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Genetic Improvement in Grain yield and Yield Related Traits of Durum wheat (*Triticum turgidum var.durum* L.) in Ethiopia

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ABSTRACT

36 durum wheat varieties released since 1966 were evaluated in three replications of the Alpha lattice Design at DebreZeit and Akaki, Ethiopia during the 2016 cropping season to estimate the amount of genetic gain made over time in grain yield potential,yield-associated traits and in protein content. Analysis of variance revealed significant differences among varieties for all 16 quantitative traits, protein content and protein harvest in Kg ha^{-1} at each of the locations.Grain yield was increased from 2705.92kg ha^{-1} to 3766.67.4kg ha^{-1} over the past 49 years. Regression analysis revealed that grain yield has increased by 22.24 kg ha^{-1} year^{-1} with relative genetic gain of 0.83% year^{-1} for the period of 1966- 2015. A significant decline of 11.4% in spike length, 6.7% in spikelets spike^{-1}, 17.9% in protein content and 31.2% in protein yield ha^{-1} and a significant increase of 41.1% in grains spikelet^{-1}, 32.9% in number of grains spike^{-1}, 22.3% in thousand grain weight, 17.8% in grain filling period, 23.9% in seed grwoth rate, 40.1% in grain yield production rate, 7.9% in harvest index, 6.5% decrease in days to flowering and a 1.0% extension in days to maturity were statistically nonsignificant, this has significantly extended the grain filling period. Plant height, Tilleers plant^{-1}, biomass production rate, hectoliter weight and biomass yield ha^{-1} have remained unchanged over the 50 years of durum wheat improvement.

Keywords*:* Durum wheat, Genetic improvement, Grain yield, Yield component, Protein.

1.INTRODUCTION

Durum wheat (*Triticum durum* L.) is a member of the Gramineae family which belongs to the Triticeae tribe. It is an allotetraploid (two genomes: AABB) with a total of 28 chromosomes (2n = 4x = 28). *Triticum durum* is believed to be originated thousands of years ago from a hybridization between the wild diploid *T. monococcum* L. subsp. *Boeoticum* (Boiss.) (A genome donor) (Synonym: *Triticum urartu*: AA) and the donor of the B genome which, according to morphological, geographical and cytological evidence, has been recognized as *T. speltoides (Tauschi*) Gren. Or its closely related species (Colomba and Gregorini 2011)

There are six types of *Triticum* species of which *Triticum aestivum* and *Triticum turgidum* are the most dominantly grown species in Ethiopia. Durum wheat is grown in Ethiopia since antiquity because of its wide adaptation to the different agro-ecologiesof the country, and resistance to biotic and a biotic stresses. Zohary (1970) considered Ethiopia as the center of origin for the crop, whereas Purseglove (1975) reported existence of adequate genetic diversity in landraces of durum wheat grown in the country. The proposition that Ethiopia is the center of origin for durum wheat has been controversial because of the absence of ancestral forms and wild relatives (Pecetti *et al*.,1992).

Durum wheat is an economically important crop and widely grown in most parts of the world and Ethiopia.Wheat improvement research started in Ethiopia in 1949 (Hailu, 1991). Since then, the durum wheat breeding programme has concentrated on improving grain yield potential, adaptation, disease resistance and stress tolerance (Getinet, 1988; Tesfaye and

Jamal, 1982). In Ethiopia, durum wheat is produced in several parts of the country particularly on the central highland areas, traditionally planted on heavy black clay soils (vertisols) of the highlands between 1800-2800 meters above sea level (masl) (Tesemma and Belay 1991).

According to Central Statistics Agency CSA (2015), Durum wheat is produced on 250 thousand ha with average productivity of 25.43qt/ha.The national and regional agricultural research system have been striving to improve durum wheat production in Ethiopia since the late 1960's. As a result, 36 improved varieties of durum wheat have been released for commercial production from 1966 until 2015.

Durum wheat protein content andquality in the grain is important for human nutrition and end use processing quality. High protein determines premium prices for wheat in many regions of the world, making high grain protein content a primary target in durum and hard common wheat breeding programs (Abinassa *et al*., 2008). Besides, protein content is an important criterion for marketing and purchasing wheat and thus it is included in almost every flour specification.

Estimation of genetic progress is useful as it helps breeders to make decisions about what breeding strategy they should follow, whether they ought to pursue or if changes are required. 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 (Evans ,1993).Genotype, environment and field management interact to determine the yield of a crop. However, no method of estimating long-term improvement progress can completely separate genetic effects 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 genetic yield potential and associated changes in morpho-physiological attributes produced by genetic improvement and benefits obtained thereof, have been documented in different crops in different countries (Perry and D'Antuono, 1989) by comparing old and modern varieties.

Amsal (1994) had conducted study to estimate genetic gain using five released varieties over the periods 1966-1992 and one farmer variety of durum at a single location in 1992. However, the progress made in improving varieties after 1992 one more than one location trials were not assessed. Therefore, the present study was undertaken to overcome those limitations in durum wheat genetic gain. Therefore, the current study was done with the following objectives:

- To estimate the amount of genetic gain made in grain yield in Ethiopian durum wheat varieties
- To estimate the genetic gain made by genetic improvement on yield associated traits and grain protein content.

2. MATERIALS AND METHODS

The experiment was conducted at two locations namely, Debrezeit Agricultural Research Center (DZARC) and Akaki sub station of DZARC. DZARC is located at 08°44'N, 38°58'E and an altitude of 1900 meters above sea level. It is located at 47 km away from Addis Ababa and characterized by long term mean annual rainfall of 851 mm and mean maximum and minimum temperature of 28.3°c and 8.9°c respectively.

Akaki is located at 20 km away from Addis Ababa. It is situated at 08°52'N and 38°47'E with an altitude of 2200 m above sea level and characterized by long term average annual rainfall of 1025 mm and mean maximum and minimum temperature of 26.5°c and 7.0°c respectively.Soli type for both locations categorized as Vertisol and Planting is usually commenced from mid July to late July

The experimental materials were grown under rain fed condition during main cropping season in the year 2016/17.The experimental materials at each location was sown with row planting method (drill) using Alpha lattice design with three replications. The gross plot size of 3m^2 with six rows of 2.5m length and 1.2m width. The seed was drilled by hand at seed rate of 125kgha^{-1} and fertilizer was applied according to the specific recommendation(Urea150kgha^{-1} and 100kgha^{-1} of DAP) for each location. All phosphorous, in the form of Diamonium phosphate(DAP) was applied at planting while nitrogen, in the form of Urea was applied half at planting and the remaining half at tillering stage of crop developm

Table 1. List of durum wheat varieties included in the study, their year of release and source/origin.

S.N.	Name of Variety	Year of release	Adaptation agroecology (altitude in masl)	Source/origin
1	Arendato	1966	2200-2500	Improved land race
2	Cocorit 71	1976	1800-2500	CIMMYT
3	Gerardo	1976	1800-2500	CIMMYT
4	LD 357	1979	2200-2500	USA
5	Boohai	1982	1800-2500	CIMMYT/Ethiopia

6	Foka	1993	1800-2700	Ethiopia /CIMMYT
7	Kilinto	1994	1600-2700	CIMMYT/EIAR
8	Bichena	1995	1900-2600	CIMMYT/EIAR
9	Tob66	1996	2000-2500	CIMMYT/EIAR
10	Quamy	1997	1600-2200	CIMMYT/EIAR
11	Asassa	1999	1680-2400	CIMMYT/EIAR
12	Arsi Robe	2000	2000-2500	CIMMYT/EIAR
13	Ginchi	2002	2000-2300	CIMMYT/EIAR
14	Ude	2002	1800-2650	CIMMYT/EIAR
15	Yerer	2002	1800-2650	CIMMYT/EIAR
16	Leliso	2002	1800-2650	CIMMYT/OARI
17	Metaya	2002	1800-2650	CIMMYT/ARARI
18	Megenagna	2004	1800-2650	CIMMYT/ARARI
19	Selam	2004	1800-2650	CIMMYT/ARARI
20	Mossobo	2004	1800-2650	CIMMYT/ARARI
21	Tate	2004	1800-2700	CIMMYT/OARI
22	Oda	2004	1800-2650	CIMMYT/OARI
23	Illani	2004	1800-2650	CIMMYT/ OARI
24	Ejersa	2005	1800-2650	CIMMYT/OARI
25	Kokate	2005	1800-2700	ICARDA/SARI
26	Malefia	2005	1800-2700	CIMMYT/ARARI
27	Bekalcha	2005	1800-2700	ICARDA/ OARI
28	Obsa	2006	1800-2650	CIMMYT/OARI
29	Flakit	2007	1800-2650	ICARDA/EIAR
30	Denbi	2008	1800-2650	CIMMYT/ARARI
31	Hitossa	2008	1800-2650	CIMMYT/EIAR
32	Werer	2009	450-1200	ICARDA/EIAR
33	Mangudo	2012	1800-2700	ICARDA/EIAR
34	Mukye	2012	1800-2700	ICARDA/EIAR
35	Toltu	2012	1800-2650	CIMMYT/OARI
36	Utuba	2015	1800-2750	ICARDA/EIAR

Data were recorded on :days to flowering , days to maturity , plant height ,number of tillers per plant, harvest index, number of spikelet per spike ,spike Length ,number of grains per spike,thousand grain weight, hectoliter weight: grain yield,biomass production rate, and grain protein

Above ground biomass: Computed by dividing the above ground biomass yield to number of days to physiological maturity and expressed as kg ha^{-1} day^{-1}.

Seed growth rate: Computed by dividing the grain yield (kg ha^{-1}) to days to grain filling period and expressed as kg ha^{-1} day^{-1}

Grain Yield production rate: Calculated as the ratio of gain yield (kg ha^{-1}) to days to physiological maturity and expressed as kg ha^{-1} day^{-1}**.**

All measured parameters were subjected to the Analysis of Variance (ANOVA) using PROC GLM of SAS software version 9.1 (SAS Institute, 2004) to assess the difference among the tested varieties. The homogeneity of error mean squares between the two locations was tested by F test on variance ratio and combined analyses of variance were performed for the traits whose error mean squares are homogenous using PROC GLM procedure of SAS. Mean separation wascarried out using Duncan's Multiple Range Test (DMRT).

Annual rate of gain (b)=CovXY/VarX

Where: Cov =covariance, Var = variance, X = the year of variety release, Y = the mean value of each character for each variety. The relative gain achieved over the year of release period for traits under consideration was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and expressed as percentage. Pearson product moment correlation coefficients among all characters were computed using means of each variety in each year using PROC CORR procedure. Stepwise regression analysis was done using PROC REG procedure to identify best contributing traits to grain yield as a dependent variable

3.RESULTS AND DISCUSSION

3.1. Trait Variability

Results of ANOVA for individual location indicated that there were very highly significant differences among tested varieties for all traits at both locations (Table 2) indicating the wide variation in all traits. At Debrezeit, the mean values for grain yield of varieties ranged from 1.66for Arendato to 3.90t ha^{-1}for Mosobo with an average yield of 2.95t ha^{-1}. Similar wide ranges were observed for spike length 4.81 cm (Ejersa) to 8.08 cm (Gerardo),spikelets spike^{-1} (15.3-21.1 , Mosobo and Kokate), grains spike (37.2-65.7 for Arendato and Leliso), days to flowering (61.3-74.7 Bekalcha and Gerardo), days to maturity (99-113 for Arendato and Selam), thousand grain weight (21.3-50.7 for Mosobo and Arendato), hectoliter weight (69.4-79.7 for Mosobo and Toltu), seed growth rate (47.9-100.4 for 23 and 18), grain yield production rate (16.7-34.6 for Arendato and Mosobo), protein content (11.8-16.7 for 19 and 6), harvest index (16.3 – 41.0 for Arendato and Utuba). Mosobo and Arendatohad similarranks for grain production rate and thousand grain weight, i.e., 1st and 36th. Mossobo was the second latest maturing varietyand had the second highest harvest index (78.7%)while Arendato was the earliest maturing and had the lowest harvest index (16.3%). Arendato ranked 6th by days to flowering (68.3) and 7th by spikelets spike^{-1} (19.9), while Mosobo ranked 23rd (65.3 days)and 36th (15.3 spikelets spike^{-1}) by these two traits, respectively.Both were not among the best in number of grains spike^{-1} (31st with 45.1and 36th with 37.2 grains spike^{-1}), Plant height (28th and 18th; with 83.2 and 96.3 cm) and protein content 35th with 12.3% and 24th with 14.1%). Varieties released during 1960s, 1970s and 1980s were very similar to Arendato in many aspects; they were late flowering and early maturing, they were taller and had longer spikes with many spikelets spike^{-1} but had fewer grains spike^{-1}, and lower thousand grain weight, hectoliter weight and harvest index and gave low grain yield.

At Debrezeit Arendato was the lowest yielding variety (1.7 t ha^{-1}) and all other varieties were superior to it with yield advantage ranging from 7% (Illani) to 136% (Mossobo). Mean yield advantage over Arendato was 78% at Debrezeit.

At Akaki the mean value of grain yield ranged from 2.45 for Foka to 5.04 t ha^{-1} for Megenagna with an average yield of 3.99t ha^{-1} (Table 2, Appendix Tables 1 and 2). Varieties of 1960s, 1970s and 1980s (1 to 5) were among the botom 1/3 by grain yield at this location too. They were taller,they had longer spikes, more spikelets spike^{-1} but fewer number of grains spike^{-1} and gave lower grain yield and had lower thousand grain weight and harvest index.The error variance was homogenous over the two locations and hence the combined Analysis of Variance was carried out and these results are discussed below. Results of combined analysis of variance across the two locations showed significant ($P< 0.05$) differences among the varieties for all the traits except biomass yield, days to maturity, grain yield, biomass production rate, seed growth rate, grain yield production rate, gain protein content, tillers per plant and harvest index (Table 3).Although the varieties differed significantly in all traits at both locations this difference was significant only for eight of the 15 traits in the combined analysis. This was due to the very highly significant Variety xLocation interaction for all traits against which variety effects were tested.

Table 2.Mean squares from combined analysis of variance for seed yield and other traits in varieties evaluated over two locations (Debre Zeit and Akaki) in 2016 cropping season

TRAIT	VAR(35)	LOC(1)	V x L(35)	Error(140)	Mean	CV	R^2	Rep(Loc)
SPL	1.361**	5.011**	0.521***	0.173	5.907	7.038	0.748	0.207
SPS	5.365*	301.987***	3.006***	1.066	17.695	5.835	0.800	0.785
GPS	168.945*	221.231**	98.867***	8.418	51.805	5.601	0.891	9.749
GSPL	0.581****	4.130***	0.182***	0.045	2.947	7.174	0.833	0.068
PLH	1004.539***	6567.042***	73.992***	25.642	93.153	5.436	0.925	19.142
BHA	3.902^{NS}	0.844^{NS}	2.493***	1.093	11.146	9.381	0.630	9.113***
DTF	32.514***	2.241^{NS}	9.641***	1.484	66.444	1.833	0.877	1.415
DTM	39.453^{NS}	4629.630***	24.396***	1.984	108.870	1.294	0.961	6.575**
GFP	39.147^{NS}	4428.167***	25.633***	3.145	42.426	4.180	0.939	7.752*
TGW	120.715***	6666.667***	38.362***	12.669	39.222	9.075	0.875	47.241**
HLW	13.238*	1585.459***	7.885***	1.792	76.894	1.741	0.930	6.870**
YHA	1.318^{NS}	59.051***	0.751***	0.076	3.469	7.970	0.922	0.120
BPR	341.549^{NS}	3134.639^{NS}	262.464***	95.385	102.629	9.516	0.671	760.838***
SGR	548.700^{NS}	3412.902**	641.801***	50.613	81.787	8.698	0.865	92.947
GYPR	94.086^{NS}	2626.433***	68.473***	6.284	31.739	7.898	0.905	11.200
PRO	3.937^{NS}	356.254***	2.749***	1.109	13.226	7.963	0.799	6.823***
TPP	1.035^{NS}	5.088^{NS}	0.790***	0.164	6.080	6.664	0.772	2.239***
HI	112.166*	4442.205***	68.178***	13.880	31.442	11.849	0.849	39.863*

**and ***= Significant at P ≤ 0.01 and p=0.001; respectively; $^{@=}$ Numbers in parenthesis represent degree of freedom;SPL=spike length(cm); SPS=spiklets per spike; GPS= Number of Grains per spike; GPSL=Grains spikelet^{-1}; PLH= Plant height(cm); BHA= Above ground biomass yield (ton per hectare); DTF= Days to flowering; DTM= Days to Maturity; GFP=Grain Filling Period; TGW= 1000 grain weight (gm); HLW= Hecto liter weght (kg per hecto litter); YHA= Grain Yield (ton per hectare); BPR= Biomass production rate (kg per hectare per day); SGR= Seed growth rate (kg per hectare per day); GYPR= Grain Yield production rate (kg per hectare per day); PRO=Protein content(%); TPP = Tillers per plant and HI= Harvest index(%).

Arendato was the second lowest yielding variety in the combined data and all varieties except Gerardo outperformed Arendato. Yield advantage over Arendato varied between -17.2 for Gerardo to 60% in Megenagna with mean of 28.2%. The highest yielding varieties; Megenagna, Mossobo (55.4%), Selam (49%), Leliso (48%), Kokate (46%) and Bakalcha (45%) all had yield advantage of more than 45% over Arendato.The two locations also differed significantly in all traits except in biomass yield, days to flowering, biomass production rate and number of tillers plant^{-1}. Mean squares of variety by location interaction effects were very highly significant (P< 0.001) for all of the characters, indicating inconsistency in performance of the varieties at the two locations. Rank correlations for the same traits at the two locations were 0.87***, 0.14, 0.19, 0.48**, 0.16, 0.53***, 0.30, 0.21 and 0.22. These correlations were very weak for biomass (-0.006), grain production rate (-0.09), grain yield production rate (-0.10). Except for plant height, days to flowering, thousand grain weight, and hectoliter weight, genotypes were not ranked similarly at the two locations. This is the consequence of the very highly significant Variety x Location interaction (Table 3).

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Table 4.Trends in genetic progress in grain yield for durum wheat varieties over the average of the first older variety (Arendato) which released in 1966.

		Mean grain yield	Increment over average of the first older variety (1966)	
Variety	Year	kg ha-1	kg ha-1	%
Arendato	1966	2705.92	------------	----------------
Cocorit 71	1976	2799.88	93.96	3.47
Gerardo	1976			
LD 357	1979	3201.8	495.92	18.33
Boohai	1982	2810.33	104.42	3.86
Foka	1993	2844.25	138.33	5.11
Kilinto	1994	3056.83	350.92	12.97
Bichena	1995	3433.83	727.92	26.90
Tob 66	1996	3060.58	354.67	13.11
Quamy	1997	3439.83	733.92	27.12
Asassa	1999	3729.08	1023.17	37.81
Robe	2000	3651.25	945.33	34.94
Ginchi	2002	3491.55	785.63	29.03
Ude	2002			
Yerer	2002			
Leliso	2002			
Metaya	2002			
Megenagna	2004	3469.88	763.96	28.23
Selam	2004			
Mossobo	2004			
Tate	2004			
Oda	2004			
Illani	2004			
Ejersa	2005	3401.29	695.38	25.70
Kokate	2005			
Malefiya	2005			
Bekalcha	2005			
Obsa	2006	3044.25	338.33	12.50
Flakit	2007	3933.08	1227.17	45.35
Denbi	2008	3954.96	1249.04	46.16
Hitosa	2008			
Werer	2009	4327.41	1621.50	59.92
Mangodo	2012	4168.00	1462.08	54.03
Mukiye	2012			
Toltu	2012			
Utuba	2015	3766.67	1060.75	39.2

Table 5. Mean squares for seed yield and yield related traits of 36 durum wheat varieties evaluated at Debre Zeit and Akaki in 2016

	Debrezeit					Akaki				
Char	**Var(35)**	**Eror(70)** $^{@}$	**Mean**	**CV(%)**	R^2	**Var(35)**	**Eror(70)**	**Mean**	**CV(%)**	R^2
SPL	1.335***	0.222	6.059	7.777	0.753	0.546***	0.124	5.755	6.11	0.69
SPS	4.697***	1.296	18.878	6.03	0.647	3.685***	0.35	16.513	5.534	0.69
NGS	159.805***	9.389	52.817	5.802	0.895	107.985***	7.447	50.793	5.373	0.88
GPSL	0.441***	0.043	2.809	7.414	0.836	0.321***	0.046	3.085	6.954	0.781
PLH	694.74***	36.41	98.667	6.116	0.905	383.726***	14.87	87.639	4.4	0.928
BHA	4.266***	1.296	11.083	0.271	0.661	2.13***	0.89	11.208	8.419	0.572
DTF	26.591***	1.349	66.343	1.751	0.908	15.565***	1.618	66.546	1.911	0.829
DTM	32.655***	2.811	104.241	1.608	0.855	31.19***	1.156	113.5	0.947	0.931
GFP	33.478***	3.300	42.426	4.180	0.939	31.279***	2.990	46.954	3.683	0.841
TGW	110.853***	18.02	33.667	12.612	0.763	48.343***	7.311	44.778	6.039	0.769
HLW	17.67**	2.386	74.185	2.082	0.793	3.453***	1.198	79.604	1.375	0.602
YHA	0.757***	0.034	2.947	6.271	0.918	1.169***	0.119	3.992	8.632	0.832
BPR	432.118***	119.2	106.439	10.261	0.675	171.978***	71.494	98.82	8.556	0.577
SGR	402.924***	34.23	77.812	7.52	0.857	787.581***	66.988	85.762	9.543	0.855
YGR	62.96***	3.218	28.252	6.35	0.908	99.581***	9.349	35.226	8.68	0.843
PRO	4.044**	1.877	14.51	9.442	0.545	2.637***	0.342	11.942	4.894	0.813
TPP	0.605***	0.241	6.34	7.883	0.636	1.22***	0.087	5.927	4.973	0.877
HI	63.188***	10.455	26.907	12.017	0.761	117.171***	17.304	35.977	11.563	0.77

**and ***= Significant at $P \leq 0.01$ and p=0.001; respectively; $^{@}$ = Numbers in parenthesis represent degree of freedom;SPL=spike length(cm),SPS=spiklets per spike, GPS= Number of Grains per spike; GPSL=Grains spikelet^{-1}; PLH= Plant height(cm), BHA= Above ground biomass yield (ton per hectare), DTF= Days to flowering; DTM= Days to Maturity; GFP=Grain Filling Period; TGW= 1000 grain weight (gm),HLW= Hecto liter weght (kg per hecto litter); YHA= Grain Yield (ton per hectare); BPR= Biomass production rate (kg per hectare per day), SGR= Seed growth rate (kg per hectare per day), GYPR= Grain Yield production rate (kg per hectare per day), PRO=Protein content(%); TPP = Tillers per plant and HI= Harvest index(%).

3.2 Genetic Improvement in Durum Wheat

The annual rate of gain for traits was estimated from linear regression of mean of the trait on year of release expressed as the number of years since 1966, when the first durum wheat variety (Arendato) was released.For some traits which manifested a tendency to increase up to a certain year then showed a tendency to decrease towards 2015, we used a quadratic fit. The slope of this linear regression indicates the rate of increase (if slope is positive) or the rate of decrease (if slope is negative) of the trait per year in units of measurement for that trait. The slope of the quadratic fit indicates the tendency to increase up to a certain maximum and then decline if negative and the tendency to decline to a certain minimum and then increase if positive. There was similar trend at the two locations and in the combined data; the slopes were very similar for the two locations and for the combined data.The difference between slopes of the same trait at the two locations was not statistically significant except for grain filling period (0.161 vs 0.042). These slopes were higher in absolute value at Debrezeit for days to flowering (0.04 vs -0.01) and days to maturity (-0.118 vs -0.056),respectively, although these differences were significant only at probability of about 12% only. These traits seem to be more important under the less favorable conditions of Debrezeit.Neither was the difference between slopesat each location and the slope in the combined data statistically significant (tests not shown). Traits such as days to flowering, plant height, spike length, number of spikelets per spike, biomass yield, biomass production rateand protein content manifested a declining trend (slope negative).Number of tillers per plant remained constant over the years of improvement. Grain yield, number of grains per spike and per spikelet, the grain filling period, thousand grain weight, hectoliter weight, harvest index and seed and grain yield growth rates increased (slope positive) over the 50 years of durum wheat improvement in Ethiopia. For example the rate of decrease in plant height was -0.222, -0.285 and -0.254 cm yr^{-1} (a total decrease of about 11, 14and 12.5 cm over 49 years) at Debrezeit, Akaki and in the combined analysis, respectively. The weak positive correlation between the performance of varieties at the two location (r = 0.2 to 0.5) showed that the very highly significant Location x Treatment interaction (Table 3) was mainly due to heterogeneity of variances, not due to strong cross-over interaction. The performance at each location was also correlated with performance over locations. For example the correlation between performance at Debrezeit and Akaki on one side and performance over locations was 0.69*** and 0.83*** for grain yield, 0.93*** and 0.81*** for hectoliter weight, 0.75*** and 0.86*** for harvest index and 0.83*** and 0.52** for protein content.This is not surprising considering the number of varieties that gave above average grain yield at Debrezeit, at Akaki and in the combined data; 12 of the 19 varieties (63.2%) that gave above average grain yield at Debrezeit also gave above average grain yield in the combined data. there were 10 such varieties. 16 of the 18 varieties that gave above average grain yield at Akaki (76.2%) also gave above average grain yield in the combined data (Tables not showen). Similarly high number of varieties that gave below average grain yield at each of the location also gave below average grain yield in the combined data. Therefore the rate of change of traits only in the combined data will be discussed below.

3.2.1. Genetic Improvement in Growth Parameters

The slopes of spike length, plant height, tillers plant^{-1}, biomass yield in ton ha^{-1}and biomass growth rate in kg day^{-1} year^{-1}indicate that improvement of durum wheat over the last 50 years has reduced these traits. However, only changes in spike length were statistically significant. Spike lengh has been reduced by 0.015* cm year^{-1} and by a total of 0.735 cm over the last 49 years. It has been reduced from 6.32 to 5.60 cm; a reduction of 11.4% (Fig. 3).Although the mean of the two varieties released in 1976 had longer spikes than Arendato released in 1966, we observe that the order of the six decades was 1, 2, 3, 6, 4 and 5 by spike length. Varieties released in 1960s had longer spike than those released in 1970s which also had longer spikes than those released in the 1980s and so forth.

4.CORILATION BETWEEN TRAITS

Percent grain protein showed significant ($p \leq 0.05$) and negative correlations(r=-0.52**) with grain yield (Table 14).The correlations between percent grain protein and spike length, days to flowering, days to maturity and plant height were positive and non-significant. The results of correlation coefficient indicated that grain yield showed a highly significant ($p \leq 0.01$) and positive association with harvest index. This indicates that increasing harvest index and decreasing the biomass yield would be a more efficient way to boost up grain yield. Moreover, biomass yield showed significant positive correlation with biomass production rate (r=0.91**), grain production rate(r=0.19**), seed growth rate (r=0.16**) and harvest index (r=0.32**), but non-significant association with all other traits. Amsal (1994) on bread wheat and Wondimu (2010) on food barley reported a significant and positive association between harvest index and grain yield and a non-significant association between biomass and grain yield. In contrary with the present study, Fano *et al*., 2005 on tef, (Kebere *et al*., 2006) on haricot bean, Tamene (2008) on fababean, Hailu *et al*., 2009 and Demissew (2010) on soybean found a highly significant positive correlations between grain yield and biomass yield, but no significant correlation between grain yield and harvest index.

The association between grain yield and plant height was negative (r= -0.33). Different authors (Saleem *et al*., 2002; Hasan *et al*., 2008; Ali *et al*., 2009) found a non-significant correlation between grain yield and plant height. Similarly, Yifru and Hailu (2005), Kebere *et al*. (2006), Tamene (2008), Hailu *et al*. (2009) observed no relation between grain yield and plant height in tef, haricot bean, fababean, and soybean respectively. However, a significant correlation of these two traits (Wondimu ,2010 on food barley and Jin *et al*. 2010 on soybean).In general, grain yield in the modern varieties appears to be associated more with a higher partitioning efficiency to the grain sink than the production of a higher biomass. This indicated that partitioning efficiency might serve as an index for identifying varieties with higher seed yield. Significant and negative correlation observed between grain yield and spike length, grain yield and protein content and grain yield and number of spikelet per spike while the association of grain yields with number of seeds per spike, number of tillers per plant, 1000-grain weight and hector- liter weight were positive. This indicates that these characters are important traits used as indirect selection criteria in breeding for improving grain yield in durum wheat. Similar results were also reported by Hussain *et al*. (2014) who confirmed positive and significant association of grain yield with number of tillers, number of spikelet per spike and 1000 seed weight. Other authors reported positive and non-significant correlation of grain yield with, spike length, kernel per spike and 1000 seed weight (Majumder *et al.,* 2008; Degewione *et al.*, 2013).

5. CONCLUSIONS

Traits which had significant difference between six decades were, number of grain, number of grain per spikelet, plant height, days to flowering, days to maturity, grain filling period, grain yield per hectare, seed growth rate, grain yield production rate, and harvest index. The following traits had their maximum in the last decade (2010s): number of grain, seed growth rate, grain yield production rate, and harvest index. The following traits attained maximum in the 5th decade and second highest value in the sixth decade: number of grain per spikelet, grain yield per hectare and tillers per plant. The following traits had their minimum value in the last decade: plant height, days to flowering, and days to maturity. Varieties of the last decade were, therefore, the latest to flower and to mature, but had intermediate grain-filling period grain yield per hectare. Although the difference between decades was not statistically significant, varieties of the last decade had the lowest biomass yield per hectare and biomass production rate. Varieties of the first three decades (1960s, 1970s, and 1980s) had the highest values for spike length, spikelet per spike, and days to flowering, but lowest values in number of grain per spikelet, grain filling period, 1000-grain weight, hectoliter weight, grain yield production rate, and harvest index. The following traits maximized in the 1990s: grain filling period, 1000-grain weight, hectoliter weight, and protein content. The following were the highest in 1980s and 2nd highest in 1990s: plant height, biomass yield per hectare, and biomass production rate.

The earliest released variety Arendato (1960s release) had the lowest grain filling period, number of grain per spike, 1000 grain weight, hectoliter weight, grain yield production rate, biomass yield per hectare in 2010, number of grain per spikelet and harvest index, after 1980s, days to maturity in 2010, 1000 grain weight, hectoliter weight, grain yield production rate, and biomass yield per hectare by 2010s. Second highest spike length after 1970s, days to flowering by 1970s. It had the highest days to flowering and spikelet per spike; tillers per plant by 2010s, protein in 2009 and 2010.

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Appendix Table

Table 1. Mean values of different traits from combined analysis of variance for Durum wheat varieties in the yield potential trials at Debre Zeit and Akaki, 2016 cropping season.

	Traits									
Variety	**SL**	**SPS**	**NG**	**PLH**	**DTF**	**TGW**	**HLW**	**BPR**	**SGR**	**GYPR**
1.Arendato	6.32^{ag}	18.9^{ab}	36.77^{ae}	97.17^{ah}	70.33^{ac}	30.67^{c}	74.70^{a}	100.60^{ad}	72.97^{bc}	24.93^{bc}
2.Cocorit 71	6.07^{bh}	19.23^{ab}	52.03^{ae}	79.83^{hj}	70.17^{ad}	36.67_{ac}	75.33^{a}	101.76^{ad}	86.65^{ab}	30.77^{ac}
3.Gerardo	7.17^{a}	17.67^{ab}	51.67^{ae}	83.83^{ej}	72.33^{ab}	37.67^{ac}	75.43^{a}	91.02^{bd}	56.00^{c}	19.89^{c}
4.LD 357	6.37^{af}	18.67^{ab}	47.00^{ae}	101.50^{ae}	68.50^{be}	35.67^{ac}	74.73^{a}	108.10^{ad}	82.88^{ac}	29.59^{ac}
5.Boohai	5.79^{bh}	18.17^{ab}	48.47^{ce}	110.67^{ab}	66.33^{di}	40.00^{ac}	76.27^{a}	106.83^{ad}	67.72^{bc}	25.87^{ac}
6.Foka	5.66^{bh}	17.96^{ab}	44.10^{ae}	110.83^{ab}	65.33^{ei}	40.67^{ac}	76.70^{a}	101.91^{ad}	68.12^{bc}	26.42^{ac}
7.Kilinto	5.36^{fh}	17.76^{ab}	44.60^{ae}	111.50^{ab}	65.17^{ei}	41.33^{ac}	76.67^{a}	110.79^{ab}	73.93^{ac}	28.48^{ac}
8.Bichena	5.55^{dh}	18.1^{ab}	45.70^{ae}	114.17^{a}	67.33^{cg}	43.33^{ac}	76.80^{a}	107.48^{ad}	78.01^{ac}	30.65^{ac}
9.Arsi Robe	5.95^{bh}	17.86^{ab}	52.63^{ae}	100.00^{af}	64.33^{fi}	44.00^{ac}	77.43^{a}	99.91^{ad}	73.76^{ac}	28.85^{ac}
10.Quamy	5.50^{dh}	16.83^{ab}	51.87^{ae}	108.83^{ac}	64.83^{fi}	43.33^{ac}	77.90^{a}	101.94^{ad}	77.53^{ac}	31.28^{ac}
11.Asassa	5.70^{ch}	16.73^{ab}	57.23^{ae}	101.50^{ae}	63.83^{gi}	38.67^{ac}	78.70^{a}	106.21^{ad}	79.61^{ac}	33.59^{ab}
12.Robe	6.49^{ad}	17.46^{ab}	57.10^{ae}	98.67^{ag}	65.33^{ei}	39.33^{ac}	75.90^{a}	118.95^{ab}	83.20^{ac}	33.17^{ab}
13.Ginchi	6.46^{ae}	18.12^{ab}	53.30^{ad}	103.92^{ad}	64.67^{ei}	43.33^{ac}	77.13^{a}	111.37^{a}	85.90^{ac}	33.83^{ab}
14.Ude	5.19^{h}	15.56^{b}	51.37^{ae}	79.00^{hj}	65.83^{ei}	38.67^{ac}	75.10^{a}	99.67^{ab}	95.01^{ab}	35.77^{ab}
15.Yerer	6.80^{ab}	18.00^{ab}	48.73^{ab}	76.00^{ij}	67.00^{cg}	36.00^{ac}	76.03^{a}	104.79^{ad}	70.78^{bc}	28.56^{ac}
16.Leliso	5.99^{bh}	17.67^{ab}	54.27^{ad}	79.83^{hj}	68.33^{ce}	30.67^{c}	75.93^{a}	99.29^{ad}	96.37^{ab}	36.35^{ab}
17.Metaya	5.58^{dh}	16.74^{ab}	52.73^{ae}	81.58^{fj}	66.33^{di}	32.67^{ac}	77.67^{a}	109.02^{ac}	94.81^{ab}	36.11^{ab}
18.Megenagna	6.48^{dh}	16.46^{ab}	45.43^{ae}	80.00^{fj}	65.50^{di}	38.67^{ac}	77.53^{a}	105.21^{ad}	85.19^{a}	33.52^{a}
19.Selam	5.69^{bh}	17.37^{ab}	47.63^{ad}	96.25^{dj}	64.67^{ci}	38.67^{ab}	75.47^{a}	103.95^{ad}	73.53^{ab}	28.95^{ab}
20.Mossobo	5.64^{bh}	17.65^{b}	60.83^{ac}	83.67^{fj}	64.00^{ei}	42.67^{a}	79.40^{a}	104.74^{ad}	100.51^{ab}	40.36^{ab}
21.Tate	5.63^{dh}	17.63^{ab}	52.20^{de}	78.83^{hj}	66.67^{ci}	37.33^{ac}	77.63^{a}	93.77^{ad}	79.05^{ac}	31.08^{ac}
22.Oda	5.81^{ch}	17.56^{ab}	57.28^{ae}	82.30^{fj}	67.52^{cg}	33.83^{ac}	74.99^{a}	106.46^{ad}	89.52^{ab}	33.25^{ab}
23.Illani	5.85^{bh}	17.53^{ab}	56.50^{ae}	73.83^{j}	68.00^{cf}	32.00^{bc}	75.77^{a}	91.01^{bd}	72.19^{bc}	27.53^{ac}
24.Ejersa	5.29^{h}	16.33^{ab}	45.23^{ae}	109.17^{ac}	65.67^{ei}	40.67^{ac}	76.63^{a}	103.76^{ad}	72.63^{bc}	28.67^{ac}
25.Kokate	6.34^{ag}	19.36^{ab}	56.90^{ae}	106.92^{ac}	64.17^{fi}	42.67^{ac}	77.80^{a}	107.79^{ad}	87.22^{ab}	35.95^{ab}
26.Malefia	6.66^{ac}	18.67^{ab}	56.57^{ae}	99.17^{af}	65.50^{ei}	42.00^{ac}	79.47^{a}	99.71^{ad}	77.75^{ac}	31.14^{ac}
27.Bekalcha	5.51^{dh}	17.43^{ab}	58.33^{be}	82.25^{fj}	62.83^{i}	40.67^{ac}	78.90^{a}	99.03^{ad}	86.78^{ab}	36.29^{ab}
28.Obsa	5.44^{eh}	17.70^{ab}	49.10^{ae}	107.08^{ac}	68.00^{cf}	41.33^{ac}	76.93^{a}	105.09^{ad}	83.72^{ac}	32.58^{ac}
29.Flakit	5.34^{gh}	18.46^{ab}	51.03^{ae}	86.00^{dj}	67.67^{cg}	35.67^{ac}	76.10^{a}	81.77^{d}	73.41^{ac}	28.16^{ac}

30.Denbi	5.86^{bh}	18.33^{ab}	52.43^{ae}	109.83^{ab}	65.17^{ei}	43.33^{ac}	77.60^{a}	106.96^{ad}	85.84^{ac}	33.70^{ab}
31.Hitosa	6.48^{ad}	18.06^{ab}	56.17^{ae}	105.17^{ac}	65.00^{ei}	38.67^{ac}	77.97^{a}	104.79 ^{ad}	75.81^{ac}	30.62^{ac}
32.Werer	5.88^{bh}	17.09^{ab}	59.92^{ae}	77.79^{ij}	67.48^{cg}	33.83^{ac}	76.04^{a}	111.56^{ad}	86.46^{ab}	32.77^{ab}
33.Mangudo	5.07^{ch}	18.13^{ab}	53.67^{e}	82.67^{gj}	72.50^{ei}	47.00^{ac}	78.73^{a}	104.73^{ad}	103.45^{ac}	37.74^{ab}
34.Mukiye	5.61^{fh}	17.10^{ab}	52.90^{ac}	82.67^{bi}	64.83^{hi}	47.33^{ac}	80.30^{ab}	103.03^{ad}	105.34^{ab}	42.21^{ab}
35.Toltu	6.63^{af}	17.46^{ab}	49.73^{ae}	88.92^{cj}	64.00^{hi}	42.00^{ac}	74.53^{a}	99.37^{cd}	73.48^{ac}	29.53^{ac}
36.Utuba	5.48^{dh}	17.46^{b}	53.53^{a}	82.17^{fj}	66.83ch	41.00ac	77.97^{a}	82.31^{cd}	89.26^{ab}	34.43^{ab}
Grand mean	5.91	17.70	51.80	93.15	66.44	39.22	76.89	102.63	81.79	31.74
DMRT(max)	1.029	7.17	8.58	1731	2.65	2.89	5.84	670.2	1.69	7.30
CV(%)	6.97	5.59	5.43	9.80	1.81	1.28	8.97	7.96	7.90	12.00

† First and last letter associated with a variety. All letters between these two letters are also associated with the variety.

Abbreviations: **, = Significant at P ≤ 0.01, ns = non significant respectively; @ = Numbers in parenthesis represent degree of freedom; SL=spike length(cm),SPS=spiklet per spike, NG= Number of Grain per spike, PLH= Plant height(cm), BYPHA= Above ground biomass yield (kg per hectare), DTF= Days to flowering, DTM= Days to Maturity,TGW= 1000 grain weight (gm),HLW= Hecto liter weght (kg per hecto litter),GYPHA= Grain Yield per hectare (kg per hectare), BPR= Biomass production rate (kg per hectare per day), SGR= Seed growth rate (kg per hectare per day), GYPR= Grain Yield production rate (kg per hectare per day), PRO=Protein content(%); TPP = Tillers per plant,CV=coeficient of variation,DMRT=duncans multiple range test and HI= Harvest index(%).

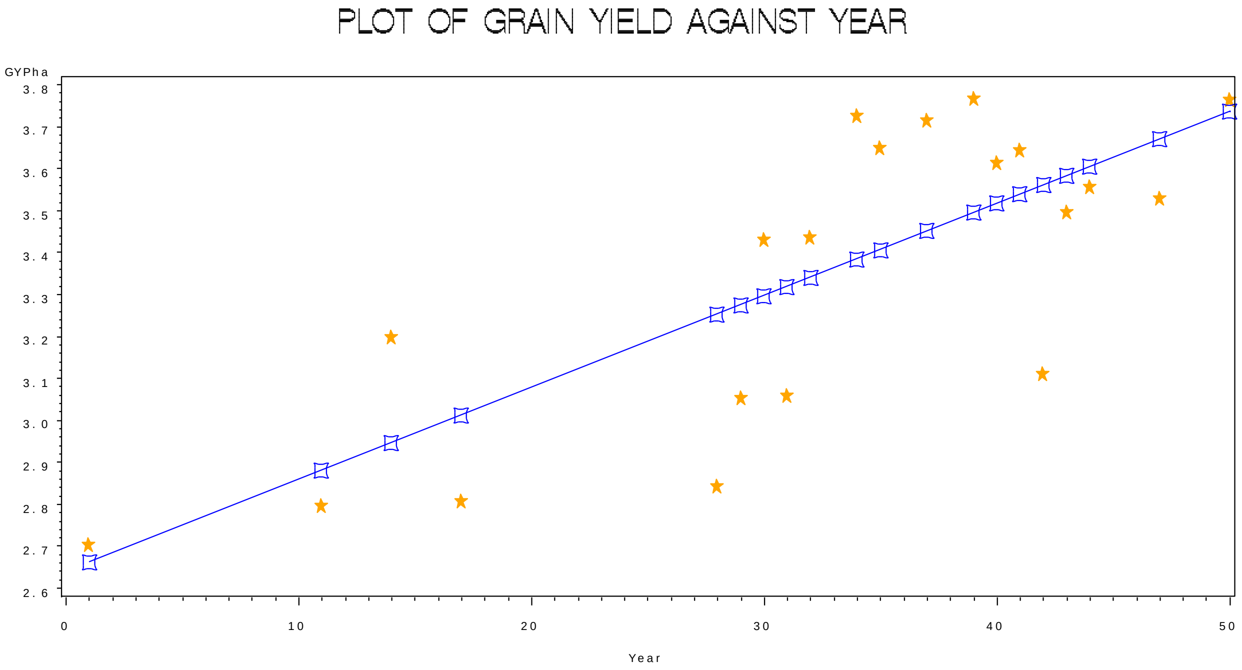

Fig1.Plot of grain yield per year of release

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