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Multi-Location Screening of Tef (*Eragrostis Tef*) Lines Targeted to Variety Release for Midlands of Southern Ethiopia

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Abstract

Tef (*Eragrostis Tef*) is one of a few endemic crops of Ethiopia having very attractive nutritional profile. Gluten free nature of Tef grain has been highly advocated by consumers outside of Ethiopia. However, wide use of unimproved cultivars and poor management practices, combined with inherent low productivity nature of the crop itself has been a major challenge in Tef production. Since Ethiopia is source of origin and diversity for Tef, there are an enormous opportunity to breed and develop relatively better yielding Tef varieties. In the present study, 18 Tef Recombinant Inbred Lines (RILs) and two check varieties such as Quncho and Ajora were evaluated at three selected Tef based research sites (Areka, Hossana and Halaba) of Southern Nations Nationalities and People's Region (SNNPR), Ethiopia in 2014 and 2015. The RILs were evaluated for grain yield and other yield related traits; however, the present article focused on grain yield potential of Tef lines. Two RILs such as DZ-01-974 x DZ-01-2788 and DZ-Cr-37 x DZ-01-2786 with overall mean grain yield of 1681 (ranged from 1701 to1877) and 1600 (ranged from 1545 to 1649) kg/ha, respectively were promoted to Variety Verification Trial (VVT). The two selected RILs and two check varieties such as Quncho and Boset were further evaluated at VVT-phase at the three research stations and on two farmers' fields nearby each of the three-station using large plots in 2017. All trials under VVT-phase across locations were evaluated by group of farmers, group of researchers and National Variety Releasing Committee (NVRC). During evaluations at VVT-phase, a line DZ-01-974 x DZ-01-2788 was realized by all evaluators to exhibit overall better field performance across the three research stations and farmers' fields. Thus, it was decided to release the line DZ-01-974 x DZ-01-2788, which was later given a breeder name "Areka-1". Therefore, we recommended Areka-1 for production to midlands of SNNPR.

Keywords: New Tef variety; Tef productivity; *Eragrostis Tef*

Introduction

Tef, *Eragrostis Tef* (Zucc.) Trotter is the leading grain crop in Ethiopia and cultivated in more than 2.86 million hectares of land annually by over 6 million smallholder farmers (2016) [1]. However, the recent report by MOA indicated that the crop is grown in more than 3 million hectares [2]. According to the same report, no other individual grain crop is used to be grown per annum in such a large area of land in the country. Although Kebebew et al. reported Tef as a staple food crop for a half of Ethiopian peoples, the product is well known and deliciously consumed by almost all Ethiopians throughout the country [3,4]. Opposed to the larger area allocated annually for Tef cultivation in Ethiopia, on farm productivity of Tef is too low compared to majority of other grain crops such as other cereals, pulses and oil crops. Nonetheless, Tef cultivation has never been blocked up due to its low productivity; rather, its production has been continued very extensively in Ethiopia. It is due to a number of merits the crop had, which are detailed by previous reports. Ability to grow in various soil types, relative resilience to serious epidemics of pests and diseases and low post harvest losses are few of the advantages compared to production of all other grain crops [4,5]. Kebebew et al. also described benefits of Tef with respect to utilization [4]. The food values of Tef grain have also been highly advocated. Tef grain contains 14%-15% protein; thus, it is an important crop especially for peoples whose protein consumption comes mostly from plants. Tef grain contains 11-33 mg iron, 100-150 mg calcium, and rich in potassium, phosphorus and other significantly important elements which are useful for human health [6]. USDA reported lots of essential amino acids in Tef grain such as alanine, methionine, threonine and tyrosine [7]. Gluten free nature of Tef has got special attention especially by consumers outside of Ethiopia.

Although considerable variations exist in Tef productivity among plots growing Tef across Ethiopia, productivity of Tef per unit area is low as indicated earlier [8]. Average productivity of the crop was too low particularly before 2011. During those times, the research outputs have not been sufficiently available and/or little adopted by farmers [3]. Hailu et al. illustrated that levels of input use and the management practices employed supposed to be some of the drivers at the back of productivity differences [8]. Massive replacement of low yielding local varieties with improved ones through country-wide and vast pre-scaling up programs have brought significant effect that led to significant growth in Tef productivity [9]. Thus, Tef productivity could rise up to 1.56 and 1.30 tons/ha at national and SNNPR levels, respectively (Figures 1 and 2) [1].

Although mostly specific to agro-ecologies, to-date, more than 42 improved Tef varieties have been released at national level in Ethiopia; however, only few are widely grown in the country due to various reasons such as limited adaptability under all available agro-climatic conditions [10]. As described above, adoption of some of the applicable improved and better yielding Tef verities along with improved husbandry practices has progressively led to improved farm

productivity of Tef (Figures 1 and 2) [9]. To overcome the challenge of low productivity associated with Tef production in Ethiopia, the research focusing replacement of new better yielding Tef varieties and development and innovation of improved husbandry practices need to be continued to sustain better Tef productivity at national (Ethiopia) and regional (SNNPR) levels. Therefore, the present study was initiated with the following objectives:

- To identify promising Tef line with better grain yield across locations.
- To verify candidate Tef varieties on-farms and on-stations before release for wider production.

Materials and Methods

Description of the study areas

The research site at Hossana (in Hadya zone) is located at 7°34'N and 37°50'E and at an altitude of 2200 meter above sea level (masl). The mean annual rainfall and mean annual temperature ranges 1200-1300 mm and 18-28°C, respectively. The dominant soil type is lixi sols. Areka (in Wolyta zone) is located at 7°04'N latitude and 37°41'E longitude at an altitude of 1830 masl. The mean annual rainfall is 1500 mm and the daily mean annual temperature ranges from 13°C to 25°C. The soil of the Research Station is formed from pyroclastic rocks, and is clayey in texture. The dominant soil type in the area is nitisols [11]. Halabasite (in Halaba zone) is located at an altitude of 1700masl with the dominant soil type andosol [12].

Experimental materials

A total of 72 RILs of Tef were acquired from Debre Zeit Agricultural Research Center and evaluated at nursery level at Areka ARC in 2013. Based on better performance in terms of grain yield and other yield related traits, 18 RILs were selected and promoted to RVT trials and evaluated for two years from 2014-2015 at Areka, Hossana and Halaba. The selected RILs and the two check varieties namely Kuncho and Ajora-1 were evaluated at RVT level where all experiments at this level were conducted at only Research Stations. At the end of RVT, two outstanding RILs such as DZ-01-974 x DZ-01-2788 and DZ-Cr-37 x DZ-01-2786 along with two standard checks such Kuncho and Boset were promoted to next stage of evaluation, VVT. Based up on the existing trend for variety releasing in Ethiopia, the experiments at VVT-phase were conducted using large plots at the three Research Stations and fields of two more farmers at the vicinities of each Research Station for one year (in 2016). Group of farmers, researchers and NVRC evaluated the candidate varieties with respect to standard checks.

Seed rate of 25 kg/ha was used throughout the experiments from nursery evaluation to VVT. A plot size of 2 m by 2 m and 10 m by 10 m was used for RVT and VVT, respectively. The seeds were sown by drilling in rows spaced by 20 cm during all experiments. To RVTs, DAP/urea was applied at rates of 100/50 kg/ha, respectively where all DAP and all urea were applied at planting and 35 days after emergence, respectively. However, NPS (as it was recommended and made available to replace DAP during VVT) was applied at a rate of 120 kg/ha during VVT, but with the same rate of urea and time of application as was used during RVT. During all trials from nursery to VVT, weeds were managed manually by hand whenever occurred.

Data collection and analysis

In a plot of 2 m by 2 m, which consisted of 10 rows of 2 m long spaced by 20 cm, only eight central rows (by excluding border rows) were considered for all data collections. The records on panicle length, lodging, grain yield and other agronomic parameters were based on the eight central rows. For the present article, we have given a due consideration on data only for the most important parameter, Tef grain yield (kg/ha). The grain yield from RVT (six environments) was analyzed using SAS software [13]. Homogeneity of error variance was tested taking into account the largest error mean square and the smallest error mean square.

Results

The data generated from six environments were subjected to SAS software version 9.0. Statistically significant differences ($P<0.05$) were exhibited for mean grain yield among test lines, which includes 18 Tef RILs and two check varieties at each Research Station, Hossana, Areka and Halaba.

Furthermore, the ANOVA depicted significant differences among all lines and check varieties for overall mean obtained from across years and locations (Table 1). Number of Tef lines exhibited mean grain yield of below 1 ton/ha in each location. The overall (sub grand) means for grain yield obtained from each location were also too low with no/little differences: 1102, 1113 and 1092 kg/ha at Areka, Hossana and Alaba, respectively. This implies that the majority of (near to all) RILs and check varieties included in the present study had low mean grain yield in each location. However, two RILs such as DZ-01-974 x DZ-01-2788 and DZ-Cr-37 x DZ-01-2786 showed significantly higher grain yield consistently at each location and years, each with overall mean grain yield of 1681 and 1600 kg/ha, respectively. These both values were significantly higher than average grain yield recorded for check variety Kuncho (1333 kg/ha) and grand mean (1098 kg/ha). No statistically significant difference was exhibited between the two lines (DZ-01-974 x DZ-01-2788 and DZ-Cr-37 x DZ-01-2786). Therefore, the two RILs were identified as candidate varieties during the first phase (RVT-phase) and both lines were, thus, promoted to the second phase (VVT-phase). At VVT-phase, the two candidate and the two check varieties (the four Tef materials) were planted to larger plots (10 m × 10 m) side by side at each of the three Research Stations and on fields of two farmers neighboring each Research Station. All plots were treated and managed uniformly. For evaluation at VVT stage, farmers, researchers and NVRC often set evaluation criteria and all trials (across on-stations and on-farms) were subjected for evaluation of the candidate varieties with respect to the standard checks. Regardless of better results from RVT, the decision given by the three groups of evaluators at VVT-phase matters to accept or reject both or either of the candidate varieties. The decision attained by the evaluators from the evaluation task made across on farm and on station performance of Tef candidate varieties were submitted to summit of experts at Ministry of Agriculture (MOA) level for final approval; and thus, only RIL designated with its pedigree name DZ-01-974 x DZ-01-2788 was approved to be registered as a Variety [10].

No	Tef genotypes	Average grain yield (kg/ha) with duncan grouping			
		Areka (over years)	Hossana (over years)	Halaba (over years)	Across environments
1	DZ-01-974 x DZ-01-2788	1041cebd	860gh	997cbd	966hfge
2	DZ-01-1276 x DZ-01-196	886f	892gfh	903d	894hg
3	DZ-01-974 x DZ-01-2788	981fed	1146dfce	1092cbd	1073dfce
4	DZ-01-974 x D2	795f	921gfh	886d	868h
5	DZ-01-974 x DZ-01-2788	925fed	1219dc	1011cbd	1052dfce
6	DZ-01-974 x DZ-01-2788	1059cebd	1325c	1152cb	1179c
7	DZ-01-974 x DZ-01-2788	1136cb	1120gdfe	1193b	1150dc
8	DZ-01-196 x DZ-01-2789	1128cb	835h	1096cbd	1020dfce
9	DZ-01-1276 x DZ-01-196	1023cebd	915gfh	877d	939hfg
10	DZ-01-974 x DZ-01-2788	1179cb	1086gfe	1008cbd	1091dce
11	DZ-01-974 x DZ-01-2788	1701a	1875a	1474a	1681a
12	DZ-01-196 x DZ-01-2789	1034cebd	1180dcf	1037cbd	1084dce
13	DZ-01-1276 x DZ-01-196	953fed	1003gfe	1018cbd	992hfge
14	DZ-Cr-37 x DZ-01-2786	1649a	1605b	1545a	1600ab
15	DZ-01-1276 x DZ-01-196	984fed	884gfh	997cbd	955hfge
16	DZ-01-1276 x DZ-01-196	1085cbd	1140dfce	1017cbd	1081dce
17	DZ-01-974 x DZ-01-2788	1111cbd	1219dc	1227b	1186cd
18	DZ-01-354 x DZ-01-196	924fe	968gfe	983cbd	959hfge
19	Kuncho	1422bc	1371bc	1208cbd	1333c
20	Ajora-1	1071cebd	1117gdfe	1226b	1138dc
Sub grand		1102	1113	1092	1098
CV		15.3	19.8	19.4	18.4

Table 1: Mean grain yield (kg/ha) in each and over locations for Tef lines evaluated across three locations in 2014 and 2015.

Discussion

Tef is a leading cereal crop in terms of area coverage, and it is a staple food crop for the majority of the population in Ethiopia and Eritrea. However, its productivity is inherently low compared to other cereals and most of the other grain crops [4,14]. Although the productivity is generally low, previous studies reported diversities among Tef germplasm for different agronomic characters including grain yield, providing opportunities to develop relatively better yielding Tef varieties.

Most of Tef growing farmers at regional and national levels have been using low yielding local cultivars whose productivity does not exceed 1 ton/ha. Lower Tef grain yield is also attributed to low soil fertility, especially, nitrogen (N) and phosphorus (P) deficiencies [15]. Tef productivity is also significantly affected by inappropriate tillage and weed control practices [16-18]. Tef era and Belay revealed the possibility to improve Tef productivity up to 2500 kg/ha through production approach that combines use of both improved cultivars and management practices [19]. Like for many other crops, analysis of production constraints associated with Tef production also forms a corner stone to lay down strategies to overcome the existing Tef production constraints. As several reports in earlier studies described, low Tef productivity has been one of the major Tef production constraints in Ethiopia and SNNPR. This particular constraint could be addressed either by using existing (natural) variability or creation of artificial variability through targeted hybridization using parental lines with desired traits. Using both approaches, to-date, 42 Tef varieties have been developed in Ethiopia. Although little adoption has been realized after its development by Areka ARC, Tef variety Ajora, was approved for release in 2004 [20]. This variety was developed through series of screening activities using Tef accessions, which were part of natural variability and collected from Ethiopian biodiversity institute, the then PGRC (Plant Genetic Resource Center of Ethiopia). Immediately after development of Tef variety Ajora, the other variety

synthesized through hybridization and named Quncho was released in 2006 by Debre Zeit ARC [21]. Quncho was high yielding across Tef based agro-ecologies and adopted widely in the country including southern Ethiopia [4,9]. A variety Quncho was aggressively disseminated country wide in general and to SNNPR in particular through pre-scaling up programme as of 2010 [9]. Before such a pre-scaling up programme, the average Tef productivity at both national (Ethiopia) and regional (SNNPR) levels was not exceeding 1 ton/ha. The variety Quncho played a vital role in significant increase of yield nationally and regionally (Figure 1) [9]. Although the Tef variety Ajora was officially released due to its superior performance over the standard checks used during the then experiments, its popularization in SNNPR couldn't proceed; and even was appeared hindered as it was competitively dominated by variety Quncho that came from national research system [20,21]. Pre-scaling up of Quncho was continued nationally and in SNNPR since 2011. Taking both Quncho and Ajora as check varieties, various Tef lines were screened at different levels in three Tef based agro-ecologies i.e. we used both varieties during all field experiments which were conducted prior to VVT-phase. However, during this phase, we again used Quncho and Tef variety Boset which was released in 2012 [22].

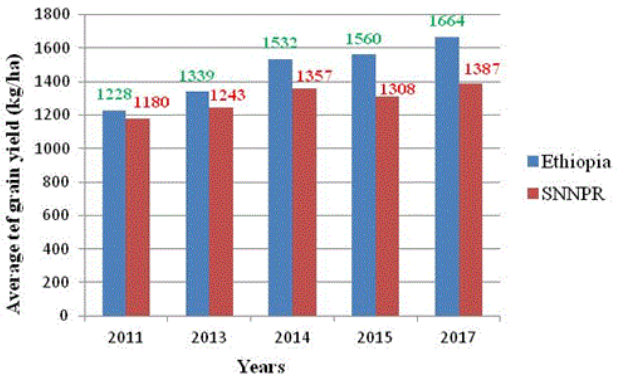

Figure 1: Mean Tef productivity recorded for five years in between 2011-2017 at national (Ethiopia) and regional (SNNPR) levels [23-27].

Although most of the test RILs included in the present study exhibited low grain yield per hectare during RVTs at each and across locations, the study revealed variability among the test lines (RILs) for grain yield. As indicated in earlier sections, two Tef RILs with pedigree names DZ-01-974 x DZ-01-2788 and DZ-Cr-37 x DZ-01-2786 gave overall mean grain yield of 1681 and 1600 kg/ha, respectively. However, the former line, which latter named a variety Areka-1, which exhibited overall mean grain yield of 1681 kg/ha was officially approved for wider production for the agro-ecologies like midlands of SNNPR. According to CSA, as also illustrated on Figure 1, mean grain yield per hectare of 1664 and 1387 kg/ha was recorded for Tef productivity at national (Ethiopia) and regional (SNNPR) levels, respectively [27]. It appeared that deployment of variety Areka-1 is more important to significantly lift-up regional productivity in SNNPR than at national level. CSA reported average Tef productivity of 1443, 1468 and 1245 kg/ha for Wolyta, Hadya and Halaba zones (Figure 2) [27]. Considering performance in specific agro-ecologies, the present new Tef variety, Areka-1 (DZ-01-974 x DZ-01-2788) had mean grain yield per hectare of 1701, 1875 and 1474 kg/ha at Areka (in Wolyta zone), Hossana (in Hadya zone) and Hallaba (in Halaba zone), respectively (Table 1). The mean grain yield obtained at both Areka and Hossana were relatively better than that of national and regional Tef productivity recorded during 2017 (Figure 1) [27]. This may imply that adoption of variety Areka-1 may improve overall Tef productivity at the three (though not possibly limited) zones where the research has originally been conducted.

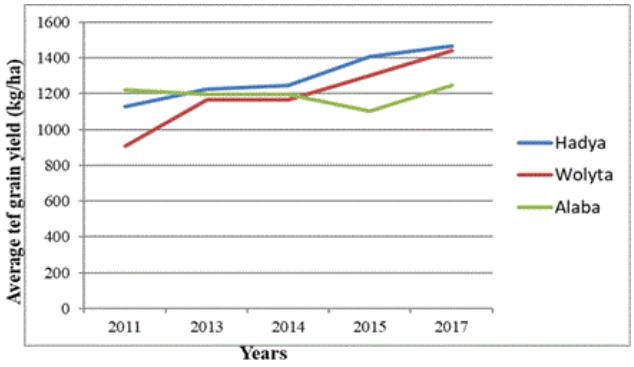

Figure 2: Mean Tef productivity recorded for five years in between 2011-2017 in Hadya, Wolyta and Halaba zones (Source: Reports of CSA during the years indicated in Figure 2).

Conclusions and Recommendations

Historically, Tef was consumed by both rural and urban population of northern part of the country; however, the consumption was limited to only urban dwellers in most of the other (western, eastern and southern) parts of Ethiopia. Currently, an alarmingly enhanced urbanization and tendencies to change life styles are the key drivers for an increased Tef demand in Ethiopia where use of Tef as food had been insignificant before. This has caused Tef consumption higher than ever before throughout the country (including rural and urban areas), and has resulted in significantly higher demand than the actual supply. The observed deficit in supply cannot be corrected by imports, which used as a short-term strategy for other crops like wheat. Although Tef production appears in small quantities in Eritrea, and recently in South Africa, the United States, Israel, the Netherlands and Spain, the crop is mainly grown and restricted to Ethiopia and no other known countries are engaged in a wider production as a cereal grain; thus, there is no any other source to import and meet the current demand of Tef seed in Ethiopia. Since the crop is economically and socially imperative to Ethiopians, it always appeared essential to put proper and strong strategies in order to balance the supply of the product with its demand by the country itself. Although more than 22 districts are known to be major Tef producers in only three zones namely Hadya, Kembata-Tembaro and Wolyta zones (and many more districts in other zones) under SNNPR, it seems that only little attention has been given to Tef research in the region. Tef research needs to be strengthened in order to regularly develop and supply farmers with Tef improved varieties and improved husbandry practices. Strengthening the seed system and regular monitoring of the status of newly deployed Tef varieties appeared to be crucial to avoid untimely decline of productivity, which could happen due to depreciation of true-to-types within short time. Although Tef is known to be self-pollinated, the depreciation of true-to-types may arise due to seed mixtures because the Tef seed is too tiny

to easily affect its genetic purity. From the present study, we recommended to deploy variety Areka-1 to midlands of SNNPR. However, combining both variety and improved management practices, which are recommended for Tef production may maintain the achieved productivity of the newly released Tef variety.

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