American Journal of Bioscience and Bioengineering
2022; 10(2): 23-28
http://www.sciencepublishinggroup.com/j/bio
doi: 10.11648/j.bio.20221002.11
ISSN: 2328-5885 (Print); ISSN: 2328-5893 (Online)

Tef (*Eragrostis tef*) Variety Development for High Potential Areas of Ethiopia

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To cite this article:

Worku Kebede, Kidist Tolosa, Tsion Fikre, Yazachew Genet, Solomon Chanyalew, Mengistu Demissie, Kebebew Assefa, Habte Jifar, Nigus Belay, Getahun Bekana, Kidu Gebremeskel, Girma Chemeda, Molalign Assefa, Sewagegn Tariku, Zerihun Tadele. Tef (*Eragrostis tef*) Variety Development for High Potential Areas of Ethiopia. *American Journal of Bioscience and Bioengineering*. Vol. 10, No. 2, 2022, pp. 23-28. doi: 10.11648/j.bio.20221002.11

Received: February 9, 2022; **Accepted**: March 3, 2022; **Published**: March 18, 2022

Abstract: The aims of the experiment are to determine and understand the effect of genotype, environment, and their interaction on grain yield of tef, and to identify and release stable and high yielding tef genotype for high potential areas of country. Twelve tef genotypes including two checks were laid out in randomized complete block design using four replications for two years (2016 and 2017) at twelve representative locations of high potential areas of the country. The trial was conducted on the plot size of 2m*2m with 10 rows per plot throughout all trial sites and 1.5m between replication, 1m between plot, and 20cm between rows. Agronomic and yield data were collected and subjected to statistical analysis in order to identify the best genotypes of the evaluated genotypes. Data from individual environments and combined over twelve locations were analyzed by using R 3.5 software version. The combined data analysis over locations and years indicated that the candidate variety Kaye Murri X 3774-1 (RIL18) performed better than the two checks and the other test genotypes. It gave 7.5% and 10.65% grain yield advantages over the standard check (Quncho) and local check, respectively. The significant genotypes x environments interaction effects indicated the inconsistent performance of genotypes across the tested environments. The candidate variety DZ-Cr-458 (RIL18) is the shortest vector from the AEC axis that identified as the most stable genotype. The National Variety Release Committee in Ethiopia investigated the two-year performance of Kaye Murri X 3774-1 (RIL18) and visited several locations where the new candidate variety was grown for evaluation under variety verification trial. Based on the critiques, the National Variety Release Committee the candidate variety was approved for release Kaye Murri X 3774-1 (RIL18), for high potential areas of the country with the vernacular name of "Ebba" as a standing witnessed for the earliest known tef scientist, Dr. Tadesse Ebba.

Keywords: Tef, *Ebba*, GGE Biplot, Stability Variety Release

1. Introduction

Tef is one of the most important crop in which 70% of Ethiopian used it as stable food. It is a resilient crop that performs better than other cereals under marginal conditions including drought, water logging, and poor soil fertility. Since it

produces a reasonable yield when grown in areas that experience moisture scarcity, it is considered as a low risk crop [11].

Tef is nutritious due to its high protein and mineral content [4, 1], and the absence of gluten [12] makes it an alternative food for people suffering from coeliac disease. It has become globally known, and various products are available in Europe and North America as health foods especially for persons with gluten intolerance [10]. In South Africa, India, Pakistan, Uganda, Kenya and Mozambique tef is mainly grown as a forage or pasture crop [8]. Tef grows under a wide range of ecological conditions from sea level up to 3000 meters above sea level (m.a.s.l). It is annually cultivated on over three million hectares of land, and as such it accounts for about 30% of the total area and 20% of the gross grain production of cereals grown in the country [3].

However, the productivity of tef is relatively low compared to most other crops. The national breeding program for tef has since nearly six decades been striving in many ways to increase the production and productivity of tef by eliminating and/or reducing the yield limiting factors. Lodging is one the most yield limiting factors, which occurs when plants grow long in height and fail to hold the panicle. The effect of the length of basal internodes on lodging has been demonstrated in rice [6]. In line with our knowledge, the impact of the lengths of the lower basal culm internodes at the lodging tolerance behavior of tef flora has not been addressed or reported so far. Decreasing the height of tef is one of the mechanisms presumed to remedy accommodations problem.

In a plant breeding programs many new genotypes are usually evaluated in different environments (location and years) to identify and advance desirable ones towards release. A genotype or cultivar stable if it has adaptability for a trait of economic importance across diverse environments. The environmental component (E) generally represents the largest component in analyses of variance, but it is not relevant to cultivar selection; only G and GE are relevant to meaningful cultivar evaluation and must be considered simultaneously for making selection decisions [17].

Genotype by environment (G x E) interaction affects the efficiency of crop improvement programs that may lead to complicates recommendation of varieties across divers' environments. Therefore, information on the structure and nature of G x E interaction is particularly useful to breeders [19].

Consequently, the objective of the present work has been to determine and understand the effect of genotype, environment, and their interaction on grain yield of tef and to identify and release stable, lodging tolerant and high yielding tef genotype, and farmers and consumers preferred tef varieties for high potential areas of country.

2. Materials and Methods

2.1. Experimental Sites

The field experiment was carried out over a two years (2016 and 2017) at twelve tef growing sites at high potential areas of the country (Debre Zeit, Minjar, Holeta, Adet, Fenote Selam, Akaki, Assosa, Jimma, Ginchi, Hatsebo, Adadi Mariam and Bichena).

2.2. Plant Materials

The genetic materials used in the study were obtained from the intra-specific cross made in 2011. The crossing method used to develop these materials was standard surgical hand emasculation and pollination technique. Female and male parents used for the crossing were Kaye Murri and 3774-13 ("*Kegne*"), respectively. Kaye Murri was selected as a maternal or ovule parent for its extra-white seed color, thick culm and vigorous growth habit, while 3774-13 ("*Kegne*") was identified at the University of Bern in Switzerland from screening 5000 mutagenized tef populations [7] using the method of TILLING (Targeted Induced Local Lesions IN Genomes). The candidate variety with the pedigree DZ-Cr-458 (Kaye Murri X 3774-13 (RIL8)) was identified from F7 homozygous recombinant inbred lines (RILs) advanced using the single seed descent method (SSD) from F_2-derived seeds. The crossing combinations and names of recombinant inbred lines as well as control materials used in the current study are shown on Table 1.

2.3. Genotypes, Testing Sites, and Experimental Design

Crossing and early generation testing for all breeding populations were performed at Debre Zeit Agricultural Research Center from where the National Tef Breeding Program is coordinated. The performance of 12 tef genotypes which includes 10 inberd lines from the two independent crosses to semi-dwarf tef lines as well as two controls (farmers' check and improved *Quncho* variety were tested at several locations (Debre Zeit, Minjar, Holeta, Adet, Fenote Selam, Akaki, Assosa, Jimma, Ginchi, Hatsebo, Adadi Mariam and Bichena) using Randomized Complete Block Design with four replications. The trial was conducted on the plot size of 2m*2m with 10 rows per plot throughout all trial sites and 1.5m between replication, 1m between plot and 20cm between rows. Agronomic and yield data were collected and subjected to statistical analysis in order to identify the best genotypes of the evaluated genotypes. A variety verification trial was conducted at (Debre Zeit, Minjar, Holeta, Adet and Bichena) on the trial station and in ten farmers' field during 2018 main production season.

2.4. Data Collection

Data on grain yield and yield-related traits were collected on plot and plant basis from each plot, respectively. Data on lodging index was taken during 90% physiological maturity of the crop. The value recorded following the method of [2] who defined lodging index as the product sum of each scale or degree of lodging (0-5) and their respective percentage divided by five. Lodging index = Sum (Lodging scores or degree X the respective percentage area lodged)/5. The

calculated values for lodging index is between 0 (no lodging or erect) and 100 (complete lodging). Data for plant height (cm), Panicle length (cm) were collected on the basis of five sample plants which were randomly taken from each plot and the average of five sample plants was used for analysis. Grain yield (g) of each plot was measured on clean, dried seed and the measured. Grain yield and biomass yield values (g) were converted to kilogram per hectare for analysis. All agronomic practices were done as per the recommendation for tef.

2.5. Data Analysis and Analysis of Variance

Data on grain yield and yield-related traits were collected on plot and plant basis from each plot, respectively. Data from individual environments and combined over twelve locations were analyzed by using R software (3.5 version). The analysis of variance for grain yield and yield-related traits for each environment and over twelve environments was analyzed by using randomized complete block design. 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 was used to assess the homogeneity of error variances prior to doing combine analysis over environments. Mean comparison using Duncan's Multiple Range Test (DMRT) was performed to explain the significant differences among means of genotypes and environments.

R software (3.5 version) was used to visualize GEI patterns. Based on principles of GGE biplot, for the yield characters; Environmental evaluation (the power of environments to discriminate among genotypes), Genotype evaluation (the mean performance and stability) and Mega-environment analysis (which-won-where pattern), whereby specific genotypes can be recommended for specific mega-environments [18].

3. Results and Discussion

3.1. Analysis of Variance

The combined analysis of variance for grain yield of the 12 tef genotypes across 12 testing environments revealed highly significant ($P < 0.01$) effects due to genotypes, environments and genotype by environment interactions. The significant variability among the tef varieties in the present study is in line with the previous reports in tef [9, 5].

3.2. Distinguishing Features and Performance of the New Variety

The candidate variety Kaye Murri X 3774-13 (RIL 18) is the progeny product of hybridization between Kaye Murri and 3774-13. Kaye Murri was selected as a maternal or ovule parent for its extra-white seed color, thick culm and vigorous growth habit, while 3774-13 was selected as a pollen parent for it's very white seed color. The major distinguishing characters of Kaye Murri X 3774-13 (RIL 18) are semi-dwarf, yellowish lemma color, yellowish anther color, and a very white seed color.

Highly significant variations among the genotypes were observed in shoot biomass and total grain yield in all study years and locations. The average grain yield of Kaye Murri X 3774-13 (RIL 18) was 2000-2600 kg ha^{-1} at research centers and 1900-2300 kg ha^{-1} on farmers' fields. On the average, Kaye Murri X 3774-13 (RIL 18) reaches the panicle emergence stage in 48 days and physiological maturity in 102 days after sowing. From the average plant height of 85-100 cm the panicle of Kaye Murri X 3774-13 (RIL 18) contributes to 36-44%. Kaye Murri X 3774-13 (RIL 18) is released for mid to optimum rainfall and high potential areas of the country.

The candidate variety gave 7.5% and 10.65% grain yield advantages over the standard check (*Quncho*) and local checks, respectively (Table 1). The candidates has also comparable shoot biomass yield. It has got an immense farmer's attention due to its high yielding potential, white seed color and good straw yield. It is to be noted that the straw yield is equally important as grain in tef for the livestock feed. Moreover, the candidate variety had new identified character which is semi-dwarf in height (92 cm), which might help in reducing yield loss due to lodging.

Based on a two-year multi-location trial, Kaye Murri X 3774-13 (RIL 18) was selected for its high grain and biomass yield as well as additional traits (Tables 1 and 2). Hence, Kaye Murri X 3774-13 (RIL 18) was selected and put under variety verification trial for release as a new variety. Based on the application for release, the National Variety Release Committee in Ethiopia scrutinized the two-year performance of Kaye Murri X 3774-13 (RIL 18) and visited several locations where the new variety was grown for evaluation. Consequently, the committee approved the release of Kaye Murri X 3774-13 (RIL 18) as a new variety. The new variety was christened as '*Ebba*' as a standing witnessed for the earliest known tef scientist, Dr. Tadesse Ebba.

Table 1. *Mean performance of tef genotypes in the white-seeded semi-dwarf late set national tef variety trial over twelve locations.*

Gen.Code	Genotypes	Grain yield (kg/ha)	Biomass yield (kg/ha)	Lodging index	Plant height (cm)
1	DZ-Cr-387	2109	8645	65	103
2	GA-10-3 X Kaye Murri (RIL182)	2163	8141	65	92
3	DZ-Cr-387 X GA-10-3 (RIL176)	2124	8323	65	104
4	GA-10-3 X Kaye Murri (RIL184)	2046	6899	66	90
5	DZ-Cr-387 X GA-10-3 (RIL182)	2187	7756	70	91
6	DZ-Cr-387 X GA-10-3 (RIL178)	2190	8236	63	99
7	DZ-Cr-387 X GA-10-3 (RIL210)	2112	8874	64	104
8	DZ-Cr-387 X GA-10-3 (RIL157)	2221	8527	65	100

Gen.Code	Genotypes	Grain yield (kg/ha)	Biomass yield (kg/ha)	Lodging index	Plant height (cm)
9	Kaye Murri X 3774-13 (RIL18)	2265	7868	60	92
10	GA-10-3 X Kaye Murri (RIL281)	2086	7821	63	94
11	DZ-Cr-387 X GA-10-3 (RIL91)	2231	8674	65	101
12	Local check	2047	7569	72	92
	Mean	2150	8111	65	97
	Coefficient of variation (%)	16.72	25	10	8
	LSD (0.05)	124.9	66.8	5.2	6.0
	Coefficient of determination (R^2)	90.0	75	73	75

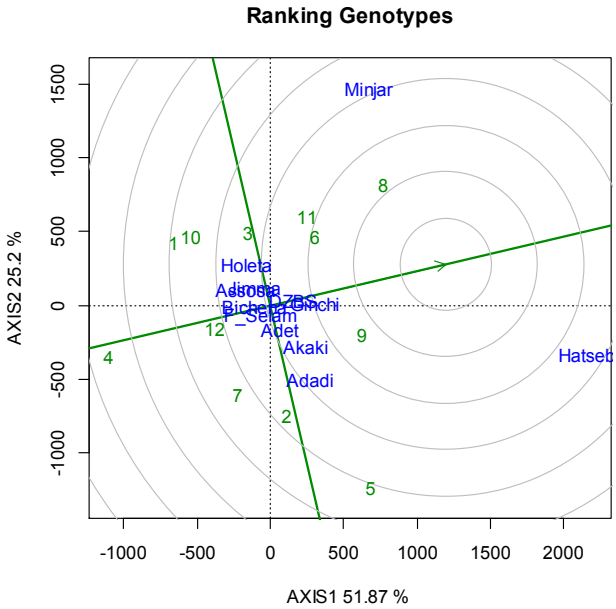

Figure 1. *Ranking genotypes relative to ideal genotypes.*

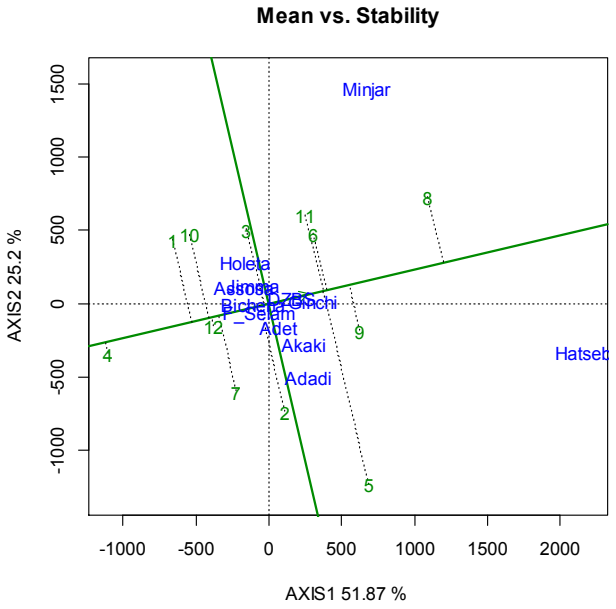

Figure 2. *Ranking of genotypes based on mean performance and stability.*

3.3. Ranking of Genotypes Relative to Ideal Genotypes

The average environment coordination view of the GGE biplot shows the ranking of genotypes based on the performance of an ideal genotype (Figure 1). The relative adaptation of the ideal genotype is evaluated by drawing a line passing through the biplot origin and the best genotype marker. This line is called a genotype axis and is connected to the best genotype [13]. Such ranking of genotypes based on performance of the ideal genotype revealed that genotype code 8(DZ-Cr-387 X GA-10-3(RIL157)), 9(Kaye Murri X 3774-13(RIL18)), 6(DZ-Cr-387 X GA-10-3(RIL178)) and 11(DZ-Cr-387 X GA-10-3 (RIL91) in that diminishing order were among the top yielding genotypes.

3.4. Genotypes Mean Yield and Stability

The average environment coordinate (AEC) is a line that passes through the origin and points to the higher mean yield across environments, and it shows the increase in rank of genotypes towards the positive end [14]. This line was reported to be useful to evaluate mean grain yield and stability of genotypes [15, 16]. According to such reports, genotypes considered to be stable are those that appear closer to the origin with the shortest vector from the AEC. Accordingly, Figure 2 shows the mean performance and stability of the genotypes in the present study. Based on this, the candidate variety genotype code 9(Kaye Murri X 3774-13(RIL18)), genotype 6(DZ-Cr-387 X GA-10-3(RIL178)), and genotype 8(DZ-Cr-387 X GA-10-3(RIL157), with the shortest vector from the AEC axis were identified as the most stable genotypes, while genotype code 5(DZ-Cr-387 X GA-10-3(RIL182) and 2(GA-10-3 X Kaye Murri(RIL182)) with the longest vector from AEC were the most unstable genotypes. On the other hand, genotype code 8(DZ-Cr-387 X GA-10-3(RIL157)) and 9(Kaye Murri X 3774-13(RIL18)) followed by genotype code 6(DZ-Cr-387 X GA-10-3(RIL178)) and 11(DZ-Cr-387 X GA-10-3 (RIL91) scored higher grain yield. The genotype mean yield stability indicated that the candidate genotype Kaye Murri X 3774-13(RIL18) has the highest grain yield performance and most stable genotypes.

3.5. GGE Biplot Pattern of Tef Genotypes

On Figure 3, Genotypes code 9(Kaye Murri X 3774-13(RIL18), 8(DZ-Cr-387 X GA-10-3(RIL157)), 5(DZ-Cr-387 X GA-10-3(RIL182)), 6(DZ-Cr-387 X GA-10-3(RIL178)), 11(DZ-Cr-387 X GA-10-3 (RIL91) and 2(GA-10-3 X Kaye Murri(RIL182) showed positive interaction with most of the environments (*viz*., Minjar, Hatseb, Akaki, Adadi Mariam, Adet, Ginchi, Fenote Selam and Debre Zeit). However, the remaining genotypes did not show positive interaction with most of the environments. These indicated that, the genotype Kaye Murri X 3774-13 (RIL18) showed broad stability to all environments.

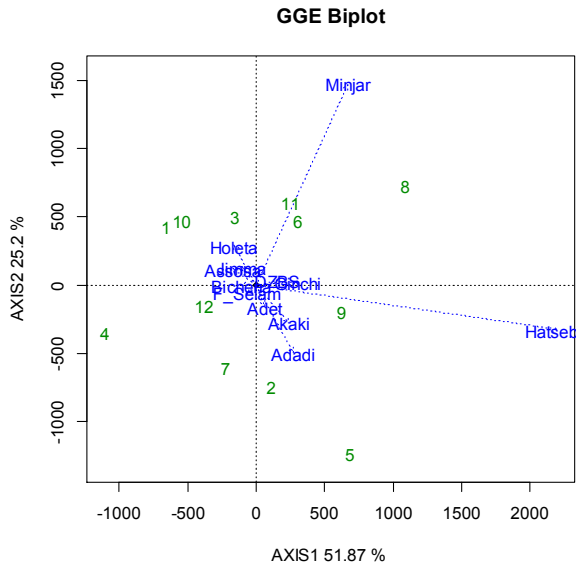

Figure 3. *GGE biplot analysis of 12 tef genotypes tested at twelve locations.*

3.6. Brief Description of the Variety

A brief description of the candidate tef variety Kaye Murri X 3774-13(RIL18) including its names, distinguishing pheno-morphic features and yield is given on Table 2.

Table 2. *Summary of description of the new tef variety Ebba.*

No.	Descriptor parameter	Description
1	Breeder's name	DZ-Cr-458 RIL18
2	Pedigree	Kaye Murri x 3774-13-RIL18
3	Vernacular name given	Ebba
4	Days to panicle emergence	44-52
5	Days to maturity	98-110
4	Plant height (cm)	85-100
5	Panicle length (cm)	36-44
6	Lemma color	Yellowish
7	Anther color	Yellowish
8	Caryopsis color	Very white
9	Grain yield – On-station (kg/ha)	20000-2600
10	Grain yield- On-farm (kg/ha)	1900-2300
11	Straw yield (kg/ha)	7868-11300

4. Conclusion

Genotype by environment interaction has a key effect on crop variety development by complicating the release of varieties across challenging environments. Analysis of variance for every individual location and combined over locations showed significant differences among genotypes, environments, and genotypes x environments interaction (GEI) for grain yield and most of the yield-related traits. The significant genotypes x environments interaction effects indicated the inconsistent performance of genotypes across the tested environments.

Among the tested genotypes, the genotype code 8(DZ-Cr-387 X GA-10-3(RIL157)) and 9(Kaye Murri X 3774-13(RIL18)) followed by genotype code 6(DZ-Cr-387 X GA-10-3(RIL178)) and 11(DZ-Cr-387 X GA-10-3(RIL91) scored higher grain yield. Considering over the environments data and field performance evaluation during the variety verification trial, the national variety releasing committee has approved the official release of candidate genotype Kaye Murri X 3774-13(RIL18), for high potential areas of the country with the vernacular name of "*Ebba*" as a standing witnessed for the earliest known tef scientist, Dr. Tadesse Ebba.

Acknowledgements

The authors are very grateful to Ethiopian Institute of Agricultural Research, University of Bern, Syngenta Foundation for Sustainable Agriculture, Debre Zeit Agricultural Research Center and other federal and regional research centers for the implanting the experiment and also to all researchers and technician assistance for participating on data collection and analyses.

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