Vol. 16(12), pp. 1710-1720, December, 2020
DOI: 10.5897/AJAR2020.15122
Article Number: 05A3EC565580
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Effects of genotypes and sowing time on phenology and yield performance traits of tef [Eragrostis tef (Zucc.) Trotter] in low moisture stress environments

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Received 7 August, 2020; Accepted 7 October, 2020

Tef *(Eragrostis tef (*Zucc.) Trotter) is among the most important cereals in Ethiopia in terms of both acreage and production. However, its productivity is relatively low as compared to other cereals mainly due to drought and climate variability coupled with lack of drought tolerant varieties. A field experiment was conducted with the objectives of assessing the effects of genotypes and sowing dates on the growth and yield performances of tef. The experiment consisted of 36 entire factorial combinations of three sowing dates, and 12 tef genotypes including two standards checks with three replications laid out in split plot design of sowing dates as the main plots and genotypes as sub-plots were planted at Melkassa and Alme Tena during 2017/2018 main season. The combined analysis of variance over locations revealed highly significant (P≤0.01) variations for both sowing dates, and genotypes for most of the traits evaluated. The dates that ranged from July 15 to July 20 would be recommendable as appropriate time for sowing and the genotype Dtt2XDtt13 (RIL No.37) mean grain yield of 1345 kg ha^{-1} over locations out-performed the rest of the genotypes including the standard checks. Hence, this genotype can be used for further testing. Since this is a mono-season experiment, further studies over multiple seasons and locations are required to make comprehensive conclusions and recommendations.

Key words: Genotypes, grain yield, growth parameters, phenology, sowing dates, tef.

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is an ancient crop in Ethiopia, and the country is considered to be center of both origin and diversity for the species (Vavilov, 1951). Tef belongs to the grass family Poaceae. It is a C4; self-pollinated chasmogamous annual cereal (Ketema, 1993). It is an allotetraploid species with a chromosome number

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of 2n = 4X = 40 (Tavassoli, 1986).

Tef plays an essential role in the Ethiopian agriculture in general and the food crop production system in particular. Nearly seven million farmers grow the crop that occupies 22% of the total cultivated area (CSA, 2018). With annual acreage of 3.02 million ha from which 1 about 5.283 million tons are harvested, tef accounts for about 30% of the total acreage and 20% of the gross grain production of all cereals cultivated in Ethiopia (CSA, 2018). It is second only to maize in terms of production. Being produced by about 6.77 million Ethiopian smallholder farmers that constitute over 43% of all the country's farmers' households (CSA, 2018), tef mainly serves as the major staple cereal for over 70% of the estimated 110 million Ethiopian population. In spite of its supreme agricultural sand economic significance, the productivity of tef is very low compared to other cereals mainly due to lack of adequate scientific improvement on the crop, widespread use of local varieties and lack of drought tolerant varieties. In South Africa, India, Pakistan, Uganda, Kenya and Mozambique tef is mainly grown as forage or pasture crop (Assefa et al., 2011a,b).

In recent years, tef has been gaining enormous global popularity and various products are available in Europe and North America as health foods especially for persons with gluten in tolerance (Saturni et al., 2010). Besides, the crop is currently increasing receiving global attention as "health and performance food" for its nutritional advantages because it is rich in nutrients. In Ethiopia, consumers prefer tef not only because it makes good quality "*injera*", pancake-like soft bread, but it is also nutritious due to its high protein and mineral contents (Bultosa et al., 2002). Furthermore, tef is a good flour source for segments of the population suffering from gluten intolerance (Spaenij-Dekking et al., 2005). Notwithstanding its numerous relative advantages and economic importance, the productivity of tef in Ethiopia is low amounting 1.75 tons ha^{-1} (CSA, 2018). Among the major yield limiting factors in tef are lack of cultivars tolerant to lodging and drought (Assefa et al., 2011). Yield losses are estimated to reach up to 40% during severe moisture stress (Ayele, 1993). Further, yield reduction of 69 to 77% has been reported to have occurred as a result of drought at the anthesis stage of tef (Tekele, 2001). Nevertheless, drought is one of the most important factors that limit crop production in the moisture deficit environment. The best option for crop production under drought stress environments is to develop tolerant varieties which will reduce yield loss due to drought stress (Richards et al., 2002). Furthermore, about 75% Ethiopia landmass is categorized as, experiencing moisture stress during most months of the year and having between 45 and 120 days of growing season per year (Giorgis et al., 2018). Therefore, this study was initiated to examine the phenologic plasticity, and evaluate the effects of different tef genotype characters and planting time on tef growth performance in the low moisture stress tef growing areas in central Ethiopia.

MATERIALS AND METHODS

Plant materials

Ten selected recombinant inbred lines (RILs) and two early maturing standard checks were used for the study (Table 1). The RILs have been developed at DZARC by the National Tef Improvement Program, and they were relatively early maturing types and selected based on their high grain and biomass yield in the moisture stress environments of the rift valley areas of Ethiopia in earlier observation nurseries. The parents of the RILS were developed through Target Induced Local Lesions in Genomes (TILLING). The seed colors of all the test genotypes were white.

Experimental sites and season

The field experiment was carried out at two terminal drought-prone locations (*viz.* Melkassa Agricultural Research Center and Alem Tena sub-station of Debre Zeit Agricultural Research Center) during the 2017/2018 main cropping season. Melkassa is located in East Shewa Zone of Oromiya, about 115 km South East of Addis Ababa. Alem Tena is also located in East Shewa Zone of Oromiya about 112 km south-south east of Addis Ababa. Detail description of the two locations during the growing period is summarized and presented in Table 2.

Experimental design and management

The field experiment consisted of 36 entire factorial treatment combinations of three sowing dates and twelve tef genotypes including two standards checks. It was carried out in three replications of split plot design with sowing dates as main plots and genotypes as sub-plots. The size of the main plots was 23 m × 27 m and the sub-plots 2 m × 1 m (2 m^2). The total number of rows per sub plot was five and the spacings were 0.2 m between rows, and 1.5 and 1 m between blocks and plots, respectively. As per the research recommendations 15 kg ha^{-1} (3 g $plot^{-1}$) of seeds was hand broadcast on the surfaces of each row.

Fertilizers used were 40 kg N and 60 kg P_2O_5 per hectare as recommended for "Nitosols" (light soils) (Mamo et al., 2002). DAP was applied in all planting stages, while urea was applied three weeks after sowing and top dressed at tillering stage. Hand weeding was made two times during the crop growth stages (early and late tillering) depending on the weed infestation. All other pre- and post-stand establishment management practices were performed as per the recommended cultural practices of the specific test locations.

Data collection

Data on days to panicle emergence, maturity, lodging index (Caldicott and Nuttall, 1979), 100-kernel weight, biomass yield, grain yield and harvest index were taken on whole plot basis, while plant height, panicle length, panicle weight and grain yield per panicle were taken from five random samples of plants from the three central rows of each plot; and the averages of the five samples of plants were used for statistical analysis.

Table 1. Description of the tef genotypes used in the field experiment.

S/N	Genotype	Panicle form	Lemma Color (Immature)	Phenology	
				Days to heading	Days to maturity
1	Dtt_2 X Dtt_{13}/RIL182	Loose	Variegated (purple and yellow)	35	78
2	Dtt_2 X Dtt_{13}/RIL78	Loose	Yellowish green	34	78
3	Dtt_2 X Dtt_{13}/RIL270	Very loose	Yellowish green	35	77
4	Dtt_2 X Dtt_{13}/RIL128	Very loose	Variegated (purple and yellow)	35	76
5	Dtt_2 X Dtt_{13}/RIL96	Loose	Yellowish green	33	78
6	Dtt_2 X Dtt_{13}/RIL37	Loose	Yellowish green	38	78
7	Dtt_2 X Dtt_{13}/RIL101	Very Loose	Yellowish green	35	79
8	Dtt_2 X Dtt_{13}/RIL70	Loose	Yellowish green	34	78
9	Dtt_2 (Parental line)	Very loose	Yellowish green	35	76
10	Dtt_{13} (Parental line)	Very loose	Yellowish green	35	78
11	Boset (DZ-Cr-409) (Standard check)	Fairly loose	Variegated (red and yellowish)	37	78
12	Simada (DZ-Cr-385) (Standard check)	Fairly loose	Yellowish green	34	76

Dtt refers to "drought tolerant".

Table 2. Geographical coordinates and weather data of the test locations.

Location	Latitude(N)	Longitude(E)	Altitude(masl)	Rainfall (mm)	Mean temperature (°C)		Soil type
					Maximum	Minimum	
Melkassa	8°23'52"	39°20'6"	1539	591	28.56	16.07	"*Nitosols*"
Alem Tena	8°18'27"	38°20'6"	1575	589	29.49	15.29	"*Nitosols*"

Data analyses

All measured variables were subjected to analyses of variance (ANOVA) on individual location basis using the standard procedure for split plot design in randomized complete blocks as described by Gomez and Gomez (1984). Homogeneity of error variance was checked using the method of F-max test method of Hartley (1950), which is based on the ratio of the larger mean square of error (MSE) from the separate analysis of variance to the smaller mean square of error. Combined analysis of variance over locations was done after getting positive results from the testing for homogeneity of error variances using SAS statistical package (SAS, 2002).

RESULTS AND DISCUSSION

Phenology

Days to seedling emergence

The analyses of variance showed highly ($P<0.01$) significant variation of sowing dates on days to seedling emergence both at Alem Tena and Melkassa, whereas the interaction effects of sowing dates and genotypes on days to seedling emergence were statistically not significant at both locations (Appendix Table 1). On the other hand, the combined analysis of variance over locations revealed highly significant effects of locations, sowing dates, and interaction of sowing dates, whereas some trait was not significantly affected by genotypes, and the interactions of sowing dates and genotypes, locations and genotypes as well as locations, sowing dates and genotypes (Appendix Table 1). The differential responses of the tef genotypes in terms of number of days to seedling emergence can be attributed to the inherent genetic differences among the genotypes, which were expressed only at Alem Tena but not at Melkassa and on the average over the two locations.

Days to heading

The analyses of variance for days to heading showed significant main effects of sowing dates and genotypes at both locations as well as in the combined analysis over the two locations; while the interaction effect of the two factors was significant only at Melkassa, but not at Alem Tena and in the combined analysis across the two locations (Appendix Table 1). At Alem Tena, the standard check variety Boset (DZ-Cr-409) coupled with the genotype

Table 3. Means of number of days to seedling emergence, heading and maturity of tef as affected by sowing dates and genotypes at two locations.

Treatments	Days to seedling emergence*			Days to heading*			Days to maturity*		
	Alem Tena	Melk-assa	Mean	Alem Tena	Melk-assa	Mean	Alem Tena	Melk-assa	Mean
Means of sowing dates (Over all genotypes)									
D1	12.19[a]	12.36[a]	12.27[a]	36.36[a]	39.77[a]	38.06[a]	79.16[a]	86.41[a]	82.79[a]
D2	6.36[b]	4.72[b]	5.54[b]	33.80[b]	37.02[b]	35.41[b]	78.19[a]	82.08[b]	80.13[a]
D3	6.94[b]	4.00[c]	5.47[b]	31.63[c]	33.97[c]	32.80[c]	69.63[b]	72.88[c]	71.26[b]
LSD (0.05)	0.74	0.64	4.75	1.04	1.12	1.75	1.49	1.84	6.53
Means of genotypes (over all sowing dates)									
Dtt2XDtt13 (RIL No.182)	8.33	7.44	7.88[abc]	33.00[b]	37.22[abc]	35.11[c]	76.77	79.44	78.11
Dtt2XDtt13 (RIL No.78)	9.11	7.33	8.22[ab]	32.44[b]	36.77[bc]	34.61[c]	76.67	80.66	78.66
Dtt2XDtt13 (RIL No. 27-0)	8.88	7.55	8.22[ab]	32.66[b]	37.77[ab]	35.22[c]	75.22	79.44	77.33
Dtt2XDtt13 (RILNo.128)	9.55	7.22	8.38[a]	34.33[b]	36.88[abc]	35.61[bc]	74.44	79.22	76.83
Dtt2XDtt13 (RIL No.96)	8.44	7.00	7.72[abc]	32.44[b]	35.22[c]	33.83[c]	75.77	80.88	78.33
Dtt2 XDtt13 (RIL No.37)	8.88	6.67	7.77[abc]	37.44[a]	39.11[a]	38.27[a]	76.33	80.00	78.33
Dtt2 XDtt13 (RIL No.101)	8.44	7.11	7.77[abc]	33.44[b]	37.11[abc]	35.27[c]	77.67	81.77	79.72
Dtt2 XDtt13 (RIL No.70)	8.55	6.67	7.61[bc]	33.44[b]	35.77[bc]	34.61[c]	75.88	8188	78.88
Dtt2 (Parental line)	8.33	7.22	7.77[abc]	34.00[b]	36.11[bc]	35.05[c]	73.67	79.77	76.72
Dtt13 (Parental line)	7.55	6.11	6.83[d]	33.22[b]	37.33[abc]	35.27[c]	76.00	80.67	78.33
Boset (DZ-Cr-409) (Stan. check)	8.00	7.11	7.55[bcd]	37.88[a]	37.55[ab]	37.72[ab]	75.22	82.44	78.83
Simada (DZ-Cr-385) (Stan. check)	7.88	6.89	7.38	32.88[b]	36.22[bc]	34.55[c]	74.33	79.00	76.66
LSD	NS	NS	NS	2.08	2.25	2.29	NS	NS	NS
Overall mean$^{\delta}$	8.50a	7.02b	7.76	33.93b	36.92[a]	35.43	75.67[b]	80.46[a]	78.06
(Pr >F)	0.3861	0.6681	0.1737	<.0001	<.0001	<.0001	0.3180	0.6843	0.2111
CV (%)	18.75	19.43	19.12	6.54	6.49	6.52	4.19	4.88	4.57

*Means in the same column and same treatment category followed by the same letter are not significantly different as judged by LSD at P≤0.05; NS=not significant at P≤0.05. $^{\delta}$Overall means of the two locations followed by different letters indicate significant differences at P≤0.05.

(Dtt2 XDtt13 RIL.37) depicted significantly higher mean number of days to heading (37.44 -37.88) than all of the remaining genotypes which showed statistically comparable lower means (Table 3). Likewise, at Melkassa and on the average across the two locations, the highest means for number of days to heading occurred for the genotype Dtt2 XDtt13 (RIL No.37) (Table 3). The statistically significant interaction effects of sowing dates and genotypes on days to heading at Melkassa indicated differential heading date responses of the tef genotypes to sowing dates at this particular location. Generally, low mean for number of days to heading were noted for the standard check variety Simada (DZ-Cr-385).

Days to physiological maturity

The main effects of sowing dates on number of days to maturity were significant at both locations and in the combined analysis over the two locations, while the main effects of genotypes were not on days to maturity were not statistically significant at both locations (Appendix Table 1). On the other hand, the interaction effect of sowing dates and genotypes on days to maturity were statistically significant (P≤0.05) only in the combined analysis over the two locations, but it was not significant at each of the individual test locations.

In the present study, the test tef genotypes did not show significant variations in number of days to maturity (Table 3). In contrast, studies on tef germplasm populations collected from different altitudinal zones showed significant genetic diversity in the range of 82-113 for days to maturity (Kebebew et al., 2001a). Such variations are very essential to augment the efforts to develop varieties fitting to various agro-ecologies and cropping systems to increase tef production and productivity. Thus, it enables breeders to develop variety that can escape late season drought by focusing on traits related to earliness.

Plant height and its components

Except for the main effects of sowing date at Alem Tena, plant was significantly (P≤0.05) affected by the main effects of both sowing dates and genotypes, and the interaction of sowing dates and genotypes at Melkassa, Alem Tena and the combined analysis over the two locations (Table 4). The test tef genotypes showed significant variations in plant height ranging from 82.55-94.46 cm at Alem Tena, 83.71-95.73 at Melkassa, and 84.10-94.51 cm on the average over the two locations (Table 4). In line with the present results, previous studies of Tefera et al. (1992), van de Wouw et al. (2010) revealed substantial genotype differences in tef plant height ranging from 73.6 -123 cm. Compared to the present findings, the total height of tef plant based on review of studies made using different genotypes at different locations was characterized with a much wider range of 20-156 cm (Assefa et al., 2001; Chanyalew et al., 2013; Degu, 2010). Key Murri consistently showed larger plant height and longer primary root than E.pilosa under drought Quantitative trait loci (QTLs).

The analysis of variance showed that at Alem Tena culm length was significantly affected by only sowing dates, while neither the main effects nor the interaction effects of sowing dates and genotypes exerted any statistically significant effects on culm length at Melkassa (Appendix Table 1). On the other hand, the combined analysis of variance over the two locations revealed that culm length was significantly affected by location and genotypes (Appendix Table 1). At Alem Tena, the means of culm length depicted that the tef plants were significantly taller for the latest sowing date than that of the two earlier sowing dates showing statistically similar means (Table 6). Generally, the mean culm length of the tef test genotypes over the two locations ranged from 18.17 cm for the parental line Dtt13 to 20.96 for the genotype Dtt2 X Dtt13 (RIL No.128).

The analysis of variance for panicle length showed significant main effects of both sowing dates and genotypes at Alem Tena, and significant main effects of only genotypes at Melkassa, while the interaction effects were not significant at both locations (data not shown). The panicle length means of the tef genotypes showed substantial variation at each of the two locations as well as on the average across the two test locations (Table 4). Both at each location as well as on average across the two locations, the highest mean panicle length of 42-44 cm was noted for the genotype (Dtt2 X Dtt13 RIL101). The substantial variation in panicle length of the genotypes can be attributed to their inherent genetic variation. Averaged over the two locations, the mean panicle length of the test tef genotypes which are in the loose panicle form types ranged from 33.74-42.14 cm. In comparison to this, Ebba (1975). in characterizing tef cultivars, described tef panicles with length of 7-65 cm; while the inflorescence takes one of four forms, namely: very loose; fairly loose; semi-compact (fairly loose and pyramidal); and very compact. Likewise, the length of the panicles of tef plants based on review of various studies made using diverse genotypes at different locations has been described as ranging from 10-65 cm (Assefa et al., 2001; Chanyalew et al., 2013). Descriptive statistical values of the plant are phenological traits, components of height, shoot biomass, harvest, index, flag leaf area and culm thickness for 2255 pure line accessions of tef (Ketema, 1993).

Yield and yield related traits

Number of fertile tillers per plant (NFT)

At Melkassa, the mean of fertile tillers per plant for the first and third sowing dates was greater than that of the second sowing date (Table 4). The means for number of fertile tillers per plant combined across locations showed significant differences among the genotypes and locations. However, it was not significant at each individual location (Table 4). Mean performance across locations and sowing dates, substantially the highest mean number of fertile tillers per plant out of all the genotypes was noted for the genotype Dtt2 X Dtt13 (RIL37), while a number of genotypes scored statistically comparable lower means (Table 4).

Similar to the present findings significant effects of locations and genotypes on the number of fertile tillers per plant were also noted in previous other studies on tef by Legesse (2004) and Gebretsadik et al. (2009). As most of the quantitative traits including yield are

Table 4. Means of plant height, culm length, and panicle length of tef as affected by sowing dates and genotypes at two locations.

Treatments	Plant height (cm)*			Culm length (cm)*			Panicle length (cm)*		
	Alem Tena	Melk-Assa	Mean	Alem Tena	Melk-Assa	Mean	Alem Tena	Melk-assa	Mean
Means of sowing dates (Over all genotypes)									
D1	86.56	84.17^{b}	85.48^{b}	19.61^{b}	18.30	18.95	38.93^{a}	34.44	36.68
D2	88.05	87.45^{a}	87.53^{ab}	20.13^{b}	19.70	19.91	36.65^{b}	35.66	36.15
D3	87.65	88.80^{a}	88.80^{a}	21.91^{a}	19.12	18.95	36.00^{b}	36.20	36.10
LSD (0.05)	NS	2.75	2.47	1.04	NS	NS	2.13	NS	NS
Means of genotypes (over all sowing dates)									
Dtt$_2$XDtt$_{13}$ (RIL182)	89.64^{a-d}	86.46^{cd}	88.05^{bc}	20.84	20.82	20.83^{a}	35.68^{c}	34.81^{cd}	34.81^{cd}
Dtt$_2$XDtt$_{13}$ (RIL78)	82.55^{d}	85.64^{cd}	84.10^{d}	21.22	19.73	20.47^{ab}	34.97^{c}	34.77^{cd}	34.77^{cd}
Dtt$_2$XDtt$_{13}$ (RIL27-0)	84.86^{bcd}	86.20^{cd}	85.53^{cd}	20.80	18.86	19.83^{a-d}	34.97^{c}	34.74^{cd}	34.74^{cd}
Dtt$_2$XDtt$_{13}$ (RIL128)	87.62^{a-d}	88.80^{bc}	88.21^{bc}	20.95	20.97	20.96^{a}	35.00^{c}	36.28^{cd}	36.28^{cd}
Dtt$_2$XDtt$_{13}$ (RIL96)	86.80^{a-d}	84.53^{cd}	85.66^{cd}	20.26	18.77	19.52^{a-d}	35.73^{c}	34.76^{cd}	34.76^{cd}
Dtt$_2$ X Dtt$_{13}$ (RIL37)	94.46^{a}	93.73^{ab}	94.10^{a}	21.13	18.60	19.86^{a-d}	43.68^{a}	42.14^{a}	42.14^{a}
Dtt$_2$ X Dtt$_{13}$ (RIL101)	93.68^{ab}	95.33^{a}	94.51^{a}	21.35	20.17	20.76^{a}	40.33^{ab}	39.71^{ab}	39.71^{ab}
Dtt$_2$ X Dtt$_{13}$ (RIL70)	84.60^{cd}	81.93^{d}	83.26^{d}	20.71	19.84	20.27^{abc}	37.40^{bc}	39.71^{ab}	35.48^{cd}
Dtt$_2$ (Parent line)	84.68^{cd}	81.15^{d}	82.92^{d}	19.68	17.60	18.64^{cd}	37.35^{bc}	35.48^{cd}	36.70b^{cd}
Dtt$_{13}$ (Paren line)	86.60^{a-d}	85.84^{cd}	86.22^{dc}	19.66	16.68	18.17^{d}	36.53^{bc}	36.70^{cd}	35.08^{cd}
Boset (DZ-Cr-409) (check)	92.73^{abc}	89.28^{bc}	91.01^{ab}	20.62	17.22	18.92^{bcd}	40.44^{ab}	35.08^{cd}	37.52^{bc}
Simada (DZ-Cr-385) (check)	84.66^{cd}	82.75^{d}	83.71^{d}	19.37	19.17	19.27^{a-d}	34.22^{c}	37.52^{bc}	33.74^{d}
LSD (0.05)	3.67	5.51	3.52	NS	NS	1.76	4.27	3.23	3.23
Overall mean$^{\delta}$	87.42	86.80	87.27	20.53a	19.04b	19.79	37.19a	36.31b	35.43
CV (%)	10.76	6.75	9.00	11.11	17.30	14.32	12.22	12.46	12.71

*Means in the same column and same treatment category followed by the same letter are not significantly different as judged by LSD at P≤0.05; NS=not significant at P≤0.05. $^{\delta}$Overall means of the two locations followed by different letters indicate significant differences at P≤0.05.

polygenically controlled and are much influenced by environmental factors, an understanding of inheritance and study of association between yield and its components are necessary for planning an effective selection program in identifying high yielding varieties

Harvest index

At Alem Tena, harvest index was significantly (P≤0.05) affected by sowing dates as well as genotypes, but the interaction effect of sowing date and genotypes was not statistically significant (Appendix Table 1). Likewise harvest index at Melkassa was highly significantly (≤0.01) affected by both sowing dates and genotypes, while the interaction effect of the two factors was not statistically significant (Appendix Table 1).

In addition, the combined analysis of variance over locations depicted that harvest index of tef was highly significantly (P≤0.05) affected by sowing dates, locations and genotypes, and significantly (P≤0.05) by the interaction of sowing dates and locations. While the interaction effects of sowing dates and genotypes and that of sowing dates, location and genotypes were not statistically significant (Appendix Table 1).

Lodging index

The analysis of variance showed that at Alem Tena lodging index was significantly affected by both sowing dates and genotypes, whereas the interaction effects of sowing dates and genotypes were not statistically significant (Table 5) Likewise, lodging index at Melkassa did not show statistically significant effects of both sowing dates and genotypes as well as the interaction of these two factors (Appendix Table 1).

At Alem Tena, the first two sowing dates gave statistically comparable lodging index means that were significantly higher than that of the last sowing date (Table 5). At this location the genotype (Dtt2 X Dtt13 RIL No.27-0) exhibited the highest mean lodging index (74.88), while the lowest mean (63.22) was recorded for the standard check variety Boset (Table 5). Averaged over the two locations and all sowing dates, the maximum mean lodging index was recorded for the standard check variety Simada, and the least mean lodging index (63.05) occurred for the genotype (Dtt2 X Dtt13 RIL 128). Regarding the locations, the mean lodging index was higher for Alem Tana than for Melkassa (Table 5). Similar to the present study, studies of genetic gain in tef breeding using varieties released until 2013 revealed significant lodging index differences among tef varieties at both test locations of Debre Zeit and Melkassa (Dargo et al., 2016).This study also showed that the mean lodging indices were 66 and 63 at Debre Zeit and Melkassa, respectively.

Number of fertile florets per central primary panicle branch

At Alem Tena, the highest mean number of fertile florets per central primary panicle branch occurred for the last sowing date, and this significantly excelled only the lowest mean noted for the earliest sowing date (Table 4). Averaged over the two locations and sowing dates, the highest mean number of fertile florets per central primary panicle branch was observed for the genotype (Dtt2 X Dtt13 9RIL37) followed by the genotypes (Dtt2 X Dtt13 RIL96) and the standard check variety Boset (Table 4). The two standard check varieties showed the lowest means for number of fertile florets per central primary panicle branch. Variability of some agronomic characters of tef germplasm was found to be high variations in some agronomic and morphologic characters of 506 tef accessions (Ayele and Ketema, 1995; Ketema, 1997). Its spikelet's have 2-12 florets. Each floret has a lemma, palea, three stamens, an ovary and mostly two, in exceptional cases three, feathery stigmas. These studies investigated that no significant differences were obtained among diverse altitude zones for parameters like days to panicle emergence, culm and panicle length, number of panicle branches, counts of fertile florets/spikelet, and shoot biomass (Assefa et al., 2001a,b).

Above-ground dry biomass yield

The combined analysis of variance over locations revealed that above-ground dry shoot biomass yield of tef was highly and significantly (P≤0.05) affected by sowing dates, locations, and genotypes; while none of the first order or the second order interactions of these factors exerted statistically significant effects on above-ground tef shoot biomass yield (Appendix Table 1).

At each of the individual test locations of Alem Tena as well as on the average over these two locations, the means for above-ground dry tef shoot biomass yield for the first sowing date were significantly lower than those of the second and third sowing dates which exhibited statistically comparable means; substantial genotype differences in above-ground dry shoot biomass yield were also noted at both test locations as well as on the average over the two locations (Table 6). Accordingly, both at Alem Tena and Melkassa and when averaged over these two locations, the highest means of above-ground shoot biomass yield were recorded for the genotype Dtt2 X Dtt13 (RIL No. 37) and the standard check variety Boset which showed statistically comparable means (Table 6). On the other hand, the lowest means of above-ground dry shoot biomass yield was recorded for the genotype Dtt2 X Dtt13 (RIL No. 27-0) at Alem Tena and on the average of over the two locations, and for the genotype Dtt2 X Dtt13 (RIL No. 182) at Melkassa. Of the two locations, statistically higher mean above-ground shoot biomass yield was noted for Alem Tena (7026 kg/ha) than for Melkassa (5039 kg/ha). Similar to the present results, former studies also showed that above-ground biomass yield showed a similar trend to that of plant height and tillering capacity and shoot biomass (Birhanu et al., 2020).

Grain yield

The analysis of variance showed that both at Alem Tena and Melkassa Grain yield was highly significantly (P≤0.05) affected by sowing date as well as genotypes, while sowing dates and genotypes did not significantly interact

Table 5. Means of number of fertile tillers/plant and fertile florets per central primary panicle branch, and lodging index of tef as affected by sowing dates and genotypes at Two Locations

Treatments	No. fertile tillers/plant*			No. fertile florets/central primary panicle branch*			Logging Index*		
	Alem Tena	Melk-Assa	Mean	Alem Tena	Melk-Assa	Mean	Alem Tena	Melk-assa	Mean
Means of sowing dates (Over all genotypes)									
D1	8.07	10.37^{a}	9.64^{a}	157.08^{b}	146.31	157.08	72.94a	62.42	67.68
D2	7.43	8.83^{b}	9.45^{a}	163.27^{ab}	156.93	163.27	70.75a	65.31	68.02
D3	7.12	9.88^{a}	10.45^{a}	173.64^{a}	153.63	173.64	64.05b	63.83	63.94
LSD (0.05)	NS	0.99	NS	13.04	NS	NS	4.39	NS	NS
Means of genotypes (over all sowing dates)									
Dtt$_2$ X Dtt$_{13}$ (RIL182)	7.77	10.11	9.58^{d}	158.96	173.67	151.52^{ab}	73.88^{abc}	65.00	69.44^{abc}
Dtt$_2$ X Dtt$_{13}$ (RIL78)	7.11	9.06	9.43^{d}	159.11	154.69	156.90^{ab}	67.77^{a-e}	62.33	65.05^{abc}
Dtt$_2$ X Dtt$_{13}$ (RIL270)	8.04	8.80	8.77^{d}	159.40	151.82	155.61^{ab}	74.88^{a}	60.33	67.61^{abc}
Dtt$_2$ X Dtt$_{13}$ (RIL128)	7.75	9.53	9.48^{d}	178.64	147.51	163.08^{ab}	64.77^{de}	67.44	66.11^{abc}
Dtt$_2$ X Dtt$_{13}$ (RIL96)	8.51	9.04	9.75^{d}	157.58	130.69	144.13^{b}	71.22^{a-e}	54.93	63.05^{c}
Dtt$_2$ X Dtt$_{13}$ (RIL37)	7.17	10.82	12.77^{a}	183.62	170.94	183.86^{a}	65.46^{cde}	60.91	63.17^{bc}
Dtt$_2$ X Dtt$_{13}$ (RIL101)	6.57	9.26	9.22^{d}	170.13	160.69	165.41^{ab}	65.55^{b-e}	61.00	63.27^{abc}
Dtt$_2$ X Dtt$_{13}$ (RIL70)	7.13	9.60	8.95^{d}	168.71	142.58	155.65^{ab}	67.51^{a-e}	60.33	63.92^{abc}
Dtt$_2$ (Parental line)	7.60	9.77	8.63^{d}	155.78	144.53	150.16^{ab}	69.55^{a-e}	65.33	67.44^{abc}
Dtt$_{13}$ (Parental line)	8.13	9.53	9.22^{d}	160.22	148.19	154.21^{ab}	72.88^{a-e}	71.66	72.27^{ab}
Boset (DZ-Cr-409) (Stan. check)	6.36	10.51	11.26^{b}	158.69	156.13	173.16^{bc}	63.22^{e}	66.44	64.83^{abc}
Simada (DZ-Cr-385) (Stan. check)	8.35	10.33	11.08^{bc}	165.18	146.09	155.63^{ab}	74.22^{ab}	70.56	72.38^{a}
LSD (0.05)	NS	NS	1.39	NS	NS	34.85	8.78	NS	9.16
Overall mean$^{\delta}$	7.54b	9.70a	9.85	164.66	152.29	159.10	69.24a	63.85b	66.55
CV (%)	24.51	21.87	24.00	16.85	21.23	19.15	13.39	16.60	14.98

*Means in the same column and same treatment category followed by the same letter are not significantly different as judged by LSD at P≤0.05; NS=not significant at P≤0.05. . $^{\delta}$Overall means of the two locations followed by different letters indicate significant differences at P≤0.05.

on this parameter at either of the two locations. The combined analysis of variance over locations revealed that grain yield of tef was highly significantly (P≤0.05) affected by sowing dates, locations, and genotypes while neither the first order nor the second order interactions of these factors exerted statistically significant effects on grain yield (Appendix Table 1).

At Alem Tena, the highest mean grain yield (1521 kgha^{-1}) was recorded for the latest 3rd sowing date, and this was statistically and significantly greater than only the mean (1302 kg/ha) of the second sowing date (10 July 2017); while the mean yield (1380 kg/ha) of the first sowing date (01 July 2017) was not statistically different from either the lowest or the highest means of the second and third sowing dates, respectively (Table 6). Likewise, at Melkassa, the two later sowing dates with statistically comparable mean grain yields (831-884 kg/ha) significantly excelled the earliest sowing date which exhibited

Table 6. Means of above-ground shoot biomass, and grain yield of tef as affected by sowing dates at two locations.

Treatments	Above-ground shoot biomass (kg ha^{-1})			Grain yield (kg ha^{-1})*		
	Alem Tena	Melk-Assa	Mean	Alem Tena	Melk-Assa	Mean
Means of sowing dates (Over all genotypes)						
D1	6625.0^{b}	4520.8^{b}	5572.92^{b}	1380.35^{ab}	710.83^{b}	1045.6
D2	7138.9^{a}	5208.3^{a}	6173.61^{a}	1302.22^{b}	830.83^{a}	1066.5
D3	7312.5^{a}	5388.9^{a}	6350.69^{a}	1520.76^{a}	883.75^{a}	1202.2
LSD (0.05)	594.06	313.88	311.24	146.65	75.44	NS
Means of genotypes (over all sowing dates)						
Dtt_2 X Dtt_{13} (RIL No.182)	6500.0^{cde}	4305.6^{e}	5402.8^{de}	1206.1^{d}	667.78^{c}	936.94^{d}
Dtt_2 X Dtt_{13} (RIL No.78)	6611.1^{cde}	4638.9^{ed}	5625.0^{cde}	1509.0^{abc}	775.00^{bc}	1142.22^{bc}
Dtt_2 X Dtt_{13} (RIL No. 27-0)	6083.3^{e}	4388.9^{ed}	5236.1^{e}	1374.4^{bcd}	665.56^{c}	1020.00^{cd}
Dtt_2 X Dtt_{13} (RILNo.128)	6833.3^{cde}	4916.7^{bcde}	5875.0^{bcde}	1502.5^{abc}	740.00^{bc}	1121.28^{bcd}
Dtt_2 XDtt_{13} (RIL No.96)	6750.0^{cde}	4750.0^{cbde}	5750.0^{cde}	1290.6^{cd}	751.11^{bc}	1020.83^{cd}
Dtt_2 XDtt_{13} (RIL No.37)	9055.6^{a}	6111.1^{a}	7583.3^{a}	1691.7^{a}	998.33^{a}	1344.72^{a}
Dtt_2 XDtt_{13} (RIL No.101)	6250.0^{de}	4861.1^{bcde}	5555.6^{cde}	1292.2^{cd}	822.78^{b}	1057.50^{cd}
Dtt_2 XDtt_{13} (RIL No.70)	6305.6^{ed}	4861.1^{bcde}	5583.3^{cde}	1314.4^{cd}	855.00^{ab}	1084.72^{cd}
Dtt_2 (Parental line)	7277.8^{bcd}	4972.2^{bcd}	6125.0^{bc}	1404.7^{abcd}	757.78^{bc}	1081.28^{cd}
Dtt_{13} (Parental line)	6805.6^{cde}	5083.3^{bc}	5944.4^{bcd}	1230.6^{cd}	863.89^{ab}	1047.22^{cd}
Boset (DZ-Cr-409) (Stan. check)	8222.2^{ba}	6250.0^{a}	7236.1^{a}	1607.8^{ab}	982.22^{a}	1295.00^{ab}
Simada (DZ-Cr-385) (Stan. check)	7611.1^{bc}	5333.3^{b}	6472.2^{b}	1388.9^{bcd}	822.22^{b}	1105.56^{cd}
LSD	1188.1	627.76	656.8	293.3	150.89	191.89
LSD	594.06	313.88	311.24	146.65	75.44	323.39
Overall mean$^{\delta}$	7025.46^{a}	5039.35^{b}	6032.40	1401.11^{a}	808.47^{b}	1104.77
(Pr >F)	<.0001	<.0001	<.0001	0.0322	0.0002	<.0001
CV (%)	17.98	13.24	16.75	22.26	19.85	22.45

*Means in the same column and same treatment category followed by the same letter are not significantly different as judged by LSD at P≤0.05; NS=not significant at P≤0.05. $^{\delta}$Overall means of the two locations followed by different letters indicate significant differences at P≤0.05.

mean grain yield of 711 kg/ha (Table 5). Both at Alem Tena and Melkassa and the average over the two locations, the highest means of grain yield was recorded for the genotype Dtt2 X Dtt13 (RIL37) followed by the standard check variety Boset; while the lowest means of grain yield was recorded for the genotype Dtt2 X Dtt13 (RIL182) (Table 6). Comparing the two locations, the higher mean tef grain yield was obtained at Alem Tena (1401 kg/ha) than at Melkassa 998 kg/ha) (Table 6).

CONCLUSION AND RECOMMENDATIONS

The location-wise as well as the combined analysis of variance over locations revealed highly (P≤0.01) significant differences among sowing dates and genotypes for most of the traits evaluated including dry shoot biomass yield and grain yield; while the sowing date by genotype interaction effect was also significant for some of the traits. The very good rainfall distribution in the test season with about 79.2 and 55.83% of the total yearly rainfall received at Alem Tena and Melkssa, respectively generally resulted in good performance of the experimental tef crops at both locations.Hence the test tef genotypes, the recombinant inbred lines appeared to have displayed transgressive segregation as some of them excelled both of the parental lines in many of the evaluated traits including above-ground dry shoot biomass yield, grain yield and harvest index. Overall, the range of sowing date from 15-20 July has proved superior and recommendable, in- general, the genotype Dtt2 X Dtt13 (RIL No.37), gave highest shoot biomass and grain yield at both locations and over all the two locations. This genotype should be used in the future tef breeding program for further evaluation at multiple environments involving many and diverse locations over several seasons in the variety development process for terminal drought-prone areas of Ethiopia. For conclusive recommendations on planting time and suitable genotypes, it would be worth repeating the experiment over many locations and several seasons

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix Table 1. Mean squares from the combined analyses of variance of data on different traits of tef in a sowing date by genotype experiment over two locations

	Mean squares								
Traits	**Sowing dates (df =2)**	**Loc. (df=1)**	**Sowing date X location interaction (df = 2)**	**Error(a) (df = 4)**	**Genotypes (df = 11)**	**Sowing date x genotype interaction (df = 22)**	**Genotype x location interaction (df = 11)**	**Sowing date X location X genotype interaction (df = 22)**	**Error(b)**
DSE	1100.34**	117.04**	43.93	19.36	3.11NS	1.61NS	1.08NS	1.39NS	1.34
DTH	498.76**	483.00**	6.00NS	10.12	30.08**	6.27NS	9.77*	3.24NS	3.24
DTM	2624.31**	1242.24**	83.11*	182.19	17.02NS	7.37*	6.42NS	10.88NS	0.65
GFP	982.34**	161.89*	3.84NS	108.00	43.26*	8.97NS	27.68*	17.59NS	17.59
PH (cm)	201.07*	47.41NS	38.98NS	259.93	292.76**	71.71NS	23.04NS	111.75*	111.75
CUL (cm)	44.79*	123.60*	106.87*	31.74	14.96*	9.93NS	5.76NS	8.98NS	8.98
PAL (cm)	7.58ns	167.48*	44.06*	55.71	107.02**	24.07NS	19.41NS	17.06*	17.06
NFT	3.84NS	88.93**	1194.31NS	25.42	27.34**	7.28NS	3.69NS	5.15NS	5.15
NFF	1475.75NS	2068.63NS	478.46*	19574.63	2114.80*	990.25NS	2256.51*	1378.84*	1378.84
LI (%)	369.55*	1572.48**	0.0007NS	427.17	202.53*	77.42NS	156.00NS	71.35NS	71.35
TSW (mg)	0.00047NS	0.06303**	25147.53NS	0.00139	0.00105*	0.0009*	0.0007NS	0.00057NS	0.0005
HI (%)	138.95**	1677.57**	25.36*	102.19	112.80**	10.00NS	106190.08NS	139161.77NS	13.91
SHB(kg/ha) ($\times 10^3$)	11965.57**	213010.42**	188368.1NS	4991.03	9481.27**	629.08NS	801452.0NS	1104403.4NS	1104.40
GY (kg/ha) ($\times 10^3$)	520.40NS	18969.48**	203365.60*	123.68	236.19**	54.31NS	68407.81NS	83524.08NS	83.52
DDSE	148723.02*	16651.44**	6252.06**	2654.5	426.76NS	204.57(ns)	142.51NS	177.26NS	142.51
DDH	85548.33**	79166.10**	1522.60NS	1303.13	5174.16**	1084.77NS	1997.56NS	455.16NS	1997.56
DDM	335839.57**	160922.58**	13863.87*	18781.54	1820.41NS	898.49NS	1206.74NS	1218.20NS	1206.74

[a]df = degrees of freedom ; NS= not significant,* and ** significant at P≤0.05 and P≤0.01, respectively
DSE= Days to seedling emergence, DTH. Days to heading, DTM = days to maturity, PH = plant height, CUL=Culm length, PAL = panicle length NFT = No. of fertile tillers, NFF=No of fertile florets, LI= lodging index, TSW=thousand seed weight, HI= harvest index, SHB =shoot biomass, GY=grain yield, DDSE = Degree days for seedling emergence, DDH = Degree days for heading, DDM = Degree days for maturity.