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Estimating the Genetic Variance Components and Trait Association Coefficients among Improved *Tef* (*Eragrostis tef* (Zucc.) Trotter) Genotypes

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ABSTRACT

Background and Objective: The *tef* is one of the most indispensible food crops in Ethiopia. Evaluating the variability is also vital to identify the best substantial traits for enhancement. The objectives of the study were: To assess the extent of genetic variability, estimate the phenotypic and genotypic variances and association coefficients for yield and yield attributed traits among the genotypes. **Materials and Methods:** Forty-nine *tef* (*Eragrostis tef* (Zucc.) Trotter) genotypes were evaluated in the Awi Zone at Ayehu Guagussa District (3tu Segno FTC) in the 2021 and 2022 cropping seasons. A simple lattice design of 7×7 with 2 replications was used. Days to 50% seed emergence (DE), days to 50% heading (DH), days to 50% maturity (DM), plant height (PH), panicle length (PL), lodging index (LI), plant stand (Pst), leaf rust (LR), biological yield (BY) and grain yield (GY) data were recorded and used for the static analysis using SAS software. **Results:** Pooled ANOVA of the two years revealed a highly significant ($p<0.01$) difference in yield and yield attributed traits except for LR. The highest GY recorded from DZ-Cr-453 RIL120B (Bora) (2269.6 kg/ha^2) followed by DZ-Cr-458 RIL18 (Ebba) (2171.8 kg/ha^2) and DZ-01-3186 (Etsub) (1998.6 kg/ha^2) while the lowest from local check 1006.40 kg/ha. The PCV, GCV, h^2 and GAM estimates observed were moderate to high for GY and BY, PH and PL. The GY showed positive significant associations ($p<0.05$) at the genotypic and phenotypic levels with DH, Pst and BY. DH, DM, Pst, PH and PL also exhibited positive significance with BY while LR and LI showed negative significant associations with DH, DM, PH, Pst and PL. **Conclusion:** This study exhibited the existence of variation in the extent of variability, heritability, genetic advance and associations in traits in the study which enable selection and hybridization for extra enhancement of essential traits in *tef*. Moreover in the study areas; these selected varieties could be demonstrated and promoted to farmers with their production packages to boost their production.

KEYWORDS

Association, genotypes, heritability, variability, phenotypes, *tef*

INTRODUCTION

Agriculture has the highest share in the Ethiopian economy critically which relies on crops and livestock production. Crop production is the leading segment in the economy. The *tef* (*Eragrostis tef* (Zucc.) Trotter))

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is one of the most indispensible cereals with 1.85 ton/ha as the national productivity of Ethiopia. From the total 10.5 million hectares of production area coverage in cereals, it is grown in more than 3.1 million hectares of land (24.11%) and second in its grain production (17.11%) next to maize[1]. Most areas of Ethiopia are gifted for *tef* production and the crop is imperative in the food security of the country[2,3]. Amhara region *tef* is highly produced in North and South Gondar, North and South Wollo, East and West Gojam, North Shewa, Wagihumra and Awi zones of the region. It is the third most productive in the Awi zone (2.02 ton/ha) next to East and West Gojam produced which (2.08 and 2.06 ton/ha), respectively[1].

The *tef* has a very traditional value for injera making and has the highest privilege fascinating gusts in the country. It is also used for other food preparation like, porridge; 'anebabero', 'kita' and alcoholic drinks ('tella' and 'arekie') in the communities. The *tef* is not only a privileged product, but also the core nutritive for physical fitness and sustenance in Ethiopia[4]. It is certified as a supper nutritional food in the international market[5]. The nourishing value of the grain is similar to other grains while the *tef* grain consists of an admirable amino acid organization to be favored over consuming barley and wheat meals in the diets. Since the *tef* grain is gluten-free or has very small gluten it also has a high amount of iron which makes it prevalent in human fitness[6].

However, there are different biotic and abiotic factors responsible for low yield in *tef*. Among those, the absence of improved cultivars resistant/tolerant to lodging, drought and insect pests are the most abiotic and biotic yield limiting factors[7,8]. The biological yield, economical yield and qualitative traits are also diverging with the soil type, environment, time and varieties. Most Ethiopian highland areas are rich in iron and aluminum oxide which causes soil acidity in addition to phosphorus deficiency[9,10]. Genetic inconsistency and/or poor adaptability of varieties are also current major production constraints for *tef* in most parts of Ethiopia. These factors are also very serious in the Amhara region mainly the Awi zone. In the Awi Zone, agriculture is the mainstay and the livelihood economy depends on different cereal crops like Cereals, pulses, vegetables, roots and tubers and fruit crops including coffee. The *tef* has the highest social traditions among cereals in this zone and is prominently valued by farmers and consumers for human food consumption as injera and its straw for animal feed. Both improved and local varieties are produced in most areas of the zone, but traditional cultivars are the most dominant. In Ayehu Guagussa District (AGD) *tef* is not a very common crop while maize is the leading followed by wheat among cereals. Peppers are the first most common cash vegetable crops in the District. The productivity of peppers is challenged by biotic factors and *tef* become a very substantial crop in AGD. But its productivity so far varied in the district due to the absence of improved varieties; hence its productivity is very low. Genetic variability is valuable for evaluating the genotypes and takes precise selection. It is also vital for the enhancement of wider adaptability across environments. The magnitude of heritability and the correlation of traits determine genetic advancement through direct and indirect selection[11]. Bogale[12] stated that heritability; genetic advance and correlation of traits in *tef* genotypes are flexible up on the trial environments. Hence synchrony of highly heritable and correlated traits in the targeted environment is essential for extreme selection in the commodity. Even though about 58 *tef* varieties were released by different regional and federal agricultural research centers[13], most of them were not evaluated before and after release at AGD. The objectives of this study were to assess the extent of genetic variability among the genotypes, to estimate the phenotypic and genotypic variances and heritability, to examine the phenotypic and genotypic association coefficients for yield and yield attributed traits in the genotypes and to recommend the best adapted varieties.

MATERIALS AND METHODS

Description of the study area: The experiment was conducted in the 2021 and 2022 main cropping season at 3tu segno FTC in Ayehu Guagussa District, Awi zone, Ethiopia. The trial site was located at the Latitude of 10°46.600'N and Longitude of 36°50.038'E with an altitude of 2098 m.a.s.l. The meteorological data indicates a minimum annual rainfall of 900 mm and a maximum of 1500 mm with the minimum and maximum temperature of the study site being 12.5 and 25°C, respectively. The rainfall distribution of the study area is an unimodal pattern and the main rainfall extends from May to October with a peak in June to September. In Awi Guangua District Nito and verti sol soil types are common types while the experiment was laid in Nito soil.

Plant materials and methods: The experiment comprised 49 *tef* genotypes as shown in Table 1.

Table 1: Description of released *tef* varieties used in the 2021 and 2022 main study seasons

Pedigree name	Local name	Year of release	Releasing center	Adaptation zone (m.a.s.l)	Seed color
DZ-01-99	Asgori	1970	Debre Zeit	1600-2700	Brown
DZ-01-196	Magna	1970	Debre Zeit	1800-2700	Very white
DZ-01-354	Enatite	1970	Debre Zeit	1600-2400	Pale white
DZ-01-787	Wellenkomi	1978	Debre Zeit	1600-2400	Pale white
DZ-Cr-44	Menagesha	1982	Debre Zeit	1800-2500	White
DZ-Cr-82	Melko	1982	Debre Zeit	1400-2000	Pale white
DZ-Cr-37	Tsedey	1984	Debre Zeit	1200-2200	White
DZ-Cr-255	Gibe	1993	Debre Zeit	1200-2200	White
DZ-01-974	Dukam	1995	Debre Zeit	1400-2400	White
DZ-Cr-358	Ziquala	1995	Debre Zeit	150-700	White
DZ-01-2053	Holeta Key	1998	Holeta	1800-2600	Brown
DZ-01-1278	AmboToke	1999	Holeta	2000-2600	White
DZ-01-2054	Gola	2003	Sirinka	1800-2200	White
DZ-01-1285	Koye	2002	Debre Zeit	1800-2200	White
DZ-01-1281	Gerado	2002	Debre Zeit	1500-1850	White
DZ-01-1681	Key Tena	2002	Debre Zeit	1600-2200	Brown
PGRC/E205396	Ajora	2004	Areka	900-1200	White
DZ-01-1868	Yilmana	2005	Adet	1000-1400	White
DZ-01-2423	Dima	2005	Adet	2000-2300	Brown
DZ-01-1821	Zobel	2005	Sirinka	1200-1650	White
DZ-01-146	Genete	2005	Sirinka	1200-1650	Pale white
DZ-01-899	Gimbichu	2005	Debre Zeit	2000-2500	White
DZ-Cr-387 RIL355	Quncho	2006	Debre Zeit	1800-2400	Very white
DZ-01-1880	Guduru	2006	Bako	1200-1800	White
DZ-Cr-136	Amarach	2006	Debre Zeit	900-1200	White
Acc. 205953	Mechare	2007	Sirinka	660-1025	Pale white
DZ-Cr-387 RIL127	Gemechis	2007	Melkassa	690-965	White
23-Tafi-Adi-72 (Kena)	Kena	2008	Bako	1000-1200	Very white
DZ-01-3186	Etsub	2008	Adet	1600-2200	White
DZ-Cr-385 RIL295	Simada	2009	Debre Zeit	300-700	White
DZ-Cr-387 RIL273	Lakech	2009	Sirinka	1400-1650	
DZ-Cr-409	Boset	2012	Debre Zeit	750-1500	Very white
DZ-Cr-438 RIL133B	Kora	2014	Debre Zeit	1500-2000	Vey white
Acc. 214746A	Werekiyu	2014	Sirinka	1200-1800	White
DZ-Cr-438 RIL7	Abola	2016	Adet	1500-2200	Very white
DZ-Cr-438 RIL91A	Dagim	2016	Debre Zeit	1700-2400	Very white
DZ-Cr-429 RIL125	Negus	2017	Debre Zeit	2000-2700	Very white
DZ-Cr-442 RIL77C	Felagot	2017	Debre Zeit	1700-2500	Brown
DZ-Cr-457 RIL181	Tesfa	2017	Debre Zeit	1500-2200	White
DZ-Cr-419	Heber-1	2017	Adet	1500-2200	White
DZ-Cr-401	Areka-1	2017	Areka	1500-2800	White
Acc # 225931	Abay	2018	Adet	1500-1850	White
ACC.236952	Dursi	2018	Adet	1800-2500	White
DZ-01-256	Jitu	2019	Bako	1800-2500	White
DZ-Cr-458 RIL18	Ebba	2019	Debre Zeit	1700-2500	Very white
DZ-Cr-429 RIl 29	Washera	2019	Adet	2000-2500	Very white
DZ-Cr-453 RIL120B	Bora	2019	Debre Zeit	750-1500	Very white
DZ Cr- 428	Mena	2019	Sirinka	1800-2500	Very white
Local Check	Local	Existed	Awi zone	1100-1800	Sergegna

The trial was conducted using a 7×7 simple lattice design with 2 replications and spacing of 1m between plots and 1.5 m between blocks for 2 years (2021 to 2022) main cropping seasons. The treatments were sown on a 2×2 m plot area with 0.2 m inter row planting space. Evaluated genotypes were collected from the Debre Zeit Agricultural Research Center. Each experimental plot area was 4 m^2 (2×2 m) and 15 kg/ha seed rate with 20 cm between rows of spacing. Fertilizer was applied at the rate of 90 kg/ha NPS at planting and 120 kg/ha urea two weeks after the seeds germinated. All other agronomic practices were equal for all treatments on the same date.

Data collection: At each experimental season surveillance and data collection were made. Data were recorded on plant and plot bases including panicle length (cm), plant height (cm), days to 50% seed emergence, days to 50% heading, days to 50% maturity, plant stand (0-5 scale), leaf rust (1-5 scale), lodging index (%), biomass and grain yield (gram per plot) then converted to kilogram per hectare. Phenological data were also recorded like days to seed emergency, days to heading and days to maturity.

Statistical analysis: The two years of data were combined for the analysis of variance, phenotypic and genotypic correlations including variability components using packages in SAS version 9.4[14]. The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were calculated as per[15]. The PCV and GCV were considered as low if the magnitudes were less than 10%, moderate if 10-20% and high if ≥20% as presented[16]. Heritability (%) was also categorized as low if <20%, medium 20-40% and high if ≥40% based on Adhikari *et al.*[17]. Genetic advance (GA) and genetic advance as the means (GAM %) were calculated by using the formulas stated by Johnson *et al.*[18]. Correlation coefficient among two traits was intended via components of variance and covariance as in Weber and Moorthy[19].

RESULTS AND DISCUSSION

Mean comparisons of *tef* genotypes: The combined mean over year analysis of variance was computed using the proc Glm (general linear model) of the simple lattice design which revealed highly significant (≤0.01) variation for all traits except leaf rust and exposed the presence of substantial genetic variability among the genotypes (Table 2). The means, mean squares and standard deviations of each trait of the evaluated genotypes were also computed and presented in Table 3. A comparable result was reported by Demelash[20] with highly significant variations among the genotypes for days to heading, days to maturity and shoots biomass, Abraha *et al.*[11] for all traits except lodging index. Assefa[21] also reported considerable variation with days to maturity, plant height, panicle length, lodging index, grain and biological yield. The highest variance among the genotypes indicated the probability of enlightening diverse measurable and qualitative traits through selection. The minimum and maximum grain yield was recorded from local check and DZ-Cr-453 RIL120B (Bora) with 1006.4 and 2269.6 kg/ha, respectively and the overall mean grain yield of 1622.56 kg/ha. Similarly, the minimum and maximum biological yields were recorded from DZ-Cr-442 RIL77C (Felagot) and Local check 5305 and 12820 kg/ha, respectively with the grand mean of 8170.2 kg/ha. This result was similar to that previously reported by Bayable *et al.*[22] that the grain and biological yield were exhibited highly significant differences among the genotypes. Even if, Assefa *et al.*[23] reported that biological yield is the main contributor to grain yield, this result partially contrasted that the highest biological yield is not only the provider of the highest grain yield, but if it may not be improved variety its production could be the highest in straw production like the local check in this research. The minimum days to heading (50.5 days) were recorded in DZ-01-1281 (Gerado) while the maximum (62 days) was recorded from DZ-Cr-438 RIL133B (Kora) and DZ-Cr-419 (Heber-1) with 56.8 entire mean of days to heading. The lowest days to maturity were recorded as 117 in DZ-Cr-442 RIL77C (Felagot), DZ-Cr-385 RIL295 (Simada) and DZ-01-2053 (Holeta Key) which are the earliest genotypes and the highest days to maturity was also recorded as 125 in DZ-01-787 (Wellenkomi) and DZ-01-1880 (Guduru) with a total mean of 121.6 days (Table 2-3). An earlier comparable result was reported as having highly significant variation among the genotypes in days to heading and maturity by

Table 2: Combined mean performance analysis result of 49 *tef* genotypes in the 2021 and 2022 main cropping season at Ayehu Guagussa District (3tu Segno FTC)

Genotype	DE	DH	DM	PH	PL	LI	Pst	LR	BY	GY
DZ-Cr-453 RIL120B (Bora)	7.50	59.00	120.00	109.35	43.65	2.50	3.63	2.25	8605.00	2269.60
DZ-Cr-458 RIL18 (Ebba)	8.50	59.50	120.50	103.65	37.20	1.50	3.88	1.00	6956.00	2171.80
DZ-01-3186 (Etsub)	7.50	58.50	122.00	110.80	41.85	2.75	4.38	1.50	9554.00	1998.60
DZ-Cr-429 RII 29 (Washera)	8.50	59.00	123.00	112.50	40.75	1.50	4.25	1.00	8992.00	1926.40
DZ-Cr-387 RIL273 (Lakech)	8.00	58.50	123.00	114.05	42.45	2.00	3.88	1.75	8328.00	1890.80
DZ Cr- 428 (Mena)	8.00	58.00	123.00	115.70	43.70	2.00	4.25	1.50	11117.00	1855.80
DZ-Cr-401 (Areka-1)	7.50	52.50	123.50	105.20	43.30	2.00	4.50	1.25	8991.00	1838.90
DZ-Cr-457 RIL181 (Tesfa)	8.75	58.00	119.50	102.75	36.10	3.50	3.63	2.75	6116.00	1803.00
ACC.236952(Dursi)	8.00	58.50	123.50	132.40	52.95	2.50	3.50	1.75	9367.00	1771.20
DZ-01-1285 (Koye)	7.50	59.50	119.50	110.45	37.80	3.75	3.63	1.75	9367.00	1771.00
DZ-01-99 (Asgori)	8.00	53.50	119.50	96.30	39.90	3.50	4.13	2.25	8992.00	1768.40
DZ-Cr-419 (Heber-1)	8.50	62.00	124.00	113.55	43.50	2.00	3.88	1.50	9491.00	1757.70
DZ-01-1868 (Yilmana)	8.00	57.50	122.00	105.20	40.95	2.00	3.75	2.50	7617.00	1754.00
DZ-01-2054 (Gola)	8.00	58.00	122.00	117.90	44.25	2.00	4.13	1.50	9866.00	1730.80
DZ-01-787 (Wellenkomi)	7.50	58.50	125.00	110.75	45.75	2.75	4.00	1.50	8616.00	1674.20
DZ-Cr-429 RIL125 (Negus)	8.50	58.00	119.50	99.00	36.55	2.00	4.00	1.75	6305.00	1657.40
23-Tafi-Adi-72 (Kena)	7.50	57.00	119.50	106.75	37.15	3.00	3.75	2.25	6303.00	1657.30
DZ-01-146 (Genete)	8.00	60.00	121.50	119.50	46.00	1.00	4.25	1.00	9490.00	1632.60
DZ-01-1278 (AmboToke)	7.50	59.00	121.50	119.70	46.60	2.00	4.00	1.75	7868.00	1626.50
DZ-Cr-438 RIL91A (Dagim)	8.50	57.50	118.00	113.80	42.90	1.50	4.00	2.00	7868.00	1626.40
DZ-01-1821 (Zobel)	7.00	55.50	122.50	100.70	41.65	2.50	3.75	2.00	8242.00	1624.80
DZ-Cr-438 RIL133B (Kora)	7.00	62.00	124.50	121.50	41.05	1.50	3.88	1.75	8240.00	1624.70
DZ-01-1880 (Guduru)	7.50	59.00	125.00	116.55	42.50	2.00	4.13	1.75	11492.00	1624.00
DZ-Cr-44 (Menagesha)	7.00	59.00	123.50	107.55	39.40	2.25	4.25	1.50	8492.00	1618.00
Acc # 225931 (Abay)	8.50	57.50	122.50	126.25	49.25	3.00	3.88	2.50	8491.00	1617.90
DZ-Cr-385 RIL295 (Simada)	7.50	50.50	117.00	87.85	33.85	3.00	4.25	1.50	5992.00	1602.10
DZ-Cr-255 (Gibe)	7.00	54.00	121.50	107.40	43.65	2.25	4.13	2.25	5993.00	1601.90
DZ-01-196 (Magna)	7.50	55.00	121.00	113.05	40.35	2.00	4.13	1.75	8118.00	1595.80
DZ-01-256 (Jitu)	8.00	59.00	124.00	122.75	45.10	1.50	3.88	1.25	8616.00	1563.90
DZ-Cr-37 (Tsedey)	8.00	56.00	120.00	109.38	42.15	3.00	3.88	2.50	6680.00	1562.40
DZ-Cr-136 (Amarach)	8.00	55.50	124.00	100.50	39.05	3.00	3.25	2.25	6678.00	1562.40
DZ-Cr-387 RIL127 (Gemechis)	7.00	53.50	120.50	110.35	42.45	3.50	3.88	2.50	8617.00	1561.50
DZ-01-899 (Gimbichu)	8.00	59.00	121.00	109.60	45.55	2.00	3.88	2.00	8616.00	1561.30
Acc. 214746A (Werekiyu)	7.00	54.50	121.50	107.40	41.85	3.00	4.00	1.75	6367.00	1549.00
DZ-Cr-409 (Boset)	9.00	57.00	119.00	97.55	35.00	2.50	3.38	2.00	6367.00	1548.90
DZ-01-974 (Dukam)	7.50	57.50	121.50	119.35	46.15	2.00	4.50	1.50	8117.00	1533.40
DZ-01-354 (Enatite)	7.50	54.50	121.50	107.85	46.35	2.25	3.88	1.75	8368.00	1525.80
DZ-01-2423 (Dima)	8.00	56.00	121.00	100.60	38.30	3.25	3.75	2.50	8366.00	1525.80
DZ-Cr-358 (Ziquala)	8.50	56.00	124.00	117.40	43.90	2.25	3.75	2.00	8741.00	1485.10
DZ-01-2053 (Holeta Key)	8.75	50.50	117.00	85.85	32.20	3.25	3.63	2.75	7055.00	1473.00
DZ-Cr-387 RIL355 (Quncho)	8.00	58.00	124.00	118.00	44.75	2.25	4.00	1.00	7055.00	1473.00
DZ-Cr-438 RIL7 (Abola)	7.50	59.00	122.00	116.20	46.75	1.50	3.75	1.75	8683.00	1456.70
Acc. 205953 (Mechare)	7.50	57.00	119.50	108.40	41.15	2.50	3.88	2.00	6992.00	1393.90
DZ-01-1281 (Gerado)	8.00	50.50	122.50	105.30	44.20	2.50	3.25	2.25	8116.00	1364.10
DZ-Cr-82 (Melko)	8.00	54.50	124.00	105.75	41.00	3.00	4.25	1.75	8117.00	1363.90
DZ-01-1681 (Key Tena)	8.00	56.50	119.50	97.10	40.10	4.00	3.88	2.50	7868.00	1312.00
PGRC/E205396 (Ajora)	7.50	54.00	124.00	105.35	39.85	2.75	3.50	1.75	7865.00	1311.80
DZ-Cr-442 RIL77C (Felagot)	8.00	52.50	117.00	94.10	36.00	3.50	3.63	2.75	5368.00	1280.10
Local Check	8.25	59.50	122.00	116.70	46.45	3.00	4.38	2.50	12820.00	1006.40
CV (%)	8.70	3.77	1.35	5.16	6.66	22.17	9.11	37.88	18.65641	16.199
LSD (0.05)	0.96**	3.02***	2.31***	7.95***	3.94***	0.77***	0.50***	1.01^{ns}	2148.6***	370.50***

ED: Days to 50% seed emergence, HD: Days to 50% heading, MD: Days to 50% maturity, PH: Plant height (cm), Pl: Panicle length (cm), LI: Lodging index (1-5 scale), Pst: Plant stand (0-5 scale), LR: Leaf rust (1-5 scale), BY: Biological yield (kg/ha) and GY: Grain yield (kg/ha)

Bayable *et al.*[22]. The highest lodging index (4) was recorded from DZ-01-1681 (Key Tena) while the lowest (1) was recorded in DZ-01-146 (Genete) which implies the existence of highly significant variation among the genotypes and the probability of selection. The highest panicle length (53 cm) was recorded

Table 3: Combined (2021 to 2022) data analysis of variance for 10 traits of *Tef* genotypes main cropping season at Ayehu Guagussa District (3tu Segno FTC)

	Mean square							
Traits (%)	Year (Df = 1)	Rep (Year) (Df = 2)	Block (Year*Rep) (Df = 24)	Year*Entry (Df = 48)	Treatments (Df = 48)	Error (Df = 72)	Means	R^2
Days to 50% seed emergence	52.0***	16.76**	1.13^{ns}	0.047^{ns}	0.919***	0.466	7.85	82.6
Days to 50% heading	196***	36.7***	10.1^{ns}	0^{ns}	28.5***	4.58	56.84	85.1
Days to 50% maturity	196***	5.88^{ns}	6.37^{ns}	0^{ns}	15.6***	2.68	121.57	85.2
Plant height (cm)	1359.0***	380.85***	131.5^{ns}	42.4^{ns}	308.4***	31.8	109.29	90.6
Panicle length (cm)	1132.8***	84.34***	22.3^{ns}	8.36^{ns}	57.9***	7.79	41.90	89.9
Lodging index (%)	0.127^{ns}	8.35***	1.07***	0.049^{ns}	1.93***	0.298	2.46	86.5
Plant stand (%)	4.14***	0.231^{ns}	0.365^{ns}	0.223^{ns}	0.295***	0.127	3.92	80.7
Leaf rust (1-5 scale)	27.9***	6.69***	0.556^{ns}	0.335^{ns}	0.916^{ns}	0.511	1.89	75.7
Biological yield (kg/ha)	283377.5^{ns}	22040368***	5025221.4^{ns}	4842812.9**	8049629.2***	232	8170.16	82.4
Grain yield (kg/ha)	1322.7^{ns}	552060.2***	121224.0^{ns}	89070.0^{ns}	181301.5***	69085.84	1622.58	77.4

*Significant at 5% level, **Significant at 1% level and ***Significant at 0.1% level while and ns: No significant difference among the genotypes

Table 4: Estimation of genetic parameters for ten traits in *tef* genotypes

	Mean range								
Traits	Minimum	Maximum	σ^2p	σ^2g	PCV (%)	GCV (%)	h^2	GA	GAM (%)
Days to seed emergence	7.00	9.00	0.69	0.23	10.60	6.06	32.68	0.32	4.08
Days to heading	50.50	62.00	16.54	11.96	7.16	6.08	72.31	5.15	9.06
Days to maturity	117.00	125.00	9.16	6.48	2.49	2.09	70.74	3.71	3.05
Plant height (cm)	85.85	132.40	170.14	138.29	11.93	10.76	81.28	19.69	18.02
Panicle length (cm)	52.95	32.20	32.84	25.05	13.68	11.94	76.26	7.86	18.76
Lodging index (%)	1.00	4.00	1.11	0.81	42.80	36.61	73.17	1.36	55.18
Plant stand (0-5 scale)	3.25	4.50	0.21	0.08	11.74	7.40	39.77	0.24	6.06
Leaf rust (1-5 scale)	1.00	2.75	0.71	0.20	44.75	23.84	28.36	0.26	13.93
Biological yield (kg/ha)	5368.00	12820.00	5186498.85	2863130.35	27.87	20.71	55.20	1924.22	23.55
Grain yield (kg/ha)	1006.40	2269.60	125193.68	56107.84	21.81	14.60	44.82	218.69	13.48

σ^2p = σ^2g = PCV (%): Phenotypic coefficient of variation in percent, GCV (%): Genotypic coefficient of variation in percent, h^2 (%): Broad sense heritability, GA: Genetic advancement and GAM (%): Genetic advance as the percent of mean

in ACC.236952 (Dursi) while the lowest (32.2 cm) was recorded from DZ-01-2053 (Holeta Key). The highest plant height (132.4 cm) recorded was in ACC.236952 (Dursi) while the lowest (85.9 cm) was recorded in DZ-01-2053 (Holeta Key). Plant height is a critical trait that contributes to yield and rivals to lodging on the other side. This finding was similar and comparable with the previous report of Demelash[20]. The best plant stand (4.5) was observed in DZ-01-974 (Dukam) and DZ-Cr-401 (Areka-1) whereas the lowest (3.25) was noted in DZ-01-1281 (Gerado) and DZ-Cr-136 (Amarach). The lowest and highest days to 50% seed emergence recorded was between (7-9 days). The highest days of seed germination were recorded from DZ-Cr-409 (Boset). This implied that *tef* is highly diversified and variable in terms of morphological and agronomic traits. This was due to the inherent variations in the genetic makeup among the genotypes. Hence the results permit ending more inherited investigation for further variety improvement in our breeding strategy.

Genotypic (GCV) and phenotypic (PCV) coefficient of variations: The estimate of genotypic (GCV) and phenotypic (PCV) coefficient of variations, heritability, genetic advance (GA), genetic advance as the percent of mean (GAM), mean rages of each trait, genotypic and phenotypic variances were indicated in Table 4. The GCV and PCV were categorized as stated by Sivasubramanian and Menon[24] and classified as: less than 10 % = low, between 10 – 20 % = moderate and greater than 20 % = high:

$$\text{Genotypic variance } (\sigma^2 g) = \frac{\text{MSg} - \text{MSe}}{\text{r}}$$

Where:

r = Replication

σ^2_p = σ^2_g+mean square of error (MSe) or environmental variance (σ^2_e)[25]

$$\text{GCV } (\%) = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100^{15}$$

The variability of a crop under study is critically measured from PCV and GCV of differences of which high GCV typically emphasizes the traits of interest[26]. Hence, this study established to assess the nature and extent of genetic variability, heritability, genetic advance and trait associations of 49 genotypes brought out that estimation of GCV was high for lodging index, leaf rust and biological yield with the magnitude of 36.61, 23.84 and 20.71%, respectively whereas it was moderate for plant height, panicle length and grain yield with 10.76, 11.94 and 14.6%, respectively. This result is related to the high GCV values for biological yield as reported by Assefa *et al.*[23]. The phenological traits like days to heading and days to maturity indicated the lowest GCV with the highest heritable values. This result also goes with the studies of Bekana and Assefa[27] and Bayable *et al.*[22] were the lowest GCV and the highest heritability values were recorded for days to heading and days to maturity:

$$\text{PCV (\%)} = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100^{15}$$

Similarly, the estimations of high PCV values were recorded for grain yield (21.81%, biological yield (27.87%), lodging index (42.6%) and leaf rust (44.75%) while moderate for plant stand (11.74%), plant height (11.93%) and panicle length (13.7%). Similar results were reported by Abraha *et al.*[11] and Bekana and Assefa[27] with high PCV values for grain and biological yield, Lule and Mengistu[28] also reported high PCV and GCV values for biological yield and panicle length in the study of genetic variability and trait association of *tef* (*Eragrostis tef* (Zucc.) Trotter) evaluated under optimal and moisture stress conditions. In this study, high and moderate GCV and PCV values were recorded for biological yield, lodging index, leaf rust, grain yield, plant height and panicle length while the lowest GCV and PCV values were recorded for days to maturity and days to heading. This study is also in line with the previous finding reported by Jifar *et al.*[29] that the lowest GCV and PCV values were recorded for days to maturity. This study revealed that there is a possibility of enhancing traits. There is a minor difference concerning PCV and GCV values for days to 50% heading, days to 50% seed emergence, days to 50% maturity, plant height and panicle length which exhibited that the environmental effect on the expression of that trait is lower and selection based on those traits can be actual as a genetic advance. The differences among the GCV and PCV was high for lodging index, plant stand, leaf rust, biological yield and grain yield. Generally, the PCV values were higher than their GCV values for all the traits indicated in Table 4 which explained the environmental contribution as the highest share for phenotypic expression of the traits and low genetic variation among the genotypes due to the influence of the environment across the years and this result was also reliable with the previous studies reported by Ayalneh *et al.*[30] and Bekana and Assefa[27].

Heritability: Heritability shows how much of the phenotypic variability has a genetic source that provides fair evidence for the genetic empathy process[31]. However, heritability estimates together with genetic advance as the percent mean give a meaningful picture rather than heritability alone. The heritability values were estimated as:

$$\text{Heritability } (h^2) = \frac{\sigma^2 g}{\sigma^2 p} \times 100^{32,33}$$

Heritability varied from 28.3% for leaf rust to 81.28% for plant height. The heritability values were classified based on Johnson *et al.*[18] stated: 0-30% = low, 31-60% = medium and 61% and above = high. Plant height (81.28%), panicle length (76.26%), days to 50% heading (72.31%) and days to 50% maturity (70.74%) showed high heritable values which revealed that traits in the study are under the genetic control and not as much of influenced their countenance by the environment. A similar result of the highest heritable value was reported for days to heading by Demelash[20], panicle length by Ayalneh *et al.*[30], high for days to heading and moderate for days to seed emergence, panicle length, biological and grain yield by Bogale[12]. Days to 50% seed emergence (32.68%), plant stand (39.77%), grain yield (44.82%) and biological yield (55.2%) were moderately heritable while leaf rust (28.3%) was observed to have a low heritable value which displayed that these traits are highly influenced by the environment. Since lodging is the main production limit in *tef* production which poses serious economic losses and also limits the quality and quantity of products directly or indirectly, enhancing lodging resistance through breeding becomes a critical concern in *tef*.

Genetic advance and genetic advance as percent of mean: Genetic advance (GA) and Genetic advance as the percent mean (GAM) were calculated based on the formula stated by Johnson *et al.*[18] as indicated:

$$GA = K \times \sigma_p \times h^2$$

Where:
K = Intensity of selection at 5% (K = 2.06)
σ_p = phenotypic standard deviation
h^2 = Broad sence heritability

While,

$$GAM = \frac{GA}{\bar{x}} \times 100$$

Where:
GA = Genetic advance under selection
$\bar{x}$ = Population mean

According to the report, the GAM values of traits were also classified as, if less than 10% = low, between 10-20% = moderate and if greater than 20% = high. The GAM values ranged from 3.05% for days to maturity to 55.18% for lodging index. The highest GAM values record from lodging index and biological yield with the magnitude of 55.18% and 23.55% respectively whereas moderate values were observed for grain yield, lodging index, plant height and panicle length with values of 13.48, 13.93, 18.02 and 18.76% individually while for days to maturity, days to seed emergence, plant stand and days to heading had lowest GAM values with the magnitude of 3.05, 4.08, 6.06 and 9.06%, respectively. In general, the grain yield, plant height, panicle length and biological showed moderate to highest PCV, GCV, h^2 and GAM values which revealed the highest genetic control on those traits among the genotypes. Comparable findings were reported by Bogale[12] and Bayable *et al.*[22] that moderate heritability values were observed for panicle length, grain and biological yield and days to maturity. The overall result exposed the existence of higher phenotypic variability interims of plant morphology; phenology and yield attributed traits and genotypic variation among the genotypes indicated the possibility of enhancing the production and productivity of *tef* through the identification and hybridization via breeding with the agreement of reported by Jifar *et al.*[29].

Associations of the traits: The phenotypic and genotypic correlation coefficients among pairs of traits were computed from the element of variance and co variances as stated by Singh and Chaudhary[34] and presented in (Table 5) which revealed that days to heading exhibited a positive significant ($p<0.01$) association with grain yield (r_g = 0.334 and r_p = 0.212) at the genotypic and phenotypic levels which is similar with the previous study reported by Abrha *et al.*[11]. Likewise plant stand and biological yield showed positive and significant association with grain yield at the phenotypic and genotypic levels (r_p = 0.375 and r_g = 0.505) respectively. Both at the phenotypic and genotypic levels traits also showed positive and significant correlations with biological yield including days to heading (r_p = 0.246 and r_g = 0.413), days to maturity (r_p = 0.277 and r_g = 0.488), plant stand (r_p = 0.375 and r_g = 0.205), plant height (r_p = 0.529 and r_g = 0.366) and panicle length (r_p = 0.528 and r_g = 0.308). Days to heading also significantly and positively associated at the genotypic and phenotypic levels, respectively with days to maturity (r_g = 0.595 and r_p = 0.368) and plant height (r_g = 0.628 and r_p = 0.506). The positive association possibly showed the existence of shared genetic elements that control the traits in a similar direction. This report harmonized

Table 5: Genotypic (above diagonal) and phenotypic below diagonal correlations of ten traits of *tef*

Variable	DE	DH	DM	PH	PL	LI	Pst	LR	BY	GY
DE	1	0.093	-0.216	-0.109	-0.18	-0.019	-0.235	0.132	-0.037	0.023
DH	0.298***	1	0.375**	0.628***	0.353*	-0.465***	0.143	-0.373**	0.413**	0.334*
DM	0.025	0.368***	1	0.595***	0.561***	-0.388**	0.131	-0.449**	0.488***	0.039
PH	0.123	0.506***	0.478***	1	0.830	-0.499***	0.206	-0.377***	0.366***	0.133
PL	-0.252***	0.091	0.158	0.569***	1	-0.374**	0.194	-0.244	0.308***	0.009
LI	0.174*	-0.213***	-0.343***	-0.279***	-0.174*	1	-0.282	0.661***	-0.129	-0.102
Pst	0.094	0.149	0.187**	0.237***	-0.039	-0.171*	1	-0.467***	0.205**	0.184*
LR	-0.043	-0.248**	-0.408***	-0.179*	0.167*	0.433***	-0.364***	1	-0.035	-0.051
BY	0.037	0.246***	0.277***	0.529***	0.528***	-0.219	0.375**	-0.244	1	0.049*
GY	0.05	0.212**	-0.004	0.107	-0.022	-0.287	0.097	-0.349*	0.236***	1

*Significant at 5 percent level, **Significant at 1 percent level, ***Significant at 0.1 percent level, ED: Days to 50% seed emergence, HD: Days to 50% heading, MD: Days to 50% maturity, PH: Plant height (cm), Pl: Panicle length (cm), LI: Lodging index (1-5 scale), Pst: Plant stand (0-5 scale), LR: Leaf rust (1-5 scale), BY: Biological yield (kg/ha) and GY: Grain yield (kg/ha)

with the reported by Lule and Mengistu[28] and Kearsey and Pooni[35] stated positive significant association due to the effect of genes can be the result of the existence of strong pairing linkage among their genes or the traits might be the effect of pleiotropic genes that control these traits in the similar ways. On the contrary even though non-significant, leaf rust and lodging index are negatively associated at the genotypic and phenotypic levels with biological and grain yield. Leaf rust also significantly and negatively correlated at the genotypic and phenotypic levels with days to heading (r_g = -0.373 and r_p = -0.248), days to maturity (r_g = -0.449 and r_p = -0.408), plant height (r_g = -0.377 and r_p = -0.179) and plant stand (r_g = -0.467 and r_p = -0.364). Lodging index is also significantly and negatively associated at the genotypic and phenotypic levels with plant height (r_g = -0.499 and r_p = -0.279), days to heading (r_g = -0.465 and r_p = -0.213), days to maturity (r_g = -0.388 and r_p = -0.343) and panicle length (r_g = -0.374 and r_p = -0.174) respectively which identified leaf rust and lodging index are the most impeding factor of grain yield and value including other yield attributed traits. This study was consistent with the previous finding reported by Lule and Mengistu[28] and Jifar *et al.*[29] in which plant height was highly significant and negatively associated with lodging index both at the genotypic and phenotypic levels.

CONCLUSION

The analysis of grain and biological yield, plant height and panicle length showed moderate to high PCV, GCV, h^2 and GAM values revealed substantial variability in yield and yield attributed traits among the genotypes. Results showed that the leaf rust and lodging index are the most important limiting factors in the grain yield and yield attributed traits in *tef*. The overall result of the study indicated the existence of higher genotypic and phenotypic variability of the crop revealed the possibility of enhancing the production and productivity of *tef* through selection and hybridization. DZ-Cr-453 RIL120B (Bora), DZ-Cr-458 RIL18 (Ebba) and DZ-01-3186 (Etsub) *tef* varieties are the most promising and recommended for farmers to be demonstrated and popularized in the study areas with their full packages.

SIGNIFICANCE STATEMENT

The purpose of this study was to estimate the genetic variance components and trait associations among the genotypes and direct imperative traits for production enhancement. This study significantly identified well-adapted varieties like Bora, Ebba, Etsub and recommended to be demonstrated and promoted for farmers to enhance productivity by contributing to the food security of the country. Yield and yield-associated traits were also identified.

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