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Genetic Gain in Grain Yield Potential and Associated Traits of Tef [*Eragrostistef (Zucc.)*Trotter] in Ethiopia

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Keywords: *grain yield, harvest index, biomass yield, plant height, phenologic traits, yield attribute, productivity traits.*

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GENETICGAININGRAINYIELDPOTENTIALANDASSOCIATEDTRAITSOFTEFERAGROSTISTEFZUCCTROTTERINETHIOPIA

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Genetic Gain in Grain Yield Potential and Associated Traits of Tef [*Eragrostistef (Zucc.)*Trotter] in Ethiopia

Fano Dargo [α], Firew Mekbib [σ] & Kebebew Assefa [ρ]

Abstract- Evaluation of varieties from different years in a common environment is the most direct of the several methods that have been used to estimate breeding progress. 33 tef varieties released in Ethiopia since 1970 till now were evaluated at DebreZeit and Melkassa Agricultural Research Centers to estimate the amount of genetic gain made over time in grain yield potential and associated characters. The varieties were laid out in a randomized complete block design with three replications in 2012 cropping season. Analysis of variance revealed significant differences among varieties for all traits except hundred seed weight on both locations.Grain yield was increased from 3848.68 kg ha^{-1} to 4934.4kg ha^{-1} over the past 42 years. The average annual rate of increase per year for the period of 1970-2012 was estimated from the linear regression of mean grain yield on year of variety release was 21.53 kg ha^{-1} with a relative genetic gain of 0.56% $year^{-1}$ which was highly significantly different from zero. Grain yield potential of tef has not attained plateau in Ethiopia. Thus, development of higher yielding varieties of tef should continue to increase tef grain yields if past trends pretend the future. Biomass yield also showed highly significantly increase with annual genetic gain of 73.74 kg ha^{-1} $year^{-1}$. Similarly grain yield per day and biomass production rate at both locations showed highly significantly different from zero except biomass production rate at Melkassa which was significantly increased with year of release. On the contrary, days to panicle emergency, days to maturity and lodging index at both locations showed non-significant decreasing trend over years. Linear regression also indicated that significant improvements in yield $panicle^{-1}$ and panicle weight across location and at both location respectively. No marked changes were observed in days to seedling emergency, harvest index, plant height, panicle length and hundred seed weight during the study period which implied that tef improvement effort has failed to bring a substantial progress on these traits. Grain yield was significantly and positively associated with biomass yield, yield $panicle^{-1}$, grain yield day^{-1} and biomass production rate, where as there was no significant correlation between grain yield and phenologic traits, harvest index, plant height, hundred seed weight, panicle weight, lodging index and panicle length. Stepwise regression analysis revealed that most of the variation in grain yield of tef was caused by biomass yield and harvest index. In order to see the impact of the achievement in the genetic progress of tef research, it is imperative to undertake large scale popularization of the released varieties.

Keywords: grain yield, harvest index, biomass yield, plant height, phenologic traits, yield attribute, productivity traits.

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I. Introduction

Tef[*Eragrostistef (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). Its grain is gluten free, and is a good flour source for segments of the population suffering from gluten intolerance or Celica's disease (Spaenij-Dekkinget *al*., 2005). It has gained momentum as a forage crop and several new, improved types have been developed and commercialized (Miller, 1995).

Tef belongs to the grass family Poaceae. It is a C4; self pollinatedchasmogamous annual cereal (Seyfu, 1993). It is an allotetraploidcereal crop with a chromosome number of 2n = 4X = 40 (Tavasoli, 1986). Tef is indigenous to Ethiopia and has an amazing wealth of diversity (Seyfu, 1991). In Ethiopia, tef is grown on more than 2.7 million hectares, (CSA, 2012).

Ecologically, tef can be grown in a wide range of environments, and is presently cultivated under diverse agro-climatic conditions. It can be grown from sea level up to 2800 m.a.s.l. (Seyfu, 1993).The ability of tef to perform well on both waterlogged vertisoils in the highlands as well as in low moisture stress areas in the semi-arid regions throughout the country is one of the reasons for which tef is preferred over other grain crops such as maize or barley (Hailu, 2001). In addition, tef generally suffers less from biotic stresses compared to most other cereal crops grown in Ethiopia and it contains high levels of proteins and mineral (Seyfu, 1993). Despite the aforementioned importance and coverage of large area, its productivity is very low (1.28 t ha^{-1}) (CSA, 2012). Some of the factors contributing to low yield of tef are lack of high yielding cultivars, lodging, weed, water logging, low moisture and low soil fertility conditions (Fufa, 1998).

Documentation of the contribution of plant breeding to a given crop yield improvement and evaluation of the past gains are useful for identifying areas with potential for planning a future breeding program (Waddington *et al.,* 1987). Evans (1993) advocated that an understanding of changes produced by crop breeding on grain yield and its determinants was important to evaluate the efficiency of past improvement work to facilitate further progress.

Genotype, environment and management interact to determine the yield of a crop. However, no method of estimating long term improvement progress can completely separate genetic effects per se and their interaction effect. Nevertheless, evaluation of popular cultivars from different years in common environments is the most comprehensive and direct method that has been used to estimate progress in yield improvement. Progress made in grain yield potential and associated traits produced by genetic improvement have been documented in different crops in different countries (Perry and D'Antuono, 1989).

The national and regional agricultural research system has been striving to improve tef production in Ethiopia since the late 1970's, and 33 varieties of tef have been released so far for commercial production from 1970 until 2012. Yifru and Hailu (2005) reported study conducted on genetic gain of tef in 1997. Their study was involved one farmer variety and 10 improved varieties released over the periods 1970-1995. However, the progress made in breeding of these varieties after 1995 and two location trials were not assessed. Therefore, the present study were undertaken to overcome those limitations in tef genetic gain information with objective of;

- To estimate the amount of genetic gain made in grain yield potential of tef, and
- To assess the changes brought about by genetic improvement on associated agronomic traits

II. Materials and Methods

The experiment were conducted at Debre-Zeit and Melkassa Agricultural Research Centre in the field in the 2012 main cropping season under rain fed conditions on two soil types: DebreZeit Black Soil (Vertisol) and MelkassaLightSoil (Andosol). In both experiments, 33 improved tef varieties that were successively released between 1970 and 2012 were used. Of these varieties 19varieties were released from Debre-Zeit Agricultural Research Center and the remaining 5, 3, 2, 2, 1 and 1 varieties were released from, Sirinka, Adet, Holleta, Bako, Melkassa and Areka Agricultural Research Centers respectively (Kebebew*et al*., 2013).

The experiment was conducted using randomized complete block design (RCBD) with three replications. Each plot had six rows of 3 m long and 1.2 m width (3.6 m^2) each with 0.2 m of row spacing. The distance between blocks and the spacing between plots were 1.5 and 1m, respectively. Seed rate was 1.5 g per row on the basis of 25 kg/ha recommended rate. Fertilizers were applied at both site at the recommended nutrient rate of 100 kg/ha N and 100 kg/ha DAP respectively. All other pre and post management practices were applied in accordance with the recommendations made for the crop. Data were collected from the four middle rows.

Days from sowing to 50% of the plants emerged in a plot,Days from sowing to 50% anthesis and from sowing to 50% maturity were determined. Plant height in centimeters was measured from the base of the plant to the tip of the panicle on the primary tiller of 10 randomly selected plants per plot. Panicle length of the central tillers in centimeters was measured as the average length of the panicle from the node where the first panicle branch starts to the tip of the central tiller of 10 randomly selected plants per plot. Panicle weight in milligrams was determined as the average weight of the central panicle of 10 randomly selected plants per plot.Lodging index was recorded using the method of Caldicott and Nuttall (1979). The angle of leaning was scored on a 0-5 scale where "0" stands for completely upright plants and "5" stands for completely lodged (flat on the ground) plants. The severity for each score was recorded as the percentage of the entire plot. Then, the lodging index was obtained as the average of the product sum of each degree of lodging and the corresponding severity percent.

Table 1 : Description of the experimental released tef varieties

No.	Variety	Year of release	Breeder /maintainer	Plant height (cm)	Days to mature	On-station yield (t/ha)	On farm yield (t/ha)
1	DZ-01-99 (Asgori)	1970	DZARC	53-100	80-130	2.2-2.8	1.8-2.2
2	DZ-01-196 (Magna)	1970	DZARC	53-115	80-113	1.8-2.4	1.6-2.0
3	DZ-01-354 (Enatite)	1970	DZARC	50-117	85-100	2.4-3.2	2.0-2.4
4	DZ-01-787 (Wellenkomi)	1978	DZARC	50-110	90-130	2.4-3.0	2.0-2.4
5	DZ-Cr-44 (Menagesha)	1982	DZARC	85-110	95-140	1.8-2.4	1.8-2.2
6	DZ-Cr-82 (Melko)	1982	DZARC	96-112	112-119	1.8-2.4	1.6-2.0
7	DZ-Cr-37 (Tsedey)	1984	DZARC	67-92	82-90	1.8-2.5	1.4-2.2
8	DZ-Cr-255 (Gibe)	1993	DZARC	63-116	114-126	2.0-2.6	1.6-2.2
9	DZ-01-974 (Dukem)	1995	DZARC	84-132	76-138	2.4-3.4	2.0-2.7
10	DZ-Cr-358 (Ziquala)	1995	DZARC	70-109	85-137	2.4-3.4	2.0-2.7
11	DZ-01-2053(Holetta Key)	1998	HARC	---	---	---	---
12	DZ-01-1278(Ambo Toke)	1999	HARC	---	---	---	---
13	DZ-01-1281 (Gerado)	2002	DZARC	83-100	73-95	1.7-2.4	1.6-2.2
14	DZ-01-1285 (Koye)	2002	DZARC	80-92	104-118	1.7-2.4	1.6-2.2
15	DZ-01-1681 (KeyTena)	2002	DZARC	74-85	84-93	1.7-2.4	1.6-2.2
16	DZ-01-2054(Gola)	2003	SARC	---	---	---	---
17	Ajora (PGRC/E 205396)	2004	ArARC	---	---	---	---
18	DZ-01-899 (DegaTef)	2005	DZARC	46-68	118-137	1.5-2.2	1.6-2.0
19	DZ-Cr-2675 (Chefe)	2005	DZARC	47-91	112-123	1.5-2.4	1.4-2.2
20	DZ-01-1868(Yilmana)	2005	AARC	---	---	---	---
21	DZ-01-2423 (Dima)	2005	AARC	---	---	---	---
22	DZ-01-146 (Genete)	2005	SARC	---	---	---	---
23	DZ-01-1821 (Zobel)	2005	SARC	---	---	---	---
24	HO-Cr-136 (Amarach)	2006	DZARC	67-81	63-87	1.8-2.5	1.4-2.2
25	DZ-Cr-387 RIL 355 (Quncho)	2006	DZARC	72-104	86-151	2.0-3.2	1.8-2.6
26	DZ-01-1880 (Guduru)	2006	BARC	---	---	---	---
27	Mechare(Acc.205953)	2007	SARC	---	---	---	---
28	DZ-Cr-387 RIL127 (Gemechis)	2007	MARC	---	---	---	---
29	DZ-01-3186 (Etsub)	2008	AARC	---	---	---	---
30	Kena(23-tafi-adi-72)	2008	BARC	---	---	---	---
31	DZ-Cr-285 RIL 295 (Simada)	2009	DZARC	65-90	75-90	1.9-2.8	1.6-2.5
32	Laketch -RIL273	2009	SARC	---	---	---	---
33	DZ-Cr-409 RIL50d (Boset)	2012	DZARC	---	---	---	---

Source: Kebebewet al. (2013), and MoA (2012)

 # = Abbreviations: AARC = Adet Agricultural Research Center, ArARC = Areka Agricultural Research Center, BARC = Bako Agricultural Research Center, DZARC= DebreZeit Agricultural Research Center, HARC = Holleta Agricultural Research Center, MARC = Melkassa Agricultural Research Center and.

SARC= Sirinka Agricultural Research Center,

Yield per Panicle was determined as the average grain weight obtained from the panicle of 10 randomly selected plants per plot and 100-kernel weight in milligrams was determined from dried samples of 100 grains.

Biomass yield was taken from all plants in the 3.6 m^2 of each plot and weighed as grams of biomass yield and converted to kg/ha. Grain yield was determined by threshing all plants in the 3.6 m^2 and expressed as kg/ha. Harvest index was calculated as

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the ratio of grain yield to biomass yield. Biomass production rate was calculated as the ratio of biomass yield to days to physiological maturity and expressed as kg ha^{-1} day^{-1}. Grain yield per day was calculated as the ratio of grain yield to days to physiological maturity and expressed as kg ha^{-1} day^{-1}

All measured variables were subjected to analysis of variance procedures to assess differences among varieties. The homogeneity of error mean squares between the two locations were tested by F-test on variance ratio and combined analyses of variance were performed for the traits whose error mean squares were homogenous using PROC GLM procedure of SAS (SAS institute, 2002).Error variances were heterogeneous between the two locations for days to panicle emergence, days to maturity, plant height, lodging index, panicle weight, grain yield per day and biomass production rate. Hence, log-transformation of these traits was performed to remove heterogeneity according to Gomez and Gomez (1984). But, transformation could not stabilize error variances for the two locations for all the above traits. As a result, separate analysis of variances was done for these seven yield variables. Analysis of variance was carried out following the standard procedure given by Gomez & Gomez (1984). Mean separation was accomplished using Duncan's multiple range test (DMRT).

The annual rate of gain in grain yield potential and changes produced on agronomic traits were estimated by regressing the mean value of each character for each variety against the year of release for that variety using PROC REG procedure (SAS institute, 2002).The relative annual gain achieved over the last 42 years (1970 - 2012) was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and expressed as percentage. Determination of correlation coefficients between grain yield and its components were computed using means of each variety. Pearson correlation coefficients among all characters were made using means of each variety, PROC CORR in SAS. Stepwise regression analysis was carried out on the varietal mean using PROC STEPWISE in SAS to determine those traits that contributed much for yield variation among varieties.

III. Results

a) Grain yield potential

The combined analysis of variance across the two locations revealed highly significant ($P \leq 0.01$) difference between locations and among varieties for grain yield, but there was no significant variety x location interaction (Table 2). The average grain yield of tef varieties was 4191 kg ha^{-1}, which ranged from 3094kg ha^{-1} for the variety released in 1982 (DZ-Cr-44) to 4934 kg ha^{-1} for the variety released in 2012 (DZ-Cr-409) (Table 4). The recently released variety Boset (DZ-Cr-409) was the first best yielder among the 33 varieties, but the difference was not significantly ($P \leq 0.05$) higher than ten varieties (DZ-Cr-387, Laketch (RIL273), DZ-01-2423, DZ-Cr-387, DZ-01-1868, DZ-01-1821, DZ-01-3186, Mechare (Acc. 205953), DZ-Cr-285 and DZ-01-1281) (Table 4). As indicated in Table 5, the superiority of the higher yielder variety, DZ-Cr-409 represents 1099 kg ha^{-1} or 28.65 % increment over the average of the first four older varieties (DZ-01-99, DZ-01-196, DZ-01-354 and DZ-01-787).

Mean grain yields of varieties released in1984, 1993, 1995, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009 and 2012 exceeded that of the average of the first released four older varieties by 424.52 (11.07%), 501.12 (13.06%), 511.47 (13.33%), 427.39 (11.14%), 308.72 (8.05%), 364.62 (9.51%), 578.80 (15.09%), 529.49 (13.80%), 831.47 (21.68%), 224.12 (5.84%), 727.92 (18.98%) and 1098.82 kg ha^{-1} (28.65%), respectively. However, varieties released during 1982, 1998 and 1999s had decreased yield by -686.23 (-17.89 %), -250.18 (-6.52%) and -295.98 (-7.72%), respectively as compared with the average of four older varieties (Table 5).

Table 2 : Mean squares from the combined analysis of variance for grain yield and other traits of tef varieties evaluated over two test location (Debre Zeit and Melkassa) in 2012

Trait€	Location (1)a	Varieties (32)	Location x Varieties (32)	Error (128)	Mean	CV (%)	R^2
DSE	0.51ns	1.51**	0.65ns	0.68	7.63	10.78	0.47
PL	116.79**	62.59**	12.78**	5.02	44.46	5.04	0.80
YPP	0.31**	0.28**	0.12**	0.04	1.06	19.16	0.72
HSW	0.001*	0.0001ns	0.0001ns	0.0001	0.03	28.13	0.50
GYPha	22749171.60**	1136443.24**	133777.32ns	148968.16	4190.58	9.21	0.77
BYPha	54703673.40**	19138991.60**	6269598.20**	2605702.00	16281.00	9.91	0.72
HI	300.88**	6.47**	7.24**	2.53	25.84	6.16	0.70

[a]*Numbers in parenthesis represent degrees of freedom.*

***, *, ns= Significant at $P \leq 0.01$, significant at $P \leq 0.05$ and non significant respectively.*

€ = Abbreviations, DSE= days to seedling emergence, PL= panicle length, YPP = yield $panicle^{-1}$, HSW = hundred seed weight (g), index, GYPha = grain yield per hectare (kg ha^{-1}), BYPha = biomass yield per hectare (kg ha^{-1}), HI = harvest index,

Table 3 : Mean squares from the separate analysis of variance for grain yield and related traits of tef varieties evaluated at DebreZeit and Melkassa during the 2012 main season

Trait[€]	Source of variation									
	DebreZeit					Melkassa				
	Variety[a] (32)	Error (64)	Mean	CV (%)	R^2	Variety (32)	Error (64)	Mean	CV (%)	R^2
DPE	7.58^{**}	0.87	44.26	2.11	0.82	21.08^{**}	7.57	40.80	6.75	0.59
DM	124.75^{**}	1.08	98.33	1.06	0.98	72.50^{**}	34.56	81.88	7.18	0.51
PH	125.38^{**}	15.78	105.57	3.76	0.81	278.48^{**}	36.92	111.99	5.43	0.79
LI	323.50^{**}	75.14	66.00	13.13	0.69	0.07^{**}	0.02	0.63	23.64	0.63
PW	0.27^{**}	0.09	1.58	19.48	0.59	0.16^{**}	0.05	1.54	14.09	0.65
GYPD	104.44^{**}	14.78	46.30	8.30	0.78	119.20^{**}	38.45	47.39	13.08	0.61
BPR	1737.88^{**}	236.51	171.87	8.95	0.79	2589.59^{**}	758.63	193.96	14.20	0.63

[a] = *Numbers in parenthesis represent degrees of freedom*

***, *, ns= Significant at P ≤ 0.01, significant at P ≤ 0.05 and non significant respectively;*

[€] = *Abbreviations; DPE= days to panicle emergence, DM= days to maturity, PW = panicle weight, LI = lodging PH = plant height (cm), GYPD= grain yield per day (kg ha^{-1} day^{-1}) and BPR = biomass production rate (kg ha^{-1} day^{-1}).*

Table 4 : Mean grain yield (GYPha) in kg ha^{-1}, biomass yield (BYPha) in kg ha^{-1}, harvest index (HI) in %, grain yield per panicle (YPP) in mg, hundred seed weight (HSW) in mg, days to seedling emergency (DSE) and panicle length (PL) of tef varieties averaged over the two locations.

Varieties	GYPha	BYPha	HI	YPP	HSW	DSE	PL
DZ-01-99	3667.39^{ghij}	16805.56^{abcd}	24.37^{g}	0.79^{fgh}	0.03	7.83^{abcde}	42.48^{fgh}
DZ-01-196	3787.70^{efghij}	14138.89^{def}	28.59^{abcde}	0.80^{fgh}	0.03	8.17^{abc}	47.45^{bcd}
DZ-01-354	4090.95^{defgh}	17500.00^{abc}	26.27^{bcdefg}	1.40^{ab}	0.03	7.50^{abcde}	44.58^{cdefg}
DZ-01-787	3796.56^{efghi}	13944.44^{def}	29.30^{abc}	0.73^{gh}	0.04	6.83^{de}	44.68^{cdefg}
DZ-Cr-44	3093.84^{k}	12250.00^{f}	26.67^{bcdefg}	0.70^{gh}	0.03	7.17^{bcde}	43.5^{efg}
DZ-Cr-82	3204.95^{jk}	12027.78^{f}	26.54^{bcdefg}	0.70^{gh}	0.03	7.00^{cde}	42.50^{fgh}
DZ-Cr-37	4260.14^{cdef}	17875.00^{ab}	25.06^{fg}	0.87^{defgh}	0.03	7.17^{bcde}	39.42^{hi}
DZ-Cr-255	4336.75^{cd}	16472.22^{abcde}	29.38^{ab}	1.33^{ab}	0.04	7.67^{abcde}	45.50^{cdefg}
DZ-01-974	4387.33^{bcd}	17750.00^{ab}	27.92^{abcdef}	1.47^{ab}	0.03	7.00^{cde}	45.41^{cdefg}
DZ-Cr-358	4306.92^{cdef}	16250.00^{bcde}	28.23^{abcdef}	1.23^{abcde}	0.03	7.67^{abcde}	46.08^{cdef}
DZ-01-2053	3585.45^{hij}	13750.00^{ef}	28.28^{abcdef}	0.61^{h}	0.03	8.33^{ab}	37.32^{i}
DZ-01-1278	3539.70^{ijk}	14194.44^{def}	27.72^{abcdef}	0.87^{defgh}	0.04	8.00^{abcd}	44.99^{cdefg}
DZ-01-1281	4424.36^{abcd}	17250.06^{abcdef}	$25.75^{abcdefg}$	1.22^{abcd}	0.03	7.50^{abcde}	45.85^{cdef}
DZ-01-1285	4294.50^{cdef}	$16680.56^{abcdefg}$	$25.80^{abcdefg}$	1.27^{abc}	0.04	7.83^{abcde}	44.09^{defg}
DZ-01-1681	4070.28^{defgh}	15402.89^{defghi}	26.50^{abcdef}	0.79^{ij}	0.03	8.50^{a}	44.24^{defg}
DZ-01-2054	4144.33^{cdefg}	15077.83^{fghi}	27.90^{a}	$1.03^{cdefghi}$	0.04	8.17^{abc}	45.75^{cdef}
Ajora (PGRC/E 205396)	4200.33^{cdef}	15455.50^{defghi}	27.30^{ab}	0.87^{fghij}	0.03	7.33^{abcde}	43.85^{defg}
DZ-01-899	4281.25^{cdef}	16333.39^{bcdefg}	26.47^{abcdef}	$1.03^{cdefghi}$	0.04	7.83^{abcde}	46.96^{bcde}
DZ-Cr-2675	4275.11^{cdef}	15855.50^{cdefgh}	27.02^{abc}	$1.10^{abcdefg}$	0.03	7.67^{abcde}	44.87^{cdefg}
DZ-01-1868	4520.89^{abcd}	17958.50^{abc}	25.10^{bcdefg}	$0.96^{defghij}$	0.04	7.33^{abcde}	44.71^{cdefg}
DZ-01-2423	4574.20^{abcd}	17500.00^{abcd}	26.24^{abcdef}	1.12^{abcdef}	0.04	7.50^{abcde}	42.00^{gh}
DZ-01-146	4327.81^{cde}	16283.50^{bcdefg}	26.60^{abcdef}	1.18^{abcde}	0.03	8.17^{abc}	47.95^{bc}

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DZ-01-1821	4507.59^{abcd}	18125.06^{ab}	24.82^{cdefg}	1.23^{abcd}	0.04	8.00^{abcd}	43.84^{defg}
HO-Cr-136	4283.00^{cdef}	17327.83^{abcde}	24.80^{cdefg}	1.00^{cdefghij}	0.03	8.17^{abc}	38.55^{i}
DZ-Cr-387 RIL 355	4549.86^{abcd}	18439.00^{ab}	24.70^{efg}	1.33^{ab}	0.03	6.67^{e}	49.97^{ab}
DZ-01-1880	4262.56^{cdef}	16833.23^{abcdefg}	25.30^{bcdefg}	1.12^{abcdef}	0.03	7.17^{bcde}	51.25^{a}
Mechare (Acc.205953)	4451.61^{abcd}	17697.33^{abc}	25.20^{bcdefg}	1.37^{a}	0.03	7.33^{abcde}	47.87^{bc}
DZ-Cr-387	4882.64^{ab}	18180.67^{ab}	26.90^{abcde}	1.35^{a}	0.03	6.83^{de}	45.50^{cdefg}
DZ-01-3186	4485.50^{abcd}	17749.94^{abc}	25.31^{bcdefg}	1.25^{abc}	0.03	8.17^{abc}	47.42^{bcd}
Kena (23-tafi-adi-72)	3634.08^{hij}	13938.94^{hijk}	25.97^{abcdefg}	0.80^{hij}	0.04	8.17^{abc}	43.49^{efg}
DZ-Cr-385 RIL 295	4449.44^{abcd}	18241.78^{ab}	24.42^{fg}	1.12^{abcdef}	0.03	7.00^{cde}	37.79^{i}
Laketch - RIL273	4677.61^{abc}	18912.83^{a}	24.70^{defg}	1.38^{a}	0.03	7.83^{abcde}	47.19^{bcd}
DZ-Cr-409	4934.44^{a}	18541.56^{ab}	27.01^{abcd}	1.22^{abcd}	0.04	8.17^{abc}	40.00^{hi}
Mean	4190.58	16280.96	25.84	1.06	0.03	7.63	44.46
CV (%)	9.21	9.91	6.16	19.16	28.10	10.78	5.04
R^2	0.77	0.72	0.70	0.72	0.50	0.47	0.80

Means followed by the same letter with in a column are not significantly different from each other at P≤ 0.05 according to Duncan's Multiple Range Test, ^{x}=Abbreviations, refer to Table 2

Table 5 : Trend in genetic progress in grain yield potential of tef varieties released in 1978, 1982, 1984, 1993, 1995, 1998, 1999, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009 and 2012 over the average of the first three oldest varieties (DZ-01-99, DZ-01-196 and DZ-01-354) released in the 1970's

Varieties	Year of release	Mean grain yield	Increment over average of the first four older varieties (1970s)	
		kg ha^{-1}	kg ha^{-1}	%
DZ-01-99	1970			
DZ-01-196	1970	3848.68	-----	------
DZ-01-354	1970			
DZ-01-787	1978	3796.56	-52.12	-1.35
DZ-Cr-44	1982	3149.45	-699.23	-18.17
DZ-Cr-82	1982			
DZ-Cr-37	1984	4260.2	411.52	10.69
DZ-Cr-255	1993	4336.8	488.12	12.68
DZ-01-974	1995	4347.15	498.47	12.95
DZ-Cr-358	1995			
DZ-01-2053	1998	3585.5	-263.18	-6.84
DZ-01-1278	1999	3539.7	-308.98	-8.03
DZ-01-1281	2002			
DZ-01-1285	2002	4263.07	414.39	10.77
DZ-01-1681	2002			
DZ-01-2054	2003	4144.4	295.72	7.68
Ajora (PGRC/E 205396)	2004	4200.3	351.62	9.14

DZ-01-899	2005			
DZ-Cr-2675	2005			
DZ-01-1868	2005	4414.48	565.8	14.7
DZ-01-2423	2005			
DZ-01-146	2005			
DZ-01-1821	2005			
HO-Cr-136	2006			
DZ-Cr-387 RIL 355	2006	4365.17	516.49	13.42
DZ-01-1880	2006			
Mechare (Acc.205953)	2007	4667.15	818.47	21.27
DZ-Cr-387	2007			
DZ-01-3186	2008	4059.80	211.12	5.49
Kena (23-tafi-adi-72)	2008			
DZ-Cr-285 RIL 295	2009	4563.60	714.92	18.58
Laketch - RIL273	2009			
DZ-Cr-409	2012	4934.50	1085.82	28.21

The average rate of increase in yield potential per year of release estimated from the slope of the graph (Figure 1) was 21.53 kg ha^{-1} year^{-1} and it was significantly different from zero ($P \leq 0.05$) (Table 6). There was no indication of a yield potential plateau in tef over the period studied (Table 5).

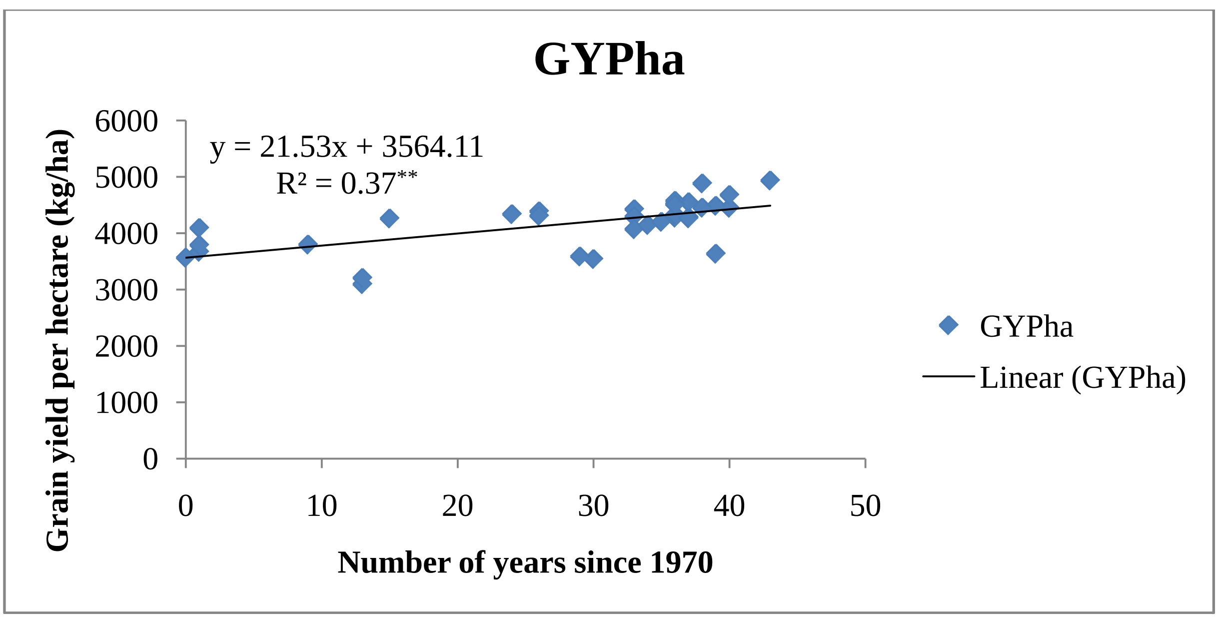

Figure 1 : Relationship between Mean Grain yield of 33 tef varieties and the year of release expressed as number of years since 1970

Table 6 : Mean values, coefficient of determination (R^2), regression coefficient (b) and intercept for various traits from linear regression of the mean value of each trait for each tef variety against the year of variety release since 1970 across location

Traits[x]	Mean	R^2	b	Intercept
DSE	7.63	0.03	0.01	7.44
PL	44.46	0.01	0.02	43.73
YPP	1.06	0.19	0.01*	0.84
HSW	0.03	0.03	0.0001	0.03
GYPha	4190.60	0.37	21.53**	3564.10
BYPha	16281.11	0.26	73.74**	14136.11
HI	25.84	0.04	0.02	25.36

** & ** = Significant at $P \le 0.05$ and $P \le 0.01$, respectively,*

[x]=Abbreviations, refer to Table 2

b) Biomass Yield, Harvest Index and Plant Height

The combined analyses of variance across locations, depicted significant ($P\le0.05$) effects of location x variety interaction, between locations and among varieties for biomass yield (Table 2). When averaged over the two sites, variety, Laketch-RIL273 was significantly ($P \le 0.05$) higher than 15 varieties such as DZ-Cr-44, DZ-Cr-82, DZ-01-2053, DZ-01-1278, and Kena (23-tafi-adi-72), while this was not significantly different from 18 of the varieties including DZ-Cr-409, DZ-Cr-387 RIL 355, DZ-Cr-285 RIL 295, and DZ-Cr-387 (Table 4). Mean biomass yield of all tef varieties, averaged across locations was 16281 kg ha^{-1} (Table 2).

The linear regression of biomass yield of tef variety means on year of variety release revealed a highly significant ($P\le0.01$) trend of increase over the period studied (Table 6). Accordingly, biomass yield increased by 73.74 kg ha^{-1} year^{-1} (Figure 2).

Unlike grain yield, the combined analysis of variance for harvest index revealed highly significant ($P\le0.01$) location x variety interaction, between locations and among varieties (Table 2). Mean harvest index of the varieties was estimated to be about 26% (0.26) (Table 4). Linear regression coefficient indicated that harvest index for the period studied was 0.02 which is not significantly ($P\le0.05$) different from zero (Table 6).

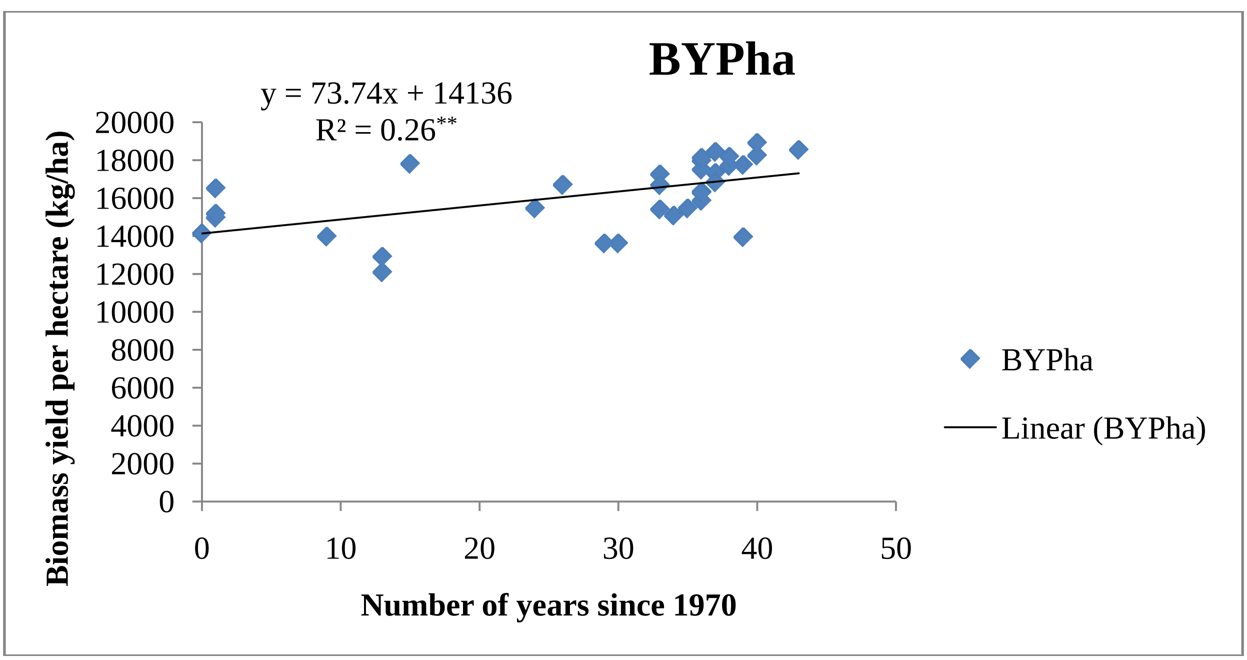

Figure 2 : Relationship between Mean Biomass yield of 33 tef varieties and the year of release expressed as number of years since 1970

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Plant height was treated separately because mean squares of error for this trait were heterogeneous for the two locations. Accordingly, there was highly significant ($P \leq 0.01$) difference observed among varieties at both locations. Mean plant height of tef varieties was 105.57 cm at DebreZeit and 111.99 cm at Melkassa (Table 3). At both locations the same variety DZ-01-1880 was relatively tallest plant height than all the other varieties (Table 8 and 9). The regression of variety means against year of release at both locations was 0.02 and 0.04 cm year^{-1} at Debre-Zeit and Melkassa respectively, and this was not significantly different from zero (Table 7).

c) Yield Attributes

From the combined analysis of variance over the two test locations, variety × location interaction revealed significant ($P \leq 0.05$) effects on yield panicle $^{-1}$. The mean yield panicle^{-1} of varieties across location was estimated to be 1.06 mg (Table 2). The varieties Laketch-RIL273, Mechare (Acc.205953), DZ-Cr-387 and DZ-Cr-387 RIL 355 produced higher yield panicles^{-1}(Table 4). The linear regression of yield panicle^{-1} of tef variety means on the year of variety release revealed significant ($P \leq 0.05$) trend of increase over the period studied (0.01 mg year^{-1})(Table 6).

Panicle weight was highly significant ($P \leq 0.01$) differences among varieties both at DebreZeit, and Melkassa. Mean Panicle weight of the tef varieties represented in this study was 1.58 mg at DebreZeit and 1.54 mg at Melkassa (Table 3). At DebreZeit, the variety Laketch-RIL273 gave the heaviest panicle of all the test varieties (Table 8). At Melkassa, the variety DZ-Cr-387 (Gemechis) produced a heavier panicle weight than all other varieties, while the variety DZ-01-2053 produced the lightest panicle that was significantly ($p \leq 0.05$) different from that of all the other varieties used in the study (Table 9). Unlike for grain yield, significant ($P \leq 0.05$) genotype × location interaction was found for panicle length. Mean panicle length of the varieties averaged over the two locations was 44.46 cm (Table 2). The variety DZ-01-1880 showed the longest mean panicle length which was significantly ($P \leq 0.05$) different that of all the other varieties represented in the study except DZ-Cr-387 RIL 355(Table 4).

The linear regression analysis showed that the regression coefficient for panicle weight for the period studied was 0.01 at both location,which is significantly ($P \leq 0.05$) different from zero (Table 7). Unlike that of panicle weight, the linear regression of panicle length for the studied period was 0.02. But it is not significantly different from zero (Table 6).

Lodging indexwas highly significant ($P \leq 0.01$) differences among genotypes at both locations. The mean lodging indices were 66 and 63 at DebreZeit and Melkassa, respectively (Table 3). At DebreZeit, the variety DZ-01-1880 lodged relativelylower than all the other varieties(Table 10).At Melkassa, the variety Laketch-RIL273 showed relatively lower lodging index than all the other varieties (Table 9). The linear regression showed a slight but not significant ($P \leq 0.05$) decreasing trend over the 42 years period (Table 7).

d) Phenologic Traits

The combined analysis of variance over locations revealed that there were no significant ($P \leq 0.05$) effects of locations and genotype×location interaction on days to seedling emergence, while, there was highly significant ($P \leq 0.01$) differences among varieties in days to seedling emergence. Mean of days to seedling emergence of all varieties across the location represented in the trial was 7.63 days (Table 2). The variety DZ-Cr-387 RIL 355 was the earliest to emerge, though it was not significantly ($P \leq 0.05$) different from some other varieties (Table 4). Linear regression analysis showed that number of days to seedling emergence in modern varieties increased but non-significantl (Table 6).

Days to panicle emergence and days to maturity were highly significant ($P \leq 0.01$) differences among genotypes at both locations. Mean days to panicle emergence of all varieties were 44.26 and 40.80 at DebreZeit and Melkassa respectively (Table 3). At both locations the same variety, variety DZ-Cr-285 had the earliest panicle emergence(Table 8 and 9). Mean of days to maturity of varieties was 98.33 days at DebreZeit and 81.88 days at Melkassa (Table 3). At DebreZeit, the variety DZ-Cr-285 RIL 295 reached physiological maturity earlier (Table 8). At Melkassa, the variety DZ-01-2053 reached maturity earlier than the other varieties (Table 9). Regression analysis of number of days to panicle emergency and days to maturity at both locations showed negative regression coefficient, which was not significantly different from zero (Table 7).

e) Productivity Traits

There was no significant variety × location interaction and among varieties difference for hundred seed weight. It could be seen that hundred seed weight of modern tef varieties was not significantly different from that of the older varieties (Table 2). The linear regression depicted no significant ($P \leq 0.05$) linear relationship to cultivar age (Table 6).

There were highly significant ($P \leq 0.01$) differences among varieties in both biomass production rate and grain yield per day both at DebreZeit and Melkassa (Table 3). At DebreZeit, the newly released improved varieties, DZ-Cr-409 (Boset) and DZ-Cr-285 (Simada) depicted relatively the highest grain yield per day and biological production rate, respectively (Table 8). At Melkassa, nevertheless, DZ-Cr-387 (Gemechis) and DZ-Cr-409 (Boset) in that order gave significantly highest grain yield per day and biological production rate compared to all of the other varieties (Table 9).

Linear regression coefficient showed a highly significant (P≤0.01) increase in grain yield per day and biomass production rate at both locations except biomass production rate at melkassa which is significantly (P≤0.05) different from zero (Table 7).

Table 7 : Estimates of mean values, coefficient of determination (R^2), regression coefficient (b) and intercept for various traits from linear regression of the mean value of each traits for each tef variety against the year of variety release since 1970 for each locations

Traits^x	Location							
	Debre-Zeit				Melkassa			
	Mean	R^2	b	Intercept	Mean	R^2	b	Intercept
DPE	44.26	0.001	-0.004	44.37	40.80	0.0003	-0.004	40.91
DM	98.33	0.01	-0.04	99.45	81.88	0.0001	-0.004	81.89
PH	105.57	0.002	0.02	104.93	111.99	0.002	0.04	110.94
LI	66.03	0.01	-0.001	68.92	62.54	0.05	-0.28	70.56
PW	1.58	0.17	0.01*	1.28	1.54	0.18	0.01*	1.30
GYPD (kg/ha/day)	46.30	0.29	0.26**	38.88	47.39	0.25	0.25**	40.00
BPR (kg/ha/day)	171.87	0.21	0.88**	146.24	193.96	0.13	0.84*	169.48

^{x}=*Abbreviations, refer to Table 3*

f) Association of Grain Yield with other Traits

Grain yield was highly significantly (r = 0.93**) and positively correlated with biomass yield, whereas it was not significantly (r = 0.05**) associated with harvest index and plant height (r = 0.08**) (Table 10). Yield per panicle showed highly significant (r = 0.79**) and positive association with grain yield (Table 10). Yield attributes such as panicle weight, panicle length and lodging index showed a non-significant association with grain yield of r = 0.29, r = -0.02, and r = -0.13, respectively (Table 10).Phonologic traits (day to seedling emergence, days to panicle emergence and days to maturity) were observed absence of association with grain yield (Table 10). Correlation of grain yield with hundred seed weight was not significant (r = 0.14) (Table 10). There was highly significant positive association of grain yield with biomass production rate (r = 0.83) and grain yield day^{-1} (r = 0.90) (Table 10).

Step wise regression analysis of mean grain yield (dependent variable) on selected yield components (independent variable) indicated that biomass yield and harvest index were the two most important yield components which accounted for 99.7% of the variation in grain yield (Table 11).

Table 8 : Mean value of days to panicle emergency, days to maturity, lodging index, panicle weight, plant height, grain yield per day and biomass production rate of tef varieties at DebreZeit

Varieties	Trait€						
	DPE	DM	LI	PW	PH	GYPD	BPR
DZ-01-99	44.00^{efghi}	93.00^{ij}	80^{abc}	1.33^{cdefg}	98.60^{fgh}	43.94^{cdef}	180.80^{abcd}
DZ-01-196	45.33^{bcdef}	105.00^{b}	55^{ghi}	1.20^{defg}	110.70^{abc}	38.19^{fgh}	134.66^{fg}
DZ-01-354	44.33^{defghi}	100.33^{c}	64^{bcdefgh}	1.90^{abc}	109.60^{abc}	45.76^{bcde}	174.48^{bcde}
DZ-01-787	45.67^{bcde}	104.33^{b}	65^{bcdefgh}	1.34^{cdefg}	105.40^{bcdef}	39.20^{efg}	133.79^{fg}
DZ-Cr-44	45.33^{bcdef}	99.00^{cde}	62^{defgh}	1.00^{g}	105.10^{bcdef}	33.00^{gh}	123.74^{g}
DZ-Cr-82	44.33^{defghi}	99.00^{cde}	62^{defgh}	1.13^{efg}	105.60^{bcdef}	32.06^{h}	121.66^{g}
DZ-Cr-37	42.00^{jkl}	89.67^{lm}	78^{abcd}	1.2d^{efg}	96.60^{ghi}	49.84^{abc}	199.43^{ab}
DZ-Cr-255	44.33^{defghi}	104.00^{b}	71^{abcdefg}	1.72^{abcdef}	108.10^{bcd}	46.51^{bcd}	158.39^{def}
DZ-01-974	43.33^{ghijk}	97.67^{defg}	66^{bcdefgh}	1.93^{abc}	108.60^{bcd}	50.72^{abc}	181.72^{abcd}
DZ-Cr-358	43.33^{ghijk}	98.00^{def}	65^{bcdefgh}	1.75^{abcd}	107.60^{bcd}	46.82^{bcd}	165.86^{cde}
DZ-01-2053	43.00^{hijk}	92.67^{jk}	85^{a}	1.12^{fg}	91.60^{i}	41.92^{def}	148.24^{efg}
DZ-01-1278	44.67^{cdefgh}	105.00^{b}	81^{ab}	1.20^{defg}	104.50^{bcdef}	37.31^{fgh}	135.19^{fg}

DZ-01-1281	43.67^{fghij}	94.67^{hi}	$71^{abcdefg}$	1.67^{abcdef}	104.20^{cdef}	49.41^{abcd}	185.23^{abcd}
DZ-01-1285	43.00^{hijk}	97.33^{efg}	74^{abcdef}	1.90^{abc}	104.90^{bcdef}	46.66^{bcd}	171.50^{bcde}
DZ-01-1681	43.00^{hijk}	91.33^{jkl}	84^{a}	1.23^{defg}	100.80^{defgh}	49.71^{abc}	180.12^{abcd}
DZ-01-2054	44.00^{efghi}	99.00^{cde}	60^{efgh}	1.82^{abcd}	108.80^{bc}	47.75^{bcd}	181.86^{abcd}
Ajora (PGRC/E 205396)	42.00^{jkl}	96.67^{fg}	75^{abcde}	1.69^{abcdef}	107.70^{bcd}	48.52^{abcd}	173.39^{bcde}
DZ-01-899	45.00^{bcdefg}	103.67^{b}	62^{defgh}	1.87^{abc}	103.80^{cdefg}	47.15^{bcd}	187.53^{abcd}
DZ-Cr-2675	44.00^{efghi}	99.33^{cd}	$69^{abcdefg}$	1.87^{abc}	107.30^{bcde}	48.50^{abcd}	182.11^{abcd}
DZ-01-1868	45.33^{bcdef}	104.00^{b}	63^{cdefgh}	1.35^{cdefg}	105.40^{bcdef}	46.58^{bcd}	180.29^{abcd}
DZ-01-2423	43.67^{fghij}	96.00^{gh}	61^{efgh}	$1.52^{abcdefg}$	106.30^{bcdef}	50.88^{abc}	192.42^{abc}
DZ-01-146	45.00^{bcdefg}	98.00^{def}	57^{fgh}	1.76^{abcd}	112.50^{ab}	48.37^{abcd}	167.23^{cde}
DZ-01-1821	45.00^{bcdefg}	105.00^{b}	51^{hi}	1.64^{abcdef}	111.60^{abc}	46.07^{bcde}	182.01^{abcd}
HO-Cr-136	42.67^{ijk}	89.00^{m}	77^{abcde}	1.20^{defg}	96.20^{hi}	50.86^{abc}	196.63^{abc}
DZ-Cr-387 RIL 355	48.67^{a}	94.67^{hi}	57^{fgh}	1.80^{abcd}	110.50^{abc}	51.65^{abc}	198.66^{ab}
DZ-01-1880	46.00^{bcd}	96.67^{fg}	40^{i}	1.73^{abcde}	116.90^{a}	46.84^{bcd}	177.24^{abcde}
Mechare (Acc.205953)	44.67^{cdefgh}	96.67^{fg}	63^{cdefgh}	1.97^{ab}	109.30^{abc}	49.91^{abc}	184.56^{abcd}
DZ-Cr-387	45.00^{bcdefg}	93.00^{ij}	$70^{abcdefg}$	1.90^{abc}	107.70^{bcd}	53.48^{ab}	194.44^{abc}
DZ-01-3186	45.00^{bcdefg}	105.00^{b}	55^{ghi}	1.77^{abcd}	112.30^{ab}	46.75^{bcd}	173.54^{bcde}
Kena (23-tafi-adi-72)	46.33^{bc}	121.00^{a}	51^{hi}	1.37^{bcdefg}	110.80^{abc}	34.05^{gh}	120.97^{g}
DZ-Cr-385 RIL 295	40.67^{k}	88.00^{m}	76^{abcde}	$1.50^{abcdefg}$	84.90^{j}	53.39^{ab}	206.11^{a}
Laketch - RIL273	46.67^{b}	97.33^{efg}	57^{fgh}	2.00^{a}	110.40^{abc}	50.18^{abc}	196.20^{abc}
DZ-Cr-409	41.67^{kl}	91.00^{l}	$72^{abcdefg}$	1.67^{abcdef}	99.50^{efgh}	55.83^{a}	181.62^{abcd}
Mean	44.26	98.33	0.66	1.58	105.57	46.3	171.87
CV (%)	2.11	1.06	13.13	19.48	3.76	8.3	8.95
R^2	0.82	0.98	0.69	0.59	0.81	0.78	0.79

Means with in a column followed by the same letter are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test, € = Abbreviations: DPE= days to panicle emergence, DM= days to physiological maturity, PH = plant height, PW = panicle weight, LI = lodging index, GYPD= grain yield per day (Kg ha^{-1} day^{-1}) and BPR = biomass production rate (Kg ha^{-1} day^{-1}).

Table 9 : Mean value of days to panicle emergency, days to maturity, lodging index, panicle weight, plant height, grain yield per day and biomass production rate of tef varieties at Melkassa

Varieties	Trait€						
	DPE	DM	LI	PW	PH	GYPD	BPR
DZ-01-99	39.67^{cdefgh}	76.67^{ef}	78.33^{abcd}	1.20^{e}	100.40^{jkl}	42.95^{cdefgh}	173.56^{defgh}
DZ-01-196	$42.67^{abcdefg}$	84.00^{abcdef}	69.67^{abcdef}	1.58^{abcde}	116.60^{bcdefg}	42.94^{cdefgh}	186.03^{cdefgh}
DZ-01-354	40.33^{bcdefg}	82.67^{abcdef}	70.33^{abcdef}	1.43^{abcde}	111.40^{efghij}	43.07^{cdefgh}	196.95^{bcdefg}
DZ-01-787	44.00^{abcde}	90.33^{ab}	67.67^{abcdef}	1.40^{bcde}	114.80^{cdefgh}	38.83^{fgh}	154.99^{fgh}
DZ-Cr-44	40.00^{cdefgh}	80.33^{abcdef}	$59.33^{bcdefgh}$	1.30^{de}	117.30^{bcdef}	36.86^{gh}	149.97^{gh}
DZ-Cr-82	38.33^{fgh}	81.00^{abcdef}	52.67^{defgh}	1.33^{cde}	121.70^{abcde}	40.08^{efgh}	170.61^{defgh}

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DZ-Cr-37	38.00[gh]	76.00[ef]	73.33[abcde]	1.47[abcde]	101.30[ijkl]	53.59[abc]	234.57[abc]
DZ-Cr-255	41.67[abcdefg]	87.33[abcde]	55.00[cdefgh]	1.30[de]	105[ghijk]	44.14[bcdefgh]	166.61[efgh]
DZ-01-974	45.67[ab]	79.33[abcdef]	55.00[cdefgh]	1.53[abcde]	125.30[abc]	48.47[bcdefg]	198.73[bcdefg]
DZ-Cr-358	42.33[abcdefg]	90.67[a]	73.00[abcde]	1.77[abc]	114.60[cdefgh]	44.42[bcdefgh]	188.77[bcdefgh]
DZ-01-2053	41.33[abcdefg]	75.00[f]	93.00[a]	0.80[f]	91[lm]	43.84[bcdefgh]	179.90[cdefgh]
DZ-01-1278	38.00[gh]	78.67[bcdef]	61.00[bcdefgh]	1.40[bcde]	110[efghij]	40.15[efgh]	165.01[efgh]
DZ-01-1281	40.67[bcdefg]	85.00[abcdef]	72.00[abcde]	1.73[abcd]	107[fghij]	49.06[bcdefg]	198.99[bcdefg]
DZ-01-1285	39.67[cdefgh]	81.67[abcdef]	57.67[cdefgh]	1.70[abcd]	112.90[defghi]	49.97[abcdef]	205.95[bcdef]
DZ-01-1681	38.67[efgh]	77.33[def]	79.33[abcd]	1.35[cde]	103.20[hijk]	47.56[bcdefg]	189.64[bcdefgh]
DZ-01-2054	41.67[abcdefg]	87.33[abcde]	46.67[efgh]	1.20[e]	119.10[abcdef]	40.80[defgh]	139.18[h]
Ajora (PGRC/E 205396)	37.67[gh]	76.00[ef]	69.00[abcdef]	1.49[abcde]	107.40[fghij]	48.85[bcdefg]	186.33[cdefgh]
DZ-01-899	40.33[bcdefg]	83.00[abcdef]	50.67[defgh]	1.36[cde]	117.30[bcdef]	44.34[bcdefgh]	159.87[fgh]
DZ-Cr-2675	40.00[cdefgh]	79.00[abcdef]	51.00[defgh]	1.52[abcde]	113.90[cdefgh]	47.33[bcdefg]	172.98[defgh]
DZ-01-1868	40.67[bcdefg]	83.00[abcdef]	66.00[abcdefg]	1.70[abcd]	109.30[fghij]	50.58[abcdef]	207.96[bcdef]
DZ-01-2423	39.33[defgh]	76.67[ef]	56.33[cdefgh]	1.83[ab]	109.10[fghij]	55.68[ab]	216.15[abcde]
DZ-01-146	40.33[bcdefg]	78.00[cdef]	35.33[h]	1.83[ab]	115.50[bcdefg]	50.88[abcdef]	209.91[bcdef]
DZ-01-1821	42.00[abcdefg]	87.00[abcde]	52.33[defgh]	1.77[abc]	112.50[defghi]	48.16[bcdefg]	197.19[bcdefg]
HO-Cr-136	37.67[gh]	76.33[ef]	87.67[ab]	1.67[abcd]	94.70[klm]	53.01[abcd]	225.37[abcd]
DZ-Cr-387 RIL 355	46.33[a]	80.67[abcdef]	77.67[abcd]	1.83[ab]	127.20[ab]	52.19[abcde]	224.47[abcd]
DZ-01-1880	45.00[abc]	88.67[abcd]	41.67[fgh]	1.53[abcde]	130[a]	45.24[bcdefgh]	186.82[cdefgh]
Mechare (Acc.205953)	40.00[cdefgh]	82.00[abcdef]	61.00[bcdefgh]	1.77[abc]	116.40[bcdefg]	50.22[abcdef]	216.68[abcde]
DZ-Cr-387	39.00[efgh]	78.67[bcdef]	68.67[abcdef]	1.87[a]	113[defghi]	61.56[a]	234.75[abc]
DZ-01-3186	44.00[abcde]	86.67[abcdef]	37.00[gh]	1.67[abcd]	119.20[abcdef]	46.97[bcdefgh]	199.81[bcdefg]
Kena (23-tafi-adi-72)	43.67[abcdef]	90.00[ab]	55.33[cdefgh]	1.43[bcde]	116.30[bcdefg]	34.96[h]	147.00[gh]
DZ-Cr-385 RIL 295	34.67[h]	75.67[ef]	84.33[abc]	1.63[abcd]	88.50[m]	55.53[ab]	242.49[ab]
Laketch - RIL273	44.67[abcd]	89.33[abc]	33.00[h]	1.70[abcd]	124.30[abcd]	50.06[abcdef]	209.82[bcdef]
DZ-Cr-409	38.33[fgh]	78.00[cdef]	72.67[abcde]	1.64[abcd]	109.40[fghij]	61.50[a]	263.65[a]
Mean	40.8	81.88	0.63	1.54	111.99	47.39	193.96
CV (%)	6.75	7.18	23.64	14.09	5.43	13.08	14.20
R^2	0.59	0.51	0.63	0.65	0.79	0.61	0.63

Means with in a column followed by the same letter are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test, € = Abbreviations: DPE= days to panicle emergence, DM= days to physiological maturity, PH = plant height, PW = panicle weight, LI = lodging index, GYPD= grain yield per day (Kg ha^{-1} day^{-1}) and BPR = biomass production rate (Kg ha^{-1} day^{-1}).

Table 10 : Estimate of simple correlation coefficient of different traits with grain yield (R_{GYPha}), year of release of the variety (R_{YoR}) and biomass yield (R_{BYPha}).

Traits	Correlation coefficient (R)		
	R_{GYPha}	R_{YoR}	R_{BYPha}
Days to seedling emergence	0.19	0.16	0.27
Days to panicle emergence	-0.06	0.001	-0.08

Days to Maturity	-0.04	-0.03	0.01
Plant height	0.08	0.05	0.03
Panicle length	-0.02	0.10	-0.04
Lodging index	-0.13	-0.20	-0.09
Panicle Weight	0.29	0.41	0.19
Yield / panicle	0.79**	0.43	0.78**
Hundred seed weight	0.14	0.18	0.12
Grain yield/ha	-------	0.61*	0.93**
Grain yield per day	0.90**	0.54*	0.86**
Biological yield	0.93**	0.51*	-------
Biomass production rate	0.83**	0.44*	0.91**
Harvest Index	0.05	0.20	-0.31

**, ** = Significant at P ≤ 0.05 and P ≤ 0.01, respectively*

Table 11 : Summary of selection from stepwise regression analysis of mean grain yield of tef as dependent variable on the other traits as independent variables

Independent variables	Constant	Regression coefficient (b)	R^2	Variation Inflation Factor
Biomass yield per hectare	-4017.7	0.26	0.872	0.002
Harvest index		156.52	0.125	3.82

All regression coefficients are significant at P ≤ 0.01

IV. Discussion

As indicated in Table 5, the superiority of the higher yielder variety, DZ-Cr-409 represents 1086 kg ha^{-1} or 28.21 % increment over the average of the first three older varieties (DZ-01-99, DZ-01-196 and DZ-01-354). Nearly similar trends of genetic progress were reported in different crops in different parts of the world. In tef at DebreZeit grain yield of the recently released cultivar, DZ-01–974, showed significantly (P ≤ 0.05) higher grain yield than all varieties tested in the trial (Yifru and Hailu, 2005). It exceeded the farmer's variety and DZ-01-354, which is the most popular and the first improved variety by 34.3% and 41.44% respectively. In winter wheat in UK, seed yield of newly released cultivars was found to be 27.6% greater than the older cultivars (Shearman *et al*., 2005). Likewise, Wondimu (2010) who worked on malt barley reported that an increment in seed yield of 1690 kg/ha (51%) and 1388 kg/ha (38%) of modern varieties over the farmers variety, Balami and the oldest improved variety, IAR/H/485 respectively. Consistent yield improvement was observed in different years as indicating in Table 5. This revealed that grain yield potential of tef has not attained a plateau in Ethiopia; thus, provide that an opportunity for breeders to further improve tef yield through the existing breeding strategy. In line with the present findings, Amsal (1994) in wheat and Wondimu (2010) in barley found no trends of a plateau.

The average rate of increase in grain yield was 21.53 kg ha^{-1} $year^{-1}$, and it was highly significantly (P ≤ 0.01) different from zero. This reveals that tef breeders have made considerable efforts over the last 42 years to improve the yields of tef in the country. Similar trends have been reported by Yifru and Hailu (2005) in tef with comparable genetic gains of 27.16 kg/ha (0.79%) per year of release. Likewise Amsal (1994) in durum wheat, Wondimu (2010) in barley and Demissew (2010) in soybean reported respective increases of 64, 27.16, 44.24, and 13.26 kg ha^{-1} $year^{-1}$ in grain yield potential of varieties over the year of release in Ethiopia.

An improved biomass yield, days to seedling emergency, panicle length, yield per panicle and harvest index were the characteristics of most of the modern tef genotypes. Regression analysis of these traits over year of cultivar release (since1970) showed significant and positive regression coefficients for biomass yield and yield per panicle (Table 6). These result simply that the tef improvement program has made substantial progress in improving these traits. Likewise, Yifru and Hailu (2005) in tef, Mihret (2012) in sorghum at both location (Melkassa and Mieso) found an increase of biomass yield of modern varieties. From the separate analysis days to panicle emergency, days to maturity and lodging index were decreased non-significantly. Panicle weights, plant height, grain yield per day and biomass production rate were increased with year of release. Out of these panicle weight, grain yield per day and biomass production rate were increased significantly (Table 7).Similar to the present study, Mihret (2012) in sorghum reported that an increased trend in biomass production rate and grain filling rate at Melkassa and Mieso. Likewise, Wonidmu (2010) in barley observed significant changes in the total grain sink filling rate with year of cultivar release. In contrary, Yifru and Hailu (2005) and Wondimu (2010) observed non-significant increases in biomass production rate in tef and food barley yield, respectively.

Examination of components of yield by a series of simple correlations indicated that grain yield was positively and highly significantly associated only with biomass yield(r = 0.93**), yield per panicle (r = 0.79**), biomass production rate (r = 0.83**) and grain yield per day (r = 0.90**) (Table 10). Similarly, positive association of biomass yield, biomass production rate and grain yield per day with grain yield were also reported by Yifru and Hailu (2005) in tef, Mihret (2012) in sorghum and Wondimu (2010) in barley. The other traits have no positive and negative contribution on grain yield. This was supported the findings of Yifru and Hailu (2005) in tef. Similarly, Mihret (2012) found non-significant negative association for grain yield with days to flowering and day to maturity in sorghum. Step wise regression analysis of mean grain yield (dependent variable) on selected yield components (independent variable) indicated that biomass yield and harvest index were the two most important yield components which accounted for 99.7% of the variation in grain yield (Table 11). It is, therefore, concluded that genetic yield potential improvement of tef over the last 42 years has been associated mostly with a corresponding increase in biomass yield and harvest index. This is in agreement with the findings of Mihret (2012) in sorghum at Mieso and Wondimu (2010) in malt barley indicated that biomass yield and harvest index were the most important traits contributing to the variation in the improvement programs.

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