Boni: Improved Tef Variety for Drought-Prone Areas of Ethiopia

Worku Kebede[1], Solomon Chanyalew[1], Tsion Fikre[1], Kidist Tolosa[1], Yazachew Genet[1], Mengistu Demissie[1], Kebebew Assefa[1], Habte Jifar[1], Solomon Mitiku[2], Kidu Gebremeskel[3], Sewagegn Tariku[4] and Zerihun Tadele[5]

[1]Ethiopian Institute of Agricultural Research (EIAR), Debre Zeit Agricultural Research Center, P.O.Box 32, Debre Zeit;[2]Amhara Regional Agricultural Research Institute (ARARI), Sirinka Research Center,P.O.Box:74,Woldia, Ethiopia;[3]Tigray Agricultural Research Institute (TARI), Axum Research Center, P.O.Box30, Axum, Ethiopia;[4]ARARI, Adet Agricultural Research Center, P.O. Box 8, Bahir Dar, Ethiopia;[5]University of Bern, Institute of Plant Sciences, Altenbergrain 21, CH-3013 Bern, Switzerland

Corresponding author: workukebede121@gmail.com

Abstract

Tef [Eragrostis tef (Zucc.) Trotter] is extensively cultivated cereal crop in Ethiopia where it is annually grown by about 6.5 million smallholder farmers on about 30% of the total area allocated to cereal crops. However, the productivity of tef is very low compared to other cereals mainly due to little scientific research on the crop, widespread use of local varieties coupled with traditional cultural practices, and lack of drought tolerant varieties. A multi-environment field experiment was, therefore, carried with the objectives of identifying and releasing high yielding and farmer- and consumer-preferred tef variety for moisture deficit areas of the country. The drought tolerant tef genotypes tested were derived from two independent crosses of Dtt_2 *x* Dtt_{13} *and DZ-Cr-387 x* Dtt_2*. The parental lines* Dtt_2 *(drought tolerant tef2) and* Dtt_{13} *(drought tolerant tef 13) were obtained by screening 5,000 ethylmethane sulfonate (EMS) mutagenized populations from an improved variety called Tsedey. Twelve candidate droughts tolerant tef genotypes from preliminary variety trials and a local as well as standard check varieties (Boset) were tested over two years (2018 and 2019 main cropping seasons) at five moisture deficit tef growing areas in Ethiopia (viz. Debre Zeit light soil, Minjar, Alemtena, Melkassa and Sirinka) using randomized complete block design with four replications. Late sowing combined with light textured soils was used to simulate terminal drought stress at Debre Zeit light soil and Minjar. The combined analyses of variance did not exhibit statistically significant difference for genotype by environment interaction. However, among the tested lines, the candidate line RIL 37 from* Dtt_2 *x* Dtt_{13} cross was *found superior in grain yield over the standard check Boset variety (by 13.2%) and the local cultivar (by 27.6%). The candidate line was further evaluated in the variety verification trial during the 2020 main cropping season and approved for the release by the National Variety Release Committee in 2021 with name DZ-Cr-498 (RIL 37) or Boni.*

Keywords: Boni, tef breeding, Drought tolerant tef (Dtt), drought tolerance, Eragrostis tef, moisture scarcity, tef

Introduction

Tef, [*Eragrostis tef* (Zucc.) Trotter] is a member of the Grass or Poaceae Family and belongs to Chlorodoideae sub-family. Tef is an allotetraploid (2n=4x=40) with estimated genome size 622 Mbp (VanBuren *et al*., 2020), which is approximately 60% larger than the rice genome. It is self-pollinated with very low degree of out-crossing that ranges from 0.2% to 1.0% (Seyfu, 1997). Ethiopia is the center of both origin and diversity for tef (Vavilov, 1951). Tef represents a unique biodiversity component in the agriculture and food security systems of millions of poor farmers in Ethiopia. It is the most important cereal crop of Ethiopia, where the last two decades (1995 to 2015) have shown tremendous increases in both the total area under cultivation and the total production (CSA, 2015). Tef production increased from 1.7 million metric tons in 1995 to 5.25 million metric tons in 2015, which was equivalent to an average growth rate of 7.97% per annum. More importantly, tef yield has been increased by 5.06% per annum during the same period (CSA, 2015)**.**

Tef plays an essential role in the Ethiopian food crop production system. Nearly seven million farmers grow the crop that occupies 22% of the total cultivated area (CSA, 2020), and it is second in terms of total production next to maize. Being produced by over 43% of all Ethiopian farmers and in lieu of the fact that it is a very labour-intensive crop (Setotaw, 2013), tef production is a source of employment and livelihood for an estimated 25-30 million people. Furthermore, tef is the most commercialized crop in Ethiopia with approximately 36% of the total produced tef being marketed (Minten *et al*., 2013).

Tef has an optimum amount of energy and protein compared to other common cereals (Baye, 2014; Nurse, 2015). The absence of gluten (Jeffrey, 2015) makes tef valuable for preparing dietary products for gluten intolerant people. It has been heralded as a super food or super grain and has high nutritional values (Spaenij-Dekking et al., 2005; Provost and Jobson, 2014; Jeffrey, 2015). Furthermore, tef possesses additional nutritional advantages over many common bowls of cereal such as maize, barley, wheat and sorghum. For instance, tef, due to the low glycemic index (74) and high gelatinization temperature (68–800C), is a slow-digesting carbohydrate (Baye, 2014). Because of these nutritional properties, tef has attracted the interest of the western consumers and gaining global attention. Compared with other cereals such as maize and wheat, tef is also known to be tolerant to extreme climatic and soil conditions; hence, it is a favorite crop in the semi-arid areas with moisture limitations (Zerihun and Kebebew, 2012).

Despite its low yields as per the national average grain yield of 1.85 t ha^{-1} (CSA, 2020), tef remains to be very popular among Ethiopian farmers. This, among others, has been due to the fact that i) tef fetches higher prices than the other major cereals and therefore serves as a cash crop for many farmers (Bekabil *et al*., 2013); ii) its straw also fetches high prices as it is the most preferred feed source for livestock and is used as construction material (Alemu, 2013). iii) tef is endemic and therefore little affected by epidemics of diseases and pests and can be stored for a long period of time without being attacked by storage pests, and iv) tef can be grown under drought stressed and water-logged conditions, and performs well on different soil types.

Not with standing its numerous relative advantages and economic importance, the productivity of tef in Ethiopia is low. Among the major yield limiting factors in tef are lack of cultivars tolerant to lodging and drought (Kebebew *et al*., 2011), as well as small seed size. Yield losses in tef are estimated to reach up to 40% during severe moisture stress (Mulu, 1993). A yield reduction of 69% to 77% was when moisture scarcity occurred during the anthesis or flowering stage of tef plant (Abuhay *et al*., 2001).

In Ethiopia, in order to increase tef productivity, more than 50 improved varieties have been developed and released by national and regional agricultural research institutes (MoA, 2020). Among these, recently released varieties including *Quncho* (Kebebew *et al.*, 2013), *Kora* (Kebebew *et al.*, 2017), *Dagim* (Solomon *et al*., 2017), *Tesfa* (Worku *et al.*, 2018) and *Bora* (Worku *et al.,* 2020) showed significant yield benefits. The majority of these varieties were designed for favourable and/or broad environments, not for challenging environment in terms of moisture scarcity.

The tef variety named DZ-Cr-387 RIL 355 (Quncho), has been promoted the national level for its farmers'- and consumers'-preferred traits such as high grain yield, white seed color, high biomass yield and good '*injera*' making quality. However, this variety was poorly adopted by tef growers in low moisture areas of Ethiopia due to poor performance under extreme environmental conditions. The level of yield reduction due to moisture stress warrants targeted breeding of tef for low moisture stress environments in Ethiopia (Mizan *et al*., 2017). Accordingly, one of the primary goals of the National Tef Breeding Program in Ethiopia is to develop high yielding and drought tolerant tef varieties (Kebebew *et al*., 2011).

Many different genotypes are typically evaluated in various environments (locations and periods) in plant breeding programs in order to identify and develop suitable genotypes for release. If a genotype or cultivar can adapt to a trait of economic importance in a wide range of conditions, it is considered stable. Only genotype and genotype by environment interaction are relevant to meaningful cultivar evaluation and must be considered simultaneously for making selection decisions; the environmental component is typically the largest component in analyses of variance, but it is not relevant to variety choice exclusively (Yan and Kang 2003). Breeders might gain from information on the structure and nature of genotype by environment interactions (Yayis *et al*., 2014).

As a result, a multi-environment national variety trial was initiated with the aim of identifying and release high-yielding, stable and farmer- and consumer-preferred tef variety for moisture deficient areas across the country. In this paper describes the performance of tef variety *Boni* (also known as DZ-Cr-498 RIL 37) which was recently approved for the release. Key beneficial features and morphological traits of this variety are presented.

Materials and Methods

Experimental sites and seasons

The field experiment was conducted for two years during the main cropping seasons of 2018 and 2019 in seven environments (namely, Debre Zeit, Minjar, Alemtena, Melkassa in 2018 and Debre Zeit, Minjar, and Sirinka in 2019) in the country's low moisture stress areas. At some of the locations such as Debre Zeit and Minjar low moisture stress was simulated by late sowing in addition to the light textured soils of low water holding capacity.

Plant materials

Two independent crossings were made between Dtt_2 and Dtt_{13}, and DZ-Cr-387 and Dtt_2 at Debre Zeit Agricultural Research Center in 2013. Dtt_2 (drought tolerant tef 2) and Dtt_{13} (drought tolerant tef 13) were mutant lines obtained from screening 5,000 ethylmethane sulfonate (EMS) mutagenized populations of the tef variety *Tsedey* (DZ-Cr-37) (Blösch *et al*. 2019). These mutant lines had depicted excellent performance under moisture scarcity. The unique morphological difference between the *Dtt* and the original parental tef variety *Tsedey* (DZ-Cr-37) is the size and number of stomata. The stomata on the adaxial or upper side of the two *Dtt* lines are smaller both in size and number compared to the original parental tef line (Cannarozzi *et al*., 2018). These small-sized stomata in the *Dtt* lines might contribute towards making the plants more tolerant to drought as less water is lost through transpiration. *Dtt* lines were tolerant to drought for three weeks, whereas the original *Tsedey* variety was badly injured. The Dtt lines were not only drought tolerant, but they also had shorter stomata than the *Tsedey* lines (Blösch *et al*., 2019).

After a successful crossing, 400 F_2 populations were generated and substantially advanced to F7 generations using the single seed descent method. Eventually, the populations were reduced to few lines with best performance after seven generations of successive selection targeting seed color, standing ability, grain yield, and leaf area index. Hybridization and early generation testing, i.e., Observation Nursery and Preliminary Variety Trial were done at Debre Zeit Agricultural Research Center from where the national tef breeding program is coordinated.

Subsequently, at the National Variety Trial where a total of 12 genotypes including 10 selected drought-tolerant inbred lines from the two crosses, a local check or farmers' variety from each test site, and a standard check variety Boset were evaluated at five drought-prone areas in Ethiopia.

Experimental Design and Management

The performance of the twelve tef genotypes including 10 selected drought tolerant inbred lines from the two crosses as well as two controls (farmers’ variety as a local check and improved variety *Boset* as a standard check*)* were tested at Debre Zeit light soil, Minjar, Alem Tena, Melkassa and Sirinka using Randomized Complete Block Design with four replications. *Boset* variety released in 2013 was used as a standard check since the variety is characterized as drought escaper due to its early maturing nature. The trial was conducted on the plot size of 2m x 2m with 10 rows per plot, and spacing of 1.5m between replications or blocks, 1m between plots within blocks and 20cm between rows. All pre- and post-stand establishment cultural practices were performed as per the research recommendations of the respective test sites.

Data collection

Data on agronomic, yield and yield-related traits were collected both on plot and individual plant bases. Days to heading or panicle emergence using the sowing date as a reference, lodging indexes as well as grain and biomass yield were taken on plot basis. Data on individual plant traits such as plant height and panicle length were collected on the basis of five random samples of plants from the central rows of each plot, and the averages of five sample plants were used for analysis.

Data Analysis

Analyses of variance (ANOVA) of data from individual environments and combined over five locations and two years were made using R core Team (2021) software 4.2.0 version. The combined analysis of variance across the environment was done in order to determine the differences between genotypes across environments, among environments and their interaction. Bartlett’s test of homogeneity of error variances was performed prior to making the combined analysis of variance over environments (years and locations). Mean comparison for significant differences in the analyses of variance were made using Least Significant Difference (LSD).

Results and Discussion

Field performance variations

According to the results of the combined analysis of variance over environments (Table 1), grain yield was highly significantly ($P<0.0001$) affected by genotypes and environments, which accounted for about 7.88% and 41.13% of the total variance, respectively. However, the genotype by environment (G*E) interaction effects on grain yield were not significant; indicating that the genotypes tested were performed similarly across the test environments. This, in other words, implies that the genotypes tested did not exhibit differential adaptation to specific environments.

The genotype x location interactions were not significant, indicating that the genotypes performed consistently across locations in terms of grain yield. This is expected on the basis of the similar agro-climatic classification of the test locations (Kebebew *et al.*, 2003). If varieties perform similarly across locations, breeders may be able to reduce the cost of thorough varietal evaluation by eliminating unnecessary testing sites and altering breeding programs.

Table1.Sum of squares, mean squares and percent of variance explained by different sources of variation from the analyses of variance of grain yield of 12 tef genotypes tested at six environments

Source	Degrees of freedom	Sum of squares	Mean squares	Explained variance (%)
Genotypes	11	8219139.76	747194.52**	7.88
Environments	6	42885619.84	7147603.31**	41.13
Reps/Environments	21	16627723.17	791796.34**	15.94
Environment *Genotypes	66	7774627.29	117797.38^{NS}	7.45
Error	231	28749561.30	124457.00	27.57
Corrected Total	335	104256671.40		

*. ** denote significance at $P\leq0.05$ and $P\leq0.01$, respectively; NS = Not significant

Highly significant variations among the genotypes were observed in days to heading, days to maturity, grain filling period, plant height, panicle length, lodging index, shoot biomass yield and grain yield in all the study years and locations (Table 2). Similar significant results were reported for most traits in earlier studies (Hailu *et al.*, 2003a; Kebebew *et al.* 2003; Solomon *et al.*, 2009; Habte *et al.*, 2015, Tsion, 2016 and Habte *et al.* 2017). The presence of variations among genotypes for the traits indicates the higher chance of improving the crop through selection.

Table 2. Mean agronomic performance of tef genotypes evaluated in the national variety trial (Drought Tolerant) across locations and over years

Genotypes	Days to heading	Days to maturity	Grain filling period (days)	Plant height (cm)	Panicle length (cm)	Lodging index (%)	Shoot biomass yield (kgha^{-1})	Grain yield (kgha^{-1})
Standard Check (Boset)	41.00	83.79	42.79	89.94	36.54	81.08	11156.25	2131.38
Dtt$_2$ x Dtt$_{13}$ RIL 37	**40.96**	**80.32**	**39.36**	**91.84**	**39.80**	**83.50**	**11810.27**	**2455.33**
Dtt$_2$ x Dtt$_{13}$ RIL56	40.43	82.50	42.07	87.34	36.24	85.13	10417.41	2175.18
Dtt$_2$ x Dtt$_{13}$ RIL79	39.07	81.36	42.29	84.12	34.29	82.58	9714.29	2030.69
Dtt$_2$ x Dtt$_{13}$ RIL 80	39.21	78.46	39.25	85.28	34.30	83.83	10116.07	1975.18
Dtt$_2$ x Dtt$_{13}$ RIL 87	38.89	80.75	41.86	83.45	33.51	83.63	9171.88	1986.79
DZ-Cr-387 x Dtt$_2$ RIL 98	41.68	83.36	41.68	90.44	38.20	80.92	10569.20	2157.57
DZ-Cr-387 x Dtt$_2$ RIL15	42.46	83.96	41.50	92.89	39.39	76.67	12265.63	2217.03
DZ-Cr-387 x Dtt$_2$ RIL 177	41.32	83.57	42.25	95.84	41.47	78.58	11312.50	2080.18
DZ-Cr-387 x Dtt$_2$ RIL 199	41.14	82.96	41.82	93.22	39.86	80.00	10305.80	2121.76
DZ-Cr-387 x Dtt$_2$ RIL 97	40.00	83.61	43.61	91.12	40.01	83.79	10705.36	2184.35
Local Check	43.32	85.86	42.54	96.93	40.99	80.17	10866.07	1778.77
Mean	40.79	82.54	41.75	90.20	37.88	81.66	10660.71	2107.85
LSD (0.05)	0.81	1.46	1.55	2.85	1.48	4.82	1666.80	211.33
CV (%)	3.79	3.34	7.04	6.01	7.42	10.37	29.70	19.04
R^2	0.95	0.89	0.83	0.89	0.66	0.70	0.58	0.61

Averaged over environments, Dtt2 x Dtt13 RIL 37 reaches the panicle emergence stage in 40 days and physiological maturity in 80 days after sowing. These desirable traits can be suggested for fast-track release and to be used as parental lines for future tef breeding programs. From the average total plant height of 90 cm the panicle of Dtt2 x Dtt13 RIL 37 contributes to 40%. The relationship between plant height and panicle length indicates the possibility of increasing grain yield and biomass yield by improving either of the two traits (Table 2).

The average grain yield of Dtt2 x Dtt13 RIL 37 was (2455.33 kgha-1) and shoot biomass yield (11810.27 kgha-1) (Table 2), which is the highest grain yield and biomass yield recorded among tested genotypes across pooled environments. The genotype Dtt$_2$ x Dtt$_{13}$ RIL 37 ranked first in grain yield performance in four of the seven environments (Debre Zeit and Minjar in 2018 and; Minjar and Sirinka in 2019). Similarly, three other best-performing genotypes DZ-Cr-387 x Dtt$_2$ RIL 97, DZ-Cr-387 x Dtt$_2$ RIL 15 and Dtt$_2$ x Dtt$_{13}$ RIL 87 ranked first in grain yield at Melkassa in 2018, Alemtena in 2019 and Debre Zeit in 2019, respectively (Table 3).

The average grain yield of Dtt2 x Dtt13 RIL 37 across the seven environments ranged from 1114 to 3051 kgha^{-1}, with an overall mean of 2455 kgha^{-1} (Table 3). It performs very well in areas having an altitude 1200-1800m above sea level, thus being suitable for low rainfall and terminal low moisture stress areas of the country. Therefore, based on the two-year multi-location data, Dtt$_2$ x Dtt$_{13}$ RIL 37 has been selected for its high grain yield and moisture stress tolerance as well as other desirable traits. Consequently, the candidate line was then tested in a variety verification trial during the main cropping season of 2020, and the National Variety Release Committee approved for release in 2021.

The current study's findings revealed that the range values for some traits are low when compared to the range values reported in prior tef researchers (Kebebew *et al.*, 2001b; Habtamu, 2015 and Tsion, 2016). This could be due to the current study's use of drought-tolerant tef genotypes as experimental materials, as well as the fact that the experiment was conducted in a drought-prone area of the country, which are both different from the experimental plant materials and locations used in previous studies.

Table 3. Mean grain yield (kgha^{-1}) performance of tef genotypes evaluated in national variety trial (for drought prone areas) across seven environments

Code No.	Genotypes	Mean grain yield (kgha^{-1})							Mean
		2018			2019				
		Melkassa	Debr eZeit	Minjar	Alem-tena	Debre Zeit	Minjar	Sirinka	
1	Standard Check (Boset)	1691	2488	2361	1617	2056	2690	2016	2131
2	**Dtt$_2$ x Dtt$_{13}$ RIL 37**	**2153**	**3051**	**2960**	**1698**	**2089**	**3003**	**2235**	**2455**
3	Dtt$_2$ x Dtt$_{13}$ RIL56	1971	2697	2113	1727	1969	2545	2203	2175
4	Dtt$_2$ x Dtt$_{13}$ RIL79	1821	2704	2273	1453	1940	2131	1893	2031
5	Dtt$_2$ x Dtt$_{13}$ RIL 80	1502	2693	2311	1589	1717	2179	1836	1975
6	Dtt$_2$ x Dtt$_{13}$ RIL 87	1776	2364	1991	1538	2200	2015	2024	1987
7	DZ-Cr-387 x Dtt$_2$ RIL 98	1871	2998	2280	1495	1907	2523	2029	2158
8	DZ-Cr-387 x Dtt$_2$ RIL 15	2112	2789	2214	1764	2073	2553	2015	2217
9	DZ-Cr-387 x Dtt$_2$ RIL 177	1754	2300	2437	1645	1862	2594	1970	2080
10	DZ-Cr-387 x Dtt$_2$ RIL199	1731	2818	2191	1460	2055	2621	1976	2122
11	DZ-Cr-387 x Dtt$_2$ RIL 97	2207	2513	2269	1471	2013	2609	2210	2184
12	Local Check	1426	2423	2188	1114	1256	2185	1861	1779
	Mean	1835	2653	2299	1548	1928	2471	2022	2108
	LSD (0.05)	429.3	664.5	642.9	402.9	389.8	673.2	345.2	211.3
	CV (%)	16.26	14.78	19.44	18.10	14.05	18.94	11.86	19.04

Genotype grain yield performance with respect to environment (Which Won Where)

The GGE polygon view of the 10 drought tef genotypes and two controls (local check and standard check Boset tested in the seven environments is presented on Figure 1 polygon view helps to identify winning genotypes in different environments by visualizing GEI (Yan and Kang, 2003) in MET and in estimating possible existence of different mega environments (Gauch, and Zobel, 1996; Yan and Rajcan, 2002; Yan and Tinker, 2005).

In the present investigation, the partitioning of GE interaction through GGE biplot analysis showed that AXIS$_1$ and AXIS$_2$ accounted for 55.08% and 19.73% of GGE sum of squares, respectively, explained 74.81% of the total variance (Figure

1). The polygon view was created by connecting the vertex genotypes codes (2, 6, 8 and 12) which were having the largest distance from the origin. These genotypes were the highest yielding in their respective environments or sector. The biplot is divided into four sections by the four rays with genotypes falling in all sections while the environments fall in two areas. According to the findings of Yan and Tinker (2005), the vertex genotypes were the most responsive genotypes, as they have the longest distance from the origin in their direction. In this finding the genotype code "2" is the only one in vertices of the polygon in which all environments are contained except E5. Thus, genotype code "2" is the most productive in those six environments in terms of grain yield. The other genotypes 8, 6 and 12 on the vertices of the polygon not containing any of the seven environments are unfavorable in the seven test environments. The best performing genotype in grain yield was genotype code "2"being the furthest to the right.

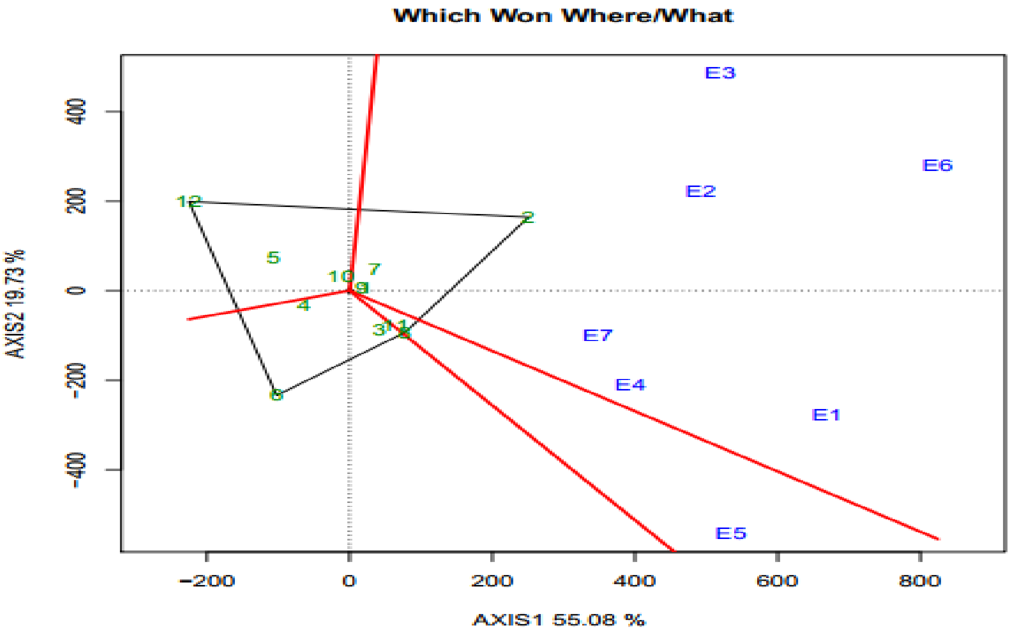

Figure 1. Adaptability and performance of tef test genotypes with respect to test environments. Genotype code is indicated in Table 2and 3.

Genotypes Mean Yield and their Stability

Visualization of mean performance and stability analysis of genotypes is an important issue in crop genotype evaluation. The estimation of yield and stability of genotypes were done by using the average environment axis (AEA) methods (Figure 2) (Yan, 2001 and Yan and Hunt, 2001). The line passing through biplot origin from lower right to upper left is the average environment axis (AEA) as defined by the first two AXISs of the environments scores (Yan and Kang, 2003). The furthest from the arrow is the genotype with the highest yield ranking in a particular environment; the environment axis through the origin and that specific environment, genotypes closer to the environment along the axis are high yielding and *vice versa*. Genotype axis through the biplot origin and that genotype, along that axis are the rankings of the environments.

Genotypes located closer to the ideal genotype are more desirable than others. For selection, the ideal genotypes are those with both high mean yield and high stability. In this study, the genotype code "2" was ranked best in the entire tested environment and had the higher stability as well as higher mean yield across all tested environments. This result is in agreement with those obtained by (Akter, 2015) in rice and (Naheif, 2013) in wheat.

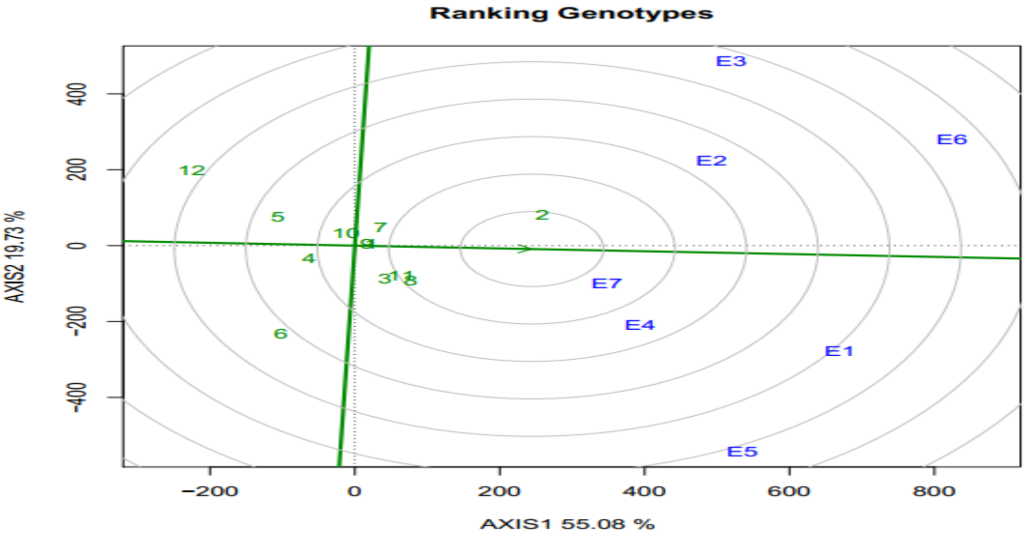

Figure 2. Ranking of tef test genotypes with respect to test environments. Genotype code is indicated in Table 2 and 3.

Description of the Candidate variety Dtt2 x Dtt13 (DZ-Cr-498 RIL 37) (Boni)

The distinctive pheno-morphologic and agronomic description of the genotype Dtt$_2$ x Dtt$_{13}$ RIL 37 selected as candidate variety is summarized in Table 4. The candidate line has got very loose panicle form which often correlated with high yield compared to the compact panicle types (Seyfu, 1997) and the lemmas are yellowish green when immature and yellowish white when mature. In the current finding, Dtt$_2$ x Dtt$_{13}$ (DZ-Cr-498 RIL 37) belongs to the early maturity group (80 days to mature), which almost equally divided between the days taken to head and the grain filling period (i.e., the days from heading to physiological maturity). Furthermore, the genotype produces good outputs, particularly in terms of grain yield, and is comparable to standard checks in terms of biomass yield in general.

Table 4. Distinguishing phenologic, morphological and agronomic characteristics the candidate variety Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37).

No.	Characteristics	Description		
I	**Qualitative traits**	**Yellowish green**		
1	Basal stalk color	Yellowish green		
2	Panicle form	Very loose		
3	Lemma color	Yellowish green when immature and yellowish white when mature		
4	Anther color	Yellowish white		
5	Seed color	Very white		
II	**Quantitative traits**	**Minimum**	**Maximum**	**Mean ± SE**
1	Days to panicle emergence	27	49	41 ±1.21
2	Days to maturity	62	88	80 ±1.51
3	Grain filling period (days)	27	46	39 ±0.92
4	Plant height (cm)	57	109	92 ±2.72
5	Culm length (cm)	18	67	52 ±2.6
6	Panicle length (cm)	33	44	40 ±0.53
7	Biomass yield (t/ha)	6.5	20	11.33 ±0.60
8	Grain yield (t/ha)	1.70	3.5	2.46 ± 0.110
9	Lodging index	62	100	83 ±2.63
10	Harvest index (%)	13	40	26 ±1.4

Distinguishing and beneficial features of the Candidate variety Dtt2 x Dtt13 (DZ-Cr-498 RIL 37) (Boni)

The candidate variety Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37) selected for release possessed the following noteworthy distinguishing characteristics.

1) It showed grain yield advantages of 13.19% and 27.55% over the standard check (Boset) and local cultivar, respectively.
2) Moreover, the selected genotype will be highly valuable in view of the prevailing climate change and thereby suitable for drought-prone areas since it is tolerant to drought both at early stage during seedling emergence and also escapes terminal drought through its early maturing characteristics,
3) This genotype has also got immense farmers' preference and attention due the favorable combination of drought tolerance, early maturity and white caryopsis color

Conclusions and Recommendations

From the study we can conclude that, the evaluated drought tolerant tef genotypes showed significant variance for the studied traits in seven environments encompassing two years

(2018 and 2019 main seasons) and five tef growing sites in moisture stress areas of the country. The candidate variety Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37) had the highest mean grain yield, followed by genotype DZ-Cr-387 x Dtt_2 RIL 15 and DZ-Cr-387 x Dtt_2 RIL 97. In comparison, the genotype DZ-Cr-387 x Dtt_2 RIL 80 and local check had the lowest mean yield.

The candidate variety Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37) ranked first in four of the seven environments. GEI effects showed that genotypes performed similarly to the variations in the test environments. The genotype code "2" ranked best and most productive in all the test environments in terms of grain yield. The candidate variety Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37) has double advantage on moisture stress area or drought prone areas because tolerate drought conditions both at early stage during seedling emergence and also escape drought through early maturing.

Therefore, this genotype recommended for all moisture stress areas of Ethiopia. Considering the seven environments' data and field performance evaluation during the variety verification trial, the national variety releasing committee has approved the official release of candidate genotype, Dtt_2 x Dtt_{13} (DZ-Cr-498 RIL 37), with the vernacular name of “Boni” for moisture stress areas of the country.

Author Contributions

Kebebew Assefa, Solomon Chanyalew and Zerihun Tadele conceived and supervised the research. Worku Kebede, Tsion Fikre and Yazachew Genet contributed to the research design and data interpretation. Worku Kebede, Tsion Fikre, Yazachew Genet, Kidist Tolosa, Mengistu Demissie, Habte Jifar, Solomon Mitiku, Kidu Gebremeskel and Sewagegn Tariku collected data and conducted phenotypic analysis. Worku Kebede, Habte Jifar and Kebebew Assefa analyzed and interpreted data. Worku Kebede and Kebebew Assefa drafted the manuscript and produced figures. All authors approved the final version of the manuscript.

Acknowledgments

We are grateful to Syngenta Foundation for Sustainable Agriculture and EIAR-University of Bern Collaborative Tef Research Project for financial and technical support. The federal and regional research institutions as well as researchers and technical assistants involved in the study are highly acknowledged.

References

Abuhay Takele. 2001. Canopy temperatures and excised leaf water loss of tef [*Eragrostis tef* (Zucc.) Trotter] cultivars under water deficit conditions at anthesis. *Acta Agronomica Hungarica* 49(2): 109-117.

Akter, A., Hasan, M. J., Kulsum, U., Rahman, M. H., Khatun, M. and Islam, M. R. 2015. GGE biplot analysis for yield stability in multi-environment trials of promising hybrid rice (Oryza sativa L.). Bangladesh Rice Journal, 19 (1), pp. 1-8.

AlemuYami. 2013. Tef Straw: A valuable feed resource to improve animal production and productivity. *In*: Kebebew Assefa, Solomon Chanyalew and Zerihun Tadele (*eds.*), Achievements and Prospects of Tef Improvement; Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland. pp. 233-251.

Baye K (2014) Teff: nutrient composition and health benefits. Intl Food Policy Res Inst.Bekabil Fufa, Befekadu Behute, Kathryne Benesh, Rupert Simons and Tareke Berhe. 2013. Analysis of the tef value chain in Ethiopia. *In*: Kebebew Assefa, Solomon Chanyalew and ZerihunTadele (eds.). Achievements and Prospects of Tef Improvement; Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland. pp. 305-322.

Cannarozzi, G., Solomon Chanyalew, Kebebew Assefa, Abate Bekele, Annett Weichert R.B., Klauser D., Plaza-Wuthrich S., Esfeld K., Jost M., Rindisbacher A., Habte Jifar, Johnson-Chadwick V., Ermias Abate, Wang W., Kamies R., NegussuHusein, WorkuKebede, KidistTolosa, Yazachew Genet, KiduGebremeskel, BriktiFerede, FirewMekbib, Federico Martinelli F., Hans Christian Pedersen H.C., Rafudeen S., Shimelis Hussein, Muluneh Tamiru, Nakayama N., Mike Robinson M., Ian Barker I., Samuel Zeeman S. and Zerihun Tadele. 2018. Technology generation to dissemination: lessons learned from the tef improvement project. *Euphytica* 214: 31.

CSA. 2020. Central Statistical Agency, Agricultural Sample Survey 2019/2020 (2012 E.C). Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin 587. Addis Ababa, Ethiopia.

CSA.2015. Central Statistical Agency, Agricultural Sample Survey. Volume I, Report on Area, Production and Yield of Major Crops (Private Peasant Holdings, *Meher*Season), Statistical Bulletin 278, Addis Ababa, Ethiopia.

Gauch, H. G., and Zobel, R. W. 1996.AMMI analysis in yield trials. Kang, M.S., Gauch, H.G. (eds), Genotype by Environment Interaction.CRC Press, Boca Raton. pp. 85-122.http://dx.doi.org/10.1201/9781420049374.ch4

Geremew Bultosa, Hall A.N. and Taylor J.R.N. 2002. Physico-chemical characterization of grain tef [*Eragrostistef*(Zucc.) Trotter] starch. *Starch-Starke* 54: 461-468.

Habtamu Hailekiros. 2015. Genetic Variability and Associations Among Grain Yield and Yield Related Traits in Recombinant Inbred Lines of Tef [Eragrostis Tef (Zucc.) Trotter] at Laelay Maichew District, Northern Ethiopia. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Habtamu Hailekiros. 2015. Genetic Variability and Associations Among Grain Yield and Yield Related Traits in Recombinant Inbred Lines of Tef [Eragrostis Tef (Zucc.) Trotter] at Laelay Maichew District, Northern Ethiopia. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Habte Jifar, Kasahun Tesfaye, Kebebew Assefa, Solomon Chanyalew and Zerihun Tadele. 2017. Semi-dwarf tef lines for high seed yield and lodging tolerance in central Ethiopia. African Crop Science Journal, 25: 419 - 43.

Hailu Tefera, Kebebew Assefa and Getachew Belay. 2003a. Evaluation of interspecific recombinant inbred lines of Eragrostis tef x E .pilosa. Journal of Genetics and Breeding, 57: 21-30.

Jeffrey, J. (2015). Will Ethiopia's teff be the next 'super grain? BBC, London.Kebebew Assefa, Arnulf Merker and Hailu Tefera. 2003. Multivariate analysis of diversity of tef [Eragrostis tef (Zucc.)Trotter] germplasms from western and southern Ethiopia. Hereditas, 138: 248–236.

Kebebew Assefa, Hailu Tefera, Arnulf Merker, Tirunesh Kefyalew, and Fufa Hundera. 2001b. Quantitative trait diversity in tef [Eragrostis tef (Zucc.)Trotter] germplasm from Central and Northern Ethiopia. Genetic Resources and Crop Evolution, 48: 53-61.

Kebebew Assefa, Sherif Aliye, Getachew Belay, Gizaw Metaferia, Hailu Tefera, Sorrells, M. E. 2013. Quncho: The firstpopular tef variety in Ethiopia. International Journal of Agricultural Sustainability 9: 25–34.

Kebebew Assefa, Solomon Chanyalew, Yazachew Genet, Mitiku Asfaw, Tsion Fikre, Habte Jifar, Nigussu Hussen, Mihireteab H/Sellassie, and Molalign Assefa. 2017. Tef (*Eragrostis tef*) variety “Kora”.*Ethiop. J. Agri.Sci.* 27(2):137-140.

Kebebew Assefa, Yu, J.K., Zeid, M., Getachew Belay, Hailu Tefera and Sorrells M.E. 2011. Breeding tef [*Eragrostis tef* (Zucc.) Trotter]: conventional and molecular approaches. *Plant Breeding* 130: 1-9.

Minten, B., Seneshaw Tamru, Ermias Engidaand Tadesse Kuma. 2013. Ethiopia’s Value Chains on the Move: The Case of Teff. ESSP Working Paper 52. International Food Policy Research Institute, Ethiopia Strategy Support Program II, Addis Ababa, Ethiopia.

Mizan Tesfaye, Shimelis Hussein, Laing M. and Kebebew Assefa. 2017. Genetic variation and trait association of tef [*Eragrostistef* (Zucc.) Trotter] evaluated under optimal and moisture stressed environments. *Australian Journal of Crop Science* 11(03): 241-247.

MoA. 2020. Ministry of Agriculture, Plant Variety Release, Protection and Seed Quality Control Directorate, Crop Variety Register, Issue No. 22, June 2019, Addis Ababa, Ethiopia.

Mulu Ayele. 1993. Use of excised-leaf water content in breeding tef [Eragrostistef (Zucc.) Trotter] for moisture stress areas. Acta Agronomica Hungarica 42: 261-265.

Naheif, E, M Mohammad, 2013. Genotype x environment interactions for grain yield in bread wheat (Triticum aestivum L.). Global Sci. Res. J. 1 (1): 045-052.

Nurse, E. (2015). Tef, the Ethiopian superfood that used to be banned, CNN, Africa, Discover teff: A gluten free superfood from Ethiopia.

Provost, C. and Jobson E. (2014). Move over quinoa, Ethiopian's teff is poised to be the next big super grain.

R core Team (2021). R: A language and environmental for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Regula Blösch, Abiel Rindisbacher, Sonia Plaza-Wüthrich, Nora Röckel, Annett Weichert, Gina Cannarozzi and Zerihun Tadele 2019. Identification of Drought Tolerant Mutant Lines of Tef [*Eragrostis tef* (Zucc.) Trotter]. Afrika focus 32(2): 25-37.

Setotaw Ferede. 2013. Technological change and economic viability in tef production, *In*: Kebebew Assefa, Solomon Chanyalew and Zerihun Tadele (eds.), Achievements and Prospects of Tef Improvement; Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia; Institute of Plant

Sciences, University of Bern, Switzerland. pp. 255-273.

Seyfu Ketema. 1997. Tef: [*Eragrostistef* (Zucc.) Trotter]: Promoting the Conservation and Use of Underutilized and Neglected Crops12 Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy.

Solomon Chanyalew, Hailu Tefera and Singh H. 2009. Genetic variability, heritability and trait relationships in recombinant inbred lines of tef [Eragrostis tef (Zucc.) Trotter]. Research Journal of Agriculture and Biological Sciences, 5: 474-479.

Solomon Chanyalew, Kebebew Assefa, Mitiku Asfaw, Yazachew Genet, Kidist Tolossa, Worku Kebede, Tsion Fikre, Nigussu Hussen, Habite Jifar, Atinikut Fentahun, Kidu Gebremeskel, Girma Chemeda and TegegnBelete. 2017. Tef (*Eragrostistef*) variety “Dagim”.*Ethiop.J.Agri.Sci.* 27(2): 131-135.

Spaenij-Dekking, L., Kooy-Winkelaar Y. and Koning F. 2005.The Ethiopian cereal tef in celiac disease. *The New England Journal of Medicine* 353: 1748-1749.

Tsion Fikire. 2016. Variability Genetic Diversity of Ethiopian Tef (Eragrostis tef (Zucc.) Trotter) Varieties as Revealed by Morphological and Microsatellite Markers. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

VanBuren, R., Man Wai, C., Wang, X., Pardo, J., Yocca, A. E., Wang, H., Chaluvadi, S. R., Han, G., Bryant, D., Edger, P. P., Messing, J., Sorrells, M. E., Mockler, T. C., Bennetzen, J. L., & Michael, T. P. (2020). Exceptional subgenome stability and functional divergence in the allotetraploid Ethiopian cereal teff. Nature Communications, 11(1), 1–11.

Vavilov, N.I. 1951. The Origin, Variation, Immunity and Breeding of Cultivated Plants. Ronald Press, New York. [Translated from Russian by Chester, S. K.].

Worku Kebede, Kidist Tolossa, Nigussu Hussein, Tsion Fikre, Yazachew Genet, Abate Bekele, Kidu Gebremeskel, Atinkut Fentahun, Habte Jifar, Sonia Plaza-Wüthrich, Regula Blösch, Solomon Chanyalew, Kebebew Assefa, and ZerihunTadele.2018. Tef (*Eragrostis tef*) Variety ‘*Tesfa’*(DZ-Cr-387 X 3774-13RIL120B.*Ethiop.J.Agri.Sci*. 28(2): 107-112.

Worku Kebede, Yazachew Genet, Tsion Fikre, Kidist Tolosa, Solomon Chanyalew, Mengistu Demissie, Kebebew Assefa, Kidu G/Meskel, Atinkut Fantahun and Zerihun Tadele 2020. Tef (*Eragrostis tef*) variety development for moisture stress areas of Ethiopia: *Journal of Innovative Agriculture*: 7(4): 1-6.

Yan W, Hunt LA.2001. Interpretation of genotype× environment interaction for winterwheat yield in Ontario. Crop Sci. 41: 19-25.

Yan, W. 2001. GGE biplot a Windows application for graphical analysis of multi- environment trial data and other types of two-way data. Agro, J. 93: 1111‑1118.

Yan, W. and Rajcan, I. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario.*Crop Science*42 (1): 11-20.

Yan, W., and Tinker, N. A. 2005. An integrated biplot analysis system for displaying, interpreting, and exploring genotype environment interaction. *Crop Science45* (3): 1004-1016.

Yan, W.and Kang, M. S. 2003.GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists, and Agronomists. CRC Press.

Yayis Rezene, Agdew Bekele, Yasin Goa. 2014. GGE and Ammi Biplot Analysis for Field Pea Yield Stability in SNNPR State, Ethiopia. *International Journal of Sustainable Agriculture*1: 28-38.

Zerihun Tadele and Kebebew Assefa. 2012. Increasing food production in Africa by boosting the productivity of understudied crops. *Agronomy* 2: 240–28.