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Genetic Variation for Grain Yield and Yield Related Traits in Tef [*Eragrostis tef* (Zucc.)Trotter] under Moisture Stress and Non-Stress Environments

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ABSTRACT

Tef [*Eragrostis tef* (Zucc.)Trotter] is an ancient and major cereal crop in Ethiopia. Increasing tef grain yield partly requires developing cultivars that are adapted to drought stress environment. 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 genetic variation, heritability and correlations of grain yield and yield related traits. Broad-sense heritability values under respective stress and non-stress environments were grain yield (g/m^2) 0.80 and 0.89, total biomass (g/m^2) 0.89 and 0.73, harvest index 0.69 and 0.79, panicle weight (g/plant) 0.93 and 0.92, and seed weight (g/plant) 0.96 and 0.86. The correlations of grain yield under respective stress and non-stress environments were total biomass $r_p = 0.64$, $r_g = 0.70$, and $r_p = 0.48$, $r_g = 0.56$, harvest index $r_p = 0.70$, $r_g = 0.64$, and $r_p = 0.87$, $r_g = 0.90$, panicle weight $r_p = 0.98$, $r_g = 1.00$, and $r_p = 0.96$, $r_g = 1.00$, and seed weight/plant $r_p = 0.98$, $r_g = 1.00$, and $r_p = 0.90$, $r_g = 1.00$. The present experiment showed that either grain yield *per se*, or seed weight/plant could be used to improve grain yield under stress and non-stress environments.

Keywords: Variability; Broad-Sense Heritability; Correlations; Moisture Stress; *Eragrostis tef*

1. Introduction

Tef [*Eragrostis tef* (Zucc.)Trotter] is an ancient and major cereal crop in Ethiopia. It grows widely from sea level up to 2800 m above sea level under various rainfall conditions although good productivity is obtained in areas where growing season rainfall exceeds 300 mm [1]. The average yield of tef is less than 1 tone/ha [2] which is partly attributed to low moisture supply [3,4].

The estimation of genetic parameters for agronomic traits is necessary in the selection of superior genotypes and to evaluate the breeding strategies. The key genetic parameters are heritability, and phenotypic and genetic correlations [5]. The broad-sense heritability is the proportion of phenotypic variation that is due to total (additive and non-additive) genetic effects. It provides an estimate of the genetic advance expected from selection applied to genetic materials under certain environment. The higher the heritability estimates, the simpler are the selection procedures [6,7].

Phenotypic correlation measures how different traits co-vary across phenotypes. A genetic correlation measures the degree to which different traits are controlled by the same gene or genes that are closely linked. Early studies in tef showed considerable genetic variation, heritability, and correlations among a range of agronomic traits [8-10]. However, these studies were done under non-moisture stress environments and may not be applicable for drought conditions. The major objectives of the present study were 1) to estimate the variances and broad-sense heritability, and 2) to examine the phenotypic and genetic correlation coefficients for grain yield and yield related traits in tef under moisture stress and non-stress environments.

2. Materials and Methods

A field experiment was conducted 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 annual average rainfall and temperature of 255 mm and 22.3˚C, respectively. The soil of the experimental field is sandy loam.

Eighteen tef genotypes were planted at recommended seeding rate of 25 kg/ha on September 2, 2010, at the end

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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˚C, 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 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, panicle weight and seed weight/plant. Grain yield and total biomass 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˚C. The data were analyzed using GLM procedure of SAS software [11].

Broad-sense heritability (h^2) was calculated as the ratio of the genotypic variance to the phenotypic variance as:

$$h^2 = \sigma_g^2 \Big/ \sigma_p^2$$

where σ_g^2 the genotypic variance [$(MSG - MSE)/r$], σ_p^2 the phenotypic variance (genotypic variance plus error variance), σ_e^2 error variance (MSE/r), MSG mean square of genotypes, MSE mean square of error and r are number of replications.

The genotypic and phenotypic coefficients of variation were computed according to the methods of Burton [12] and Kumar *et al*. [13] as:

$$GCV = \left(\sigma_g^2\right)^{0.5} \Big/ z \times 100$$

$$PCV = \left(\sigma_p^2\right)^{0.5} \Big/ z \times 100$$

where *GCV* and *PCV* are the genotypic and phenotypic coefficient of variation, respectively, and σ_g^2 the genotypic variance, σ_p^2 the phenotypic variance and z the general mean of a trait.

Genetic and phenotypic correlation coefficients between pairs of traits were calculated using estimates of variances and covariances according to Kibite and Evans [14] as:

$$r_g = COV_{gxy} \Big/ \left(\sigma_x^2 \times \sigma_y^2\right)^{0.5}$$

where r_g is the genetic correlation coefficient, COV_{gxy} the genetic covariance between traits x and y, and σ_x^2 and σ_y^2 are the genetic variances for traits x and y, respectively. Similar analyses were made for phenotypic correlation coefficients (r_p) using the phenotypic variances and covariances.

3. 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.

Grain yield (g/m^2) ranged from 55 (genotype Denkeye) to 100 (genotype DZ-Cr-387) under stress, and from 108 (genotype Rubicunda) to 203 (genotype DZ-01-974) under non-stress environment. Total biomass (g/m^2) ranged from 537 (genotype Addisie) to 866 (genotype DZ-01-974) under stress, and from 737 (genotype Rubicunda) to 1056 (genotype DZ-01-974) under non-stress environment (**Table 2**). Genotypes also showed considerable variations for days to maturity, grain filling period, harvest index, plant height, panicle weight and seed weight/plant under both stress and non-stress environments.

The $ð_g^2$ values were much higher than that of $ð_e^2$ for grain yield and yield related traits (**Table 3**). Both genotypic and phenotypic coefficients of variation were high for grain yield compared to total biomass and harvest index under both environments. The decrease in values of genotypic and phenotypic coefficients of variation for days to maturity, grain filling period, plant height, grain yield, and harvest index, and the increase for total biomass, panicle weight, and seed weight/plant were obtained under stress environment. Broad-sense heritability values under respective stress and non-stress environments were grain yield 0.80 and 0.89, total biomass 0.89 and 0.73, harvest index 0.69 and 0.79, panicle weight 0.93 and 0.92, and seed weight/plant 0.96 and 0.86.

The correlations of grain yield in respective stress and non-stress environments were total biomass $r_p = 0.64$, $r_g = 0.70$, and $r_p = 0.48$, $r_g = 0.56$, harvest index $r_p = 0.70$, $r_g = 0.64$, and $r_p = 0.87$, $r_g = 0.90$, panicle weight $r_p = 0.98$, $r_g = 1.00$, and $r_p = 0.96$, $r_g = 1.00$, and seed weight/plant $r_p = 0.98$, $r_g = 1.00$, and $r_p = 0.90$, $r_g = 1.00$ (**Table 4**). The correlations of total biomass in respective stress and non-stress environments were panicle weight $r_p = 0.64$, $r_g = 0.68$ and $r_p = 0.33$, $r_g = 0.38$, and seed weight/plant $r_p = 0.58$, $r_g = 64$, and $r_p = 0.44$, $r_g = 0.55$. The correlations of harvest index in respective stress and non-stress environments were grain filling period $r_p = –0.54$, $r_g = –0.96$,

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[a]	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*	11.54 ns	0.025 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 × 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
Stress									
Replication	2	5.69 ns	12.24 ns	735**	2869 ns	18.04**	7.39 ns	0.048 ns	0.003 ns
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
CV, %		3.32	7.57	11.44	7.51	15.16	7.61	9.61	27.08
Non-stress									
Replication	2	0.91 ns	6.17 ns	89 ns	3995 ns	1.8 ns	15.69 ns	0.003 ns	0.064 ns
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
CV, %		2.43	4.70	15.10	8.84	13.45	5.67	9.56	28.44

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

Table 2. Mean values of eight grain yield and yield related traits of 18 tef genotypes grown under stress (S) and non-stress (N) environments.

Genotypes[1]	DTM		GFP		GY		TB		HI		PHT		PW		SW	
	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N
Addisie	86	98	42	53	57	111	537	989	0.11	0.11	60	72	0.91	1.13	0.06	0.32
Denkeye	87	95	47	55	55	120	667	891	0.08	0.13	60	74	0.92	1.26	0.05	0.29
Enatite	82	93	40	52	65	138	651	861	0.10	0.16	69	86	1.17	1.48	0.13	0.50
Gofarie	83	93	42	51	59	118	607	925	0.10	0.13	64	76	1.07	1.15	0.09	0.19
Gommadie	88	102	42	56	57	113	632	935	0.09	0.12	71	76	1.02	1.05	0.07	0.35
Manya	79	94	37	52	61	121	662	795	0.09	0.15	67	81	1.07	1.31	0.09	0.35
Rubicunda	86	96	44	53	63	108	630	737	0.10	0.15	60	71	1.12	1.41	0.11	0.46
Variegata	80	94	39	52	62	131	707	793	0.09	0.17	62	66	1.07	1.36	0.11	0.45
DZ-01-99	83	96	40	54	69	137	550	808	0.13	0.17	73	85	1.29	1.43	0.27	0.47
DZ-01-196	83	91	42	50	74	148	728	807	0.10	0.18	73	85	1.44	1.54	0.39	0.55
DZ-01-354	80	94	39	52	68	158	731	844	0.09	0.19	75	90	1.13	1.64	0.17	0.59
DZ-01-787	82	94	39	52	92	164	755	981	0.12	0.17	76	86	1.63	1.68	0.52	0.63
DZ-01-974	79	95	39	54	94	203	866	1056	0.11	0.19	81	97	1.76	2.04	0.55	1.26
DZ-01-1285	89	107	39	57	90	157	688	889	0.13	0.18	77	86	1.52	1.60	0.47	0.59
DZ-01-1681	80	91	40	51	72	176	703	894	0.10	0.20	76	93	1.39	1.79	0.23	0.73
DZ-Cr-255	77	80	38	41	68	186	575	873	0.12	0.21	78	105	1.23	1.92	0.21	0.75
DZ-Cr-358	75	88	35	48	82	165	569	912	0.14	0.19	77	100	1.47	1.72	0.45	0.69
DZ-Cr-387	79	99	38	57	100	190	810	1031	0.12	0.18	67	85	1.78	1.95	0.62	0.75
Mean	82	94	40	52	72	147	670	890	0.11	0.17	70	84	1.28	1.53	0.25	0.55
$LSD_{0.05}$	2.60	2.18	2.89	2.34	10.28	16.01	47.97	75.03	0.015	0.021	5.11	4.55	0.12	0.14	0.066	0.149

[1]Genotypes Addisie to Variegata are landraces and DZ-01-99 to DZ-Cr-387 are improved cultivars; DTM = days to maturity; GFP = grain filling period; GY = grain yield (g/m^2); TB = total biomass (g/m^2); HI = harvest index; PHT = plant height (cm); PW = panicle weight (g/plant); SW = seed weight (g/plant).

Table 3. Estimates of variances, coefficients of variations and broad-sense heritability (h^2) for eight grain yield and yield related traits across 18 tef genotypes under stress (S) and non-stress (N) environments.

Traits	Environment	$ð^2_g$	$ð^2_p$	$ð^2_e$	GCV	PCV	h^2
Days to maturity	S	13.22	15.69	2.47	4.43	4.83	0.84
	N	28.91	30.66	1.75	5.69	5.86	0.94
Grain filling period	S	4.35	7.42	3.08	5.20	6.80	0.59
	N	11.29	13.31	2.02	6.43	6.98	0.85
Grain yield (g/m^2)	S	159	198	39	17.60	19.6	0.80
	N	783	877	94	19.10	20.20	0.89
Total biomass (g/m^2)	S	7045	7889	844	12.50	13.30	0.89
	N	5451	7516	2065	8.30	9.74	0.73
Harvest index	S	1.91	2.79	0.88	12.90	15.60	0.69
	N	6.34	7.99	1.66	15.20	17.10	0.79
Plant height (cm)	S	37.00	46.84	9.56	8.67	9.72	0.80
	N	105	113	7.58	12.20	12.60	0.93
Panicle weight (g/plant)	S	0.069	0.074	0.005	20.60	21.30	0.93
	N	0.078	0.085	0.007	18.30	19.10	0.92
Seed weight (g/plant)	S	0.036	0.037	0.002	74.10	75.70	0.96
	N	0.051	0.059	0.008	40.90	44.10	0.86

Table 4. Phenotypic (r_p) and genetic (r_g) correlation coefficients for eight grain yield and yield related traits across 18 tef genotypes under stress (below diagonal) and non-stress (above diagonal) environments.

	Traits		1	2	3	4	5	6	7	8
1	Days to maturity	r_p		0.93**	–0.30 ns	0.18 ns	–0.45 ns	–0.50*	–0.34 ns	–0.20 ns
		r_g		0.96**	–0.33 ns	0.24 ns	–0.55*	–0.53*	–0.38 ns	–0.22 ns
2	Grain filling period	r_p	0.75**		–0.24 ns	0.23 ns	–0.43 ns	–0.52*	–0.26 ns	–0.13 ns
		r_g	0.75**		–0.30 ns	0.32 ns	–0.58*	–0.58*	–0.33 ns	–0.14 ns
3	Grain yield (g/m^2)	r_p	–0.33 ns	–0.49*		0.48*	0.87**	0.82**	0.96**	0.90**
		r_g	–0.43 ns	–0.75**		0.56*	0.90**	0.90**	1.00**	1.00**
4	Total biomass (g/m^2)	r_p	–0.17 ns	–0.12 ns	0.64**		–0.01 ns	0.27 ns	0.33 ns	0.44 ns
		r_g	–0.18 ns	–0.11 ns	0.70**		0.15 ns	0.32 ns	0.38 ns	0.55*
5	Harvest index	r_p	–0.30 ns	–0.54*	0.70**	–0.10 ns		0.80**	0.90**	0.77**
		r_g	–0.45 ns	–0.96**	0.64**	–0.10 ns		0.95**	1.00**	0.92**
6	Plant height (cm)	r_p	–0.40 ns	–0.56*	0.62**	0.30 ns	0.56*		0.79**	0.72**
		r_g	–0.54*	–0.87**	0.76**	0.35 ns	0.73**		0.88**	0.82**
7	Panicle weight (g/plant)	r_p	–0.39 ns	–0.48*	0.98**	0.64**	0.67**	0.67**		0.91**
		r_g	–0.46*	–0.66**	1.00**	0.68**	0.82**	0.73**		1.00**
8	Seed weight (g/plant)	r_p	–0.34 ns	–0.47*	0.98**	0.58*	0.74**	0.63*	0.98**	
		r_g	–0.38 ns	–0.63**	1.00**	0.64**	0.91**	0.71**	1.00**	

*, ** = significant at $p < 0.05$ and $p < 0.01$, respectively; ns = not significant.

and r_p = –0.43, r_g = –0.58, panicle weight r_p = 0.67, r_g = 0.82, and r_p = 0.90, r_g = 1.00, and seed weight/plant r_p = 0.74, r_g = 91, and r_p = 0.77, r_g = 0.92.

4. Discussion

The reduction in performance due to moisture stress observed in present experiment agrees with the previous studies in tef [15], and wheat [16,17]. Water deficit occurring from flowering to maturity usually results in poor assimilation, reduced translocation of photosynthates to the grain and higher respiratory losses [18,19]. Consequently, the effect of moisture stress was manifested in low panicle weight, seed weight/plant and grain yield. The highest grain yield was obtained under both environments for genotypes DZ-01-974 and DZ-Cr-387 indicating that these genotypes may be used in future breeding programs to improve grain yield under stress and non-stress environments.

In the present experiment, the phenotypic coefficient of variation was higher than the genotypic coefficient of variation, but in most cases the two values differed only slightly, indicating small environmental effects in estimating these traits. On the other hand, the high broad-sense heritability observed in this study suggests the feasibility of selection to improve tef grain yield under stress as well as non-stress environments. However, heritability is a value of a character only for the population and the environment to which the genetic materials are subjected [5]. Thus, value of heritability depends on the magnitude of all the components of variance, and a change in any of these will affect it. As to the present experiment, the decrease in broad-sense heritability under stress environment for grain yield [20,21], and harvest index and plant height [21,22], and the increase in that of total biomass [22] has been reported for wheat.

The negative correlation (r_g = –0.75, r_p = –0.49) between grain yield and grain filling period under stress environment suggests the possibility of using rapid maturity to escape the effects of drought [1]. The importance of total biomass to improve grain yield was low (r_p = 0.48, r_g = 0.56) under non-stress compared to stress environment (r_p = 0.64, r_g = 0.70). This could be related to low variability of total biomass under non-stress environment as was suggested by Donald and Hamblin [23]. On the other hand, the strong correlation between grain yield and seed weight/plant suggests that either grain yield *per se* or the latter trait can be used to improve grain yield under stress and non-stress environments. However, high error coefficient of variation associated to seed weight/plant suggests a careful handling of it to reduce sampling error.

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