GGE Biplot analysis and agronomic performance of tef genotypes in moisture deficit stress areas of eastern Amhara Regional State

Sewagegne Tariku,[1] Atinkut Fentahun[1], Gedefaw Misganaw[1], Atalay Fentahun[1], Tesfaye Alemayehu[2], Abiy Legesse [3]and Solomon Mitiku[4]

[1]Adet Agricultural Research Center, [2] Sekota Dryland Agricultural Research Center [3]Debre Berhane Agricultural Research Center [4]Sirinka Agricultural Research Center

ABSTRACT

Moisture deficit stress, as a recurrent phenomenon in eastern Amhara Regional State, has constrained tef productivity. This necessitates the development of moisture deficit stress tolerant varieties. The objective of the present study was to identify and recommend higher yielding genotypes for wide and/or specific adaptation in moisture deficit stress areas. Sixteen tef genotypes, bred for moisture deficit stress conditions, were evaluated at Sirinka, Simada, Shewarobit and Sekota in 2014 and 2015. The study was laid out in RCBD with three replications. The combined analysis of variance showed that the environment, genotype, and genotype by environment interaction were significant ($p<0.05$) for yield and yield related parameters. The highest grain yield (2.73 t ha^{-1}) was recorded by G1 followed by G7 (2.52 t ha^{-1}). The first two principal components, IPC1 and IPC2, accounted for 74.63% and 12.91% of the total variation, respectively. G1 was the best genotype at Simada, Shewarobit and Sekota while G11 was the best at Sirinka. Visualizing the mean and stability parameters of the genotypes, G1 had both high grain yield and stability and can be categorized for wide adaptation while G5, G7, G9 and G11 had high mean performance but low stability, and can be categorized for specific adaptation. The remaining genotypes exhibited low mean grain yield and low stability in which they adapted nowhere in the test locations. According to the ideal-genotype biplot, G1 followed by G7 were the most desirable genotypes. These were, thus, promoted to variety release verification, and G1 was officially released with the vernacular name "Hiber-1" for production in moisture deficit stress tef growing areas of eastern Amhara Regional State.

Keywords: Early maturing variety, gluten free, ideal location, stability categories, which-won-where pattern analysis

INTRODUCTION

Tef [(Zucc.) Trotter] is a staple food crop for over 50 million people in Ethiopia and its straw is also a valuable source of livestock feed (Assefa . 2013). Ethiopia is the center of diversity and origin of tef (Vavilov, 1951) and its cultivation has been sustained for centuries because of its merits in husbandry and utilization (Ketema, 1993). The cultivation of tef as a food grain has largely been restricted to Ethiopia. However, in recent years tef has been receiving global attention as healthy food since it is gluten free and rich in nutrients (Spaenij-Dekking 2005).

Tef has a wide range of ecological adaptation in Ethiopia. It can be cultivated from sea level up to 3000 meter above sea level (masl) under various rainfall, temperature and soil regimes; however, its best performance occurs between 1800 to 2200 masl. (Ketema, 1997). The annual rainfall requirement of the crop for optimum yield is in the range of 950 to 1500 mm while moderate yields are still produced under conditions of low rainfall, in the range of 450 to 550 mm (Ketema, 1997). It is adapted to temperatures ranging from 10 to 27 °C and performs best with day lengths of 12 h.

Among the cereal crops cultivated in Amhara Regional State, tef ranks first with estimated area coverage of over one million hectares and involving more than 2.5 million smallholder households (CSA, 2018). However, the productivity of the crop is relatively low. Its overall regional average grain yield is about 1.7 t ha^{-1} while in moisture stressed areas of the region it is about 1.3 t ha^{-1} (CSA, 2018) although it has the genetic potential to yield up to 6 t ha^{-1} (Ketema, 1993). The low productivity of tef is mainly attributed to its susceptibility to lodging, poor pre- and post-harvest agronomic practices and moisture stresses (Ketema , 1997; Assefa . 2011). In eastern part of the Amhara Regional State where moisture stresses is a recurrent phenomenon (Mohamed . 2017), tef takes the lion's share in terms of area coverage (about 0.21 million hectares) and in the number of households involved in tef production (about 0.7 million) as compared with the other cereal crops (CSA, 2018).

Different authors have emphasized the negative impact of moisture stress on tef productivity at different growth stages. Mengiste . (2013) reported one t ha^{-1} grain yield reduction due to 25% soil moisture deficit at mid growth stage of the crop. Similarly, 25.5% and 51% grain yield reduction caused by moisture stress was reported during pre-and post-anthesis period, respectively (Shiferaw . 2012). Yield losses of tef due to low moisture are estimated to reach up to 40% during severe stress (Ayele, 1993). The negative impact of moisture stress implies that by improving tef productivity in moisture stress areas of eastern Amhara Regional State, it would be possible to bring a difference in supporting the food self-sufficiency program in the region.

Taking moisture stress as the major constraint in tef productivity, developing moisture stress tolerant varieties with high yield potential is one of the major objectives of the national tef breeding program (Assefa . 2011). Accordingly, varieties have been released nationally for moisture stress areas. However, most of them have limited adoption because of their poor grain yield performance despite their early maturity. Some of the recently released tef varieties such as Abola (Quncho *Kaye Murri code1), Estub (DZ-01-3186), Quncho [DZ-Cr-387(RIL-355)] and Kora [DZ-Cr-438 (RIL No. 133B)] are suitable for areas with optimum moisture but do not perform well in moisture limited and variable rainfall conditions. This indicates the need to develop improved varieties which can give reasonably higher grain yield, early maturing and stable in order to sustain productivity and production of tef in the moisture stress areas. To this end, proper evaluation of tef genotypes in a multi-environment trial is of a paramount importance.

The sensitivity of crops to environmental variations frequently results in significant genotype (G) by environment (E) interaction (GEI). The large GEI usually impairs the accuracy of yield estimation and reduces the relationship between genotypic and phenotypic values. The detection of GEI has led to the development of different statistical models to describe GEI. Genotype plus genotype by environment interaction biplot (GGE biplot) analysis is one of the multivariate statistical models for graphical display of GEI pattern of multi-environment trials' (MET) data with many advantages (Yan . 2000). It is an effective tool for mega-environment analysis, and genotype and environmental evaluation. It has been proposed that GGE biplot analysis was a useful method for the analysis of GEI and had been exploited in the variety evaluation of wheat (Yan . 2000), maize (Fan 2007) , rice (Balestre . 2010) and tef (Habte .,2019). Therefore, this study was conducted to identify and recommend higher yielding genotypes for wide and/or specific adaptation in moisture deficit stress areas.

MATERIALS AND METHODS

Description of Test Locations

The study was conducted at Sirinka, Simada, Shewarobit and Sekota in 2014 to 2015. These test locations are selected for they are representative for moisture deficit areas in the eastern Amhara Regional State. The location-year combinations represent eight environments. The geographic coordinate, altitude, average annual total rainfall, annual average minimum and maximum temperatures, and soil types of the test locations are indicated in Table 1.

Table 1. Agro-ecological descriptions of the test locations

Location	Latitude	Longitude	Altitude (masl)	Mean annual rainfall (mm)	Mean temperature (^{0}C)		Soil type
					Maximum	Minimum	
Sirinka	11^0 45'N	39^0 36'E	1850	876	32	21	Nitosols
Simada	11^0 51'N	38^0 01'E	1950	950	28	10	Nitosols
Shewarobit	$10^{\ 0}$ 0 'N	39^0 54'E	1450	1089	32	16	Vertisols

Sekota	12^0 23’ N	38^0 44’E	2100	622	29	15	Vertisols

Source: District Agricultural and Natural Resource Office in each test location

Plant Materials and Experimental Management

Sixteen tef genotypes including the standard and local checks, bred for moisture deficit stress conditions (Table 2) were evaluated in a randomized complete block design (RCBD) with three replications on a plot size of 4 m^2 for each genotype (10 rows of 2 m length and 0.2 m apart). Urea as source of N and di-ammonium phosphate (DAP) as source of P and N were applied at a rate of 100 kg ha^{-1} each on Vertisols at Shewarobit and Sekota while 100 kg ha^{-1} DAP and 50 kg ha^{-1} Urea were applied on Nitosols at Sirinka and Simada. All DAP was applied at planting while Urea was applied half at 15 to 18 days after planting and the remaining half at 35 to 40 days after planting. Row planting seed rate of 10 kg ha^{-1} was used for each genotype. Seed was drilled in rows of each plot. Date of planting was adopted following the majority of farmers’ practices which depend on soil type and the onset of rain fall in each respective location. Red soil is planted earlier than the black soil because of the difference in moisture holding capacity and readiness for planting between them. On the other hand, locations with the same soil type may have different sowing date because of the difference in the onset of rain fall between the locations. All other recommended agronomic practices such as, land preparation (ploughing three times; the 1st ploughing immediately after harvesting, the 2nd ploughing four weeks after the 1st ploughing, the 3rd ploughing three weeks after the 2nd ploughing), weeding (1st weeding 15-18 days after sowing, 2nd weeding 35- 40 days after sowing), and time of harvesting (when the panicle and straw changed in to yellow color) were applied (Berhe . 2013).

Data Collection

Data on days to 50% flowering and days to 75% physiological maturity after the date of sowing (75% is the safest stage when the crop is saved from losing both the quality and quantity of seed resulted from both under drying and over drying conditions , respectively), grain filling period (determined by subtracting the number of days to flowering from the number of days to physiological maturity)., plant height (measured in centimeters as the distance from the base of the plant to the tip of the longest panicle), panicle length (measured in centimeters as the distance from the base of the panicle to the tip of the longest panicle) (cm), above-ground dry biomass (straw + grain and measured in kg plot^{-1}), grain yield (dry seed measured in g plot^{-1}) and harvest index (determined by dividing the grain yield to above ground dry biomass and expressed in percent) were collected from the central eight harvestable rows.

Statistical Analysis

Data on grain yield and other measured parameters were analyzed separately for each environment using the SAS version 8.1 software. Before doing combined analysis of variance across environments, homogeneity of variance was checked using Bartlett's test (Gomez and Gomez, 1984). The local check was not included in the combined analysis of variance since different local variety was used in each test location.

The grain yield data were also graphically visualized for interpreting GEI using the GGE biplot software. GGE biplot methodology, which is composed of two concepts, the biplot concept and the GGE concept (Yan 2000), was used to visually analyze the multi environment data. This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and the sources of variation in GEI analysis of multi environment data (Yan . 2000). The graphs were generated based on (i) "which-won-where" pattern, (ii) ranking of genotypes on the basis of yield and stability, (iii) comparison of genotypes to an ideal genotype, and (iv) comparison of locations to an ideal location.

Table 2. List of tef genotypes evaluated in the study

Genotype	Code	Source	Genotype	Code	Source
DZ-01-974 x PI222988 (code 1)	G-1	DZARC	DZ-Cr-387 x DZ-Cr-37 (line 57)	G-9	DZARC
DZ-Cr-387 x DZ-Cr-37 (code 6)	G-2	DZARC	PI x DZ-01-99 (code 20)	G-10	DZARC
DZ-01-354 x Rosea (code 7)	G-3	DZARC	DZ-Cr-387 x DZ-Cr-37 (Line 80)	G-11	DZARC
DZ-Cr-387 x DZ-Cr-37 (code 18)	G-4	DZARC	Acc # 225938-1	G-12	EBI
DZ-Cr-387 x DZ-Cr-37 (code 6)	G-5	DZARC	Acc # 236960-3	G-13	EBI
Boset (standard check)	G-6	AARC	Acc # 202390-2	G-14	EBI
DZ-Cr-387 x DZ-Cr-37 (code 13)	G-7	DZARC	Acc # 212713-1	G-15	EBI
P1 x P6 (Line 104)	G-8	DZARC	Local check	G-16	ERTL

Note: DZARC = Debre Zeit Agricultural Research Center; EBI = Ethiopian Biodiversity Institute; ERTL = each respective testing location

RESULTS AND DISCUSSIONS

Combined Analysis of Variance

The results of the combined analysis of variance across environments revealed that the genotype (G), environment (E), and genotype by environment interaction (GEI) effects were significant for grain yield (Table 3) and other measured parameters (Table 4). This implies that there were differences in performance among the genotypes. The results of the present study were in agreement with Tesfay . (2017) and Bakala . (2018) who reported significant differences among tef genotypes in grain yield and yield related traits evaluated under moisture stress conditions.

Grain Yield

The significant GEI effects for grain yield demonstrated that the genotypes responded differently to the variation in environmental conditions (Table 5) indicating the necessity of testing at multiple locations. The significant GEI for grain yield also indicates the need to divide the moisture stressed tef growing environments in the region into different mega-environments and deploying different cultivars in different mega-environments is the best way as a future breeding strategy to utilize GEI. However, data from multiple years are essential to decide whether or not the target region can be divided into different mega-environments. The result of the current study can serve as a driving force to show the importance of conducting further studies to classify the moisture deficit stress tef growing areas in eastern Amahara Regional State. Disaggregation into the contributing factors to the overall variation revealed that grain yield was affected by genotype (20.93%), environment (43.71%), and their interaction (21.20 %) (Table 3). The results of the present study were in agreement with the findings of Gauch and Zobel (1997) who reported that environment takes the lion's share of the total variation while the share of G and GE is very minimal in normal MET. However, it is G and GE that are relevant to cultivar evaluation (Yan and Hunt, 2001). In our study, the variation among the test locations in terms of soil type and fertility status, the amount and distribution of rainfall, and temperature intensity could probably be the major attributes (Table 1) which made the environment to take the largest share in total variation.

It is commonly reported that MET data may constitute a mixture of cross- over and non-cross over types of GEI. The former indicates the change in yield ranking of genotypes across environments and the later shows constant yield rankings of genotypes across environments. In this study, inconsistency of grain yield ranking was observed across environments (Table 5), indicating the presence of possible cross over GEI as described by Kaya (2006). However, crossover GEI is not always the case. For instance, some genotypes showed consistent ranking but differential change in mean yield at two or more environments (Table 5) which was in agreement with the findings of Kaya . (2006). Therefore, the differential change of yield mean but not of ranking of genotypes showed that GEI may also have a non-crossover nature.

Table 3. Summary of combined analysis results over location-year environments for grain yield (t ha^{-1}) of tef genotypes

Source of variation	Degree of freedom	Sum of squares	Mean squares	Explained variation (%)
Total	359	221.2		
Replication	2	0.44		
Genotype (G)	14	46.3	3.31**	20.93
Environment (E)	7	96.7	13.8**	43,71
G*E	98	46.9	0.47**	21.20
Error	238	30.6		

Note: ** = significant at p <1%

Table 4. Mean squares of measured agronomic parameters of tef genotypes in the combined analysis over location-year environments

Source of variation	Degree of freedom	Days to heading	Days to maturity	Grain filling period	Plant height (cm)	Panicle length (cm)	Dry biomass (t ha^{-1})	Harvest index (%)
Replication	2	183.2^{ns}	51.0ns	59.0^{ns}	156.1*	23.9^{ns}	4.6^{ns}	68.4^{ns}
G	14	365.8*	170.6**	289.9*	2967.3**	434.9**	36.4**	186.8**
E	7	4355.3*	1718.4**	2833.2**	7394.7**	1768.3*	674.3**	2811.6*
G*E	98	305.1*	129.2**	333.2*	211.5**	28.2**	5.6**	146.8**
Error	238	258.5	21.3	276.0	51.0	12.2	2.1	

grand mean yield was found to be low; on the other hand, the grand mean of the same parameters was low at Sirinka and Sekota where the grand mean yield of the testing genotypes was found to be high (Table 7). This indicates that extended maturity in moisture stress areas has a negative effect on the productivity of the crop. Among the tested genotypes, G1 and G7 were observed as having plasticity to flowering and maturity depending on moisture status in different testing locations (Table 7). De Rouw and Winkel (1998) noted that plasticity in flowering and maturity enables the crop plants to have wide adaptation to environmental fluctuation by adjusting their growth duration to the specific environmental condition.

Table 5. Grain yield (t ha^{-1}) performance of tef genotypes in each of 8 location-year environments

Geno-types	8 location-year environments (E1-E8)								Mean	R
	E1	E2	E3	E4	E5	E6	E7	E8		
G1	3.16	1.55	**2.24**	**3.46**	**3.81**	1.77	**2.77**	3.05	2.73	1
G2	3.06	1.87	1.51	2.22	2.44	1.63	2.28	2.93	2.24	6
G3	2.84	2.19	1.33	2.69	2.04	1.46	2.17	**3.09**	2.22	7
G4	2.91	2.27	1.32	1.56	2.29	1.99	2.05	2.81	2.15	9
G5	3.37	1.95	1.24	1.60	2.78	2.02	2.45	2.59	2.25	5
G6	3.13	1.99	1.31	1.65	2.42	1.16	2.07	2.33	2.00	11
G7	3.63	2.40	1.48	2.00	3.11	**2.44**	2.26	2.85	2.52	2
G8	2.56	2.19	1.12	1.48	2.65	1.88	2.44	2.68	2.12	10
G9	3.64	2.35	1.37	1.59	2.99	1.34	1.73	3.40	2.30	4
G10	2.66	2.11	1.78	1.75	2.53	2.05	1.87	2.97	2.21	8
G11	**3.68**	1.79	1.49	1.53	3.16	1.98	2.10	2.73	2.31	3
G12	2.30	1.82	1.38	1.48	2.20	0.86	2.08	2.13	1.78	12
G13	2.80	**2.40**	1.16	1.78	2.05	1.45	1.16	1.25	1.75	13
G14	2.49	1.59	1.06	0.51	2.52	0.61	1.06	1.06	1.36	15
G15	3.00	1.89	0.9	1.14	1.85	0.82	0.90	1.07	1.44	14
Mean	**3.01**	**2.02**	**1.37**	**1.76**	**2.58**	**1.56**	**1.95**	**2.46**	**2.09**	

Note: E1=Sirinka-2014; E2=Simada-2014; E3=Shewarobit-2014; E4=Sekota-2014; E5=Sirinka-2015; E6=Simada-2015; E7=Shewarobit-2015; E8=Sekota-2015; underlined values are highest yields at each test environments.

GGE-Biplot Analysis

GGE biplot identifies GEI pattern of multi-location data and clearly shows which variety performs best in which location. In our study, the first principal component axis (PC1) explained 74.63% of total variation while the second principal component axis (PC2) explained 12.91%. Thus, the two axes together accounted for 87.54 % of the GGE variation for grain yield (Figures 1, 2, 3 and 4). The GGE biplot results are presented in four sections. The first section presents the results of “which won-where” to identify the best genotypes for each location. The second section deals with the mean performance and stability of genotypes, the third section presents comparison of all genotypes with the ideal genotype and the fourth one shows comparison of all locations with the ideal location.

Table 6. Mean performance of 15 tef genotypes for measured agronomic traits across 8 location-year environments

Geno-types	Days to flowering	Days to maturity	Grain filling period	Plant height (cm)	Panicle length (cm)	Dry biomass (t ha^{-1})	Grain yield (t ha^{-1})	Harvest index (%)
G1	60.9^{abcd}	107.0^{a}	46.1	103.0^{a}	36.1^{b}	10.1^{a}	2.7^{a}	29.6^{bcd}
G2	58.2^{abcd}	103.3^{bc}	45.1	93.9^{bcd}	33.7^{cde}	9.5^{abc}	2.2^{b}	27.0^{bcd}
G3	57.2^{abcd}	103.3^{bc}	46.0	93.3^{cd}	34.3^{bcd}	8.9^{cde}	2.2^{b}	28.0^{bcd}
G4	53.6^{cd}	99.9^{d}	46.3	90.8^{de}	32.3^{def}	8.3^{de}	2.1^{bc}	29.1^{bcd}
G5	55.4^{bcd}	100.8^{cd}	45.4	95.3^{bc}	34.0^{cde}	8.9^{cde}	2.2^{b}	27.0^{bcd}
G6	61.2^{abcd}	103.2^{bc}	42.0	79.8^{f}	27.1^{g}	7.0^{gh}	2.0^{c}	34.1^{a}
G7	55.7^{bcd}	100.5^{d}	44.7	97.4^{b}	35.2^{bc}	9.1^{bcd}	2.5^{a}	30.7^{ab}
G8	53.2^{d}	99.4^{d}	46.2	88.7^{e}	32.3^{ef}	8.1^{ef}	2.1^{bc}	30.0^{abc}
G9	65.8^{a}	98.8^{d}	33.0	87.1^{e}	30.9^{f}	8.4^{de}	2.3^{b}	29.8^{abc}
G10	52.2^{d}	99.0^{d}	46.8	88.6^{e}	32.7^{def}	8.8^{cde}	2.2^{b}	28.2^{bcd}
G11	58.5^{abcd}	104.7^{ab}	46.1	102.9^{a}	38.7^{a}	9.8^{ab}	2.3^{b}	26.3^{cd}
G12	62.8^{ab}	106.5^{a}	43.7	74.2^{g}	26.5^{g}	7.4^{fg}	1.7^{d}	29.6^{bcd}
G13	57.3^{abcd}	101.3^{cd}	44.0	74.3^{g}	26.8^{g}	6.9^{ghi}	1.7^{d}	28.3^{bcd}
G14	62.4^{abc}	104.8^{ab}	42.4	79.3^{f}	28.2^{g}	6.5^{hi}	1.3^{e}	21.6^{e}
G15	59.5^{abcd}	101.1^{cd}	41.5	64.5e	23.3^{h}	6.1^{i}	1.4^{e}	25.5^{de}
Mean	58.3	102.2	43.9	87.58	31.51	8.2	2.09	28.3
CV (%)	27.5	4.5	17.6	8.2	11.1	17.5	17.1	26.0
G	*	**	*	**	**	**	**	**
E	*	**	**	**	**	**	**	**
G*E	*	**	ns	**	**	**	**	**

Note: G = genotype; E = environment; *, ** = significant at 5% and 1% level of probability, respectively, ns= not statistically significant

Which-won-where pattern analysis

In the which-won-where concept of GGE biplot, genotype markers farthest from the biplot origin are connected with straight lines to form a polygon such that markers of all other genotypes are contained in the polygon. To each side of the polygon, a perpendicular line, starting from the origin of the biplot is drawn and extended beyond the polygon so that the biplot is divided into several sectors. The markers of test locations are separated into different sectors and the genotype at the vertex for each sector is the winner genotype at locations included in that sector.

Figure 1 represents "which-won-where" GGE biplot view of tef genotypes MET data. Accordingly, G1, G3, G11, G7, G12 and G14 were the vertex genotypes indicating that they are the best or the poorest genotypes in some or all of the locations since they were farthest from the origin of the biplot (Yan and Kang 2003). In this biplot, five sectors are formed. The first sector represents Simada, Shewarobit and Sekota with G1 and G7 as the best genotypes, the second sector represents Sirinka with G11 as the highest yielder, while no location fell in the third, fourth and fifth sectors where G14, G12 and G3, respectively were the vertex genotypes. This means that G14, G12 and G3 were not the winner in any of the locations; rather, they were likely to be the poorest genotype in some or all of the locations (Figure 1). The standard check (G6) was found in the sector where G14 was the vertex genotype and not appeared with any of the locations, indicating its poor performance in most of the environments. On the other hand, most of the locations fell in the sector where G1 was the winner.

Mean yield and stability performance of genotypes

Ranking of 15 tef genotypes based on mean yield performance and stability is presented in Figure 2. The single arrow line passing through the biplot origin and the average environment indicated by the small circle is the average environments coordinate (AEC) axis, which is defined by the average PC1 and PC2 scores of all environments (Yan and Kang, 2003). This line points towards higher mean yield across environments. Hence, Figure 2 shows thatG1 gave the highest mean yield followed by G7, G11, G9, G5, G2, G3, G10, G4 and G8. The remaining genotypes including the standard check (G6) had below grand mean yield.

The line which passes through the biplot origin and is perpendicular to the AEC axis shows measure of stability. Either direction away from the biplot origin, on this axis, indicates greater GE interaction and poor stability or vice versa (Kaya 2006). Thus, in terms of stability, our test genotypes are ranked as G6>G1>G13>G8>G4>G15>G5>G2>G10>G14>G9>G12>G7>G11 >G3. Figure 2 also shows that G1 can be categorized as generally adapted; G5, G7, G9 and G11 as specifically adapted; and G2, G3, G4, G10, G12, G14, and G15 can be categorized as genotypes adapted nowhere. The remaining genotypes (G6, G8 and G13) had better stability but with low mean grain yield, indicating that their adaptation could not be categorized. In line with our study, Yan and Kang (2003) also classified genotypes into three categories based on their grain yield and stability performances: (1) generally adapted, genotypes with high yield and high stability performance; (2) specifically adapted genotypes with high mean yield but low stability performance; and (3) genotypes adapted nowhere with low grain yield and low stability performance. Stability was reported to have lower heritability than mean performance (Eskridge, 1996), hence, it is useful only when considered jointly with mean performance. Yan and Tinker (2006) also noted that stability refers to the relative performance of a genotype, and it is meaningful only when associated with mean performance.

Table 7. Mean performance of the tested genotypes for days to flowering, days to maturity and grain yield at each location across years

Genotype	Sirinka			Simada			Shewarobit			Sekota		
	DTF	DTM	GY	DTF	DTM	GY	DTF	DTM	GY	DTF	DTM	GY
G1	46	99	3.4	71	116	2.6	70	115	2.5	56	98	3.0
G2	45	97	2.7	70	114	1.7	66	103	1.9	53	100	2.5
G3	42	101	2.4	69	111	1.8	66	102	1.7	52	99	2.8
G4	39	93	2.6	64	110	2.1	63	100	1.6	49	97	2.1
G5	41	98	3.1	67	109	1.9	64	101	1.8	50	97	2.1
G6	43	96	2.7	66	101	1.5	73	105	1.6	64	95	1.9
G7	41	97	3.3	66	113	2.4	67	105	2.0	49	95	2.6
G8	41	95	2.6	60	107	2.0	63	99	1.7	49	96	2.0
G9	40	93	3.3	63	108	1.8	62	98	1.5	48	96	2.5
G10	40	91	2.6	60	110	2.0	61	99	1.8	48	97	2.3
G11	44	103	3.4	70	113	1.8	68	104	1.7	53	99	2.1
G12	44	100	2.2	70	103	1.3	74	112	1.7	64	102	1.8

G13	39	93	2.4	60	93	1.9	69	105	1.1	63	104	1.5
G14	45	99	2.5	72	105	1.1	69	102	1.0	65	98	0.7
G15	40	93	2.4	64	94	1.3	71	105	0.9	64	100	1.1
G16	41	91	2.4	63	99	1.1	73	106	0.8	61	97	0.8
Mean	**45**	**96**	**2.7**	**66**	**107**	**1.8**	**67**	**105**	**1.6**	**55**	**98.0**	**2.0**

Note: DTF = days to flowering, DTM = days to maturity, GY = grain yield (t ha^{-1})

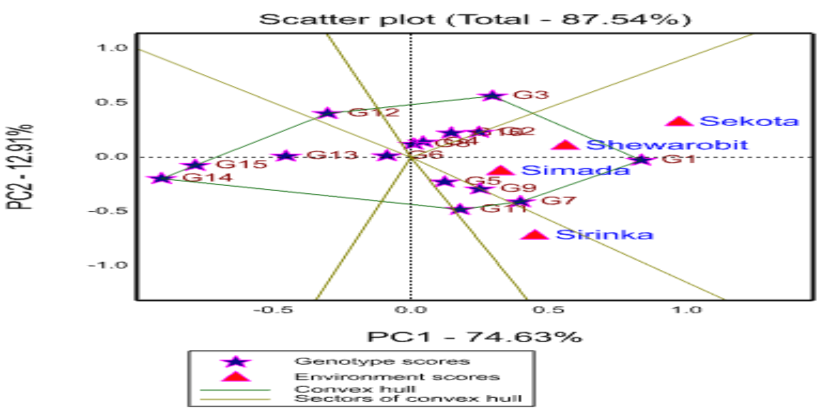

Figure 1. Polygon views of the GGE-biplot based on symmetrical scaling for the “which-won-where” pattern analysis for grain yield of genotypes and locations

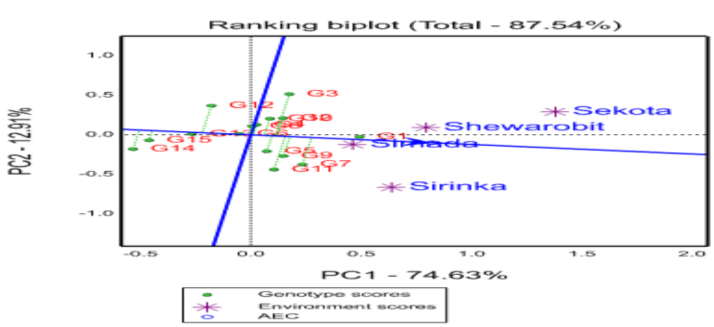

Figure 2. GGE-biplot based on location-focused scaling for the grain yield mean performance and stability of genotypes.

Evaluation of genotypes relative to an ideal genotype

An ideal genotype should have the highest mean performance and be absolutely stable (Karimizadehi 2013). Such an ideal genotype is defined by having the greatest vector length of the high yielding genotypes with zero GEI, as represented by an arrow pointing to it in Figure 3 of our study. Although such an ideal genotype may not exist in reality, it can be used as a reference for genotype evaluation (Karimizadehi . 2013). Thus, using the ideal genotype as the center, concentric circles were drawn to visualize the distance between each genotype and the ideal genotype. A genotype is more favorable if it is closer to the ideal genotype. Accordingly, G1 followed by G7 were closer to the ideal genotype, and therefore, they were most desirable than the other tested genotypes.

Rank of the other genotypes based on their closeness to the ideal genotype was G9>G11>G6>G10>G2>G4>G5>G3>G8. On the other hand, the lower yielding genotypes including G12, G13, G14, and G15 were unfavorable because they were located far from the ideal genotype. The relative contributions of stability and grain yield to the identification of desirable genotypes by the ideal genotype procedure of the GGE biplot in our study were similar to those reported in other crop stability studies (Fan . 2007).

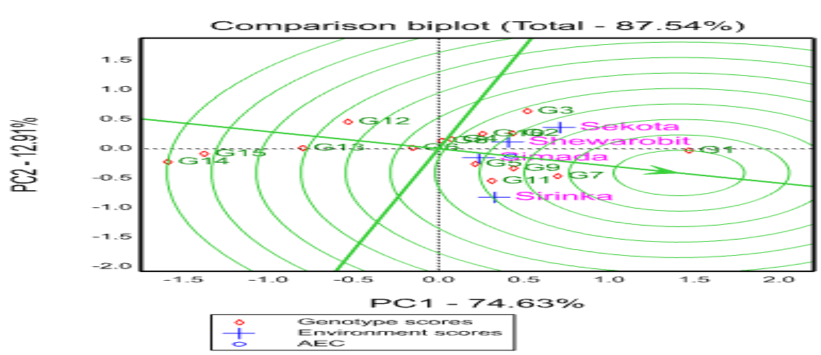

Figure 3. GGE biplot of ideal genotype and comparison of the genotypes with the ideal genotype based on grain yield productivity

Evaluation of locations relative to an ideal location

Similar to the ideal genotype, it is possible to define ideal location for ranking of test locations according to their discriminating ability and suitability of representation. According to Yan . (2000), the ideal test location should have large PC1 scores (more power to discriminate genotypes and small PC2 scores (more representative of the overall environments)). Such an ideal location is represented by an arrow pointing to it as indicated in Figure 4 of our study. Although such an ideal location may not exist in reality, it can be used as a reference for genotype selection in the multi environment yield trials (Karimizadehi . 2013). A location is more desirable if it is located closer to the ideal location. Thus, using the ideal location as the center, concentric circles were drawn to help visualize the distance between each location and the ideal location. Figure 4 shows that Sekota followed by Shewarobit among the test locations are located closer to the ideal location, indicating their relative idealness in terms of discriminating ability and representativeness to the overall test locations.

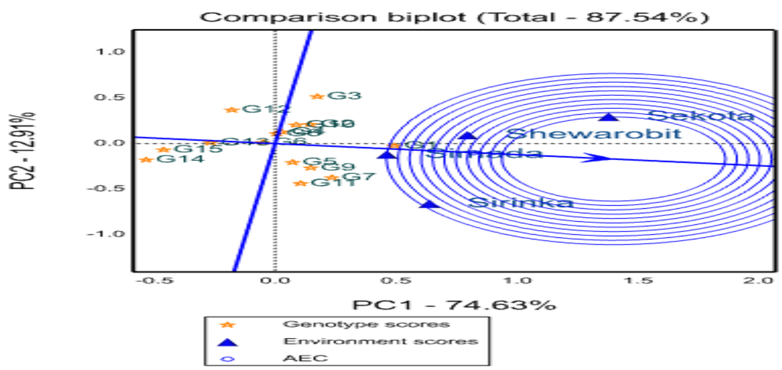

Figure 4. GGE biplot based on location focused scaling for comparison of the test locations with the ideal location based on grain yield productivity.

CONCLUSION

The combined analysis of variance revealed significant effects of genotypes, environments and their interactions for grain yield and all other measured parameters. Grain yield performance of the genotypes was highly influenced by environment followed by GEI and genotype effects. Wide performance variation was observed among the tested genotypes for different parameters. Among the tested genotypes, G1 and G7 gave 25% and 20% grain yield advantage over the standard check (Boset), respectively.

The GGE biplot analysis allowed a meaningful and useful summary of GEI data. According to "which-won-where" GGE biplot, G1 showed best performance at Simada, Shewarobit and Sekota while G11 performed best at Sirinka. In terms of mean performance and stability, the tested genotypes were mainly grouped into three categories: generally adapted, specifically adapted and adapted nowhere. Among the tested genotypes, G1 followed by G7 were found to be the most favorable ones in terms of idealness relative to the ideal genotype. The results of

GGE biplot analysis for evaluating the locations relative to the ideal location showed that Sekota followed by Shewarobit were found relatively ideal in terms of discriminating ability and representativeness to the overall test locations. This result calls for conducting mega environment determination study at many locations over several years to design tef breeding strategy in moisture deficit stress areas of the region.

The results of both combined analysis of variance and GGE biplot revealed that G1 and G7 significantly outperformed the standard check and the other tested genotypes which show the possibility of releasing a new variety for moisture deficit stress areas. Accordingly, G1 and G7 were promoted into variety verification. Of these, G1 was officially released with the name "Hiber-1" for wide production in in tef growing moisture deficit stress areas of eastern Amhara Regional State and similar areas. Its release was justified considering its merits including higher grain yield and biomass, white seed color, long panicle, wide adaptability and its plasticity nature of maturity depending on the availability of moisture.

REFERENCES

Assefa K, You J K, Zeid M, Belay G, Tefera H and Sorrells M E (2011). Breeding tef [(Zucc.) Trotter]: Conventional and molecular approaches (review). 130, 1-9.

Assefa K, Chanyalew S and Metaferia G (2013). Conventional and molecular tef breeding. In: Assefa K, Chanyalew S and Tadele Z (eds). . Proceedings of the Second International Tef Workshop, November 7-9, 2011, Debre Zeit, Ethiopia, 33-51.

Ayele M (1993). Use of excised-leaf water content in breeding tef [(Zucc.) Trotter] for moisture stress areas. 42, 261-265.

Balestre M, Souza J C, von Pinho R G, Oliveira R L, Paes M V P (2010). Yield stability and adaptability of maize hybrids based on GGE biplot analysis characteristics. 9, 226-234.

Bakala N, Taye T and Shimalis Y (2018). Performance evaluation and adaptation trial of tef genotypes for moisture stress areas of Borana, Southern Oromia. **7(5),** 1-6.

Berhe T, Gebretsadik Z, Edwards S and Arya H. (2013). Boosting tef productivity using improved agronomic practices and appropriate fertilizer. In: Assefa K, Chanyalew S and Tadele Z (eds.). Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia, 133-140.

Blum A (2011). . Springer, New York, USA

CSA, Central Statistical Agency (2018). . CSA, Addis Ababa, Ethiopia.

de Rouw A and Winkel T (1998). Drought avoidance by asynchronous flowering in pearl millet stands cultivated on-farm and on-station in Niger. 34, 19-39.

Eskridge K M (1996). Analysis of multiple environment trials using the probability of out-performing a check. In: Kang M S and Gauch J H G (eds.). . CRC Press, Boca Raton, FL., 273-307.

Fan X M, Kang M S, Chen H, Zhang Y, Tan J and Xu C (2007). Yield stability of maize hybrids evaluated in multi environment trials in Yunnan, China. 99, 220-228.

Gauch G H and Zobel R W (1997). Interpreting mega environments and targeting genotypes. 37, 311-326.

Gomez K A and Gomez A A (1984). . 2nd edition. John Willey and Sons, INC. New York, USA.

Habte J, Kebebew A, Kassahun T, Kifle D and Zerihun T (2019). Genotype-by-environment interaction and stability analysis in grain yield of improved tef ( ) varieties evaluated in Ethiopia . 35(5): 1-13.

Karimizadehi R, Mohtasham M N, Sabaghn A A, Mahmood B and Roustami F (2013). GGE biplot analysis of yield stability in multi-environment trials of lentil genotypes under rain-fed condition. 5(2), 256-262.

Kaya Y, Akcura M and Taner S (2006). GGE-biplot analysis of multi environment yield trials in bread wheat. 30, 325-337.

Ketema S (1993). . Institute of Agricultural Research, Addis Ababa, Ethiopia.

Ketema S (1997). Tef ((Zucc)Trotter): Promoting the conservation and use of under-utilized and neglected crops. 12. The Institute of Plant Genetics and Crop Plant Research. Gatersleben/International Plant Genetic Resources Institute). Rome, Italy.

Mengiste Y, Mehari A, Schultz B and Erkossa T (2013). Crop water productivity of irrigated teff in a water stressed region. 7, 3115-3125.

Mohamed A, Tana T, Singh P, Korecha D and Molla A (2017). Management options for rain-fed chickpea (L.) in northeast Ethiopia under climate change condition. 16,222-230.

Tesfay M, Hussein S, Laing M and Assefa K (2017). Genetic variation and trait association of tef [(Zucc.) Trotter] evaluated under optimal and moisture stressed environments. 11(03), 241-247.

Spaenij-Dekking L, Kooy-Winkelaar Y and Koning F (2005). The Ethiopian cereal tef in celiac disease. 353, 1748-1749.

Shiferaw W, Balcha A and Mohammed H (2012). Genetic variation for grain yield and yield related traits in tef [(Zucc.) Trotter] under moisture stress and non-stress environments. 3, 1041-1046.

Vavilov N I (1951). , (translated from the Russian by K. Starr Chester). The Ronald Press Company, NewYork.

Yan W and Hunt L A (2001). Interpretation of genotype x environment interaction for winter wheat yield in Ontario. 41, 19-25.

Yan W, Hunt L A, Sheng Q and Szlavnics Z (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. 40, 597-605.

Yan W and Kang M S (2003). GGE biplot analysis: A graphical tool for breeders. : Kang M S (ed.). t. CRC Press, Boca Raton, FL

Yan W and Tinker N A (2006). Biplot analysis of multi- environment trial data: Principles and applications. 86, 623-645.