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Full Length Research Paper

Evaluation of drought tolerance indices in Tef [*Eragrostis tef* (Zucc.)Trotter]

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Tef [*Eragrostis tef* (Zucc.)Trotter] is an ancient and major cereal crop in Ethiopia. Increasing tef yield partly requires developing cultivars that are tolerant to low moisture supply. An experiment was carried out using 18 tef genotypes grown during September to December, 2010, under two water supply environments (stress during grain filling period, and non-stress) to identify genotypic variations in drought tolerance indices and to investigate the relationships between grain yield and drought tolerance indices in tef. Grain yield (gm^{-2}) in respective stress (Ys) and non-stress (Yp) environments ranged from 55 to 100 and 108 to 203, respectively. Tolerance index(TOL), stress susceptibility index(SSI), stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), and yield index (YI) ranged from 45 to 118, 0.82 to 1.24, 0.29 to 0.88, 84 to 149, 80 to 138, and 0.76 to 1.39, respectively. The correlations among Yp, Ys, MP, GMP, STI, and YI were positive ($r \geq 0.80$, $p<0.01$). TOL was positively correlated with Yp ($r= 0.91$, $p < 0.01$), Ys($r= 0.48$, $p<0.05$), and SSI($r= 0.72$, $p< 0.01$). This experiment suggests the possibility of using MP, GMP, STI and YI to improve Tef yield under moderate stress and non-stress environments.

Key words: Tef, *Eragrostis tef*, grain yield, drought tolerance indices.

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.)Trotter] is an ancient and a major cereal crop in Ethiopia. It grows widely from sea level up to 2800 m above sea level under various rainfall conditions, although, it gives good yield in areas where the growing season rainfall exceeds 300 mm (Ketema, 1993). The average yield of tef is less than 1 t/ha (CSA, 2003), which is partly due to moisture stress (Shiferaw, 1991; Ayele and Ketema, 1995). Drought is the most important factor that limits crop production in the world. 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). However, breeding for drought tolerance by selecting merely for grain yield is difficult, because the heritability of yield under stress environment is low due to small genotypic variance or large genotype-environment interaction variances as compared to non-stress environments (Blum, 1988; Ludlow and Muchow, 1990;Kirigiwi et al., 2004). Thus, drought tolerance indices based on relative yield performances of genotypes in stress and non-stress environments are commonly used in the selection of genotypes for use in breeding for moisture stress environments (Fisher and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992; Sio- Se Mardeh et al., 2006; Talebi et al., 2009). The indices commonly used in the study of drought tolerance are stress susceptibility index (Fischer and Maurer, 1978), stress tolerance and mean productivity (Rosielle and Hamblin 1981), geometric mean productivity and stress tolerance index (Fernandez, 1992), and yield index (Gavuzzi et al., 1997). Although, early studies in tef showed considerable genotypic variations in drought tolerance in relation to depth of root growth and osmotic adjustment (Ayele et al., 2001), the

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Table 1. Significance of mean squares for eight grain yield and yield related traits for 18 tef genotypes and two water supply environments (stress and non-stress).

Source of variation	D. F	Days to maturity	Grain filling period	Grain yield (g/m^2)	Total biomass(g/m^2)	Harvest index[1]	Plant height (cm)	Panicle weight (g/plant)	Seed weight (g/plant)
Replication/E	4	3.30^{ns}	9.20^{ns}	412^{ns}	3432^{ns}	9.92^{ns}	11.544^{ns}	0.0255^{ns}	0.033^{ns}
Environment (E)	1	4156.48**	4009**	152701**	1302997**	922.18**	5070.37**	1.668**	2.367**
Genotype (G)	17	116.55**	40.14**	2616**	31678**	22.80**	432.59**	0.432**	0.247**
G x E	17	22.50**	22.06**	607**	14537**	9.56**	46.51*	0.044**	0.041**
Error	68	6.33	7.64	199	4364	3.80	25.71	0.018	0.015
CV,%		2.85	5.98	12.90	8.47	14.30	6.56	9.62	30.10

[1]Harvest index was multiplied by 10^{-4}; *, **= significant at $p< 0.05$ and $p<0.01$, respectively.

information on drought tolerance indices based on grain yield is scanty. The present study was carried out to (1) identify genotypic variations in drought tolerance indices, and (2) to investigate the relationships between grain yield and drought tolerance indices in tef.

MATERIALS AND METHODS

A field experiment was carried out at Jinka Agricultural Research Center of South Agricultural Research Institute, Ethiopia. Jinka is located at 5° 52' N, 36° 38' E, and 1450 m above sea level with an annual average rainfall and temperature of 255 mm and 22.3℃, respectively. The soil of the experimental field is sandy loam. Eighteen Tef genotypes were planted at a recommended seed rate of 25 kg/ha on September 2nd 2010, at the end of main rainy season which extends from June to October. The average rainfall and temperature during the experiment duration of September to December, 2010, were 60 mm and 22.4℃, respectively. A randomized complete block design with three replications was used under stress and non-stress environments. Each plot consisted of four rows, 1 m long with spacing of 20 cm between rows. The distance between replications was 1.5 m and that between stress and non-stress environments was 4 m. Supplemental irrigation was withdrawn from stress environment after the majority of genotypes attained 50% flowering stage. Non-stress environment on the other hand received supplemental irrigation from date of planting until physiological maturity. The stress environment was covered with roof of polythene sheet to protect it from rainfall and a furrow was prepared around it to prevent water entry. The 40 kg/ha N in the form of urea and diammonium phosphate (DAP) and 60 kg/ha P_2O_5 (in the form of DAP) were applied at planting. Each plot was kept free from weeds with frequent hand weeding.

At physiological maturity, five random plants within each plot were manually uprooted to determine plant height (cm), panicle weight (g/plant) and seed weight (g/plant). Grain yield (g/m^2) and total biomass (g/m^2) were determined after harvesting the whole plot at ground level using sickles and oven drying the grain and straw samples to constant weight at 65℃. The data were analyzed using GLM procedure of SAS software (SAS Institute, 1996). Drought resistance indices were calculated as follows:

Tolerance Index (TOL) = Ypi-Ysi (Hossain et al., 1990)

Mean Productivity (MP) = $(Ypi+Ysi)/_2$ (Hossain et al., 1990)

Geometric mean productivity (GMP) = $(Ypi \times Ysi)^{1/2}$ (Fernandez, 1992)

Stress susceptibility index (SSI) = (1-(Ysi/Ypi))/SI (Fischer and Maurer, 1978)

Stress tolerance index (STI) = $(Ypi \times Ysi)/Yp^2$ (Fernandez, 1992)

Yield index (YI) = Ysi/Ys (Gavuzzi et al., 1997)

where Ysi is yield of a genotype in stress environment, Ypi is yield of a genotype in non-stress environment, SI (stress intensity) is 1- (Ys/Yp), Ys is mean yield in stress environment, and Yp is mean yield in non-stress environment.

RESULTS

The analysis of variance showed that grain yield and yield related traits were significantly affected by environment, genotype and genotype by environment interactions (Table 1). The effect of genotypes was also significant ($p<0.01$) for these traits under each environment (Table 2). Total biomass, harvest index, plant height, panicle weight and seed weight/plant varied from 537 to 866, 0.08 to 0.14, 60 to 81, 0.91 to 1.78, and 0.05 to 0..62, respectively, under stress environment, and from 737 to 1056, 0.11 to 0.21, 66 to 105, 1.05 to 2.04, and 0.19 to1.26, respectively, under non- stress environment. Grain yield under stress (Ys) ranged from 55 (genotype Denkeye) to 100 (DZ-Cr-387) and that under non-stress (Yp) from 108 (genotype Rubicunda) to 203 (DZ-01-974). TOL, MP, GMP, SSI, STI, and YI ranged from 45 to 118, 80 to 138, 84 to 149, 0.82 to 1.24, 0.29 to 0.88, and 0.76 to 1.39, respectively (Table 3).

Yp was positively correlated ($r \geq 0.80$, $p<0.01$) with Ys, TOL, MP, GMP, STI and YI (Table 4). Ys was also positively correlated with these traits. The correlation of TOL with MP, GMP, SSI, STI, and YI was 0.80 ($p<0.01$), 0.73 ($p<0.01$), 0.72

Table 2. Significance of mean squares for eight grain yield and yield related traits for 18 tef genotypes and at two water supply environments (stress and non-stress).

Source of variation	D.F	Days to maturity	Grain filling period	Grain yield (g/m²)	Total biomass(g/m²)	Harvest index[1]	Plant height (cm)	Panicle weight (g/plant)	Seed weight (g/plant)
Stress									
Replication	2	5.69ns	12.24ns	735**	2869ns	18.04**	7.39ns	0.048ns	0.003ns
Genotype	17	47.08**	22.27**	593**	23668**	8.38**	140.52**	0.222**	0.112**
Error	34	7.41	9.22	116	2533	2.64	28.68	0.015	0.005
Range		39 - 50	35 - 47	55-100	537-866	0.08 - 0.14	60 - 81	0.91 - 1.78	0.05 - 0.62
Mean ± SE		82 ± 0.61	40 ± 0.50	72 ± 2.33	670 ± 13.10	0.11 ± 0.003	70 ± 1.09	1.28± 0.039	0.26 ± 0.027
CV,%		3.32	7.57	11.44	7.51	15.16	7.61	9.61	27.08
Non-stress									
Replication	2	0.91ns	6.17ns	89ns	3995ns	1.8ns	15.69ns	0.003ns	0.064ns
Genotype	17	91.97**	39.93**	2630**	22547**	23.98**	338.58**	0.254**	0.177**
Error	34	5.24	6.05	282	6195	4.96	22.74	0.021	0.025
Range		80-107	41-57	108 - 203	737 - 1056	0.11-0.21	66-105	1.05-2.04	0.19 - 1.26
Mean ± SE		94 ± 0.80	52 ± 0.56	147 ± 4.36	890 ± 14.50	0.17 ± 0.005	84 ± 1.51	1.53 ± 0.04	0.55 ± 0.04
CV,%		2.43	4.70	15.10	8.84	13.45	5.67	9.56	28.44

[1]Harvest index was multiplied by 10^{-4}; *, **= significant at p< 0.05 and p<0.01, respectively; ns = not significant; SE = standard error.

(p<0.01), 0.72 (p<0.01), and 0.48 (p<0.05), respectively. The correlations among MP, GMP, STI and YI were also positive. Total biomass, harvest index, plant height, panicle weight and seed weight/plant were positively correlated with MP, GMP, STI and YI in both environments (Table 5). Harvest index in non-stress environment, and plant height, panicle weight and seed weight/plant in both environments were positively correlated with TOL which had also negative correlation with days to maturity under both environments.

DISCUSSION

The reduction in grain yield and yield related traits under stress environment obtained in the present experiment could be because water deficit during reproductive period usually results in poor assimilation, reduced translocation of photosynthates to the grain and higher respiratory losses (Al-Khatib and Paulsen, 1984; Shpiler and Blum, 1991). On the other hand, the presence of genotype by environment interactions suggests that indirect selection for stress environment based on the results of non-stress environment will not be efficient. The existence of genotypic variation for Yp, Ys, MP, GMP, STI and YI suggests the possibility of using these traits in screening tef genotypes. The greater the TOL and SSI values gave the larger yield reduction for some genotypes under stress environments. It has also been suggested that genotypes with an SSI of less than a unity are drought tolerant because their yield reduction in stress environment is smaller than the mean yield reduction of all genotypes (Guttieri et al., 2001). Thus, genotypes DZ-01-1681 and DZ-Cr-255 were relatively more sensitive to moisture stress. This agrees with the reports in wheat (Sio-Se Mardeh et al., 2006; Golabadi et al., 2006; Talebi et al., 2009; Khayatnezhad et al., 2010a), maize (Golbashy et al., 2010), and lentil (Siahsar et al., 2010). However, the use of TOL and SSI as selection criteria requires precaution because low TOL and SSI may give genotypes with low yield potential and drought tolerance (Ramirez and Kelly, 1998).

The presence of positive correlation between Yp and Ys indicates that selection under non-stress environment may give high yielding genotypes under stress environment and suggests the mildness of the stress environment in the present experiment because Yp and Ys are independent under severe stress environments (Blum, 1996; Panthuwan et al., 2002). This agrees with the reports in wheat (Golabadi et al., 2006), maize (Khayatnezhad et al., 2010b) and lentil (Siahsar et al., 2010). The high correlation of TOL with Yp (r= 0.91, p < 0.01) compared to that with Ys (r= 0.48, p <

Table 3. Mean values of drought tolerance indices for 18 tef genotypes grown at moisture stress and non-stress environments.

Genotype[1]	Ys	Yp	TOL	MP	GMP	SSI	STI	YI
Addisie	57	111	54	84	80	0.95	0.29	0.79
Denkeye	55	120	65	88	81	1.06	0.31	0.76
Enatite	65	138	73	102	95	1.04	0.42	0.90
Gofarie	59	118	59	89	83	0.98	0.32	0.82
Gommadie	57	113	56	85	80	0.97	0.30	0.79
Manya	61	121	60	91	86	0.97	0.34	0.85
Rubicunda	63	108	45	86	82	0.82	0.31	0.88
Variegata	62	131	69	97	90	1.03	0.38	0.86
Dz-01-99	69	137	68	103	97	0.97	0.44	0.96
Dz-01-196	74	148	74	111	105	0.98	0.51	1.03
Dz-01-354	68	158	90	113	104	1.12	0.50	0.94
Dz-01-787	92	164	72	128	123	0.86	0.70	1.28
Dz-01-974	94	203	109	149	138	1.05	0.88	1.31
Dz-01-1285	90	157	67	124	119	0.84	0.65	1.25
Dz-01-1681	72	176	104	124	113	1.16	0.59	1.00
DZ-Cr-255	68	186	118	127	112	1.24	0.59	0.94
Dz-Cr-358	82	165	83	124	116	0.99	0.63	1.14
Dz-Cr-387	100	190	90	145	138	0.93	0.88	1.39

[1]Addisie to Variegata are landraces, DZ-01-99 to DZ-Cr-387 are improved cultivars.

Table 4. Correlation coefficients among grain yield and six drought tolerance indices across 18 tef genotypes.

Trait	Ys	TOL	MP	GMP	SSI	STI	YI
Yp	0.81**	0.91**	0.98**	0.95**	0.37^{ns}	0.94**	0.80**
Ys		0.48*	0.91**	0.95**	-0.24^{ns}	0.95**	1.00**
TOL			0.80**	0.73*	0.72**	0.72**	0.48*
MP				0.99**	0.18^{ns}	0.99**	0.91**
GMP					0.07^{ns}	1.00**	0.95**
SSI						0.05^{ns}	-0.25^{ns}
STI							0.95**

**, *= significant at p< 0.01, and p< 0.05, respectively; ^{ns} = not significant.

Table 5. Correlation between grain yield related traits under stress (S) and non- stress (P) environments and drought tolerance indices.

Trait[1]	Environment	Ys	Yp	TOL	MP	GMP	SSI	STI	YI
DTM	S	-0.32^{ns}	-0.61**	-0.68**	-0.54*	-0.49*	-0.51*	-0.48*	-0.32^{ns}
	P	0.14^{ns}	-0.30^{ns}	-0.54*	-0.16^{ns}	-0.08ns	-0.68**	-0.05^{ns}	0.14^{ns}
GFP	S	-0.53*	-0.58*	-0.48*	-0.59*	-0.58*	-0.13^{ns}	-0.56*	-0.53*
	P	0.17^{ns}	-0.24^{ns}	-0.47*	-0.11^{ns}	-0.03^{ns}	-0.60**	0.01^{ns}	0.17^{ns}
TB	S	0.63**	0.57*	0.39^{ns}	0.62**	0.64**	-0.03^{ns}	0.66**	0.63**
	P	0.52*	0.48*	0.34^{ns}	0.52*	0.53*	0.00^{ns}	0.58*	0.52*
HI	S	0.64**	0.49*	0.26^{ns}	0.56*	0.59**	-0.24^{ns}	0.57*	0.64**
	P	0.61**	0.85**	0.82**	0.80**	0.76**	0.42^{ns}	0.72**	0.60**

Table 5. Contd.

PHT	S	0.61**	0.77**	0.70**	0.75**	0.72**	0.29^{ns}	0.69**	0.61**
	P	0.53*	0.82**	0.83**	0.76**	0.70**	0.49*	0.68**	0.52*
PW	S	0.97**	0.83**	0.54*	0.92**	0.95**	-0.17^{ns}	0.95**	0.98**
	P	0.80**	0.96**	0.86**	0.95**	0.92**	0.30^{ns}	0.91**	0.79**
SW	S	0.98**	0.79**	0.47*	0.89**	0.93**	-0.24^{ns}	0.93**	0.98**
	P	0.76**	0.90**	0.80**	0.90**	0.87**	0.26^{ns}	0.88**	0.76**

[1]DTM= days to maturity, GFP=grain filling period, TB=total biomass (g/m^2), HI=harvest index, PHT=plant height(cm), PW=panicle weight(g/plant), SW=seed weight(g/plant).

0.05) also suggests that the increase in TOL will increase Yp relative to Ys. On the other hand, the lack of significant correlation of SSI with Yp and Ys suggests that SSI is not good predictor of yield under moderate stress. This agrees with the reports in wheat (Golabadi et al. 2006; Talebi et al., 2009). The positive correlation (r $\geq$ 0.80, p<0.01) of Yp and Ys with MP, GMP , STI and YI, and the strong correlation among the later suggests that the later traits would be used separately or in combination to increase yield in both environments as it was suggested for maize (Khayatnezhad et al., 2010b), and lentil (Siahsar et al., 2010). However, the use of these traits as selection indices requires precaution because they are not related to yield under severe stress environments which result in large differences between Yp and Ys (Mohammadi et al., 2010; Siahsar et at., 2010; Dadbakhsh and Sepas, 2011).

The negative correlation of grain filling period with Ys, MP, GMP, STI and YI suggests that increasing grain filling period makes plants more susceptible to stress. On the other hand, positive correlation of MP, GMP, STI and YI with total biomass, harvest index, panicle weight and seed weight/plant suggests that the former could be used to improve the later in stress and non-stress environments. This experiment suggests the possibility of using MP, GMP, STI and YI to improve tef yield under moderate stress and non-stress environments.

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