Registration of "Takusa" Tef [*Eragrostis tef* (Zucc) Trotter] Variety

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Abstract

Background: Tef is the most important staple food and it takes the largest share in annual area crop coverage in Ethiopia. However, the productivity of the crop is far below its potential. Limited availability of stable and high yielding improved varieties and wider use of low yielding farmers' cultivars is one of the major factors constraining tef productivity.

Objective: The objective of the research was to identify and release stable and high yielding tef genotypes with desirable agronomic and morphological traits

Materials and Methods: Eighteen tef genotypes including *Takusa* [DZ-01-974*GA-10-3 (RIL-104)] plus the standard (*Abay*) and local checks were evaluated in a regional variety trial at *Adet, Mota, Bichena, Takusa and Alem Ketema* districts in northwestern part of Ethiopia during the 2018 and 2019 main rainy cropping seasons in a randomized complete block design.

Results: The results of the combined analysis of variance for grain yield across 10 environments revealed that the new variety, *Takusa* was the highest yielder among the tested genotypes. The results of genotype plus genotype by environment interaction (GGE) biplot analysis revealed that *Takusa* was the most stable and high yielding (2.4 t ha^{-1}) genotype from among the tested genotypes. It showed 16.7% yield advantage over the standard check, *Abay*.

Conclusion: Takusa gained farmers' acclaim and acceptance for its high grain and biomass yields, wider adaptation and other desirable agronomic and morphological traits such as white seed color, medium time of maturity, and moderate tolerance to lodging. Takusa tef variety was officially approved for cultivation in 2021 in Adet*, Mota, Bichena, Takusa, Alem ketema* and similar agro-ecologies in Ethiopia.

Keywords: Genotype by environment interaction; Genotype and genotype by environment interaction biplot; Ideal genotype; Lodging tolerance; Stability

1. Introduction

Tef [*Eragrostis tef* (Zucc) Trotter] is originated in Ethiopia and it is the first among cereal crops in coverage of cultivated area in different agro-ecologies and serves as a staple food crop for over 70 million people in the country. Ethiopian farmers have continued growing tef over the millennia due to its relative merits compared to the other cereal crops with respect to husbandry, utilization, and high market prices (Kebebew Assefa *et al*., 2011) as well as short time of maturity that gives it a relative advantage of drought escape over other cereal crops. The nutritional content of tef is comparable to that of the major world cereal crops but it is superior in minerals and essential amino acids (USDA, 2015). In recent years, tef has become popular and the demand for its grain has been increasing in the country as a healthy food in the global market because its freedom from gluten and its richness in contents of nutrients (Spaenij-Dekking *et al*., 2005).

Tef is widely cultivated in central and mid north and northwestern parts of the country, including many districts (= *woredas)* in the Amhara Regional State around Lake Tana and in many other places stretching from Bahir

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Dar to Addis Ababa. Of the top 25 tef producing *woredas* in the country, 15 are located in the Amhara Regional State and the remaining 10 are in Oromia Regional State (Warner *et al*., 2015). In the main (m*eher*) season of 2019/20, tef production keeps its first rank in terms of area coverage (24.11%) among cereal crops and the crop is produced by over 7.15 million smallholder farmers on about 3.1 million hectares of land with the average grain yield of about 1.85 t ha^{-1} (CSA, 2020). The average tef productivity is low compared to the genetic potential of the crop (up to 6 t ha^{-1}) as indicated by Seifu Ketema (1993) and the yield potential of tef under optimal management conditions can rich as high as 4.6 t ha^{-1} (Yifru Teklu and Hailu Tefera , 2005).

One of the many constraints of tef production is limited availability of stable and high-yielding tef varieties and the widespread use of low yielding local cultivars by the majority of farming community (Kibebew Assefa *et al*. 2017; Abate Bekele *et al.,* 2019). Therefore, developing of stable and high-yielding varieties with desirable agronomic traits is an important task to bridge the gap between the ever-increasing demand and supply for the grain of tef in the country and abroad.

2. Varietal Origin and Evaluation

Takusa (DZ-01-974*GA-10-3 (RIL-104) was obtained by crossing between DZ-01-974 as maternal parent for its high yielding ability and wide adaptability and GA-10-3 353 as a pollen parent for its dwarfism. After a successful crossing was made at Debre Zeit Agricultural Research Center (DZARC) in 2011, a single-seed, descent method was used to develop recombinant inbred lines with rapid generation advancement up to two to three generations per year using off-season irrigation facilities. *Takusa* together with 19 genotypes of which one standard commercial variety and one farmers' cultivar as local checks were evaluated at five locations (Adet, Mota, Bichena, Takusa and Alem Ketema) in the Amhara Regional State. The regional variety trial was conducted for two consecutive years (2018 and 2019 main cropping seasons) in a randomized complete block design with three replications. The genotype obtained from crossing of DZ-01-974 X GA-10-3(RILL104) was identified as high yielding, widely adaptable, and stable across locations over several years. As a result, the variety was recommended for cultivation in Adet, Mota, Bichena, Takusa, Alem ketema and similar agro-ecologies in Ethiopia named as *Takusa* in 2021. *Takusa* could be cultivated in tef growing agro-ecologies of the country and the objective of presenting the results of this study is to provide information on agronomic performances and stability of the variety for yield to users and to register it as a new variety in Ethiopia.

3. Grain Yield and Stability

Combined analysis of variance for grain yield and other measured parameters of the 20 tef genotypes across the 10 environments revealed significant ($P < 0.01$) variations due to genotype (G), environment (E) and genotype by environment interaction (GEI). *Takusa* (DZ-01-974 X GA-10-3 (RIL-104) had significantly highest mean grain yield of 2.4 t ha^{-1} over 10 environments and *Abay* (Acc#225931) used as standard check commercial variety produced the second highest mean grain yield of 2.04 t ha^{-1} but it had non-significant difference with mean grain yield of DZ- cr-387 X (DZ-cr-387 X GA-10-3(RILL-96) (G-13). *Takusa* had 0.36 t ha^{-1} (17.65%) mean yield advantages over the standard check commercial variety (*Abay*) and 0.72 ha^{-1} (42.86%) mean yield advantages over farmers cultivar included as a local check. *Takusa* was also one of the five genotypes that had significantly higher dry shoot biomass (7 t ha^{-1}) and had 0.5 t ha^{-1} (7.69%) and 0.3 t ha^{-1} (4.48%) dry biomass yield advantages over the standard check commercial variety (*Abay*) and farmers' cultivar, respectively (Table 1). Tef is primarily grown as human food in Ethiopia. However, its straw is highly preferable by cattle as fodder and its price is higher than the straw of other cereals (Seifu Ketema, 1997). Thus, the new variety, *Takusa* had desirable trait of both higher grain dry biomass yields than the standard check and farmers' varieties.

Table 1. Combined mean performance of 20 tef genotypes for grain yield and some other agronomic traits as evaluated in a regional variety trial at 10 environments during the 2018 and 2019 main rainy growing seasons.

GC [1]	Genotype	Plant parameters [2]					
		DTH	DTM	PH (cm)	PL (cm)	DSB (t ha–1)	GY (t ha–1)
G-1	DZ-cr-387 x Rosea (RILL-92)	60.5a	104.8ab	109.8a	39.4a	6.8 b–f	1.58g
G-2	DZ-cr-387 x Alba (RILL-279)	59.2bc	103.6a–e	111.6a	39.4a	7.1a–c	1.77c–f
G-3	DZ-cr-387 x Alba (RILL-216)	52.3jk	99.3h	96.6gh	32.3e	6.5f–h	1.80 c–f
G-4	GA-10-3 X Key muri (RILL121)	51.4k	102.8a–f	98.0f–h	35.4cd	6.1h	1.82c–e
G-5	GA-10-3 X Key muri (RILL184)	53.7hi	104.1a–d	100.4d–f	34.9d	6.1h	1.78c–f
G-6	Key muri X 3774-13 (RILL-18)	55.5f	101.5c–h	101.9bd	36.2b–d	6.7c–f	1.83c–e
G-7	DZ-01-974 X GA-10-3(RILL17)	56.8de	100.5f–h	103.6bc	35.0 d	6.5e–h	1.69c–f
G-8	DZ-01-974 X GA-10-3(RILL19)	55.3fg	100.4f–h	97.0gh	32.6e	6.4f–h	1.77c–f
G-9	DZ-01-974 X GA-10-3(RILL34A)	58.7c	105.5a	110.0a	40.7a	7.1a–d	1.77c–f
G-10	DZ-01-974 X GA-10-3(RILL47)	59.6a–c	105.0ab	111.8a	40.5a	6.6d–h	1.78c–f
G-11	DZ-01-974 X GA-10-3(RILL50)	55.2fg	99.4gh	96. 0gh	35.1d	6.2f–h	1.66fg
G-12	DZ-01-974 X GA-10-3(RILL66)	53.4ij	102.8a-f	100.8c–f	36.9b	7.1a–d	1.84cd
G-13	DZ- cr-387 X (DZ-cr-387 X GA -10-3(RILL-96)	54.9f–h	100.5f–h	102.5b–d	37.4b	7.2ab	1.91bc
G-14	DZ-01-974 X GA-10-3(RILL104)	53.7i	99.7gh	98.5e–g	32.8e	7.0 a–e	2.40 a
G-15	DZ-01-974 X GA-10-3(RILL-122B)	52.5jk	100.6e–h	95.5h	33.0e	6.1gh	1.79 c–f
G-16	DZ-01-974 X GA-10-3(RILL72)	57.2d	104.4a–c	104.4b	37.1 b	6.5e–h	1.78c–f
G-17	DZ-01-974 X GA-10-3(RILL83)	54.4g–i	101.3d–h	98.2f–h	36.1b–d	6.5e–h	1.85c
G-18	DZ-01-974 X GA-10-3(RILL84)	57d	102.3b–g	110.1a	37.4b	6.7c–g	1.76c–f
G-19	Acc#225931 (Abay, Standard check)	59.9ab	105.2ab	112.6a	40.4a	6.5e–h	2.04b
G-20	Local check	55.8ef	102.4b–g	101.2c–e	36.8bc	6.7e–f	1.68e–g
Mean		55.8	102.3	103.1	36.5	6.7	1.8
LSD (5%)		1.1	3.0	2.9	1.4	0.5	0.1
CV (%)		4.0	5.8	5.6	7.6	15.4	16.8
Genotype (G)		**	**	**	**	**	**
Environment (E)		**	**	**	**	**	**
G*E		**	**	**	**	**	**

Note: [1] *GC = Genotype code.* [2] *DTH = Days to heading; DTM = Days to maturity; PH = Plant height (cm); PL = Panicle length; DSB = Dry shoot biomass (t ha–1); and GY = Grain yield (t ha–1).* and ** significant at P ≤ 5% and P ≤ 1% level of probability, respectively. Mean values designated by similar letter(s) had non-significant difference at P < 0.05. LSD = Least significant difference at P < 0.05. CV = Percentage of coefficient of variation.*

The genotypes had the highest mean grain yield (2.11 t ha–1) at Bichena, followed by 2.09 t ha–1 mean yield at Takusa during the 2018 cropping season. The genotypes had the lowest mean grain yield (1.62 t ha–1) at Adet during the 2019 cropping season. The mean grain yield performance of *Takusa* coded as G-14 ranged from 2.08 at Adet during the 2019 cropping season to 3.01 t ha–1 at Takusa during the 2018 cropping season. The check variety, *Abay* had a mean grain yield of about 1.52 t ha–1 at Adet in 2019 and 2.36 t ha–1 at Bichena in 2018. *Takusa* had better mean grain yield over locations and years than *Abay* variety except at Bichena in 2019. *Takusa* had a yield advantage of 7.69% at Alem Ketema during the 2019 cropping season and 39.75% at Alem Ketema during the 2018 cropping season. However, it had 3.85% lower yield than Abay at Bichena in 2019 cropping season (Table 2). The results showed yield performances of the genotypes varied over locations and seasons, which evidently proved the presence of GEI effect on their yields. In such situations, breeders should look for genotypes that show relatively stable performance across environments.

The significant genotype x environment interaction (GEI) effects on grain yield has demonstrated that the genotypes responded differently to the variation in environmental conditions. In agreement with the present study, Shafii and Price (1998) noted that significant GEI seriously impaired efforts in selecting superior genotypes in a variety development program. Thus, stability analysis for grain yield was conducted using a genotype plus genotype by environment interaction biplot (GGE-biplot). The results from GGE-biplot for ranking of genotypes relative to an ideal genotype showed that the released variety (*Takusa*) fell very close to the central circle away from the vertical mean line, indicating its high yield potential and wider adaptability compared to the other genotypes subjected to the study (Figure 1). According to Yan and Tinker (2006) and Karmizadeh *et al.* (2013), the genotypes that are very close to the central circle away from vertical mean line are more stable than the genotypes located far away from the concentric circle.

Table 2. Mean grain yield (t ha^{-1}) of 20 tef genotypes across five locations over two years during the 2018 and 2019 main rainy cropping seasons.

Genotype code	Adet		Motta		Bichena		Takusa		Alem ketema		LI (0–5) [a]
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	
G-1	1.58	1.51	1.6	1.88	2.05	1.53	1.53	1.35	1.14	1.66	2.6
G-2	1.71	1.59	1.62	2.02	2.01	1.7	1.9	1.94	1.61	1.63	2.4
G-3	1.87	1.86	1.51	2.17	1.83	1.59	1.26	1.66	2.15	2.12	2.6
G-4	2.04	1.96	1.63	2.03	2.1	1.52	2.3	1.12	1.88	1.65	2.3
G-5	1.97	1.77	1.25	1.61	2.07	1.73	2.53	1.23	1.71	1.89	2.4
G-6	1.78	1.74	1.85	1.69	2.22	1.69	2.58	1.44	1.59	1.73	2.3
G-7	1.68	1.69	1.4	2.05	1.96	1.38	2	1.69	1.59	1.43	2.2
G-8	1.95	1.6	1.89	1.75	2.11	1.63	1.77	1.5	1.68	1.89	2.7
G-9	1.87	1.46	1.74	2.34	2.07	1.81	1.49	1.56	1.47	1.84	2.3
G-10	1.95	1.53	1.62	1.84	2.14	1.93	1.78	1.34	1.58	2.11	2.5
G-11	1.73	1.82	1.32	1.73	1.74	1.23	1.95	1.76	1.55	1.79	3
G-12	2.07	1.35	2.0	1.83	2.25	1.4	2.23	1.78	1.74	1.74	2.5
G-13	1.69	1.73	1.82	1.78	2.29	1.82	2.57	1.67	1.98	1.77	2.4
G-14	2.22	2.08	2.25	2.27	2.87	2.25	3.01	2.57	2.25	2.24	1.2
G-15	1.7	1.52	1.7	1.85	2.17	1.72	2.11	2.01	1.44	1.7	2.7
G-16	1.79	1.44	1.5	1.91	1.82	1.71	2.44	1.95	1.73	1.49	2.3
G-17	1.73	1.8	1.61	1.69	2.1	1.8	2.54	1.95	1.57	1.69	2.2
G-18	1.73	1.61	1.62	1.83	1.95	1.71	2.22	1.8	1.6	1.54	2.4
G-19	1.94	1.52	1.87	2.2	2.36	2.34	2.32	2.2	1.61	2.08	2.2
G-20	1.49	1	1.86	1.91	2.2	1.72	1.45	1.63	1.77	1.78	2.9
Mean	1.82	1.62	1.67	1.91	2.11	1.7	2.09	1.7	1.67	1.78	
CV (%)	11	13.3	15.9	14	11	18.5	19.4	13.8	14.3	14.8	
LSD (5%)	0.3	0.4	0.4	0.4	0.4	0.5	0.9	0.3	0.4	0.4	
F-value	*	**	*	*	*	*	*	**	**	*	

Note: [a] *LI (0–5 scale) = Lodging index; where, 0 = No lodging and 5 = 100% lodging. * and ** significant difference at P < 0.05 and P < 0.01 probability level, respectively. LSD = Least significant difference at P < 0.05. CV = Percentage of coefficient of variation.*

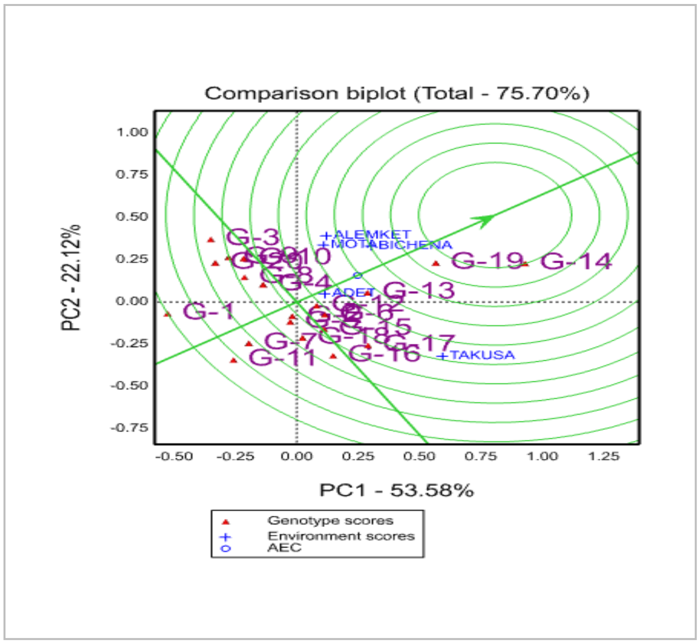

Figure 1. Ranking of genotypes relative to an ideal genotype. Genotype code from G1 to G20 represents as listed in Table 1.

4. Performance of the Newly Released Variety, *Takusa*, in Variety Verification Trial

The performance of *Takusa* (DZ-01-974 X GA-10-3 (RILL-104) for grain yield and other agronomic traits was verified together with the recently released commercial variety, *Washera* (353**Keymuri* (RIL29) as a standard check and a local check from each respective location at Adet, Mota, and Takusa both on station and on farm in 2021 (Table 3). The technical committee (TC) which was delegated by the National Variety Release Committee (NVRC) of Ethiopia evaluated the verification trial following the variety release guideline. The verification trial data indicated that *Takusa* produced 0.42 t ha^{-1}(22.34%) mean yield advantages over the standard check commercial variety (*Washera*) and 0.83 t ha^{-1} (56.46%) mean yield advantages over the farmers' cultivar subjected to as a local check. *Takusa* produced also a higher dry shoot biomass yield (7.01 t ha^{-1}) and had 0.68 t ha^{-1} (10.74%) and 0.87 t ha^{-1} (14.17%) dry shoot biomass yield advantages over the standard check (*Washera*) and farmers' cultivar, respectively (Table 3). Therefore, considering the best performance of Takusa in both regional and variety verification trials and farmers' immense interest in the cultivation of this variety as compared to cultivating the standard and local checks, the Variety Release Technical Committee (TC) recommended *Takusa* for full release and the recommendation was accepted by the National Variety Release Committee (NVRC). Accordingly, *Takusa* (DZ-01-974 X GA-10-3(RILL-104) was officially released in 2021.

5. Descriptions of Morpho-agronomic Characteristics

The morpho-agronomic descriptions of newly released variety, *Takusa* is presented in Table 4. *Takusa* (DZ-01-974 * GA-10-3 (RIL-104) is characterized by a loose white panicle and white seed color, yellow flower color, semi erect growth habit, an average plant height and panicle length of 98.5 cm, 32.8 cm, respectively. It reaches maturity in a period of 100 days after sowing. It is moderately tolerant to lodging and has a medium maturing time, which fits double cropping calendar. It can be grown at the elevations ranging between 1700 to 2400 meters above sea level. *Takusa* is highly preferred by farmers for its better performance in grain yield, and other desirable agronomic and morphological traits as compared to the other genotypes evaluated in the regional variety trial. There was no any significant disease as well as insect pest incidence and damage observed on the tested genotypes in general and on *Takusa* in particular in the course of the study.

Table 3 Mean performance of *Takusa*, *Washera* (the standard check) and the local check for days to maturity (DTM), dry shoot biomass (DSB) and grain yield (GY) in variety verification trial at Adet, Mota and Takusa both on station (OS) and on farm (OF) in 2021.

Variety	Parameter	Locations									Mean
		Adet			Mota			Takusa			
		OS	OF1	OF2	OS	OF1	OF2	OS	OF1	OF2	
Takusa (DZ-01-974 X GA-10-3(RILL-104)	DTM	97	105	103	99	95	95	89	79	89	94.56
	DSB (t ha^{-1})	7.61	7.09	7.84	7.50	6.13	5.82	6.94	7.14	7.05	7.01
	GY (t ha^{-1})	2.34	2.22	1.74	2.38	2.29	2.02	2.98	2.40	2.35	2.30
Washera [(353*Keymuri (RIL29) Standard check]	DTM	108	112	118	109	122	116	104	100	106	110.6
	DSB (t ha^{-1})	7.07	6.59	6.34	6.15	6.38	5.88	5.95	6.26	6.40	6.33
	GY (t ha^{-1})	1.82	1.49	2.02	1.77	2.20	1.93	2.00	1.89	1.77	1.88
Local check	DTM	106	106	102	110	120	115	87	73	94	101.44
	DSB (t ha^{-1})	5.89	6.08	7.56	6.77	6.14	5.98	5.79	5.36	5.67	6.14
	GY (t ha^{-1})	1.51	1.50	1.34	1.53	1.31	1.43	1.46	1.63	1.53	1.47

Table 4. Descriptions of morpho-agronomic characteristics of *Takusa* variety released in 2021.

Characteristic parameter	Description of agronomic/morphological characteristics
Variety name:	Takusa (DZ-01-974 * GA-10-3 (RIL-104)
Adaptation area:	Adet, Mota, Bichena, Takusa , Alem ketema in western Amhara Regional state and similar agro ecologies in Ethiopia Altitude (meter above sea level): 1700–2400 Rainfall (mm): 800–1300
Seed rate (kg ha^{-1}):	15
Planting date:	Late June to July depending on the onset of rainfall
Spacing:	20 cm between rows for row drill planting
Fertilizer rate (kg ha^{-1}):	N = 17, P_2O_5 = 60, for red soil N = 64, P_2O_5 = 40, for black soil
Days to heading:	45–60
Days to mature:	93–113
Panicle length (cm):	30–41
Plant height (cm):	96–113
1000 seed weight (g):	0.3
Seed color:	White
Flower color:	Variegated (yellow)
Growth habit:	Semi erect
Panicle form:	Loose
Leaf arrangement:	Horizontal and bending
Lodging index (0–5 scale) [a]	1.2
Grain yield (t ha^{-1}):	Research field = 2.08–3.01 Farmers' field = 1.7–2.4
Year of release:	2021
Breeder/maintainer:	Adet Agricultural Research Center (AARC)
Merits of the variety:	It is medium maturing which fits a double cropping calendar and has moderate tolerance to lodging

Note: [a] *Lodging index (0–5 scale); where, 0 = No lodging and 5 =100 % lodging.*

6. Conclusion

Takusa (DZ-01-974*GA-10-3 (RIL-104) tef variety produced significantly higher grain yield and showed wider adaptation to agro-ecologies than the standard check variety and other genotypes evaluated. The results of GGE-biplot analysis revealed that *Takusa* is a stable and high yielding tef variety with 17.6% yield advantage over the standard check variety, *Abay*. *Takusa* is highly preferred by farmers for its high grain yield, white seed color, and has a moderate lodging tolerance. It has also a medium duration of maturity, which makes it fit for practicing double cropping. Therefore, the variety has been officially released for wider cultivation in northwestern Ethiopia (Adet, Mota, Bichena, Takusa, Alem Ketema) and areas with similar agro-ecologies in the country.

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