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Selection Index for Improving Grain Yield and Related Traits in Tef (*Eragrostis tef*)

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Abstract: Selection indices provide useful information to breeders who usually base selection on means and ranks. Knowledge on selection criteria for improving tef grain yield is very limited. Accordingly, the objective of this study was to develop selection criteria for improving tef grain yield through indirect yield component selection via a selection index. Different trait combinations along with three selection methods (based on best linear unbiased predictors (BLUPs), plot basis and mean of genotypes) were studied at two locations, Melkassa and Debre Zeit, Ethiopia, in 2003 and 2004, using recombinant inbred lines (RILs) of tef crosses. Selection based solely on grain yield was estimated to be less effective than selecting based on grain yield, panicle seed weight and shoot biomass. BLUPs showed smaller mean values for panicle length and shoot biomass compared with selection based on individual plots. Selection based on individual plots selected higher yielding genotypes than BLUPs method. Higher gains were obtained from selection based on grain yield, shoot biomass, panicle seed weight, panicle length and lodging index, followed by selection based on grain yield, shoot biomass and days to maturity. The use of a selection index made it possible to detect desirable correlated responses in grain yield, shoot biomass, panicle seed weight and panicle length. This suggested that the use of a selection index might be a useful indirect selection criterion to improve grain yield. Further research is required to validate the results of the present study.

Key words: Grain yield · *Eragrostis tef* · Selection index · Tef · Yield components

INTRODUCTION

Tef (*Eragrostis tef*) is an ancient crop in Ethiopia and the country is considered to be both the center of origin and center of diversity for this cereal [1]. In Ethiopia, it is annually cultivated on more than 2 million ha land with a grain production of 2 million tons [2]. In spite of the supreme importance of the crop, the national average yield of tef is low (about 1 ton ha^{-1}). This is mainly attributed to the lowest yield potential of the varieties under widespread cultivation and to the susceptibility of the plant to lodging particularly under growth and yield promoting high input husbandry conditions. The problem warrants the need for selecting better varieties either through direct selection for yield or through indirect yield components selection.

The optimal procedure for selection uses all the information available about each individual's breeding value, combined into an index of worth. It has been proposed that a better way to exploit genetic correlations with more heritable traits is to construct an index that combines information on all traits [3]. Moreover, multiple trait selection through the construction of selection indices can be used to avoid or minimize the declining level of negatively associated traits that can result from individual trait selection. Because genetic variance and heritability of grain yield are lower under stressful environments [4], direct selection for yield *per se* is often not adequately effective [5]. Hence, the use of secondary traits positively associated with grain yield, genetically variable and highly heritable is worthwhile under such conditions [6]. BLUPs have become the method of choice in crop breeding [7, 8] to predict breeding values in the process of developing a selection index. It has also been used in forestry to compare the expected genetic gains and the level of relatedness of the selected population for the various selection criteria [9].

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Hitherto there is only one report [10] in tef, where a study has been conducted to evaluate early generation selection methods for grain yield. The study evaluated four selection methods as selection criteria to identify high yielding tef plants in the F_2 and F_3 populations. However, additional information based on RIL population of tef is required to demonstrate the importance of selection criteria for multiple trait selection in tef. The objective of this study was, therefore, to develop selection criteria for improving tef yield through indirect yield component selection via a selection index.

MATERIALS AND METHODS

Plant Materials: The materials used in the present study comprised of 196 F_8 RIL populations of two intra-specific crosses of released varieties DZ-01-196×DZ-01-2356 and DZ-01-974×DZ-01-196 and one interspecific cross of *Eragrostis tef* (DZ-01-2785)×*E. pilosa* (Acc. 30-5). The crosses were made at the Debre Zeit Agricultural Research Center and F_2 plants were selfed and subsequent generations were advanced by single-seed descent method.

Field Experiment: The RILs and their parents were evaluated in field experiments at Debre Zeit (8°44' N, 38° 58' E, ca. 1860 m.a.s.l.) and Melkassa (8°33' N, 39° 17' E, ca. 1620 m.a.s.l) Agricultural Research Centers of the Ethiopian Institute of Agricultural Research (EIAR) in Ethiopia during the 2003 and 2004 main cropping seasons. The experimental design was a simple lattice. Each plot of 2 m length and 0.5 m width comprised two rows of 2 m length and the row spacing was 20 cm. Based on the recommended seeding rate of 30 kg/ha 1.2 g of seeds was broadcast along the surface of each row. At the early tillering stage, stands were thinned to 5 cm intra-row spacing. All other stand establishment and cultural management operations were done in accordance with the recommendations for each particular test site.

Data Collection: In the present study, grain yield and yield related traits were evaluated. Yield related traits evaluated were: (1) Days to maturity, (2) Shoot biomass as the total above ground biomass for the entire plot, (3) Panicle seed weight as the average weight of the seeds harvested from the primary panicle of ten pre-tagged plants, (4) Panicle length as the average length from the base of the panicle to the tip and (5) Lodging index as per the procedure of Caldicott and Nuttall [11].

Data Analysis: Selection index (I) was developed by the following formula

$$I = b_1p_1 + b_2p_2 + \ldots + b_np_n$$

Where, $p_1p_2\ldots, p_n$ are the variables measured and $b_1b_2\ldots, b_n$ are the weighing coefficients.

Gain from selection was estimated based on the following formula [12]:

$$\Delta_I = K \frac{\sum_j b_j G_{ij}}{\sqrt{\sum b_j G_i}}$$

Where,
Δ_I = Expected genetic gain for trait 1,
K = Selection differential in standardized units,
b = Weight for trait,
G_i = Genotypic value from right side of matrix equation (for example,
$G_I = a_1G_{11} + a_2G_{12} + a_3G_{13} + a_4G_{14}$),
G_{ij} = Genotypic covariance between trait 1 and trait j

$$\Delta G = (Z/v)\ \Sigma\Sigma a_ib_jG_{ij}/(\Sigma\Sigma b_ib_jp_{ij})^{1/2}$$

Where, Z/v is the standardized selection differential (s) indicating the intensity of selection (i),

a_i = economic weightage
b_j = regression coefficient
G_{ij} = genotypic variance-covariance matrix

An economic weight (chosen somewhat arbitrarily) of one was assigned to grain yield and biomass because of their ultimate importance. A negative value was assigned to lodging index and days to maturity and 0.5 was assigned to panicle seed weight and panicle length. An entry's genotypic worth was defined as the summation of individual traits multiplied by their respective economic weights. Gains from multiple trait selection were compared with those from selection for yield alone.

RESULTS

To assess selection methods for optimizing tef yields, selection indices were analyzed for different trait combinations. In this study attempts were made to select individuals with improved (longer) panicle length, high shoot biomass, panicle seed weight, improved (small index) lodging resistance and improved grain yield using different trait combinations. Mean values of lodging index, shoot biomass, days to maturity (early) and panicle

Table 1: Selection of individual plots in RILs of the cross DZ-01-196 x DZ-01-2356

Order	Index	Genotype No	Grain yield (g)	Days to maturity	Shoot biomass (g)	Panicle seed weight (g)	Panicle length (cm)	Lodging index
1	661	577	449.6	103	1818	0.67	39	38
2	641	419	316.5	100	1623	0.53	41	31
3	573	157	248.8	103	1198	0.71	40	30
4	565	384	344.6	102	1370	1.02	35	45
5	564	500	385.0	96	1439	0.29	39	27
6	556	389	289.2	104	1217	0.73	41	45
7	554	393	244.8	101	938	0.75	45	45
8	552	384	314.5	103	1221	1.16	34	43
9	548	78	293.4	92	1282	0.72	35	32

Gain from selection = 166.2

Table 2: Selection based on grain yield using BLUPs in RILs of the cross DZ-01-196 x DZ-01-2356

Order	Index	Genotype No	Grain yield (g)
1	107	577	449.6
2	92	500	385.0
3	89	238	375.5
4	82	384	344.6
5	81	416	339.4

Gain from selection = 48.37

Table 3: Mean of genotypes as a result of selection based on 6 traits using BLUPs in RILs of the cross DZ-01-196 x DZ-01-2356

Order	Index	Genotype No	Grain (g) yield	Days to maturity	Shoot biomass (g)	Panicle seed weight (g)	Panicle length (cm)	Lodging index
1	1169	419	223.4	99.8	1163	0.501	35.99	39.89
2	1152	577	255.8	102.34	1104	0.588	34.51	35.09
3	1087	377	212.3	104.03	1061	0.446	34.02	38.27
4	1071	416	218.4	91.77	1085	0.430	33.28	47.40
5	1055	523	227.8	101.49	1073	0.481	32.54	42.63
6	1051	2356	204.7	85.84	956	0.422	34.02	47.62
7	1048	500	231.9	96.42	1018	0.472	31.31	33.59
8	1044	157	196.6	103.61	961	0.611	34.51	35.21
9	1043	280	225.8	94.30	1081	0.504	32.29	46.37

Gain from selection = 227.4

Table 4: Mean of genotypes as a result of selection based on 4 traits using BLUPs in RILs of the cross DZ-01-196 x DZ-01-2356

Order	Index	Genotype No	Grain yield (g)	Days to maturity	Shoot biomass (g)	Lodging index
1	1169	577	255.8	102.34	1104	35.09
2	1152	419	223.4	99.8	1163	39.89
3	1087	367	221.2	99.38	1124	38.11
4	1071	384	240.5	101.49	1072	44.03
5	1055	500	231.9	96.42	1018	33.59

Gain from selection = 216.8

Table 5: Selection of individual plots in RILs of the cross DZ-01-2785 x Acc. 30-5

Order	Index	Genotype No	Grain yield (g)	Days to maturity	Shoot biomass(g)	Panicle seed weight (g)	Panicle length (cm)	Lodging index
1	1839	90	410.2	93	1849	1.72	41.4	24.0
2	1673	350	489.4	92	1727	1.08	42.8	23.7
3	1594	188	432.2	86	1740	1.14	43.3	25.0
4	1586	143	361.9	87	1804	1.37	41.5	34.5
5	1510	156	466.5	90	1659	0.74	33.2	23.7
6	1455	245	280.1	87	2062	1.09	42.9	24.5
7	1448	349	330.3	93	1120	1.35	36.7	26.5
8	1424	308	260.8	92	1124	1.54	43.8	22.0
9	1408	298	426.9	87	1732	0.62	38.6	24.0
10	1398	62	378.4	92	1822	0.65	38.9	23.7

Gain from selection = 448.2

Table 6: Mean of genotypes as a result of selection based on 6 traits using BLUPs in RILs of the cross DZ-01-2785 x Acc. 30-5

Order	Index	Genotype No	Days to maturity	Grain yield (g)	Shoot biomass (g)	Panicle seed weight (g)	Panicle length(cm)	Lodging index
1	1393	254	86.2	299.7	1538	0.983	40.12	32.45
2	1341	349	91.6	310.0	1275	1.32	37.32	32.73
3	1305	156	89.6	334.2	1368	0.68	33.06	37.36
4	1274	138	87.5	340.9	1278	0.61	31.40	31.89
5	1268	350	90.8	303.6	1279	1.04	38.74	35.41
6	1246	143	89.2	268.5	1353	1.05	38.98	34.80
7	1184	62	91.7	287.3	1302	0.76	37.46	39.85
8	1176	370	90.0	276.5	1322	0.63	35.76	32.14
9	1133	125	90.8	316.7	1205	0.52	33.16	44.76
10	1121	387	83.3	260.1	1376	0.54	32.78	47.06

Gain from selection = 535.2

Table 7: Mean of genotypes as a result of selection based on 6 traits using individual plots in RILs of the cross DZ-01-974 x DZ-01-196

Order	Index	Genotype No	Grain yield (g)	Days to maturity	Shoot biomass(g)	Panicle seed weight (g)	Panicle length (cm)	Lodging index
1	307	28	236	96	1386	6.3	33	92
2	260	259	255	100	1372	4.5	44	88
3	236	271	307	92	1228	2.1	47	82
4	209	974	180	95	1200	4.8	40	81
5	207	157	343	90	1801	1.6	41	80
6	200	204	337	95	1242	1.2	47	90
7	190	307	289	90	1553	1.3	46	82
8	173	155	271	93	1291	1.9	47	68
9	173	60	303	96	1383	1.4	47	84
10	171	220	280	90	1333	1.0	46	88

Gain from selection = 137.5

Table 8: Mean of genotypes as a result of selection based on 6 traits using BLUPs in RILs of the cross DZ-01-974 x DZ-01-196

Order	Index	Genotype No	Grain yield (g)	Days to maturity	Shoot biomass(g)	Panicle seed weight (g)	Panicle length (cm)	Lodging index
1	307	28	263.0	96	1386	6.3	33	92
2	260	259	255.0	100	1372	4.5	44	98
3	236	271	307.0	92	1228	2.1	47	82
4	209	974	180.0	95	1200	4.8	40	81
5	207	157	343.0	90	1801	1.6	41	80
6	200	204	337.0	95	1242	1.2	47	90
7	290	307	289.0	90	1553	1.3	46	82
8	173	155	271.0	93	1291	1.9	47	64
9	173	60	303.0	96	1383	1.4	47	84

Gain from selection = 137.5

seed weight were of similar magnitude among the selection methods. Selection based solely on grain yield was estimated to be less effective than selecting based on grain yield, panicle seed weight and shoot biomass in both populations (Tables 1, 2 and 4).

Multiple trait selection using BLUPs showed smaller mean values for panicle length and shoot biomass compared with selection based on individual plots (Tables 1 and 3). Multiple trait selection resulted in reduced yield gains based on BLUPs, whereas, selection using individual plots resulted in increased grain yield (Tables 1 and 3) in the RILs of the cross DZ-01-196×DZ-01-2356. The same was true for the other population, DZ-01-2785 ×Acc. 30-5 (Table 8).

Individuals selected using BLUPs methods were different in yield from those selected based on individual plots and by yield alone. For example, the best (order 1) yielding individual selected using the individual plot method had grain yield of 449.6 g per plot in RILs derived from DZ-01-974×DZ-01-196. Whereas the best individual selected using BLUPs showed grain yield of 223.4 g per plot (Tables 1 and 3).

Comparison Between Populations of Different Crosses: The mean of the best selected lines from crosses DZ-01-196×DZ-01-2356, DZ-01-2785×Acc. 30-5 and DZ-01-974×DZ-01-196 are presented in Tables 1, 5 and 7, respectively. Population of the interspecific cross between DZ-01-2785×Acc. 30-5 showed better gains from selection based on all selection methods used (Table 5) followed by population of the intraspecific cross between DZ-01-196×DZ-01-2356. RILs of the interspecific cross showed higher means of grain yield, maximum panicle length and smaller lodging index (Table 5). On the other hand, RILs of DZ-01-196×DZ-01-2356 showed higher means of grain yield, shoot biomass and smaller lodging index as compared to RILs of the cross DZ-01-974×DZ-01-196 for the selection methods used (Tables 7 and 8).

The mean performances of the progenies derived from the intraspecific cross of DZ-01-974×DZ-01-196 were higher than the female or male parent for grain yield (148.6 g vs 118.8 g), harvest index (0.196 vs 0.194) plant height (90.76 cm vs 88.06 cm) and panicle length (41.58 cm vs 40.12 cm). However, the mean performances of the male or female parent for other traits except lodging index were better than the mean of progenies (data not shown). For all other traits, progenies showed higher mean values than the male or female parent for plant height (33.84 cm vs 29.62 cm), shoot biomass (618.8 g vs 549.2 g), panicle seed weight (0.51 g vs 0.36 g) and panicle length (32.53 cm vs 28.41 g).

Higher gains were obtained from selection based on grain yield, shoot biomass, panicle seed weight, panicle length and lodging index (227 for the cross DZ-01-196×DZ-01-2356 and 65.22 for the cross DZ-01-974×DZ-01-196), followed by selection based on grain yield, shoot biomass and days to maturity (216 for DZ-01-196×DZ-01-2356 and 44.99 for DZ-01-974×DZ-01-196). The least gain was from selection based on solely grain yield (48.37 for DZ-01-196×DZ-01-2356 and 24.1 for DZ-01-974×DZ-01-196). However, the gains obtained from all selection methods in the interspecific cross of DZ-01-2785×Acc. 30-5 were higher than the gains of both populations of the intraspecific crosses (Tables 5 and 6).

DISCUSSION

The relative effectiveness of different selection methods will depend on many factors. These include the breeding objectives, the type of material, the number and type of traits evaluated, the relative importance of traits and the relationship among the traits. There were non-significant negative relationships between grain yield and lodging index (data not shown). Lodging index also had non-significant negative associations with panicle seed weight and panicle length indicating that selection for higher yield and related traits might not necessarily increase lodging. However, it should be noted that lodging index was assigned an economic weight of negative one, because treating the traits equally would almost assure unsatisfactory results when measured on a scale where yield is worth twice as much as the other traits. Therefore, for simultaneous improvement of grain yield and lodging resistance through selection, minimum standards must be set for one trait while selecting the other.

Differences in gains among selection methods were as large as 32.4 g in grain yield, 59 g in shoot biomass and 2.4 in days to maturity which demonstrated that selection methods utilized showed an effect on selection response. The gains obtained from all selection methods in the interspecific cross of DZ-01-2785×Acc. 30-5 were higher than the gains of both populations of the intraspecific crosses indicating that the wild parent *E. pilosa* (Acc. 30-5) contributed favorable allele to the traits measured. This is in conformity with the results of Tefera *et al*. [13] who reported the importance of *E. pilosa* in contributing favorable alleles to the tef cultivar for the appearance of transgressive lines.

The mean performances of the progenies derived from the intraspecific crosses were higher than the female or male parent for grain yield, harvest index, plant height and panicle length. This result implies the genetic superiority of some progenies compared to the parents which is expressed as genetic gain from a cross between two lines. Similarly, Tefera and Peat [10] reported superiority of F_3 families over the mid parent value.

In this study, the use of a selection index made it possible to detect desirable correlated responses in grain yield, shoot biomass, panicle seed weight and panicle length. Selection for yield via panicle weight and panicle seed weight was reported effective as a means of improving yield in rice [14]. This suggested that the use of a selection index might be a useful indirect selection criterion to improve grain yield.

Selection for increased shoot biomass, harvest index and panicle seed weight should serve as effective selection criterion for increasing tef grain yield. Correlation coefficients, however, showed the need for compromise when selecting for both grain yield and lodging resistant genotypes. Entries selected by this method were susceptible to lodging than those selected by other methods. In general, the results from different selection strategies suggest the need to consider the economic weights or the importance of individual traits in a breeding program. Further research is required to validate the results of the present study.

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