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 3766.47kg 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, 22.3% in thousand grain weight, 17.8% in grain filling period, 23.9% in seed growth 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, Tillers 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* (Tausch) 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-ecologies of 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 25.43t/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 and quality 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. Soil 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 were sown with row planting method (drill) using Alpha lattice design with three replications. The gross plot size of 3m × 1m with six rows of 2.5m length and 1.2m width. The seed was drilled by hand at seed rate of 125kg/ha and fertilizer was applied according to the specific recommendation(Urea150kg/ha⁻¹ and 100kg/ha⁻¹ of DAP) for each location. All phosphorous, in the form of Diammonium 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 development.

| 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    |
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 was carried 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 1.66 for Arendato to 3.90 for Mosobo with an average yield of 2.95 t 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 Arendato had similar ranks for grain production rate and thousand grain weight, i.e., 1st and 36th. Mosobo was the second latest maturing variety and 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 45.1, and 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% (Mosobo). 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 for Menegagna with an average yield of 3.99 t ha
−1 (Table 2, Appendix Tables 1 and 2). Varieties of 1960s, 1970s and 1980s (1 to 5) were among the bottom 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, grain 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.
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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 | R² | 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***| 0.844***| 2.493*** | 1.093      | 11.146| 9.381| 0.630| 9.113*   |
| DTF     | 32.514**| 2.241**| 9.641** | 1.484      | 66.444| 1.833| 0.877| 1.415**  |
| DTM     | 39.453***| 4629.630***| 24.396*** | 1.984     | 108.870| 1.294| 0.961| 6.575*** |
| GFP     | 39.147***| 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***| 59.051***| 0.751*** | 0.076     | 3.469 | 7.970| 0.922| 0.120    |
| BPR     | 341.549***| 3134.639***| 262.464***| 95.385    | 102.629| 9.516| 0.671| 760.838***|
| SGR     | 548.700***| 3412.902***| 641.801***| 50.613    | 81.787| 8.698| 0.865| 92.947***|
| GYPR    | 94.086***| 2626.433***| 68.473*** | 6.284     | 31.739| 7.898| 0.905| 11.200***|
| PRO     | 3.937***| 356.254***| 2.749*** | 1.109     | 13.226| 7.963| 0.799| 6.823*** |
| TPP     | 1.035***| 5.088***| 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 = spikelets per spike; GPS = Number of Grains per spike; GSPL = 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 = Hectoliter weight (kg per hectoliter); 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).
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.

| Variety   | Year | Mean grain yield kg ha-1 | Increment over average of the first older variety (1966) kg ha-1 | % |
|-----------|------|--------------------------|------------------------------------------------------------------|----|
| Arendato  | 1966 | 2705.92                  | --------                                                        |    |
| Cocorit 71| 1976 | 2799.88                  | 93.96                                                          | 3.47|
| Gerardo   | 1976 | 495.92                   | 18.33                                                          |    |
| Boohai    | 1982 | 2799.88                  | --------                                                        |    |
| 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|
| Ginch 2002|     | 3491.55                  | 785.63                                                          | 29.03|
| Ude 2002  |     | 3469.88                  | 763.96                                                          | 28.23|
| Yerer 2002|     | 3401.29                  | 695.38                                                          | 25.70|
| Leliso 2002|   | 3469.88                  | 763.96                                                          | 28.23|
| Metaya 2002|   | 3401.29                  | 695.38                                                          | 25.70|
| Megenagna 2004| |                         |                                                                 |    |
| Selam 2004|     | 3469.88                  | 763.96                                                          | 28.23|
| Mossobo 2004| |                         |                                                                 |    |
| Tate 2004 |     | 3401.29                  | 695.38                                                          | 25.70|
| Oda 2004  |     | 3469.88                  | 763.96                                                          | 28.23|
| Illani 2004|   | 3401.29                  | 695.38                                                          | 25.70|
| Ejersa 2005|     |                         |                                                                 |    |
| Kokate 2005|   | 3401.29                  | 695.38                                                          | 25.70|
| Malefiya 2005| |                         |                                                                 |    |
| Bekalcha 2005|   |                         |                                                                 |    |
| Obsa 2006 |     | 3044.25                  | 338.33                                                          | 12.50|
| Flak 2007 |     | 3933.08                  | 1227.17                                                         | 45.35|
| Denbi 2008|     | 3954.96                  | 1249.04                                                         | 46.16|
| Hitosa 2008|   | 4327.41                  | 1621.50                                                         | 59.92|
| Werer 2009|     | 4168.00                  | 1462.08                                                         | 54.03|
| Mangodo 2012|   |                         |                                                                 |    |
| Mukiye 2012| |                         |                                                                 |    |
| Tolto 2012 |     | 4168.00                  | 1462.08                                                         | 54.03|
| Utuba 2015 |     | 3766.67                  | 1060.75                                                         | 39.2 |
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

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

| Char     | Var(35)  | Eror(70) | Mean   | CV(%)  | R²    | Var(35)  | Eror(70) | Mean   | CV(%)  | R²    |
|----------|----------|----------|--------|--------|-------|----------|----------|--------|--------|-------|
| 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***  | 0.089    | 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 |
| TGG      | 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 ≤ 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 weight (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(%).
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 slopes at 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 rate and 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, 14 and 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 shown). 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 length 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. Correlation between Traits

Percent grain protein showed significant (p ≤ 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 ≤ 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.

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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 hectar- 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, hectaroliter weight, grain yield production rate, and harvest index. The following traits maximized in the 1990s: grain filling period, 1000-grain weight, hectaroliter 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, hectaroliter 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, hectaroliter 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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Table 1. Mean values of different traits from combined analysis of variance for Durum wheat varieties in the yield potential trials at Debret Zeit and Akaki, 2016 cropping season.

| Variety     | SL     | SPS     | NG     | PLH    | DTF    | TGW    | HLW    | BPR     | SGR     | GYPR     |
|-------------|--------|---------|--------|--------|--------|--------|--------|---------|---------|----------|
| 1. Arendato | 6.32   | 18.9    | 36.77  | 97.17  | 70.33  | 30.67  | 74.70  | 100.60  | 72.97   | 24.93    |
| 2. Cocorit 71| 6.07   | 19.23   | 52.03  | 79.83  | 70.17  | 36.67  | 75.33  | 101.76  | 86.65   | 30.77    |
| 3. Gerardo  | 7.17   | 17.67   | 51.67  | 83.83  | 72.33  | 37.67  | 75.43  | 91.02   | 56.00   | 19.89    |
| 4. LD 357   | 6.37   | 18.67   | 47.00  | 101.50 | 68.50  | 35.67  | 74.73  | 108.10  | 82.88   | 29.59    |
| 5. Boohai   | 5.79   | 18.17   | 48.47  | 110.67 | 66.33  | 40.00  | 76.27  | 106.83  | 67.72   | 25.87    |
| 6. Foka     | 5.66   | 17.96   | 44.10  | 110.83 | 65.33  | 40.67  | 76.70  | 101.91  | 68.12   | 26.42    |
| 7. Kilinto  | 5.36   | 17.76   | 44.60  | 111.50 | 65.17  | 41.33  | 76.67  | 110.79  | 73.93   | 28.48    |
| 8. Bichena  | 5.55   | 18.1    | 45.70  | 114.17 | 67.33  | 43.33  | 76.80  | 107.48  | 78.01   | 30.65    |
| 9. Arsi Robe| 5.95   | 17.86   | 52.63  | 100.00 | 64.33  | 44.00  | 77.43  | 99.91   | 73.76   | 28.85    |
| 10. Quamy   | 5.50   | 16.83   | 51.87  | 108.83 | 64.83  | 43.33  | 79.90  | 101.94  | 77.53   | 31.28    |
| 11. Assasa  | 5.70   | 16.73   | 57.23  | 101.50 | 63.83  | 38.67  | 78.70  | 106.21  | 79.61   | 33.59    |
| 12. Robe    | 6.49   | 17.46   | 57.1   | 98.67  | 65.33  | 39.33  | 75.90  | 118.95  | 83.20   | 33.17    |
| 13. Ginchii | 6.46   | 18.12   | 53.30  | 103.92 | 64.67  | 43.33  | 77.13  | 111.37  | 85.90   | 33.83    |
| 14. Ude     | 5.19   | 15.56   | 51.37  | 79.00  | 65.83  | 38.67  | 75.10  | 99.67   | 95.01   | 35.77    |
| 15. Yerer   | 6.80   | 18.00   | 48.73  | 76.00  | 67.00  | 36.00  | 76.03  | 104.79  | 70.78   | 28.56    |
| 16. Leliso  | 5.99   | 17.67   | 54.27  | 79.83  | 68.33  | 30.67  | 75.93  | 99.29   | 96.37   | 36.35    |
| 17. Metaya  | 5.58   | 16.74   | 52.73  | 81.58  | 66.33  | 32.67  | 77.67  | 109.02  | 94.81   | 36.11    |
| 18. Megenagna| 6.48  | 16.46   | 45.43  | 80.00  | 65.50  | 38.67  | 77.53  | 105.21  | 85.19   | 33.52    |
| 19. Selam   | 5.69   | 17.3    | 47.63  | 96.25  | 64.67  | 38.67  | 75.47  | 103.95  | 73.53   | 28.95    |
| 20. Mosobo  | 5.64   | 17.65   | 60.83  | 83.67  | 64.00  | 42.67  | 79.40  | 104.74  | 100.51  | 40.36    |
| 21. Tate    | 5.63   | 17.63   | 52.20  | 78.83  | 66.67  | 37.33  | 77.63  | 93.77   | 79.05   | 31.08    |
| 22. Oda     | 5.81   | 17.56   | 57.28  | 82.30  | 67.52  | 33.83  | 74.99  | 106.46  | 89.52   | 33.25    |
| 23. Illani  | 5.85   | 17.53   | 56.50  | 73.83  | 68.00  | 32.00  | 75.77  | 91.01   | 72.19   | 27.53    |
| 24. Ejersa  | 5.29   | 16.33   | 45.23  | 109.17 | 65.67  | 40.67  | 76.63  | 103.76  | 72.63   | 28.67    |
| 25. Kokate  | 6.34   | 19.36   | 56.90  | 106.92 | 64.17  | 42.67  | 77.80  | 107.79  | 87.22   | 35.95    |
| 26. Mafea   | 6.66   | 18.67   | 56.57  | 99.17  | 65.50  | 42.00  | 79.47  | 99.71   | 77.75   | 31.14    |
| 27. Bekalcha| 5.51   | 17.43   | 58.33  | 82.25  | 62.83  | 40.67  | 78.90  | 99.03   | 86.78   | 36.29    |
| 28. Obsa    | 5.44   | 17.70   | 49.10  | 107.08 | 68.00  | 41.33  | 76.93  | 105.09  | 83.72   | 32.58    |
| 29. Flakiti | 5.34   | 18.46   | 51.03  | 86.00  | 67.67  | 35.67  | 76.10  | 81.77   | 73.41   | 28.16    |

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| Variety   | SL (cm) | SPS | NG | PLH (cm) | BYPHA (kg/ha) | DTF | DTM | TGW (gm) | HLW (kg/ha) | GYPHA (kg/ha) | BPR (kg/ha/day) | SGR (kg/ha/day) | GYPRA (kg/ha/day) | CV (%) | DMRT (max) | HI (%) |
|-----------|--------|-----|----|---------|---------------|-----|-----|----------|-------------|---------------|----------------|----------------|----------------|-------------|---------|----------|-------|
| Denbi     | 5.86<sup>ab</sup> | 18.33<sup>ab</sup> | 52.43<sup>ae</sup> | 109.83<sup>ab</sup> | 65.17<sup>ei</sup> | 43.33<sup>ac</sup> | 77.60<sup>a</sup> | 106.96<sup>ad</sup> | 85.84<sup>ac</sup> | 33.70<sup>ab</sup> | 5.86<sup>bh</sup> | 18.33<sup>ab</sup> | 52.43<sup>ab</sup> | 109.83<sup>ab</sup> | 65.17<sup>ei</sup> | 43.33<sup>ac</sup> | 77.60<sup>a</sup> | 106.96<sup>ad</sup> | 85.84<sup>ac</sup> | 33.70<sup>ab</sup> |
| Hitosa    | 6.48<sup>ad</sup> | 18.06<sup>ab</sup> | 56.17<sup>ae</sup> | 105.17<sup>ac</sup> | 65.00<sup>ei</sup> | 38.67<sup>ac</sup> | 77.97<sup>a</sup> | 104.79<sup>ad</sup> | 75.81<sup>ac</sup> | 30.62<sup>ac</sup> | 6.48<sup>bh</sup> | 18.06<sup>ab</sup> | 56.17<sup>ab</sup> | 105.17<sup>ac</sup> | 65.00<sup>ei</sup> | 38.67<sup>ac</sup> | 77.97<sup>a</sup> | 104.79<sup>ad</sup> | 75.81<sup>ac</sup> | 30.62<sup>ac</sup> |
| Werer     | 5.88<sup>eh</sup> | 17.09<sup>ab</sup> | 59.92<sup>ae</sup> | 77.79<sup>e</sup> | 67.48<sup>e</sup> | 33.83<sup>ac</sup> | 76.04<sup>a</sup> | 111.56<sup>ad</sup> | 86.46<sup>ab</sup> | 32.77<sup>ab</sup> | 5.88<sup>bh</sup> | 17.09<sup>ab</sup> | 59.92<sup>ab</sup> | 77.79<sup>e</sup> | 67.48<sup>e</sup> | 33.83<sup>ac</sup> | 76.04<sup>a</sup> | 111.56<sup>ad</sup> | 86.46<sup>ab</sup> | 32.77<sup>ab</sup> |
| Mangudo   | 5.07<sup>eh</sup> | 18.13<sup>ab</sup> | 53.67<sup>ab</sup> | 82.67<sup>g</sup> | 72.50<sup>e</sup> | 47.00<sup>ac</sup> | 78.73<sup>a</sup> | 104.73<sup>ad</sup> | 103.45<sup>ac</sup> | 37.74<sup>ab</sup> | 5.07<sup>bh</sup> | 18.13<sup>ab</sup> | 53.67<sup>ab</sup> | 82.67<sup>g</sup> | 72.50<sup>e</sup> | 47.00<sup>ac</sup> | 78.73<sup>a</sup> | 104.73<sup>ad</sup> | 103.45<sup>ac</sup> | 37.74<sup>ab</sup> |
| Mukiye    | 5.61<sup>eh</sup> | 17.10<sup>ab</sup> | 52.90<sup>ac</sup> | 82.67<sup>g</sup> | 64.83<sup>hi</sup> | 47.33<sup>ac</sup> | 80.30<sup>ab</sup> | 103.03<sup>ad</sup> | 105.34<sup>ab</sup> | 42.21<sup>ab</sup> | 5.61<sup>bh</sup> | 17.10<sup>ab</sup> | 52.90<sup>ab</sup> | 82.67<sup>g</sup> | 64.83<sup>hi</sup> | 47.33<sup>ac</sup> | 80.30<sup>ab</sup> | 103.03<sup>ad</sup> | 105.34<sup>ab</sup> | 42.21<sup>ab</sup> |
| Tolto     | 6.63<sup>ef</sup> | 17.46<sup>eh</sup> | 49.73<sup>ae</sup> | 88.92<sup>ij</sup> | 64.00<sup>hi</sup> | 42.00<sup>ac</sup> | 74.53<sup>a</sup> | 99.37<sup>cd</sup> | 73.48<sup>ac</sup> | 29.53<sup>ac</sup> | 6.63<sup>bh</sup> | 17.46<sup>eh</sup> | 49.73<sup>ab</sup> | 88.92<sup>ij</sup> | 64.00<sup>hi</sup> | 42.00<sup>ac</sup> | 74.53<sup>a</sup> | 99.37<sup>cd</sup> | 73.48<sup>ac</sup> | 29.53<sup>ac</sup> |
| Utuba     | 5.48<sup>eh</sup> | 17.46<sup>eh</sup> | 53.53<sup>ab</sup> | 82.17<sup>ij</sup> | 66.83<sup>ch</sup> | 41.00<sup>ac</sup> | 77.97<sup>a</sup> | 82.31<sup>cd</sup> | 89.26<sup>ab</sup> | 34.43<sup>ab</sup> | 5.48<sup>bh</sup> | 17.46<sup>eh</sup> | 53.53<sup>ab</sup> | 82.17<sup>ij</sup> | 66.83<sup>ch</sup> | 41.00<sup>ac</sup> | 77.97<sup>a</sup> | 82.31<sup>cd</sup> | 89.26<sup>ab</sup> | 34.43<sup>ab</sup> |
| 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: ***, significance 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 = Hectoliter weight (kg per hectoliter), 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), GYPRA = Grain Yield production rate (kg per hectare per day), PRO = Protein content (%), TPP = Tillers per plant, CV = coefficient of variation, DMRT = Duncan's multiple range test and HI = Harvest index (%).
Fig1. Plot of grain yield per year of release