.,6*: 124-126.

Ketema, K. (1997). Tef (*Eragrostis tef (*Zucc.)Trotter): promoting the conservation and use of underutilized and neglected crops. Institute of plant genetics and crop plant research, International plant genetics resources institute, Rome, Italy. https://hdl.handle.net/10568/104306

Lema, M., Simion, T., Markos, S. (2017). Evaluation of improved Tef (*Eragrostis tef* L.) varieties in Konso area, Southern Ethiopia. *International Journal of Research in eeAgriculture and Forestry*.I11 (4), 32-34.

Manoukian, E. B., J. Maurais, R. Ouimet (1986). Exact critical values of Bartlett's test of homogeneity of variances for unequal sample sizes for two populations and power of the test. Metrika, 33 (1), 275-289.

Mathewos Ashamo and Getachew Belay.,(2012) Genotype x Environment Interaction Analysis of Tef Grown in Southern Ethiopia Using Additive Main Effects and Multiplicative Interaction Model. *Journal of Biology, Agriculture and Healthcare, 2*: 66-72.

Muluken Bayable, Atsushi Tsunekawa, Nigussie Haregeweyn, Getachew Alemayehu, Wataru Tsuji, Mitsuru Tsubo, Enyew Adgo, Asaminew Tassew, Takayoshi Ishii, Fekremariam Asaregew, Tsugiyuki Masunaga (2021).Yield Potential and Variability of Teff (Eragrostis tef (Zucc.) Trotter) Germplasms under Intensive and Conventional Management Conditions. *Agronomy 11*, 220.

Sebsib Muanenda., Abebe Yabeker., Shemsu Ligani.(2019) Effect of Environment on Different Traits of Teff Evaluated on Debrezeit Research Institution, Oromia, Ethiopia. *International Journal of Scientific and Research Publications, 9*: (2): 237-243.

Singh, B. D. (2015). Plant breeding: principles and methods. Kalyani publishers. https://www.amazon.com/Plant-Breeding-Principles-Methods/dp/9327252322

USDA, N. (2018). The plants database (http: //plants. usda. gov, 1 May 2018). National Plant Data Team, Greensboro. http://plants.usda.gov

Vavilove, N. I. (1951). The origin, variation, immunity and breeding of cultivated plants: selected writings of Vavilove. *Chronic Botanical. 13*; 1:6

Watson, L., and Dallwitz, M. J. (1992). The grass genera of the world. Wallingford, Oxon, UK : C.A.B. International.