

Yield Adaptability and Stability of Tef (*Eragrostis tef* (Zucc.) Trotter) Variety for Drought-Prone Areas of North Eastern Ethiopia

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Abstract: *The genotype by environment interaction influences the selection and recommendation of cultivars. Multi-environment varieties were conducted on 13 tef genotypes including the standard and local checks at Sirinka, Jari, Woleh and Alemketema in 2016 and 2017 main cropping seasons. The objective of the study was to identify stable and adaptable varieties for drought-prone areas of the eastern Amhara region. The experiment was laid out in a randomized complete block design with three replications. The combined analysis of variance revealed highly significant differences ($p < 0.01$) among genotypes, environment, and genotypes by environment interaction for grain yield and yield-related traits. The first four additive main effects and multiplicative interaction selections per environment indicated that DZ-01-354 x DZ-CR-37-131 has the top-performing genotypes in the grain yield throughout 8 environments. Genotype (DZ-01-354xDZ-CR-37-68) was the second-ranking genotype. Based on the view of the genotype by environment interaction biplot the two genotypes were the ideal genotypes in terms of high-yielding potential and stability compared to the rest of tested genotypes. Genotype DZ-01-354 x DZ-CR-37-131 gave the highest grain yield (2.31 tons per hectare) which had 18.4 % and 36.6% yield advantage over the standard and local check respectively. As a result, the candidate variety was verified and officially released by the national variety release committee in 2019 with the name Mena for production in drought-prone areas of Northeast Ethiopia and similar tef-producing areas.*

Keywords: Genotype by environment interaction, Moisture deficit, Stability, Tef genotypes and yield

INTRODUCTION

Teff [*Eragrostis tef* (Zucc.) Trotter] is a small cereal grain indigenous to Ethiopia. It has been recognized that Ethiopia is the center of origin and diversity of teff (Vavilov, 1951). It belongs to the grass family Poaceae and the genus *Eragrostis* (Ketema, 1993). Teff is the most important cereal grain of Ethiopia most probably domesticated thousands of years ago before the birth of Christ (Ketema, 1997).

In Ethiopia's system of producing food crops, tef is crucial. The crop, which takes up 22.56% (2,928,206.26 hectares) of the total cultivated land and is grown by nearly seven million farmers, ranks second in terms of total production after maize (CSA, 2021). Despite being a highly labor-intensive crop (Setotaw, 2013), tef production provides employment and a means of subsistence for an estimated 25–30 million people in Ethiopia, where it is grown by more than 43% of all farmers. Additionally, tef is the most commercialized crop in Ethiopia with approximately 36% of the total produced tef being marketed (Minten *et al.*, 2013). Amhara region is suitable for teff production in Ethiopia. In the region, among the total land area of 3,545,298 hectares planted by cereals, teff covered 1,086,374 hectares and obtained 2,096,462 tone grain productions (CSA, 2021). Among all the crops grown in the region, teff is the first major crop in area coverage.

A highly prized commodity, tef is mostly farmed for its grain, which is used to make injera, a staple meal for the majority of Ethiopians. Additionally, it can be utilized in a variety of other food items, including gruel, porridge, anebaberro (double-layered injera), tella, katikala, and various regional alcoholic beverages (Hailu *et al.*, 2017). Tef grain is a nutrient-dense grain that has 7–12 mg of proteins, 11–33 mg of iron, 100–150 mg of calcium, 401 mg of potassium, and 375 mg of phosphorous (National Academy of Sciences, 1996). According to (Asrat, 2019) tef' carbohydrate content varies between 72.1% and 75.2%. Tef is useful for making dietary items for persons who are gluten sensitive because it doesn't contain gluten (Kebede, 2021).

Tef has continued to be a significant crop for Ethiopian farmers for a number of reasons, including its higher grain and straw prices compared to other major cereals, its superior performance in conditions of moisture stress and flooding, and its ability to withstand weevil attacks for an extended period of time in storage. Tef' productivity is extremely low despite its significance; the national and regional (Amhara) averages are 1.87 and 1.93 tons per hectare, respectively (CSA, 2021). Moisture stress (inadequate, irregular, and uneven rainfall), lodging, low soil fertility, insect pests such as tef shoot flies, and a dearth of high-yielding cultivars are some of the factors causing the low tef yield (Assefa *et al.*, 2011). Tef is a relatively drought-tolerant crop compared to other cereal crops. However, about 25.5 to 51% grain yield reductions have been reported for tef due to moisture stress (Admas and Belay, 2011; Bacha, *et al.*, 2012). Yihun *et al.*, (2013) also reported one ton ha⁻¹ grain yield reduction due to a 25% soil moisture deficit at the mid-growth stage of the crop. Therefore, there is a need to develop improved tef varieties for moisture deficit areas following the breeding procedures. The objective of this study was to identify high-yield and adaptable tef varieties for drought-prone areas of the eastern Amhara region.

MATERIALS AND METHODS

Description of the testing sites

The field experiment was conducted in the 2016-2017 main cropping seasons in four locations representing the major tef growing moisture deficit areas of the Eastern Amhara region (Table 1), namely Sirinka, Jari, woleh and Alem ketema research stations. They are found in the North Wollo zone, South Wollo zone, Wagehumera zone and North Shewa, respectively.

Table1: Descriptions of the testing areas

Location	Altitude in m.a.s.l	Soil type	Annual Rain fall in mm	Temperature		Global position	
				Min	Max	Latitude	longitude
Sirinka	1850	Eutric vertisol	980	13	27	11 ⁰ 08' N	39 ⁰ 28'E
Jari	1680	Vertisol	1015	15	26	11 ⁰ 21' N	39 ⁰ 28'E
Woleh	2000	Vertisol	830	8	25	12 ⁰ 35' N	39 ⁰ 05' E
Alem ketema	1905	Vertisol	943	16	28	10 ⁰ 45' N	39 ⁰ 15'E

Source: Sirinka Agricultural research Center and Wikipedia for global position

Planting materials and experimental design

13 genotypes including the standard and local checks (Table 2) were evaluated in a randomized complete block design with three replications in a plot size of 4m². Sowing was done from the 16th to the 23rd of July at all locations when sufficient rain was received. A seed rate of 15 kg ha⁻¹ was broadcasted. Urea (46%N) and NPS (19%N, 38% P, 7% S) were applied at 41 kg ha⁻¹ and 121 kg ha⁻¹ respectively. All the NPS and half of urea were applied at planting while the remaining half was applied at tillering. Weeding was conducted at least three times depending on the level of weed Infection.

Data collection and statistical analysis

Data on days to heading, days to maturity, plant height, panicle length, shoot biomass and grain yield were collected. Analyses of variance for collected data were performed using the general statistics (Gen Stat) program version 18. The combined analysis of variance across the environment was done to determine the differences between genotypes across environments, among environments and their interaction. Bartlett's test of error variances was performed before the combined analysis of variance over environments (years and locations). Mean comparisons for significant differences in the analyses of variance were made using the Denken multiple range test (DMRT).

AMMI and GGE biplot of GxE analysis were performed for grain yield using GenStat software. The grain yield data were also graphically visualized to interpret GEI using the GGE-biplot and AMMI software.

RESULTS AND DISCUSSION

The combined analysis of variance across eight environments revealed a highly significant ($p < 0.01$) variation for genotypes, environments, and genotype by environment interaction for grain yield and some related traits of the genotypes (Table 2). In 2016 and 2017 the combined analyses of variance showed that there were significant differences ($p < 0.01$) among genotypes for all parameters. Environment by genotype interaction revealed highly significant variation ($p < 0.01$) only for grain yield. Similar significant results were reported for most traits in earlier studies (Belete *et al.*, (2015); Fiker (2016) and Jifar *et al.*, (2017).

The presence of variations among genotypes for the traits indicates a higher chance of improving the crop through selection.

Genotypes' average yield performance varied from 1.658 tone ha⁻¹ to 2.321 tone ha⁻¹ across all environments. G1 (DZ-01-354 x DZ-CR-37-68) and G6 (DZ-01-354 x DZ-CR-37-131) were the genotypes that performed the best in terms of grain yields, producing 2.22 and 2.321 tones ha⁻¹, respectively. The candidate (G6) produced a grain yield of 2.321 tone ha⁻¹, which is comparable to the yield of the varieties previously released for the eastern Amhara region (Solomon *et al.*, 2014). The highest yield genotype (G6) demonstrated grain yield advantages of 30.4% and 35.7% over the standard and local check, respectively.

Genotype, environment and their interaction are important in governing the expression of different traits. The genotypes were not consistent across eight environments. Thus, such inconsistency yields ranging from environment to environment indicating the presence of possible cross-over GEI described by Menesesha (2003) and Crossa (1990). This study agrees to cross over the GEI reports of Asfaw *et al.*, (2008); Mohamed, (2013) and Kebede *et al.*, (2020) in the different crops.

Table 2. The combined mean grain yield and yield related traits of tef genotypes in 2016 and 2017 Sirinka, Jari, Woleh and Alemketema.

No.	Name/pedigree of the testing genotypes	Days to heading	Days to maturity	Plant height (cm)	Panicle length(PL) (cm)	Shoot biomass (kgha ⁻¹)	Grain yield (kgha ⁻¹)
1	DZ-01-354xDZ-CR-37-68	46.12 ^{bc}	87 ^{cde}	93.71 ^a	36.08 ^{de}	9249 ^a	2220 ^b
2	DZ-01-354x DZ-CR-37-79	45.67 ^b	85 ^{ab}	93.97 ^a	38.01 ^{a-d}	8786 ^{ab}	1934 ^c
3	DZ-01-354xDZ-CR-37-78	44.75 ^{ab}	85 ^{ac}	89.84 ^{ab}	36.16 ^{de}	8686 ^{ac}	1824 ^{cd}
4	DZ-01-354xDZ-CR-37-787	43.75 ^a	84 ^a	90.58 ^{ab}	36.27 ^{de}	8604 ^{a-c}	1762 ^{de}
5	DZ-01-354xDZ-CR-37-125	47.54 ^{cd}	87 ^{b-e}	86.6 ^b	35.93 ^{de}	8586 ^{a-c}	1872 ^{cd}
6	DZ-01-354xDZ-CR-37-131	48.17 ^d	88 ^{de}	92.73 ^a	38.99 ^{ab}	8538 ^{ac}	2321 ^a
7	DZ-01-354xDZ-CR-37-134	45.62 ^b	87 ^{b-e}	90.96 ^{ab}	38.12 ^{a-d}	8520 ^{a-d}	1817 ^d
8	DZ-01-354xDZ-CR-37-187	44.83 ^{ab}	84 ^a	89.76 ^{ab}	36.58 ^{cde}	8138 ^{b-d}	1855 ^{cd}
9	DZ-01-354xDZ-CR-37-193	46.5 ^{b-d}	86 ^{b-d}	93.06 ^a	38.77 ^{a-c}	8036 ^{b-d}	1852 ^{cd}
10	DZ-01-354xDZ-CR-37-200	45.71 ^b	86 ^{bcd}	92.08 ^a	37.01 ^{b-e}	7977 ^{bcd}	1846 ^{cd}
11	DZ-01-354xDZ-CR-37-208	44.88 ^{ab}	85 ^{ab}	90.96 ^{ab}	37.29 ^{b-e}	7977 ^{bcd}	1710 ^e
12	Werekuyu (standard check)	45.83 ^{bc}	87 ^{ab}	92.77 ^a	39.68 ^a	7760 ^{cd}	1689 ^e
13	Local check	46.04 ^{bc}	89 ^e	89.26 ^{ab}	35.29 ^c	7622 ^d	1658 ^e
	Mean	46	86	91	37	83.45	1874
	CV (%)	6.2	3.8	7.7	9.8	16.5	9.3
	E	**	**	**	**	**	**
	Y	Ns	**	**	Ns	**	**
	G*E	Ns	Ns	Ns	Ns	ns	**
	G*Y	Ns	Ns	Ns	Ns	ns	**
	E*Y	**	**	**	Ns	**	**
	G*E*Y	Ns	Ns	Ns	Ns	ns	ns

*Significant at 5% probability level, **Significant at 1% probability level, ns=non –significant.

Stability analysis

Genotypes selection by AMMI model

Multi-location trials are important for selecting the best genotype for wide or specific environments before any recommendation of genotypes for future production. The four best tef genotypes selected by the AMMI model for each environment are shown in Table 3. In this study, genotypes reacted differently to environmental fluctuation (have high GEI), as a result, the best AMMI model allows the selection of relatively better genotypes that suit a specific environment. The positive and negative IPCA-1 scores revealed favorable and unfavorable environments. Thus, Alem Ketema (2016) and (2017), Sirinka (2016) and Woleh in (2017) had a positive IPCA-1 score and high mean yield in favorable environments.

Conversely, in unfavorable conditions, Jari (2016) and (2017), Sirinka (2017), and Woleh (2016) had low mean yields below the grand mean and negative IPCA-1 scores. Candidate Genotype DZ-01-354 x DZ-CR-37-131 (G6) had the best grain yield across eight environments, according to the first four AMMI selections per environment (Table 3). G1's DZ-01-354xDZ-CR-37-68 genotype is ranked second. The fact that genotype DZ-01-354 x DZ-CR-37-131 (G6) was chosen in more environments than other genotypes suggests that it can adapt to the majority of test sites.

Table3. The AMMI model's best four tef genotypes selection for grain yield per environment

Environments	Mean grain yield kg/ha ⁻¹	IPC Ac 1 Score	The first four AMMI selected genotypes			
			1	2	3	4
Alemketema 2016	2582	24.07	G1	G6	G3	G8
Alemketema 2017	2103	5.709	G1	G6	G10	G2
Sirinka 2016	1814	3.476	G6	G1	G2	G8
Woleh 2017	1075	2.338	G6	G1	G2	G8
Jari 2016	1400	-0.901	G6	G1	G2	G9
Sirinka 2017	2101	-6.063	G6	G9	G13	G1
Jari 2017	1325	-10.434	G6	G9	G1	G11
Woleh 2016	2086	-18.196	G11	G10	G6	G1

AMMI analysis of variance

The result for the additive main effects and multiplicative interaction (AMMI) model across the eight test environments is shown in Table 4. The mean squares for genotypes, environments, and GEI were very significant ($P < 0.001$), according to the AMMI analysis of variance for grain yield (kg ha⁻¹). In line with earlier findings by Solomon *et al.* (2008); Issa (2009) and Jifar *et al.* (2019), the bigger sum of a square and highly significant mean squares of environments showed that the environments were diverse.

The significant genotype by environment interaction effect was further partitioned into two interaction principal component axis (IPCA). The results of AMMI analysis showed highly significant ($P < 0.001$)

differences for the first three interaction principal component axis (IPCA). The first interaction principal component (IPCA1) captured 34.47 % the second (IPCA2) 32.38 % and the third (IPCA3) captured further explained 22.57 % and the three interaction principal components cumulatively explained 89.42 % of the genotype by environment interaction sum of a square and the rest 10.38 % was contributed due to noise.

According to Gollob (1968), the IPCA4 was non-significant, but the F-test of the three interaction main components was significant ($P < 0.001$). Consequently, the AMMI-1 that solely used the three interaction principal component axis was the most effective grain yield prediction model. This aligns with the findings of Annicchiarico (2002). The fourth interaction principal component axis did not aid in the prediction of reliable observations and primarily collected noise. Therefore, the three interaction main components were the best able to predict the interaction of the 13 genotypes with eight environments.

Table 4. Additive main effects and multiplicative interaction (AMMI) analysis of variance for grain yield (kg ha^{-1}) of 13 tef genotypes evaluated at eight environments in during 2016 and 2017 cropping season

Source	DF	SM	MS	Sum of squares % explained		
				Total	GEI	GEI cum.
Genotypes (G)	12	6437490	536457***	7.42	-	-
Environments (E)	7	69688901	9955557***	80.28	--	-
(GXE) Interactions	84	10672845	127058***	12.30	-	-
IPCA 1	18	3678519	204362***	-	34.47	34.47
IPCA 2	16	3456355	216022***	-	32.38	66.85
IPCA 3	14	2408551	172039***	-	22.57	89.42
IPCA 4	12	662030	55169 ns	-	6.20	95.62
Residuals	24	467389	19475 ns	-	-	-
Error	192	7204376	37523	-	-	-
Total	311	95487576	307034	-	-	-

***Significant at $P\text{-value} \leq 0.001$. Ns: Non-significant, IPCA: interaction principal component axis, GEI: genotype by environment interaction explained, GEI cum.: GEI cumulative, SS: sum of squares, MS: mean square.

Mean performance and stability of genotypes

The first principal components (IPCA2) and main effects of both genotypes and environments are shown in a biplot (Fig. 1) of the AMMI analysis. Grain yield was below average for the genotype and environment on the left side of the ordinate and above average for those on the right. Consequently, above-average grain yield (1874 kg ha^{-1}) was produced by genotypes G6.G1, G2, G5, and G10. Conversely, low-yielding genotypes included G13, G3, G8, G11, and G4. Environments with above-average grain yielding, such as Alemketema (2016 and 2017), Woleh (2016), and Sirinka (2016 and 2017), are considered high-yielding prospective environments. This outcome is consistent with Jifar *et al.*, (2019) earlier findings in tef.

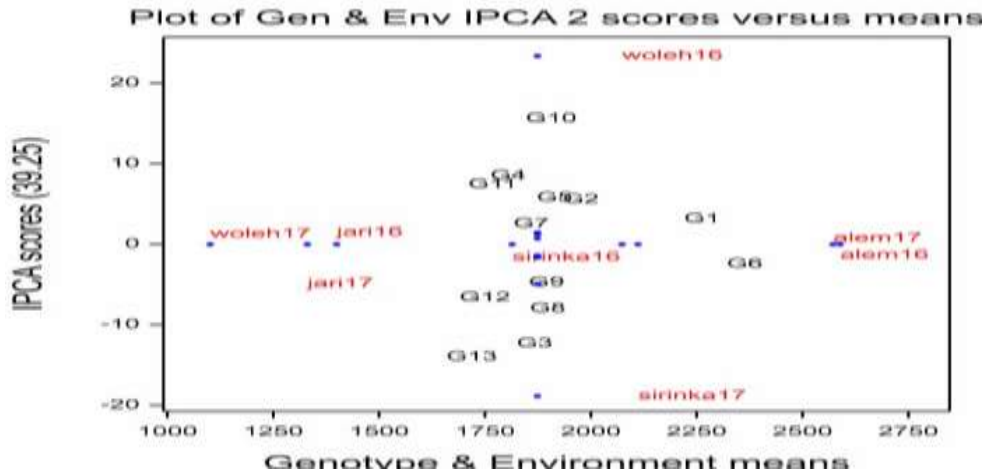


Figure.1 The mean performance and stability view of the GGE biplot of 13 tef genotypes at eight environments.

Which-Won-Where pattern and mega-environment identification

One of the most important properties of the GGE biplot is its ability to show the which-won-where pattern and mega environment differentiation from the genotype by environment interaction and hence is a concise summary of the $G \times E$ pattern of a multi-environment trials data set (Abakemal *et al.*, 2016). A mega environment is a group (cluster) of locations or environments that constantly share the same best/winning genotype. Therefore, in order to prevent the random GEI, genotype evaluation in a mega-environment should be based on both mean performance and stability. Since the genotypes on the polygene's vertex were the furthest from the biplot origin, they either performed the best or the worst in one or more regions.

In this investigation, the vertex genotypes were G11, G3, G1, and G6 (fig 2). Accordingly, the first mega environment contains the test environment Sirinka (2016 and 2017), Jari (2016 and 2017) and Woleh (2016 and 2017) which had the genotype 6 as the winner. The second mega environment contains Alemketema (2016 and 2017) with G1 as the best yielding. The vertex genotypes G3 and G11 were not the top-yielding genotypes in any environment (Fig.2). Nida *et al.* (2016) and Al-Naggar *et al.* (2018) are authors who used the GGE bi-plot to identify mega environments to evaluate the genotypes and to test the environments in tef and sorghum.

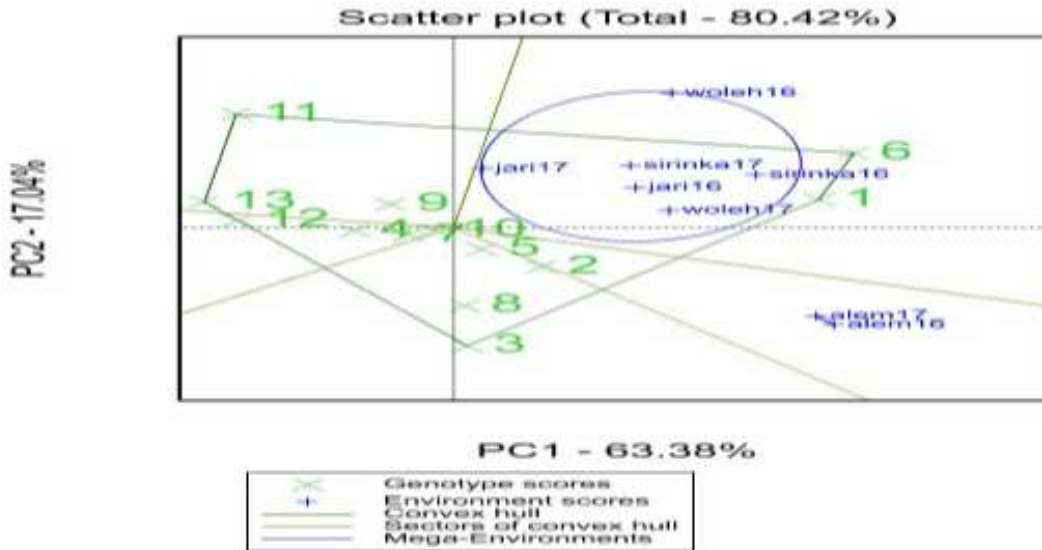


Figure 2. Polygon view of the GGE biplot shows the which-won where for 13 tef genotypes over eight test environments

Ranking genotypes relative to the ideal genotype

Environment and genotypes that fall in the central (concentric) circle are considered ideal environment and stable genotypes, respectively (Abakemal., 2016). Both environments-focused biplot and genotype-focused comparison of genotypes revealed that genotype DZ-01-354xDZ-CR-37-131(G6) fell in the central circle, was the ideal genotype interims of higher-yielding potential and stability compared to the rest of genotypes evaluated in this study (Fig 3). The remaining genotypes like, G1, G10, G7 and G4 were situated in the next concentric circle and may be regarded as desirable.

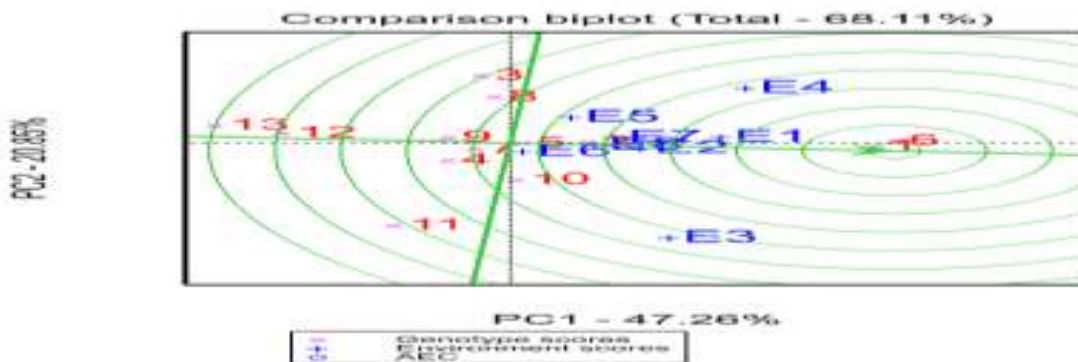


Figure3. GGE- biplot based on genotype-focused scaling for comparison the genotypes with the ideal genotype

Ranking environments relative to the ideal environment

Similarly to the ideal genotype, the best environment is founded in the first concentric circle in the environment-focused biplot (Fig 4). Desirable environments are close to the best environment. Accordingly, nearest to the first concentric circle, the environment Sirinka (2016) followed by Alem ketema (2016) was the ideal environment to select widely adapted tef genotypes, whereas Woleh (2016 and 2017), Sirinka (2017) and Jari (2017) were far from the ideal environment and considered as unstable.

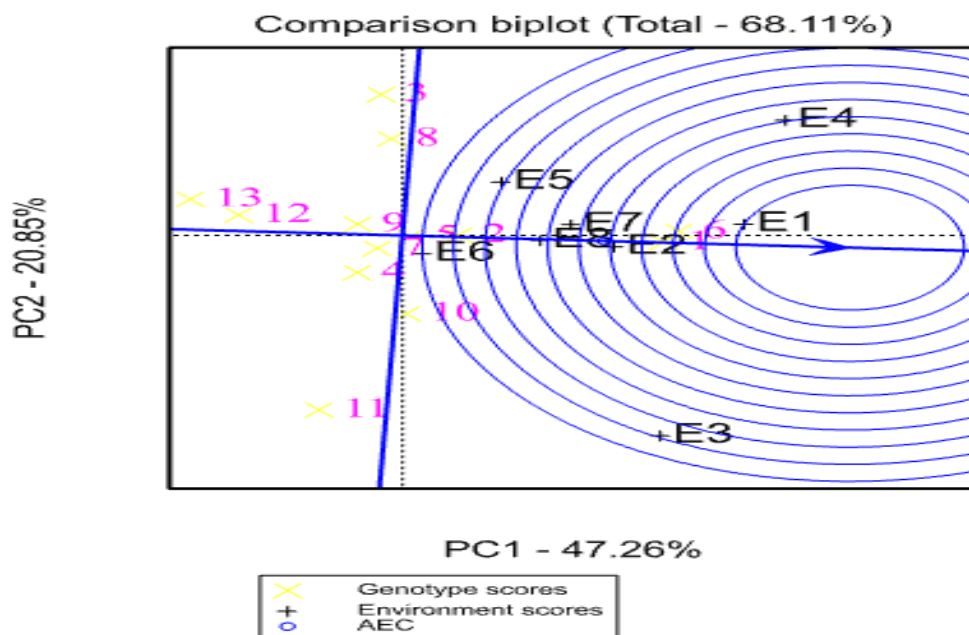


Figure 4. GGE- biplot based on environment -focused scaling for comparison the environment with the ideal environment Where E1 ,2016 & E5,2017 = Sirinka , E2 ,2016 & E6,2017 = Jari, E3 ,2016 & E7,2017 = Woleh, E4 ,2016 & E8,2017 = Alemketema

Table 5. Distinguishing phenologic, morphological and agronomic characteristics the candidate variety

Qualitative traits		Description	
1	Basal stalk color	Yellowish Green	
2	Panicle form	Loose	
3	Lemma color	Yellowish green when immature and White when mature	
4	Anther color	White	
5	Seed color	Very white	
Quantitative traits		Minimum	Maximum
1	Days to heading	46	50
2	Days to maturity	84	95
3	Grain filling period (days)	42	40
4	Plant height (cm)	77	110
5	Panicle length (cm)	32	41
6	Biomass yield (tone)	7.2	9.8
7	Grain yield (tone)	2.1	3.2
8	Harvest index %	2.9	27

DZ-01-354xDZ-CR-37-131

CONCLUSION AND RECOMMENDATION

Genotype-by-environment interaction has a key effect on crop variety development by complicating the release of varieties across challenging environments. Analysis of variance for every individual location and combined over locations showed significant differences among genotypes, environments, and genotypes x environments interaction (GEI) for grain yield and most of the yield-related traits. The significant genotypes x environments interaction effects indicated the inconsistent performance of genotypes across the tested environments. 80.28% of the total (G + E +GE) variation was explained, whereas G and GE explained 7.42 % and 12.30% of the total variation, respectively. The magnitude of the environment was 10.8 times greater than the genotype, implying that most of the variation in grain yield was due to the environment. The significant genotype by environment interaction effect was further partitioned into three interactions principal component axis (IPCA). The results of AMMI analysis showed highly significant ($P < 0.001$) differences for the first three interaction principal component axis (IPCA). The three interaction principal components cumulatively explained 89.42% of the genotype by environment interaction sum of a square and 10.58% was contributed due to noise.

Based on AMMI stability and GGE biplot analysis revealed that the candidate genotypes, namely DZ-01-354xDZ-CR-37 and DZ-01-354x DZ-CR-37-131 are stable, average grain yield of 2.3 tones ha⁻¹ was obtained and high yielding advantage over the local and standard check. That variety was evaluated by the national variety release committee with farmers and researchers. Finally, DZ-01-354x DZ-CR-37-131 has been officially released with the vernacular name Mena for production in moisture deficit areas of the eastern Amhara region and similar agro ecologies of the country.

REFERENCES

- Abakemal, D., Shimelis, H., & Derera, J. (2016). Genotype-by-environment interaction and yield stability of quality protein maize hybrids developed from tropical-highland adapted inbred lines. *Euphytica*, 209, 757-769.
- Admas, S., & Belay, G. (2011). Drought-resistance traits variability in Eragrostis tef X Eragrostis pilosa recombinant inbred lines. *African Journal of Agricultural Research*, 6(16), 3755-3761.
- Al-Naggar, A. M. M., Abd El-Salam, R. M., Asran, M. R., & Yaseen, W. (2018). Yield adaptability and stability of grain sorghum genotypes across different environments in Egypt using AMMI and GGE-biplot models. *Annual Research & Review in Biology*, 23(3), 1-16.
- Annicchiarico, P. (2002). Genotype x environment interactions: challenges and opportunities for plant breeding and cultivar recommendations..
- Asfaw Adugna, A. A. (2008). Assessment of yield stability in sorghum using univariate and multivariate statistical approaches. Asrat, W., & Frew, T. (2001). Utilization of tef in the Ethiopian diet, pp. 239-244. In Hailu Tefera, Getachew
- Asrat Yasin, U. (2019). *Effect of blending ratio and natural fermentation time on the qualities of injera prepared from quality protein maize and teff flours* (Doctoral dissertation, Haramaya University).
- Assefa, K., Chanyalew, S., & Metaferia, G. (2011, November). Conventional and molecular tef breeding. In *Achievements and prospects of tef improvement, Proceedings of the second international workshop* (pp. 33-51).
- Balcha, W. S. A., & Mohammed, H. (2012). Evaluation of drought tolerance indices in Tef [Eragrostis tef (Zucc.) Trotter]. *African Journal of Agricultural Research*, 7(23), 3433-3438.
- Belete, T., Mathewos, T., & Daba, G. (2020). Correlation of yield and yield related traits of Tef (Eragrostis tef (Zucc.) Trotter) varieties in Ethiopia. *Journal of Genetic and Environment Conservation*, 8(3), 35-39
- Crossa, J. (1990). Statistical analysis of multilocation trials *Advances in Agronomy* 44: 55-85. *Mexico DF, Mexico*.
- CSA (Central Statistical Agency). (2020/2021). Crop production forecast sample survey. Report on Area and Crop Production forecast for Major Crops (for private Peasant Holdings 'Meher' season). Addis Ababa, Ethiopia.
- Fikre, T., Tesfaye, K., & Assefa, K. (2018). Genetic diversity of Ethiopian tef [(Eragrostis tef (zucc.) trotter] released and selected farmers' varieties along with two wild relatives as revealed by microsatellite markers. *Journal of Crop Science and Biotechnology*, 21, 367-374.
- Gauch, H. J. (1992). *Statistical analysis of regional yield trials: AMMI analysis of factorial designs* (pp. xi+-278).
- Gollob, H. F. (1968). A statistical model which combines features of factor analytic and analysis of variance techniques. *Psychometrika*, 33(1), 73-115.
- Hailu, G., Weersink, A., & Minten, B. (2017). Determinants of the productivity of teff in Ethiopia. *The European Journal of Development Research*, 29, 866-892.
- Issa, A. B. (2009). Genotype by environment interaction and yield stability of maize hybrids evaluated in Ethiopia.

- Jifar, H., Assefa, K., Tesfaye, K., Dagne, K., & Tadele, Z. (2019). Genotype-by-environment interaction and stability analysis in grain yield of improved tef (*Eragrostis tef*) varieties evaluated in Ethiopia. *Journal of experimental agriculture international*, 35(5), 1-13
- Jifar, H., Tesfaye, K., Assefa, K., Chanyalew, S., & Tadele, Z. (2017). Semi-dwarf tef lines for high seed yield and lodging tolerance in Central Ethiopia. *African Crop Science Journal*, 25(4), 419-439.
- Kebede, W. (2021). Quality traits; measurement and possible breeding method to improve the quality traits of tef [*Eragrostis tef* (Zucc.) Trotter]. *International Journal of Novel Research in Life Sciences*, 8, 29-40
- Kebede, W., Genet, Y., Fikre, T., Tolosa, K., Chanyalew, S., Demissie, M., ... & Tadele, Z. (2020). Tef (*Eragrostis tef*) variety development for moisture stress areas of Ethiopia. *Journal of Innovative Agriculture*, 7(4), 1-6.
- Ketema, S. (1997). *Tef-Eragrostis tef* (Zucc.) (Vol. 12). Bioversity international..
- Ketema, S.. (1993). Tef [*Eragrostis tef* (Zucc.) Trotter]. Breeding, Genetic Resources, Agronomy, Utilization and Role in Ethiopian Agriculture. Institute of Agricultural Research, Addis Ababa, Ethiopia.
- Minten, B., Tamru, S., Engida, E., & Kuma, T. (2013). Ethiopia's value chains on the move: The case of teff. *Ethiopia Strategy Support Program II Working Paper*, 52, 1-26.
- Mohamed, N. E. (2013). Genotype by environment interactions for grain yield in bread wheat (*Triticum aestivum* L.). *Journal of Plant Breeding and Crop Science*, 5(7), 150-157.
- National Research Council, Policy, Global Affairs, Office of International Affairs, Board on Science, & Technology for International Development. (1996). *Lost crops of Africa: volume I: grains* (Vol. 1). national academies press.
- Nida, H., Seyoum, A., Gebreyohannes, A., & Gebreyohannes, A. (2016). Evaluation of yield performance of intermediate altitude sorghum (*Sorghum bicolor* (L.) Moench) genotypes using genotype x environment interaction analysis and GGE biplot in Ethiopia. *International Journal of Trend in Research and Development*, 3(2), 27-35.
- Solomon Admassu, S. A., Mandefro Nigussie, M. N., & Habtamu Zelleke, H. Z. (2008). Genotype-environment interaction and stability analysis for grain yield of maize (*Zea mays* L.) in Ethiopia.
- Solomon, A., Mulugeta, M., & Fiseha, W. (2014). Evaluation of the genotypes in the moisture Stress areas of Eastern Amhara proceedings of the 6th and 7th annual regional conference on Completed crop research Activities. Amhara Agricultural Research Institute Bahir Dar, Ethiopia
- Tefera, H., Assefa, K., Hundera, F., Kefyalew, T., & Teferra, T. (2003). Heritability and genetic advance in recombinant inbred lines of tef (*Eragrostis tef*). *Euphytica*, 131(1), 91-96.
- Jeffrey, J. (2015). Will Ethiopia's teff be the next 'super grain'? BBC, London.
- Vavilov, N. I. (1951). *The origin, variation, immunity and breeding of cultivated plants* (Vol. 72, No. 6, p. 482). LWW.
- Yihun, Y. M., Haile, A. M., Schultz, B., & Erkossa, T. (2013). Crop water productivity of irrigated teff in a water stressed region. *Water resources management*, 27, 3115-3125.