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Yield and Agronomic Performance of Selected Semi-dwarf Tef (*Eragrostis tef* (Zucc.) Trotter) Genotypes under Irrigation Farming System in Ethiopia

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Abstract: Tef is a foremost staple cereal crop with considerable role in the domestic GDP of Ethiopia. In diverse parts of Ethiopia, declining levels and high variability of rainfall is among the main causes for low crop productivity. Therefore, the study was designed to assess, pinpoint and recommend promising tef breeding lines suitable for irrigation farming conditions in the semi-arid, temperate and cool sub-humid agro-ecologies of Ethiopia. The experimental plant materials comprised forty-nine tef genotypes including forty seven recombinant inbred lines (RILs) and two standard checks varieties Quncho and Boset. The forty-seven RILs were out-sourced from three simple crosses of four parental lines. The field experiment was conducted using 7×7 simple lattice designs at three locations (Mehoni, Koga and Werer) during 2016 and 2017. Data were taken on plot and individual plant basis on nine pheno-agro-morphological characters including days to heading and to maturity, grain filling period, plant height, culm length, panicle length, above-ground shoot biomass, grain yield and harvest index. The three locations displayed highly significant ($P<0.001$) differences for a number of traits. However, panicle length did not show marked difference between locations. The cropping seasons has also showed highly significant ($P<0.001$) variation aside from plant height. Averaged over locations and seasons, differences among the genotypes were significant for all traits except days to maturity. The pooled result at the two locations (Mehoni and Koga) showed Kaye Murri X 3774-13 RIL 55 has the maximum yield of 3.1 t ha^{-1}. Thus, it is suggested to use the selected genotype for the sites and similar agro-ecologies. The use of irrigation system showed merit of achieving maximum yield of 4.7 t ha^{-1} at Mehoni during 2016 (Kaye Murri X 3774-13 RIL 66), but this is not consistent over locations and years. Nowadays, straw also has comparable values to grain yield, hence, the highest aboveground shoot biomass yield and lowest harvest index were indicated by Kaye Murri X 3774-13 RIL 110. Consequently, it would be advisable to use both (Kaye Murri X 3774-13 RIL 66 and Kaye Murri X 3774-13 RIL 110) to further test in the breeding program.

Keywords: Boset, Irrigation, Quncho, RILs, Semi-dwarf, Tef, Yield

1. Introduction

Tef (*Eragrostis tef* (Zucc.) Trotter belongs to the grass family, Poaceae (formerly Gramineae), sub-family Chloridoidae (Eragrostoidae), tribe Eragrostidae, sub-tribe Eragrosteae, and genus *Eragrostis*. The genus *Eragrostis* comprises approximately 400 morphologically distinct species distributed throughout the subtropical and tropical regions of the world [13]. *Eragrostis tef* (Zucc.) Trotter is the sole species in the genus *Eragrostis* cultivated for human consumption [27]. Tef is an allotetraploid ($2n=4x=40$) plant whose diploid progenitor (s) are not yet known. Five possible progenitors for this cereal were suggested, namely: *Eragrostis pilosa* (L.) [20, 34], *Eragrostis aethiopica* or *Eragrostis pseudo-tef* [40], *Eragrostis macilenta* [11] and *Eragrostis longifolia* [32]. Of these, the first two morphologically resemble tef more than the remaining three [12]. It is a C4 plant similar to most tropical grasses such as maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench), and these pathway permits efficient utilization of high solar heat.

Tef is the main staple cereal crop that plays a considerable role in the domestic GDP of Ethiopia. It is annually grown by over 6.7 million framers' households [14]. Based on the archeological evidences, its cultivation was found in Axum, Ethiopia dating back to 2700-2800 B. C [15]. Since then, extensive tef husbandry is continued due to its agronomic and dietary qualities. The typical agronomic merits of the crop include broad and versatile agro-ecological adaptation under varied climatic, edaphic and socio-economic condition; tolerance to both drought and water-logging conditions; fitness for various cropping systems and crop rotation schemes; usefulness as a reliable and low-risk catch crop at times of failures of other long-season crops such as maize and sorghum due to drought or pests; and little vulnerability to epidemics of pests and diseases in its major growing regions [10]. Furthermore, tef is consumed as whole-grain and its most imperative relative virtues in terms of dietary qualities is that tef grain is gluten-free and contains all eight essential amino acids, as well as high contents of fiber, minerals, and vitamins [31]. It is also known as a high-quality forage crop due, among others, to its high feed quality, crude protein content, fast growth rate, and its suitability for multiple harvests [28, 30].

Owning to its significant role and broad husbandry, however, productivity and research exertion is just a nascent. One of the main limiting factor for yield reduction in tef is moisture stress [5]. Approximately 25.5 to 51% grain yield reduction in tef has been reported due to low moisture stress [1, 36]. In different parts of Ethiopia, declining levels and high variability of rainfall is among the main causes for low crop productivity [39]. Besides, the rainfall is seasonal and concentrated in only 3 months of the year from June to August. Accordingly, the major farming system of the country is rain-fed agriculture concentrated in the high-lands that appear to shoulder the responsibility of feeding the population beyond 73.9 million [18], and when it is coupled with uneven distribution of rainfall it becomes a risky enterprise [23]. While dryland areas of Ethiopia account for more than 66% of the total landmass, it, however, contributes only less than 30% to the country's total agricultural production [33]. To this fact, food insecurity has remained to be the major problem of great concern to the country. In order to assuage the food insecurity problem with its roots in the high population growth rate and low food production level mainly attributed to insufficient moisture, it is vital to bring large areas of the arid, semi-arid and sub-humid regions with uneven rainfall distribution to irrigation production and other appropriate technology interventions [43]. Tef is highly durable to various stresses and thrives in a variety of environments [26], and due to this it becomes a preferred crop for the aforementioned and other locations which have irregular rainfall distribution. The stages of growth at which tef encounters frequent moisture stress include the seedling, vegetative and reproductive stages; however, moisture stress occurring during the anthesis and grain filling stages is considered to be critical since moisture substantially reduces yield [37]. The huge amount of yield loss accounted by moisture stress during vegetative and anthesis stage of tef reaches up to 40% [7] and 77% [37].

One of the escape mechanisms for the recurrent moisture stress is using irrigation by diverting water onto fields if there is available groundwater or river nearby. Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports [24]. It is reported that under rain-fed agriculture where tef is mainly produced the mean grain yield is 1.75 t ha^{-1} [14], while under irrigation it is 3.3 t ha^{-1} [41]. Although tef gives almost double yield under irrigation as compared to rain-fed, it is not commonly used in Ethiopia due to lack of effective technologies for irrigated agricultural system. Amongst these, lack of varieties suitable for irrigation is one problem that needs to be addressed. Currently, feeding of the ever-increasing population and meeting the huge market preference of tef has not at all been achieved by using rain-fed production system. As a result, the use of irrigation becomes compulsory. Due this fact, the National Tef Improvement Program has attempted to develop genotypes that are apt for irrigation condition considering the growing demand in very near future. Hence, the study was designed to assess, pinpoint and recommend promising tef breeding lines suitable for tef husbandry under irrigation farming conditions in the semi-arid, temperate and cool sub-humid agro-ecologies of Ethiopia.

2. Materials and Methods

2.1. Plant materials

The experimental plant materials comprised forty-nine tef genotypes including forty seven recombinant inbred lines (RILs) and two standard check varieties, Quncho and Boset. The forty-seven RILs were out-sourced from three simple crosses of four selected parental lines. The aim of the hybridization work was to develop stable, high yielding, white seeded, and farmer- and consumer-preferred tef varieties for the high rainfall and moisture stress areas as well as for irrigated farming system. The three independent crosses made in 2011 were Kaye Murri X 3774-13 (twenty three genotypes), GA-10-3 X Kaye Murri (sixteen genotypes) and DZ-Cr-387 X GA-10-3 (eight genotypes). The parental line Kaye Murri which was a local cultivar recognized and labeled by [17]. The cultivar Kaye Murri used both as female and pollen parent was selected for its thick culm, very white seed color and vigorous growth habit. One of the other parental lines is the popular variety Quncho (DZ-Cr-387 RIL 355) [4] was used as a female parent due to its high yielding ability and wide adaptability. The remaining two parents were dwarf mutant tef lines, namely 3774-13 (*Kegne*) [25] and GA-10-3 (*Kinde*) (Tadele et al., unpublished). Both of these were identified at the University of Bern in Switzerland from the screening of 5000 mutagenized tef populations, and they were selected as a pollen and female parent due to their earliness and dwarf nature in relation to lodging tolerance. The hybridization and handling of segregant population were made at Debre Zeit Agricultural Research Center (DZARC) from where the National Tef Research Program is coordinated. From each of the simple crosses, 400 F2 seeds were taken advanced upto F8 using the single seed descent method (SSD). Eventually, the recombinant inbred lines were considerably reduced to few lines through modified bulk selection. Ultimately, tough selection focusing on standing ability and grain yield was done and the best performing lines at the eight filial generations was used for the study. The crossing combinations and names of recombinant inbred lines as well as control materials used in the study are shown on Table 1.

Table 1. *List of forty-nine experimental tef genotypes.*

Code.	Parents	Lines	Code.	Parents	Lines
1	Kaye Murri X 3774-13	RIL-173	26	GA-10-3 X Kaye Murri	RIL-275
2	Kaye Murri X 3774-13	RIL-202	27	GA-10-3 X Kaye Murri	RIL-192
3	Kaye Murri X 3774-13	RIL-147	28	GA-10-3 X Kaye Murri	RIL-171
4	Kaye Murri X 3774-13	RIL-71	29	GA-10-3 X Kaye Murri	RIL-257
5	Kaye Murri X 3774-13	RIL-45	30	GA-10-3 X Kaye Murri	RIL-261
6	Kaye Murri X 3774-13	RIL-72	31	GA-10-3 X Kaye Murri	RIL-186
7	Kaye Murri X 3774-13	RIL-87	32	GA-10-3 X Kaye Murri	RIL-273
8	Kaye Murri X 3774-13	RIL-133	33	GA-10-3 X Kaye Murri	RIL-248
9	Kaye Murri X 3774-13	RIL-66	34	GA-10-3 X Kaye Murri	RIL-241
10	Kaye Murri X 3774-13	RIL-10	35	GA-10-3 X Kaye Murri	RIL-196
11	Kaye Murri X 3774-13	RIL-80	36	GA-10-3 X Kaye Murri	RIL-9
12	Kaye Murri X 3774-13	RIL-55	37	GA-10-3 X Kaye Murri	RIL-12
13	Kaye Murri X 3774-13	RIL-68	38	GA-10-3 X Kaye Murri	RIL-146
14	Kaye Murri X 3774-13	RIL-105	39	GA-10-3 X Kaye Murri	RIL-52
15	Kaye Murri X 3774-13	RIL-144	40	GA-10-3 X Kaye Murri	RIL-263
16	Kaye Murri X 3774-13	RIL-7	41	GA-10-3 X Kaye Murri	RIL-143
17	Kaye Murri X 3774-13	RIL-215	42	DZ-Cr-387 X GA-10-3	RIL-168
18	Kaye Murri X 3774-13	RIL-220	43	DZ-Cr-387 X GA-10-3	RIL-217
19	Kaye Murri X3774-13	RIL-110	44	DZ-Cr-387 X GA-10-3	RIL-181
20	Kaye Murri X3774-13	RIL-218	45	DZ-Cr-387 X GA-10-3	RIL-193
21	Kaye Murri X3774-13	RIL-136	46	DZ-Cr-387 X GA-10-3	RIL-156
22	Kaye Murri X 3774-13	RIL-60	47	DZ-Cr-387 X GA-10-3	RIL-154
23	Kaye Murri X 3774-13	RIL-58	48	DZ-Cr-387 X GA-10-3	RIL-212
24	DZ-Cr-387	Quncho	49	DZ-Cr-387 X GA-10-3	RIL -72
25	DZ-Cr-409	Boset			

2.2. Description of the Study Sites and Season

The experiment was conducted at two locations (Mehoni and Koga) for two consecutive years of 2016 and 2017, and at Werer in the year 2017 under irrigation. The locations have different contrasting features. Mehoni is located at Raya Valley (Fachagama) district in Southern Zone of Tigray Regional State, northern Ethiopia, Werer is also situated in the middle of Awash Valley, 50km north-east of the town of Awash of the Afar Region, and Koga is placed in the upper Blue Nile Basin under Mecha district in the West Gojam Zone, south of the Amhara Region. The detail description of the test locations presented on Table 2.

Table 2. *Geographical coordinates, weather data and soil type of the test locations.*

Description of parameter	Experimental locations		
	Koga	Mehoni (Fachagama)	Werer
Distance from the capital (Km)	543	678	280
Latitude (N)	11°25'20"	12°41'50"	9°16'
Longitude (E)	37°10′20"	39°42'08"	40°9'

Description of parameter	Experimental locations		
	Koga	Mehoni (Fachagama)	Werer
Altitude (m.a.s.l)	1960	1574	750
Rain fall (mm)	1118	300-750	590
Soil texture and/or type	Nitisols	Clay loam	Fluvisol
Soil pH	5.09-5.30	7.9-8.1	7.5-8.4
Max. mean daily temperature (°C)	26.8	25	40.8
Min. mean daily temperature (°C)	9.7	18	26.7
Climate	Cool semi-humid	Hot semi-arid	Hot semi-arid

Source: Modified and compiled from [16, 21, 38, 29, 6, 42].

2.3. Experimental Design and Field Management

The field experiment was carried out using 7 × 7 simple lattice design. Each plot (2 m × 1 m) consisted of five rows of 2 m length with an inter-row spacing of 0.2 m. The distances were 1 m both between plots and incomplete blocks, and 1.5 m between replications. The varieties were allotted to plots at random within each replication. As per the research recommendations of 15 kg ha^{-1}, 3 g plot^{-1} of seeds was hand broadcasted along the surface of each row. The experiment was planted at Koga, Mehoni and Werer at different times (Table 3). Fertilizers used were 40 kg N and 60 kg P_2O_5 per hectare for light soil, and 60 kg N and 60 kg P_2O_5 per hectare for black soil. DAP was applied all at planting, while urea was applied two weeks after sowing and top dressed at tillering stage. At Werer, irrigation water was applied at every ten days interval from the first initial stage to heading/flowering and after heading to maturity at eight days interval with furrow irrigation method. At Mehoni, irrigation water was provided using a groundwater resource with sprinkler irrigation system. Before sowing the soil was moist and the amount of water was measured using soil squeezing method to test soil moisture manually by hand. At Koga, irrigation was applied at every seven days interval during seedling stage and fourteen days interval after seedling stage through flood irrigation system.

Table 3. *Planting time of the three locations in two successive years.*

Locations	Planting time		
	2015	2016	2017
Werer	-	-	Beginning of February
Mehoni	-	Beginning of March	Beginning of March
Koga	End of December	Beginning of December	-

2.4. Data Collection

Data for nine quantitative pheno-agro-morphological characters were recorded on plot and individual plant basis. Of these, the six characters taken on plot basis were days to heading to maturity, grain filling period, aboveground shoot biomass yield, grain yield and harvest index. The remaining three characters were based on individual plant basis included plant height, panicle length and culm length.

2.5. Data Analyses

For each trait analysis of variance was made first for individual locations, and eventually upon getting positive results from tests of homogeneity of variances using the method F–max of [22], a combined analysis of variance was made across locations and over years. For all analyses of variance, the general linear model (PROC GLM) [19] was employed using SAS software version 9.00 [35]. After getting significant differences for traits, pair-wise mean comparison was done using Least Significant Difference (LSD) at 0.05 significance level.

3. Results and Discussion

3.1. Effect of Location on the Performance of Tef Genotypes

The three locations displayed highly significant (P<0.001) differences for a number of traits. However, panicle length did not show marked difference between locations (Table 5). Phenologic traits showed substantial effects of locations. On the average, Werer exhibited the earliest maturity date, while Koga scored the latest record (Table 4). Generally, the means of grain yield were highest at Mehoni and lowest at Werer (Figure 1). As grain yield was also better at Koga than Werer, this may imply that late phenology may be more important (within a limit) for grain yield increment as suggested that long duration plants were more vigorous [8, 9]. Hence, selection for grain yield in the set of tef genotypes is manifested by relatively long period for heading and grain filling period with short maturity time. This scenario would be practical under optimum environments since in stressed environments short grain filling time is likely to escape the water stress as the plant exerts more energy during this critical time. Likewise, it was also commending the possibility of using rapid maturity to escape the effects of drought [26].

Table 4. *Mean and standard error (SE) of mean for nine traits of 49 tef genotypes at three locations.*

Characters	Mehoni	Koga	Werer
	Mean ± SE	Mean ± SE	Mean ± SE
Days to heading (days)	57±0.55	62±1.35	36±0.72
Days to maturity (days)	93±0.25	104±1.32	66±0.99
Grain filling period (days)	36±0.45	43±0.45	30±1.19
Plant height (cm)	88±0.51	85±0.87	82±1.17
Panicle length (cm)	33±0.31	33±0.41	33±0.61
Culm length (cm)	55±0.48	52±0.58	49±0.88
Aboveground shoot biomass yield (kg/ha)	11300±230.43	7469±193.45	5251±155.03
Grain yield (kg/ha)	2525±76.37	2243±52.18	952±40.60
Harvest index (%)	22±0.45	31±0.52	18±0.65

Table 5. *Mean squares from the combined analysis of variance on nine characters of 49 tef genotypes tested in 2016 and 2017 under irrigations at two locations (Mehoni and Koga).*

Characters	Mean square							CV (%)
	G (48)	L (1)	Y (1)	G x L (48)	Gx Y (48)	Lx Y (1)	Gx Lx Y (48)	
Days to heading (days)	*	***	***	ns	ns	***	Ns	10.3
Days to maturity (days)	ns	***	***	ns	ns	***	Ns	7.4
Grain filling period (days)	***	***	***	ns	ns	***	*	11.7
Plant height (cm)	***	***	ns	***	ns	ns	Ns	9.8
Panicle length (cm)	***	ns	***	***	ns	*	Ns	12.7
Culm length (cm)	*	***	***	***	**	ns	**	11.7
Aboveground shoot biomass yield (kg/ha)	***	***	***	***	***	***	***	18.9
Grain yield (kg/ha)	***	***	***	***	***	***	***	17.1
Harvest index (%)	**	***	***	**	***	***	**	20.1

*, ** Significant at p ≤ 0.05, p ≤ 0.01 and p ≤ 0.001 probability level respectively and ^{ns} non-significant. $^{\beta}$ figures in parenthesis indicate degrees of freedom. G=genotype, L=location, Y=year, GxL=genotype x location interaction, GxY=genotype x year interaction, LxY=location x year interaction, GxLxY=genotype x location x year interaction, CV=coefficient of variation.

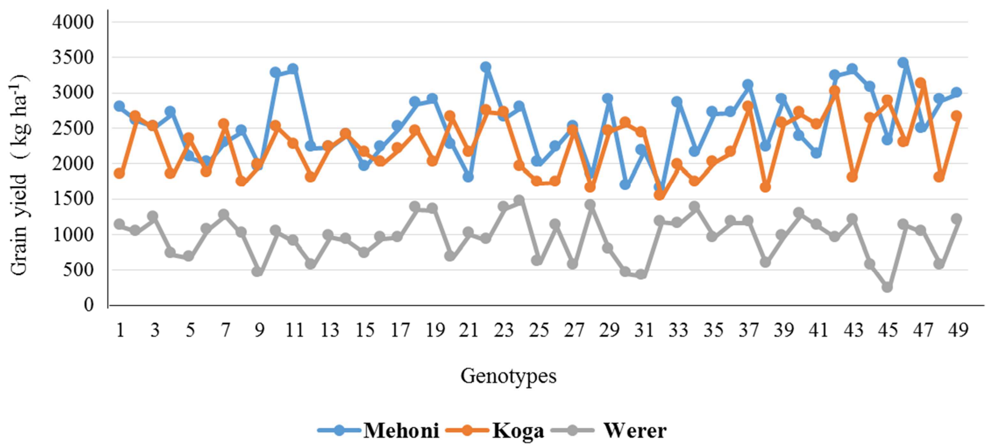

Figure 1. *Performances in grain yield of the 49 tef genotypes across three test locations.*

3.2. Interaction Effect on the Performance of Tef Genotypes

The interaction between genotype by year, location by year and genotype by location by year were significant (P<0.001) for aboveground shoot biomass yield, grain yield and harvest index, nevertheless, plant height revealed non-significant difference. The cropping seasons has also showed highly significant (P<0.001) variation except plant height. Genotype by location interaction indicated significant (P<0.001) interaction for the studied traits but phenologic characters (Table 5). When significant, genotype by location interaction effects were mostly "cross-over" type as manifested by changes in rank order of the genotypes in terms of mean grain yield (Table 6). This indicates that the three locations have diverse effects on some of the traits and that better genotypes at one location may not also be better performing at another. Such interaction depicted the differential performance of the genotypes that testing the genotypes across location were apt in order to pinout the best parental lines at the respective location and to identify trait performance in relation to location effect. This result is also anticipated due to the presence of four distinct parental lines in making the three independent crosses.

3.3. Genotype Performance

The field performance of the test tef genotypes under irrigation situation were commendable and encouraged the production potential of tef besides rain-fed farming (Figure 2 and 3). The difference among the genotypes were highly significant (P<0.01) for grain filling period, plant height, panicle length, aboveground shoot biomass and grain yield, harvest index and significant for culm length and days to heading (Table 5). Among the nine traits assessed, only days to maturity failed to show significant genotype variation. Compared to similar irrigation experiments, the present findings were in contrast with the results of [16] who found that tef genotype effects were significant on days to maturity but not on plant height, while [2] reported also that days to maturity was significant. This discrepancy may be due to the variation in the experimental locations and genotypes. The comparison of the RILs with the standard checks Boset and Quncho variety showed the excelling grain yield performances of some RILs (Table 6).

At Mehoni, Kaye Murri X 3774-13 RIL72 gave superior grain yield of 3.4 t ha^{-1} which has 22.5% and 13.8% yield advantage over Boset and Quncho, respectively. At Koga, Kaye Murri X 3774-13 RIL 80 showed the greatest yield of 3.1 t ha^{-1} having 70.2% and 17.8% yield increment over Boset and Quncho, respectively. At Werer, the maximum grain yield of 1.45 t ha^{-1} obtained from GA-10-3 X Kaye Murri RIL 273, which out-yielded Boset and Quncho by 31.4% and 23%, respectively. Averaged over the two locations (Mehoni and Koga), Kaye Murri X 3774-13 RIL 55 gave the maximum yield of 3.1 t ha^{-1}. However, there was no single genotype exhibiting consistent superiority for grain yield across locations. However, Kaye Murri X 3774-13 RIL 55 had better yield performance among the tested tef genotypes and it excelled the standard check varieties Boset significantly and Quncho only slightly. Consequently, it would be advisable to use this genotype as parental line for future breeding work under irrigation condition for cool semi-humid and hot semi-arid climate with the altitude 1574 m.a.s.l and above. For the hot semi-arid climate with range of the elevation from 750 m.a.s.l and rainfall 590 mm, GA-10-3 X Kaye Murri RIL 273 is apt. On the contrary, the low yielding genotypes were Kaye Murri X 3774-13 RIL 7 (1.674 t ha^{-1}) at Mehoni, Kaye Murri X 3774-13 RIL 105 (1.523 t ha^{-1}) at Koga, and Kaye Murri X 3774-13 RIL 71 (0.214 t ha^{-1}) at Werer. This showed that the lowest yield at Mehoni and Koga is the highest at Werer. The lowest yield at Werer may be due to environmental factor that hinders the genotype performance. Werer is one of the non-traditional tef growing areas and average grain yield was about 0.8 t ha^{-1} (personal communication). Hence, even the mean of 0.95 t ha^{-1} is better and the record of 1.45 t ha^{-1} is much superior. The major constraints at this site are high temperature and bird damage, and it is advisable to identify the proper sowing time to minimize the heat stress at the time of anthesis along with further screening efforts to identify relatively heat tolerant genotypes suitable for the area.

Figure 2. *Field performance of semi-dwarf tef genotypes at Mehoni (Fachagama) station (Photo: Esuyawkal Demis).*

Figure 3. *Field performance of semi-dwarf tef genotypes at Koga station. (Photo: Tsion Fikre in 25 April, 2017).*

Table 6. *Mean grain yield of 49 tef genotypes tested at three locations and combined over two years (2016 and 2017) at two locations (Mehoni and Koga) and a year (Werer, 2017) under irrigation condition.*

Genotypes	Grain yield (kg ha^{-1}) Locations			Combined at two locations: Mehoni and Koga
	Mehoni	Koga	Werer	
Boset	2776	1830	1107	2303
DZ-Cr-387 X GA-10-3 RIL-154	2597	2648	1034	2622
DZ-Cr-387 X GA-10-3 RIL-156	2515	2491	1215	2503
DZ-Cr-387 X GA-10-3 RIL-181	2692	1826	713	2259
DZ-Cr-387 X GA-10-3 RIL-193	2083	2331	661	2207
DZ-Cr-387 X GA-10-3 RIL-212	2001	1862	1065	1931
DZ-Cr-387 X GA-10-3 RIL-217	2295	2521	1260	2408
DZ-Cr-387 X GA-10-3 RIL-72	2451	1712	991	2081
DZ-Cr-387 X GA-10-3 RIL-168	1947	1984	438	1966
GA-10-3 X Kaye Murri RIL-143	3259	2493	1030	2876
GA-10-3 X Kaye Murri RIL-186	3314	2263	888	2788
GA-10-3 X Kaye Murri RIL-196	2217	1784	558	2000
GA-10-3 X Kaye Murri RIL-257	2229	2234	963	2231
GA-10-3 X Kaye Murri RIL-263	2403	2397	915	2400

Genotypes	Grain yield (kg ha^{-1}) Locations: Mehoni	Koga	Werer	Combined at two locations: Mehoni and Koga
GA-10-3 X Kaye Murri RIL-146	1942	2155	734	2049
GA-10-3 X Kaye Murri RIL-52	2237	1996	941	2117
GA-10-3 X Kaye Murri RIL-12	2495	2196	959	2345
GA-10-3 X Kaye Murri RIL-9	2830	2460	1352	2645
GA-10-3 X Kaye Murri RIL-171	2880	1997	1333	2439
GA-10-3 X Kaye Murri RIL-192	2260	2640	664	2450
GA-10-3 X Kaye Murri RIL-241	1790	2136	998	1963
GA-10-3 X Kaye Murri RIL-248	3340	2727	909	3033
GA-10-3 X Kaye Murri RIL-261	2637	2696	1360	2666
GA-10-3 X Kaye Murri RIL-273	2796	1936	1455	2366
GA-10-3 X Kaye Murri RIL-275	1991	1715	606	1853
Kaye Murri X 3774-13 RIL-58	2239	1728	1113	1984
Kaye Murri X 3774-13 RIL-60	2518	2456	554	2487
Kaye Murri X 3774-13 RIL-215	1832	1650	1378	1741
Kaye Murri X 3774-13 RIL-220	2886	2455	790	2671
Kaye Murri X 3774-13 RIL-7	1674	2553	441	2113
Kaye Murri X 3774-13 RIL-10	2171	2410	411	2290
Kaye Murri X 3774-13 RIL-105	1648	1523	1178	1585
Kaye Murri X 3774-13 RIL-110	2851	1966	1143	2408
Kaye Murri X 3774-13 RIL-133	2150	1728	1354	1939
Kaye Murri X 3774-13 RIL-136	2697	2014	959	2355
Kaye Murri X 3774-13 RIL-144	2705	2147	1155	2426
Kaye Murri X 3774-13 RIL-147	3098	2782	1162	2940
Kaye Murri X 3774-13 RIL-173	2231	1632	590	1931
Kaye Murri X 3774-13 RIL-202	2899	2549	966	2724
Kaye Murri X 3774-13 RIL-218	2378	2690	1272	2534
Kaye Murri X 3774-13 RIL-45	2114	2535	1115	2324
Kaye Murri X 3774-13 RIL-55	3239	3002	944	3121
Kaye Murri X 3774-13 RIL-66	3300	1789	1197	2543
Kaye Murri X 3774-13 RIL-68	3053	2623	558	2838
Kaye Murri X 3774-13 RIL-71	2307	2855	214	2581
Kaye Murri X 3774-13 RIL-72	3400	2276	1125	2838
Kaye Murri X 3774-13 RIL-80	2476	3115	1022	2795
Kaye Murri X 3774-13 RIL-87	2884	1778	557	2331
Quncho	2989	2644	1183	2816
Mean	2525	2243	952	2384
LSD (0.05%)	461.74	665.81	736.3	402.69
R^2	0.95	0.79	0.58	0.90
CV (%)	13.03	21.2	38.3	17.1

3.4. Range of Parameters

Based on the average data over the two locations (Mehoni and Koga), wide ranges between the maximal and minimal mean values were observed for the traits evaluated (Table 7). The range of days to heading, days to maturity and grain filling period were 25-89, 72-128 and 18-66 days, respectively. Similarly, wide ranges were also noted for all the traits assessed.

The result of the current study have broader range for aboveground shoot biomass and grain yield that showed discrepancy from those reported based on review of various studies by [3] under rain-fed conditions. However, days to maturity, panicle length, plant height and culm length were within the ranges of values reported by [3]. Correspondingly, the minimum value for days to heading is in line with the result of [17]. The maximum value for days to heading and harvest index and the minimum value for grain filling period were noted in the present study. These differences might be because of the growing conditions and most of the previous study reports were based on rain-fed system. Nevertheless, the irrigation system brought the merit that the maximum yield achieved which is 4.7 t ha^{-1} at Mehoni during 2016 (Kaye Murri X 3774-13 RIL 66) and has 1.4 t ha^{-1} of yield increment than the study of [41], although this was not consistently the same over locations and years. In other way, it can be elucidated that irrigation is not always worth because the lowest grain and aboveground shoot biomass yield recorded here in the study is 0.287 t ha^{-1} and 0.5 t ha^{-1}, respectively with the genotype of Kaye Murri X 3774-13 RIL 58. Thus, using the right genotype at the right location plays a pivotal role for increasing production and productivity of tef. Nowadays, straw also has comparable economic value to the grain yield, and to this effect the highest aboveground shoot biomass yield and lowest harvest index were exhibited by Kaye Murri X 3774-13 RIL 110.

Table 7. *Minimum and maximum values, means and standard errors (SE) of means for nine traits of 49 tef genotypes averages over two locations and years at Koga and Mehoni.*

Characters	Min value	Genotypes	Max value	Genotypes	Mean±SE
Days to heading (days)	25	Code 20	89	Code 11, Code 42, Code 39, Code 48	59±0.73
Days to maturity (days)	72	Code 28, Code 12	128	Code 26	99±0.73
Grain filling period (days)	18	Code 13	66	Code 20	39±0.35
Plant height (cm)	52	Code 26	113	Code 48	87±0.51
Panicle length (cm)	19	Code 42	51	Code 48	33±0.26
Culm length (cm)	28	Code 26	72	Code 42	53±0.39
Aboveground shoot biomass yield (kg ha^{-1})	500	Code 23	24330	Code 19	9385±178.77
Grain yield (kg ha^{-1})	287	Code 23	4707	Code 9	2384±46.73
Harvest index (%)	8	Code 19, Code 22, Code 1	57	Code 23	26±0.41

4. Conclusions and Recommendations

From the study, we can conclude that yield and agronomic performance of the selected tef genotypes showed wide variation for the studied traits. As grain yield is the economic trait in tef yield improvement program the parental line Kaye Murri X 3774-13 RIL 55 gave the maximum of 3.1t ha^{-1} pooled across two locations and years (Mehoni and Koga) and at Werer the best performing line was GA-10-3 X Kaye Murri RIL 273. Therefore, it is recommended to use the selected genotypes for the experimental sites and related agro-ecologies. In addition, at Werer further screening is needed since the experiment was done for only one year due to the presence of the unpredicted rainfall during the flowering time that brings significant yield reduction. Kaye Murri X 3774-13 RIL 66 gave the highest grain yield from among the selected genotypes at Mehoni during 2016, but it did not show stable performance across the test locations and over years. Hence, it is recommended to use it for further test and then incorporation in the future breeding effort.

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