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Development of Brown Seed and Release of "Biradama" Tef Variety for Potential Areas of Amhara Region and Beyond

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Abstract

Brown seed tef variety development did not get much attention as white seed in tef improvement program in Ethiopia. However, brown seed tef is locally demanded for home consumption and foreign markets. It has wider genetic variability that can be exploited in tef improvement program. Therefore, the study was conducted to develop high yielding brown seed tef variety with desirable agronomic and quality traits. Eighteen tef genotypes with standard and local checks were used for this study. The study was conducted at Adet (2019 and 2020), Mota (2019 and 2020), Takusa (2019 and 2020) and Finote Selam (2020) in Amhara region with a total of seven environments. A randomized complete block design with 3 replications was used in this experiment. The analysis of variances showed significant differences for the evaluated traits in genotypes, environments and genotypes by environment interaction. The genotype Accession # 236756-3 is a stable genotype than the other tested genotypes. The grain and straw yield performance of the genotype accession # 236756-3 was 2529 kg.ha^{-1} and 6040 kg.ha^{-1}, respectively. It had 14.3% and 25.2% grain yield advantage over standard check "Filagot", and the farmer's variety, respectively. In addition, it had 13.6% and 19.4 % straw yield advantage over "Filagot" (standard check) and the farmer's variety, respectively. A variety verification trial of the genotype accession # 236756-3 was conducted in test locations with a standard check ("Filagot") and the farmer's variety. The field performance of the verification trial was evaluated by National Technical Committee and released the variety for large production in tef production potential areas of Amhara Region and similar agro-ecologies of Ethiopia with a local name 'Biradama". This newly released variety can be used as parental material in the genetic improvements of tef.

Key words: correlation, genotype by environment interaction (GEI), genetic diversity, selection, stability analysis, yield gain

Introduction

Tef (*Eragrostis tef* Zucc.Trotter) belongs to the family Poaceae, subfamily Eragrostoideae and genus *Eragrostis.* It is cultivated from arid to moist tropics and subtropics and temperate areas. Tef is a staple small cereal crop in Ethiopia which is used to prepare diverse food (Seyfu,1997), gluten free, has stable starch, higher content of iron, calcium, essential amino acids (lysine) and better mineral content than other cereal crops (Melak,1966). In addition, tef has the highest and palatable 'injera' quality which is prepared from tef flour with thin pancake like local bread than other cereal crops such as barley, millets, rice, maize and wheat. Besides, its straw is nutritious for animal fattening (Seyfu, 1993). In general, Tef is wider adaptable to different agro ecologies; it is tolerant to moisture deficit, waterlogged, and soil acidity prone areas of which can not be used to grow other cereal crops (Assefa et al., 2015 and Abate et al., 2013). Farmers prefer to grow tef due to its resilient to stress conditions and suitable for double cropping (Seyfu, 1997). Therefore, tef area coverage in Ethiopia (about 3 million hectares) is ranked first than other cereal crops (CSA, 2021). Moreover, tef area coverage and productivity has increased year after year from about 2.6 to 3 million hectares and 1230 to 1880 kg.ha^{-1} in 2011 and 2021 respectively (CSA, 2021).

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Tef has about 350 species of which *Eragrostis tef* is the only species cultivated for human consumption (Seyfu, 1993). Ethiopian biodiversity institute is collected about 5000 tef accessions across different agro-ecologies of Ethiopia (Assefa et al., 2015). Different studies showed that there is high variability in tef accession which had significant differences in grain and biomass yield performance, yield related traits, seed color and tolerant to environmental stresses (Assefa et al, 2011, and Teklu and Tefera, 2005).

Brown seed tef is not considered as white seed tef in tef variety development program in Ethiopia. On the other hand, brown seed tef has higher nutritional contents than white seed tef such as iron (Fe), copper (Cu), aluminum (Al), amino acids, and minerals (Melak, 1966). Since 1970s to 2021, Ethiopia has been released about 54 tef varieties. Although tef variety release has been began on brown seed tef variety namely Asgori (DZ-01-99) in 1970, only 5 brown seed tef varieties were released until 2021 (MoA, 2021). Moreover, in the Amhara region, tef varieties promotion in the extension system as well as seed dissemination in the formal seed system is only focus on few white seed varieties. Because in Ethiopia, the market price of white seed tef is higher than the brown seed tef. Hereby, brown seed tef genetic diversity is reduced year after year in tef potential areas of Amhara Region.

On the other hand, currently brown seed tef is demanded by farmers due to cold tolerant in the cold prone highland areas and for house consumption in the country (Assefa et al, 2002b) as well as in the world due to its higher iron content, amino acids and mineral contents, and beverage and food production. Therefore, considering the higher genetic diversity of brown seed tef accessions and limited research studies on brown seed tef variety development, the study was initiated to develop and release a stable and higher grain yield brown seed tef variety than farmers' variety and standard check variety in tef potential areas in Ethiopia.

Materials and Methods

Plant Materials

Sixteen brown seed tef genotypes which showed good agronomic performance in both screening and preliminary yield trials were advanced to regional variety trial of which originated and collected in different agro-ecologies of Ethiopia. The description of 16 tef genotypes with "Filagot" (standard check) and the farmer's variety (the local check) were used for this study is presented in Table 1. "Filagot" is brown seed tef variety which is recently released by Debre Zeit Agricultural research Center. Farmer's variety is a local variety which is used as genetic source for tef production for each location by farmers.

Description of Testing Areas and Field Management

The study was conducted at Adet (2019 and 2020), Mota (2019 and 2020), Takusa (2019 and 2020) and Finote Selam (2020) in Amhara region with a total of seven environments. The locations represent tef producing areas from high potentials areas, i.e., Adet, Mota and Takusa, to medium potential areas, i.e., Finote Selam in Amhara region. Descriptions of testing areas are presented in Table 2. The genotypes were laid out in a randomized block design with three replications. The gross and harvestable plot area were 2m x 2m and 2m x1.6 m, respectively. Seed rate was used 15 kg.ha^{-1} in row planting method. NPS and Urea were applied at a rate of 158 and 50 kg.ha^{-1} respectively across tested environments. All NPS was applied at sowing whereas all urea was applied at tillering stage (35-40 days after sowing at 1st weeding). Sowing was done from the last week of June to the 2nd week of July in 2019 and 2020 cropping seasons. Weeding was done two times at tillering and booting stage.

Tef Genotype Phenotyping

Six quantitative traits related to yield, yield components and phenology were investigated on the tef genotypes. The investigated agronomic and phenological quantitative traits includes plant height (PH, cm), panicle length (PL, cm), grain yield (GY, kg.ha^{-1}), and straw yield (SY, kg.ha^{-1}). The first two plant height and panicle length were recorded from five randomly selected plants per plot, 15 plants per replications and 105 plants across environments for each genotype while the grain and straw yield were recorded on plot basis which is 8 rows among 10 to reduce the border effect. The two phenological traits, days to 50% heading (DH), days to 75% maturity were recorded for whole plots across replications over locations.

Statistical Analysis

The analysis of variances was analyzed using GenStat (18thed.) software to compute genotype and environment main and interaction effects, yield related traits and grain yield stability of genotypes. LSD was used to separate the means of genotypes, environments and genotypes by environments interaction. Correlation analysis was done by using

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Table 1. Description of tef genotypes used for the study*.

Code	Genotypes	Collection areas of tef genotypes				
		Altitude	Region	Zone	District	Kebele
1	Acc#236358-1	2210	Oromia	East Wollega	Gida Kiremu	Lebu
2	Acc# 225906-2	2450	Amhara	South Wollo	Kelala	Kalad
3	Acc#225907-1	2400	Amhara	South Wollo	Kelala	Jelisa
4	Acc#236261-2	1520	Oromia	-	Naziret	NA
5	Acc#242150-2	2110	Amhara	West Gojam	Bure-Wonberma	NA
6	Acc#237576-1	2250	SNNP	Kembata	Angacha	AmechoWato
7	Acc#228668-1	1750	Oromia	West Shewa	Cheliya	Abono
8	Acc#238606-2	2060	Oromia	East Shewa	Ada'aChukala	Wodoidibayu
9	Acc#242199-3	2725	Amhara	South Gonder	Tach Gaynt	Arib Gebeya
10	Acc#237575-2	1910	Oromia	East Shewa	Seraro	Yaye
11	Acc#230773-1	1220	Oromia	Borena	Moyale	Semere-Ca
12	Acc#236756-3	2100	Oromia	West Shewa	Cheliya	Gedu-Gura
13	Acc#212489-4	2530	Amhara	North Shewa	Lay Bet & Tach Bet	Dale Dibdibe
14	Acc#212487-2	1880	Amhara	North Shewa	Lay Bet & Tach Bet	Kumamba
15	Acc#202975-3	NA	NA	NA	NA	NA
16	Acc#55125-2	NA	NA	NA	NA	NA
17	"Filagot"					
18	Farmer's variety					

*Source: Ethiopian Biodiversity Institute. NA=not available, SC=standard check

Table 2. Descriptions of testing locations for this study.

Locations	Altitude (masl)	Years	Rainfall* (mm)		Temperature* (°C)		Relative humidity (%)		Soil type
			Max	Min	Max	Min	Max	Min	
Adet	2240	2019	362.7	57.2	24.1	10	69	50	Nitisol
Adet	2240	2020	334.6	23.9	24.3	11.1	76	45	Nitisol
Mota	2450	2019	343	68	22.2	11.4	74	46	Nitisol
Mota	2450	2020	387	24	22	11.1	79	43	Nitisol
Finote Selam	1850	2019	258	NA	NA	NA	NA	NA	Nitisol
Finote Selam	1850	2020	319	NA	26	11.2	NA	NA	Nitisol
Takusa	1785	2019	NA						Vertisol
Takusa	1785	2020	NA						Vertisol

*Source: Ethiopian Meteorology Agency; NA=information not available

SAS (version 9.0). GGE biplot was used to identify the stable and higher yielder of tef genotypes. GGE biplot analysis was carried out to identify high yielding and stable varieties as well as representative and discriminating environments as per Yan (2001):

Yger - βe = Σn^ n тgnδen+pge+ꞓger

Where: Yger is the grain yield of genotype (g) in environment (e) for replicate (r), βe are the environment mean deviations, ^ n is the singular value for IPCA axis n, тgn are genotype Eigenvector values for IPCA axis n, δen are the environment Eigenvector values for (PCA) axis n, pge are the residuals and ꞓger is the error term.

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Result and Discussion

Analysis of Variance Components

The analysis of variances ($P<0.05$) for grain yield, agronomic and phenological traits in tef genotypes across environments showed significant difference by genotypes, environments and genotype by environment interactions as depicted in table 3. Results of this study revealed the significant variation of the traits in tef genotypes. The genotype Acc#236756-3 showed higher grain yield and straw yield performance of which higher days to heading and maturity with longer plant height and panicle length than other tested tef genotypes. The highest straw yield (6040 kg.ha^{-1}) was scored on Acc#236756-3, whereas the lowest straw yield (4405 kg.ha^{-1}) was scored on Acc#212487-2 across environments over years. The highest grain yield (2529 kg ha^{-1}) was scored on Acc#228668-1 at Adet over years, while 940 kg.ha^{-1} was scored on Acc#55125-2 at Finote Selam which was lowest compared to other tested genotypes (Table 5). However, the interaction effects showed significant difference on the grain yield performance of tef genotypes across environments of which it needs further stability analysis. The study was in line with Worede (2020) and Habte et al. (2019) reports.

Stability Analysis of Grain Yield in Tef Genotypes

When GEI is significant across multi-environment trials, Biplot analysis is vital to visualize the multi-dimensional views into graphical forms for the identification of superior (higher yielder and stable) genotypes in specific environments and/or across environments (Yazachew et al., 2020). Amongst the stability analysis techniques of multiple

Table 3. Yield associated traits performance of tef genotypes across environments.

Code	Genotypes	DH	DPM	PH (cm)	PL (cm)	SY (kg.ha^{-1})	GY (kg.ha^{-1})
1	Acc#236358-1	52.2	101.0	98.9	35.6	5350	1832
2	Acc# 225906-2	51.2	99.0	117.7	39.0	4864	1595
3	Acc#225907-1	51.4	99.5	104.6	36.4	5184	1742
4	Acc#236261-2	57.6	105.4	106.5	39.4	5235	1954
5	Acc#242150-2	54.1	106.6	108.6	41.9	5231	1615
6	Acc#237576-1	49.6	95.3	102.4	36.9	5474	1970
7	Acc#228668-1	52.2	96.3	101.6	38.8	5513	2146
8	Acc#238606-2	50.9	95.1	97.3	35.9	4628	1758
9	Acc#242199-3	52.2	95.9	100.7	38.6	4908	1827
10	Acc#237575-2	49.4	94.5	98.6	38.5	4969	1935
11	Acc#230773-1	50.2	96.1	101.7	32.5	4541	1648
12	Acc#236756-3	53.4	104.9	120.1	42.8	6040	2177
13	Acc#212489-4	57.5	105.9	110.1	34.8	5154	1422
14	Acc#212487-2	52.0	96.5	97.8	35.5	4405	1476
15	Acc#202975-3	51.2	94.6	102.6	35.9	5787	1985
16	Acc#55125-2	51.6	97.9	100.4	35.3	5067	1904
17	“Filagot” (SC)	49.1	92.3	97.3	34.8	5315	1904
18	Farmer’s variety	53.2	102.4	104.6	38.0	5058	1739
	Mean	52.0	99.0	104	37.0	5151	1813
	LSD	2.5	4.2	7.2	4.1	484.8	109
	CV	2.7	2.7	4.3	6.7	15.5	9.9
	Gen	**	**	**	**	**	**
	Env	**	**	**	**	**	**
	G*E	**	**	**	**	ns	**

Note: DH=days to 50% heading, DPM= days to 75% physiological maturity, PH=plant height, PL=panicle length, SY= straw yield, GY= grain yield, LSD= least significant difference, CV=coefficient of variation, Gen= genotypes, Env=environments, G*E=genotype by environment interaction, ns=non-significant.

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Table 4. Grain yield (kg.ha^{-1}) performance of tef genotypes across locations.

Code	Genotypes	Grain yield across locations (kg.ha^{-1}).				
		Adet	Mota	Takusa	F/Selam	Mean
1	Acc#236358-1	1868	1888	2003	1305	1832
2	Acc# 225906-2	1741	1578	1788	953	1595
3	Acc#225907-1	1851	1696	2047	1005	1742
4	Acc#236261-2	2156	1978	2057	1296	1954
5	Acc#242150-2	1575	1743	1932	806	1615
6	Acc#237576-1	2081	1994	2042	1558	1970
7	Acc#228668-1	2529	2014	2247	1444	2146
8	Acc#238606-2	2010	1826	1793	1045	1758
9	Acc#242199-3	1827	1920	2049	1193	1827
10	Acc#237575-2	2184	1934	2044	1223	1935
11	Acc#230773-1	1888	1365	2003	1028	1648
12	Acc#236756-3	2317	2103	2255	1891	2177
13	Acc#212489-4	1643	1177	1683	947	1422
14	Acc#212487-2	1655	1332	1688	980	1476
15	Acc#202975-3	2249	1988	1989	1443	1985
16	Acc#55125-2	2058	1968	2171	940	1904
17	“Filagot” (SC)	2062	1943	2041	1237	1904
18	Farmer’s variety	1831	1804	1811	1280	1739
	Mean	1974	1792	1980	1198	1813
	LSD	201.9	180	238.9	281.8	109
	CV	8.9	8.7	10.5	14.2	9.9
	Gen	**	**	**	**	**
	Env	ns	*	**		**
	Ge*Env	**	**	**		**

Note: LSD= least significant difference, CV=coefficient of variation, Gen=genotypes, Env=environments, G*E=genotype by environment interaction, ns=non-significant.

environment trials, GGE biplot is the most important and recent ones. It is used to identify stable and higher grain yielder genotypes, ideal genotypes and environments, effectively analyze the GE interaction and best genotypes both in specific environment and under multi-environments (Molla et al., 2022 and Worede, 2020). As depicted in Figure 1, genotype G12 (Acc#236756-3) was the most stable genotype followed by G7 (Acc#228668-1) whereas G13(Acc#212489-4 is unstable and lower grain yielder as compared to the tested tef genotypes. Sewagegn et al., (2023) and Yan et al., (2002) reported that the stable genotypes are closer to the ideal environment and/or average environmental coordinate, while the unstable genotypes are far from the ideal environment and/or average environmental coordinate in GGE comparison biplot. Hereby, genotype G12 (Acc#236756-3) can be used as genetic material over the tested locations for tef production.

Trait Correlation Analysis

Yield is the result of the sum of agronomic and phenological traits resulting from the interaction of genetic and environmental factors. Therefore, it is important to identify the association of agronomic and phenological traits with yield. In the study, Straw yield showed significant positive genotypic correlation with grain yield (Table 5). This is due to inherent gene relation or dependent genetic control, the pleiotropic effects of genes that control the phenotypic expression of these traits (Assefa, 2002b) and the presence of common genetic elements that controls the traits in the same direction (Dagnachew and Grima, 2014). In terms of phenotypic correlation, with panicle length, straw yield, plant height and days to heading was showed significant positive correlation with grain

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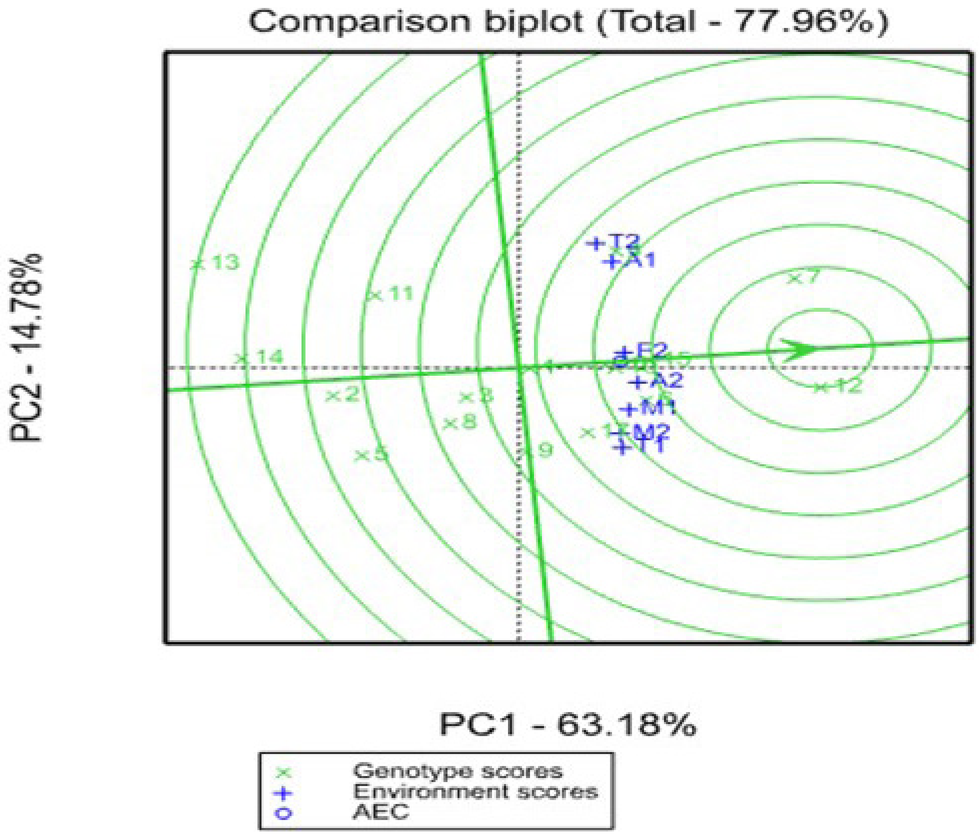

Figure 1. GGE biplot comparison of tef genotypes across environments. A1=Adet 2019, A2=Adet2020, M1=Mota 2019, M2=Mota 2020, T1=Takusa=2019, T2=takusa 2020, F2= Finote Selem=2020, 1= Acc#236358-1, 2= Acc# 225906-2, 3= Acc#225907-1, 4= Acc#236261-2, 5= Acc#242150-2, 6= Acc#237576-1, 7= Acc#228668-1, 8= Acc#238606-2, 9= Acc#242199-3, 10= Acc#237575-2, 11= Acc#230773-1, 12= Acc#236756-3, 13= Acc#212489-4, 14= Acc#212487-2, 15= Acc#202975-3, 16= Acc#55125-2, 17= "Filagot"(SC) and 18= Farmer's variety

Table 5. Genotypic (**bold**, above diagonal) and phenotypic (below diagonal) correlations of traits in tef genotypes.

Variables	DTH	DTPM	PH	PL	SY	GY
DTH		**0.88****	**0.49***	**0.32^{ns}**	**0.06^{ns}**	**-0.2^{ns}**
DTPM	0.69**		**0.67****	**0.49***	**0.13^{ns}**	**-0.19^{ns}**
PH	-0.12*	-0.16**		**0.59****	**0.28^{ns}**	**-0.01^{ns}**
PL	-0.28**	-0.26**	0.73**		**0.48***	**0.38^{ns}**
SY	0.35**	0.03^{ns}	0.44**	0.25**		**0.86****
GY	0.24**	-0.13^{ns}	0.25**	0.18**	0.62**	

Note: DTH=days to heading, DTPM= days to physiological maturity, PH= plant height, PL=panicle length, SY=straw yield and GY=grain yield.

yield. Result of this study is in line with the reports of Sewagegn et al., (2023), Nigus (2021), Misgana (2021), Jifar (2019) and Assefa (2002). The correlation of grain yield with agronomic and phenological traits in tef genotypes are varied by the genetic effects and environmental factors as Nigus (2021), Misgana et. al. (2021), Dagnachew and Girma (2014), Habte (2019) and Assefa et al. (2002b) reports. The exploitation of genetic and phenotypic correlation of grain yield with agronomic and phenological traits is vital to increase the grain yield of tef genotypes. As a result, among evaluated traits, days to heading, panicle length, plant height and straw yield are the limiting traits for grain yield increment of over the tested tef genotypes in tef potential areas.

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Conclusion

The performance of grain yield and yield related traits in tef genotypes were affected by genetic variations, environmental factors, and genotype by environment interactions. Days to heading, plant height, panicle length, and straw yield are considerable traits in the genetic improvement of tef which showed significant and positive correlation with grain yield. Genotype G12 (Acc#236756-3) was stable across environments with higher grain and straw yield performance which had 14.3% and 25.2% advantage over “Filagot” (standard check) respectively. This newly released genotype with vernacular name “Biradama” can be used as parental material in the genetic improvements of tef.

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