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Correlations and Path Coefficient Analysis of Major Quantitative Characters in Tef [*Eragrostis tef* (Zucc.) Trotter] Breeding Lines

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Abstract

Grain yield is a complex quantitative trait resulting from the interaction of various genetic and environmental factors. Knowledge of the association of characters and the direct and indirect effects of the various characters on grain yield is essential for effective selection in crop improvement. Since such studies are very limited in tef, further research is required. This study was designed to examine the interrelationship among 12 characters and their direct and indirect effect on grain yield. Thus, 28 tef genotypes were evaluated at Holetta, Debre Zeit and Alem Tena during the main cropping season of 2015 in randomized complete block design with three replications. The study results revealed significant and positive genotypic and phenotypic correlation between grain yield and all studied traits other than days to heading and to maturity, lodging index and thousand kernel weight. The estimated values of genotypic correlations were also found to be higher than their respective phenotypic correlations. In the path coefficient analysis, very high (nearly one) genotypic and phenotypic coefficients of determination (R2) were also estimated. The highest positive genotypic and phenotypic direct effects on grain yield per plot was exhibited by total biomass and harvest index, respectively. Total biomass, furthermore, showed the highest genotypic indirect effect on grain yield via all traits other than lodging index and thousand kernel weight. Total biomass, harvest index, second culm diameter, plant height and panicle length, in general, showed positive and significant genotypic association with grain yield. Hence, these characters could be used as target traits for the improvement of grain yield in tef.

Keywords: Direct effect; Improvement; Indirect effect; Recombinant inbred lines; Tef; Traits

Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is the most important indigenous crops widely grown and consumed in Ethiopia. It is a crop with various agronomic, nutritional and health merits. Though tef stands first in area coverage and second to maize in total grain production, its average productivity is still very low compared to other major cereal crops grown in Ethiopia. The productivity of tef in 2016/17, for instance, is 16.5 t/ha compared to 25.3 t/ha for sorghum, 26.7 t/ha for wheat and 36.8 t/ha for maize [1]. Poor dissemination of improved varieties and production packages, and the problem of lodging are among the major factors adversely affecting the productivity of tef.

Grain yield is a complex quantitative trait resulting from the interaction of various genetic and environmental factors. Genotypic and/or phenotypic correlation coefficients are useful to measure the association among various traits of a given crop and also enable to determine components that influence a given trait either directions [2-4]. Though correlation coefficients measure the absolute value of the correlation between variables in a given body of data, it may not provide clear picture of the relative importance of direct and indirect effect of independent traits on dependent traits [4-6]. In other words, correlation measures only mutual association without considering causation while, path coefficient measures the direct influence of one variable upon another variable. Hence, path coefficient analysis permits the partitioning of correlation coefficient into components of direct and indirect effects [5-7]. In path coefficient analysis, grain yield is usually considered to be dependent while the other traits are considered independent. Since it permits critical estimation of specific factor that produce a given correlation, path coefficient analysis has been successfully employed in formulating an effective selection strategy for a breeding program [6,7]. Thus, generating information on the association of characters and the direct and indirect effects of each traits on grain yield are essential to aid the selection process in crop improvement. The objectives of the present study were, therefore, to estimate the phenotypic and genotypic correlations among 12 morpho-agronomic traits, and to determine the direct and indirect effect of various traits on grain yield of tef.

Materials and Methods

Plant materials

Twenty-eight tef genotypes including 24 breeding lines, three improved varieties (standard checks) and one farmers' variety (local check) were evaluated at Holetta, Debre Zeit and Alem Tena in 2015 main cropping season. The studied breeding lines are entirely recombinant inbred lines (RIL). Quncho is a popular variety released for high rainfall high potential environments while, Tsedey is the name of variety released for moisture stress areas of Ethiopia. Kinde, on the other hand, is a semi-dwarf mutant line identified at the University of Bern from mutagenized tef population. Further, description of the study genotypes is given in Table 1. Regarding the study environments, Holetta and Debre Zeit are found in the central highland high rainfall area and mid altitude environment, respectively while, Alem Tena is located in the moisture deficit Rift Valley area of Ethiopia (Table 2).

S No.	Genotype names	Description	S No.	Genotype names	Description
1	RIL-13	Breeding line	15	RIL-171	Breeding line
2	RIL-81	Breeding line	16	RIL-91	Breeding line
3	RIL-302	Breeding line	17	RIL-115	Breeding line
4	RIL-232	Breeding line	18	RIL-180	Breeding line
5	RIL-227	Breeding line	19	RIL-103	Breeding line
6	RIL-181	Breeding line	20	RIL-96	Breeding line
7	RIL-110	Breeding line	21	RIL-132	Breeding line
8	RIL-121	Breeding line	22	RIL-159	Breeding line
9	RIL-69	Breeding line	23	RIL-85	Breeding line
10	RIL-134	Breeding line	24	RIL-137	Breeding line
11	RIL-11	Breeding line	25	Quncho	Released variety
12	RIL-133	Breeding line	26	Kinde	Released variety
13	RIL-271	Breeding line	27	Tsedey	Released variety
14	RIL-244	Breeding line	28	Local	Farmers' variety

Table 1: Names of study genotypes and their descriptions.

Locations	Altitude	Latitude	Longitude	rainfall (mm)	Temperature		Soil type
					Min °C	Max °C	
Alem Tena	1580	8020' N	38057'E'	500	8	29.8	Light sandy
Debre Zeit	1900	8 044' N	380 58' E	851	8.9	28.3	Pellic Vertisol
Holetta	2400	9044'N	380 30' E	1100	6	22	Nitosol

Table 2: Description of the edaphic and climatic conditions of the study locations.

The experiment was laid out in randomized complete block design with three replications. Each genotype was grown on five rows of 1.0 m length at a spacing of 0.2 m, 1 m and 1.5 m, between rows, plots and replications, respectively. All agronomic and cultural practices were applied as per the recommendation for tef production at each location. Plant height, panicle length, peduncle length, culm diameter, number of spikelet per panicle data were collected based on five randomly tagged plants before heading while days to panicle emergence, days to maturity, total biomass, grain yield, 1000-kernel weight and lodging index data were recorded on plot basis.

Statistical analysis

Before proceeding to correlation and path coefficient analysis, all quantitative traits data were subjected to analysis of variance (ANOVA) as per the suggested procedure [8]. Genotypic and phenotypic correlation analysis were then conducted using multi environment trial analysis with R for windows (META-R) version 6.0 developed by CIMMYT [9]. Genes statistical software packages version 1990.2018.39 [10] was used for path coefficient analysis while cluster analysis of the 12 studied traits was done using MINITAB software version 17.1 [11].

Results and Discussion

Correlation coefficient analysis

Estimates of genotypic and phenotypic correlations among the various traits of tef are presented in Table 3. Thus, positive and significant genotypic and phenotypic association were exhibited between grain yield and all studied traits, except days to heading and maturity, lodging index and thousand kernel weight. This suggests that genotypes heading earlier have better yield than those with longer heading date. This is contrary to most previous studies [3,5] which reported genotypes with longer heading date have higher yield than the earlier ones. On the other hand, the non-significant association detected between grain yield and days to maturity and lodging in the present study is in line with the previous report [3]. The positive association exhibited between grain yield and pant height indicates that genotypes with longer plant height have usually higher grain yield compared to those having shorter plant height. Similar findings have been reported previously [3,5]. Such observed positive correlation among the studied traits could be due to presence of common genetic elements that control the characters to the same direction.

Traits	DH	DM	PH	PL	Pdl	SCD	SPK	TBM	HI	LI	TKW	GY
DH	1.00	0.64b	0.35	0.45[c]	-0.19	0.16	0.57[b]	0.19	-0.78[a]	0.12	-0.37[c]	-0.17
DM	0.92[a]	1.00	0.48[c]	0.42[c]	0.05	0.21	0.39[c]	0.42[c]	-0.40[c]	0.16	-0.08	0.20

PH	0.44^{c}	0.73^{a}	1.00	0.87^{a}	0.27	0.50^{b}	0.70^{b}	0.89^{a}	-0.08	0.19	-0.14	0.75^{a}
PL	0.74^{a}	0.79^{a}	1.00^{a}	1.00	0.00	0.50^{b}	0.74^{a}	0.73^{a}	-0.23	0.12	-0.06	0.55^{b}
Pdl	-0.21	0.22	0.33	0.04	1.00	0.00	-0.06	0.27	0.23	-0.01	-0.19	0.33
SCD	0.34	0.44^{c}	1.00^{a}	1.00^{a}	0.08	1.00	0.46^{c}	0.62^{b}	-0.05	-0.12	-0.04	0.52^{b}
SPK	0.91^{a}	0.72^{b}	0.81^{a}	0.95^{a}	-0.13	1.00^{a}	1.00	0.63^{b}	-0.42^{c}	0.16	-0.24	0.38^{c}
TBM	0.22	0.67^{b}	1.00^{a}	1.00^{a}	0.34	1.00^{a}	0.82^{a}	1.00	0.02	0.02	-0.02	0.90^{a}
HI	-1.00^{a}	-0.63^{b}	-0.14	-0.37^{c}	0.29	-0.34	-0.83^{a}	0.21	1.00	0.14	0.27	0.45^{c}
LI	0.22	0.28	0.22	0.20	0.05	-0.19	0.24	0.09	0.25	1.00	0.12	0.11
TKW	-0.82^{a}	-0.22	-0.27	-0.09	-0.45^{c}	-0.28	-0.46^{c}	0.024	0.67^{b}	0.14	1.00	0.10
GY	-0.20	0.36	0.87^{a}	0.76^{a}	0.43^{c}	1.00^{a}	0.41^{c}	0.93^{a}	0.62^{b}	0.20	0.29	1.00

DH=Days to heading (days), DM=Days to maturity (days), PH=Plant height (cm), PL=Panicle length (cm), PdL=Peduncle length (cm), SCD=Second basal culm internode diameter (mm), SPK=No. of spikelet per panicle, TB=Total biomass (t ha^{-1}), GY= Grain yield (t ha^{-1}), LI=Lodging index (%), TKW=Thousand kernel weight (g). a,b, c shows significant association at 0.1,1,5% probability level, respectively.

Table 3: Genotypic (lower diagonal) and phenotypic (upper diagonal) correlation analysis among 12 traits tef breeding lines.

Total biomass showed positive and significant phenotypic and genotypic correlation with almost 60% of the studied traits. Harvest index, on the other hand, showed negative and significant genotypic and phenotypic association with days to heading and to maturity. In this study, furthermore, lodging index was not significantly (p=0.05) associated with all studied traits at both phenotypic and genotypic level. Un like this result, a negative and highly significant genotypic association was reported between lodging index and that of culm length, panicle length and plant height in the previous study [5].

Days to heading showed positive and significant genotypic and phenotypic association with all traits other than second culm diameter, total biomass, grain yield, harvest index, lodging index, 1000-kernel weight and grain yield. Thus, it had significant and negative association with harvest index and thousand kernel weight while it showed no significant (P=0.05) association with the remaining five traits. Days to maturity has also exhibited similar association with all traits other than peduncle length, second culm diameter, lodging index, 1000-kernel weight and grain yield at phenotypic level and peduncle length, lodging index, 1000-kernel weight and grain yield at genotypic level (Table 3). Similar results were also reported previously in tef [5,12,13] and in maize [4]. In general, the estimated higher genotypic correlations than their respective phenotypic correlations in this study is in line with the previous reports [4,5]. Besides, the positive and significant association of grain yield with biomass yield and harvest index is also in line with several previous findings [4,5,12,14-17].

Path coefficient analysis

The direct effects of various traits on grain yield ranged from -0.004 to 0.816 at genotypic level (Table 4) and from -0.012 to 0.944 at phenotypic level (Table 5). Thus, total biomass (0.816) followed by harvest index (0.273) and plant height (0.226) showed the highest positive genotypic direct effects on grain yield per plot. Similarly, in the previous studies, the highest direct effect on grain yield were reported for total biomass [3,18] and harvest index [3,5]. Such results suggest to emphasis on the genetic improvement of those traits to increase grain yield by indirect selection [2,3]. In the present study, number of spikelet per panicle had the highest negative direct effect on grain yield while, the smallest value was exhibited due to days to heading and maturity, peduncle length, second culm diameter and thousand kernel weight at genotypic level. The observed low positive direct effect of panicle length and lodging index on grain yield is in line with the previous report [5]. Days to heading and maturity, peduncle length, second culm diameter, spikelet per panicle showed negative direct effect on grain yield. Similar findings showing negative indirect effect of days to maturity on grain yield was reported previously in wheat [19] and in tef [5]. The highest indirect effect on grain yield was shown by total biomass through all traits except lodging index and thousand kernel weight. The lowest indirect effect on grain yield was, however, exhibited by days to maturity, panicle length, peduncle length, lodging index and thousand kernel weight via all studied traits. Harvest index, spikelet per panicle and plant height showed a moderately high indirect effect on grain yield via most of the studied traits at genotypic level. This indicates that selection for those traits could indirectly increase grain yield by influencing the other traits.

At phenotypic level, the highest direct effect on grain yield was exhibited for total biomass (0.944) followed by harvest index (0.424) while all remaining traits showed the lowest direct effect on grain yield. Previous finding [2], however, reported thousand kernel weight to have the highest direct effect on grain yield. In this study, days to heading, plant height and harvest index showed low positive direct effect on grain yield. Besides, all traits other than total biomass and harvest index have also showed low indirect effect on grain yield. Thus, total biomass showed moderately high indirect effect on grain yield via all traits other than harvest index, lodging index and thousand kernel weight. Similarly, harvest index also had moderately high indirect effect on grain yield via days to heading, days to maturity and spikelet per panicle.

Coefficient of determination (R2) is, generally, used to explain how much variability of one factor can be caused by its relationship to another factor [4,5]. The path analysis in the present study, therefore, revealed a genotypic and phenotypic coefficient of determination values of nearly unity at both levels. This indicates that over 99% of the variations in grain yield in the model has been explained through the independent variables.

Traits	DH	DM	PH	PL	Pdl	SCD	SPK	TBM	HI	LI	TKW	GY
DH	-0.085	-0.079	-0.038	-0.063	0.018	-0.029	-0.078	-0.019	0.093	-0.019	0.07	-0.2
DM	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.002	-0.002	0.001	-0.001	0.001	0.36
PH	0.1	0.165	0.226	0.231	0.075	0.247	0.183	0.238	-0.032	0.05	-0.061	0.87
PL	0.003	0.003	0.004	0.004	0.00	0.005	0.004	0.004	-0.001	0.001	0.00	0.76
PdL	0.01	-0.011	-0.016	-0.002	-0.048	-0.004	0.006	-0.016	-0.014	-0.002	0.022	0.43
SCD	-0.009	-0.011	-0.028	-0.034	-0.002	-0.026	-0.029	-0.037	0.009	0.005	0.007	1.1
SPK	-0.13	-0.103	-0.116	-0.136	0.019	-0.161	-0.143	-0.117	0.119	-0.034	0.066	0.41
TBM	0.18	0.547	0.857	0.849	0.278	1.168	0.669	0.816	0.171	0.073	0.016	0.93
HI	-0.297	-0.172	-0.038	-0.101	0.079	-0.093	-0.226	0.057	0.273	0.068	0.183	0.62
LI	0.014	0.017	0.014	0.012	0.003	-0.012	0.015	0.006	0.016	0.062	0.009	0.2
TKW	0.018	0.005	0.006	0.002	0.01	0.006	0.01	0.00	-0.014	-0.003	-0.021	0.29

DH=Days to heading (days), DM=Days to maturity (days), PH=Plant height (cm), PL=Panicle length (cm), PdL=Peduncle length (cm), SCD=Second basal culm internode diameter (mm), SPK=No. of spikelet per panicle, TB= Total biomass (t ha^{-1}), GY=Grain yield (t ha^{-1}), LI=Lodging index (%), TKW=Thousand kernel weight (g). Genotypic coefficient of determination = 1.00; Residual variable effect=0.00.

Table 4: Path analysis showing genotypic direct (bold) and indirect effects of various traits on grain yield of tef breeding lines.

Traits	DH	DM	PH	PL	Pdl	SCD	SPK	TBM	HI	LI	TKW	GY
DH	0.03	0.019	0.011	0.014	-0.004	0.005	0.017	0.006	-0.023	0.004	-0.14	-0.139
DM	-0.018	-0.027	-0.013	-0.012	-0.002	-0.006	-0.011	-0.012	0.011	-0.005	0.21	0.209
PH	0.006	0.007	0.015	0.013	0.004	0.008	0.011	0.014	-0.001	0.003	0.76	0.761
PL	-0.023	-0.022	-0.044	-0.051	-0.001	-0.025	-0.038	-0.038	0.012	-0.007	0.55	0.549
PdL	0.002	-0.001	-0.004	0.00	-0.014	0.00	0.001	-0.004	-0.003	0.00	0.35	0.349
SCD	-0.002	-0.003	-0.006	-0.006	.0.00	-0.012	-0.006	-0.007	0.001	0.001	0.52	0.521
SPK	-0.011	-0.008	-0.014	-0.015	0.001	-0.009	-0.02	-0.013	0.008	-0.003	0.38	0.379
TBM	0.189	0.406	0.84	0.698	0.264	0.585	0.594	0.944	0.019	0.028	0.9	0.899
HI	-0.322	-0.17	-0.034	-0.098	0.098	-0.021	-0.178	0.008	0.424	0.059	0.45	0.451
LI	0.006	0.007	0.008	0.005	0.001	-0.004	0.006	0.001	0.006	0.04	0.004	0.119
TKW	0.004	0.001	0.002	0.001	0.002	0.00	0.003	0.00	-0.003	-0.001	-0.011	0.08

DH=Days to heading (days), DM=Days to maturity (days), PH=Plant height (cm), PL=Panicle length (cm), PdL=Peduncle length (cm), SCD=Second basal culm internode diameter (mm), SPK=No. of spikelet per panicle, TB= Total biomass (t ha^{-1}), GY=Grain yield (t ha^{-1}), LI=Lodging index (%), TKW=Thousand kernel weight (g). Phenotypic coefficient of determination = 0.999; Residual variable effect=0.0298.

Table 5: Path analysis showing phenotypic direct (bold) and indirect effects of various traits on grain yield of tef breeding lines.

Principal component analysis

Principal component analysis based on 12 traits of 28 tef breeding lines showed that the first four principal components with eigenvalue greater than one contributed for 81.12% of the total variations. Thus, PC1, 2, 3 and 4 accounted for about 40, 21, 10 and 9.7%, respectively (Table 6). In such analysis, plant height followed by panicle length, total biomass and number of spikelet per panicle were the major contributing traits to PC1 while harvest index, days to heading and grain yield were to PC2. Besides, in PC3, the largest contributing traits were 1000-kernel weight, peduncle length and lodging index while that of PC4 were lodging index, peduncle length and second culm diameter. The total variation obtained in this study is in line with the findings of the previous reports [13,14].

In the PCA-biplot analysis, the studied traits and genotypes were also plotted based on the first two principal components which accounted for over 60% (PC1=40.2% and PC2=20.91%) of the total variations (Figure 1). Based on this biplot, the 28 studied tef genotypes were grouped into four categories with various important traits (Figure 1). Thus, group-I consisted of tef genotypes such as RIL-91, RIL-132, RIL-110 and RIL-271 which had higher values of total biomass, grain yield, peduncle length, lodging index, plant height and second culm diameter. The second group, on the other hand, consisted of genotypes like RIL-171, RIL-85, RIL-69, Quncho, RIL-103, RIL-137, and RIL-96 which had longer days to heading and maturity, large number of spikelet per panicle and longer panicle. The third groups of genotypes include 12 genotypes observed to have high harvest index and 1000-kernel weight. The fourth group of genotypes, however, include RIL-134, RIL-302, RIL-81 and Kinde which had relatively lower values of most of the studied traits. Based on this grouping, genotypes in group-I which have the highest grain yield and total biomass along with lower peduncle length and lodging index have a great potential for the intended yield improvement in tef.

Traits	PC1	PC2	PC3	PC4
DH	0.24	-0.49	0.01	0.13
DM	0.27	-0.22	0.11	0.24
PH	0.43	0.11	-0.01	0.09
PL	0.40	-0.01	0.13	-0.09
PdL	0.08	0.25	-0.54	0.46
SCD	0.29	0.11	-0.03	-0.45
SPK	0.37	-0.16	0.06	-0.07
TBM	0.41	0.22	-0.04	-0.08
GY	0.31	0.43	-0.01	0.01
HI	-0.11	0.55	0.06	0.12
LI	0.07	0.03	0.50	0.66
TKW	-0.09	0.23	0.65	-0.17
Eigenvalue	4.82	2.51	1.23	1.17
Variability (%)	40.20	20.91	10.26	9.74
Cumulative %	40.20	61.12	71.38	81.12

DH=Days to heading (days), DM=Days to maturity (days), PH=Plant height (cm), PL=Panicle length (cm), PdL=Peduncle length (cm), SCD=Second basal culm internode diameter (mm), SPK=No. of spikelet per panicle, TB=Total biomass (t ha^{-1}), GY= Grain yield (t ha^{-1}), LI=Lodging index (%), TKW=Thousand kernel weight (g)

Table 6: Eigenvectors and eigenvalues of the 12 traits of 28 tef breeding lines.

Like the PCA-biplot for genotypes, the PCA-biplot of the 12 studied quantitative traits also showed the formation of three groups of traits whereby group-I, II and III consisted of six, four and two traits, respectively. Thus, group-I consisted of traits such as grain yield, total biomass, plant height, peduncle length, second culm diameter and lodging index which are directly related to yield and lodging. Group-II consisted of days to heading, days to maturity, panicle length and number of spikelet per panicle which are a combination of phenological and morphological traits. The third group, however, consisted of harvest index and 1000-kernel weight.

In such plotting, in general, some groups of traits were found to have acute angle between them while, the other traits have obtuse angle. The nature of this angle is an indication of the degree of association and relationships existing between the different traits. Thus, in the present study, the traits having the smallest angle with each other are known to have strong and positive correlations so as to aid simultaneous improvement of those traits.

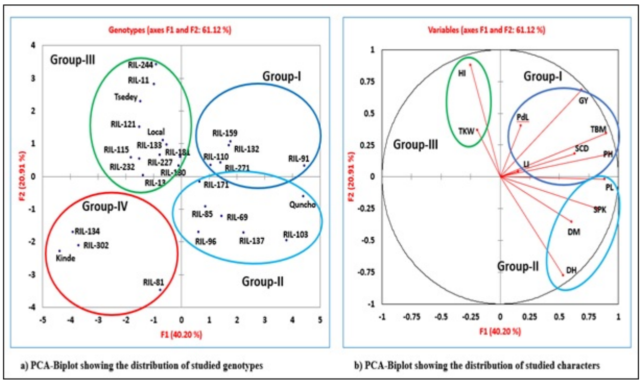

Figure 1: PCA-biplot showing the relationship between the studied genotypes (a) and traits (b).

Conclusion

Genotypic correlation analysis in this study showed positive and significant association between grain yield and that of shoot biomass yield per plot, plant height, panicle length, second culm diameter and harvest index. Such kind of association suggests existence of common genetic/physiological basis among those traits to increase their simultaneous improvement. Total biomass and harvest index which correlated positively and significantly with grain yield also exhibited the strongest direct and indirect effects on grain yield at both genotypic and phenotypic level. In general, the results from this study enabled to identify some important traits to be considered in future tef improvement program.

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