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Genetic progresses from over four decades of sorghum [*Sorghum bicolor (L.)* Moench, Poaceaea family] breeding in Ethiopia

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Information on genetic progress achieved over time from a breeding program is absolutely essential to develop effective and efficient breeding strategies. Thirty-seven improved lowland sorghum varieties released between 1976 and 2016 and promising advanced lines were evaluated to estimate the genetic progresses made in 40 years of sorghum breeding in Ethiopia. The study was conducted at 2 environments during 2018 cropping seasons in a randomized complete block design with 3 replications. Records taken on grain yield and yield attributes were subjected to statistical analysis. Combined analysis of variance revealed highly significant differences among the genotypes and the test environments for most of the traits, the G×E interaction effects being significant for grain yield. Regression analysis revealed an increase in estimated average annual rate in grain yield potential of 12.2 kg ha^{-1} year^{-1} with annual relative genetic change of 0.60% year^{-1} over the last 40 years of sorghum improvement. Increasing trends along variety release year were also evident for biomass yield, grain yield production per day, biomass production rate and seed growth rate. Stepwise regression analysis revealed that seed growth rate was the most important character, which greatly contributed to the improvement in grain yield. Grain yield was positively correlated with biomass yield, biomass production rate, grain yield production per day, seed growth rate, and thousand seed weight. It is, therefore, strategically advisable that breeding efforts in the future should give due emphasize traits such as seed growth rate.

Key words*:* Sorghum, genetic improvement, grain yield.

INTRODUCTION

Globally, sorghum [*Sorghum bicolor (L.)* Moench, Poaceaea family] 2n = 20) is the 5th most important cereal crop and is the dietary staple of more than 500 million people in 30 countries (FAO, 2011). It is grown on 40 million hectare in 105 countries of Africa, Asia, Oceania and the Americas. Africa and India account for

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the largest share (>70%) of global sorghum area while USA, India, Mexico, Nigeria, Sudan, and Ethiopia are the major producers (FAO, 2011). Sorghum plays an important role as dietary staple for millions of people, especially in arid and semi-arid countries of Africa and Asia. In Ethiopia, the crop stands third next to tef and maize both in area and total production (CSA, 2015) and it is predominantly cultivated in dry areas where drought causes frequent failures of other crops (Geremew et al., 2004). The current sorghum production in Ethiopia is estimated to be 4.3 million tones on an area of 1.8 million hectare of land giving the national average grain yield of 2.4 tones ha^{-1} (CSA, 2015). Besides being an important food crop, the grain is used for the preparation of local beverages and the stalk is used for construction, fuel and animal feed. Despite the economic importance of sorghum and Ethiopia's position in terms of domestication and diversity, its productivity has been constrained by wide array of biotic and abiotic stresses such as drought, shoofly, stem borer, midge, grain mold and *Striga*.

Since the inception of research on sorghum in Ethiopia, considerable efforts have been made to improve the productivity of sorghum targeting the dry lowland areas of Ethiopia. The researches have been focusing on addressing the major constraints mainly developing early maturing or drought tolerant varieties and varieties resistant to *Striga*, the major parasitic weed affecting sorghum production in the targeted environment (Mekbib, 2006). A total of 26 varieties were released for the dry land areas (Asfaw, 2007). In addition, 6 varieties and 5 hybrids were identified as potential and, in the process, to be verified and released for production. Even though, information on genetic progress achieved over time from a breeding program is absolutely essential to develop effective and efficient breeding strategies by assessing the efficiency of past improvement works in genetic yield potential and give suggestion on future selection direction to facilitate further genetic improvement (Slafer, 2003). Likewise, the importance of this study may be used as the base line for yield potential experiments for several years.

In Ethiopia, apart from some comparative observations in variety trials by breeders, results of field demonstrations and popularization programs by different stakeholders, where a few varieties might be tested together under common environments. Among a few studies in Ethiopia include studies on wheat (*Triticum aestivum* L.) (Amsal et al., 1995a, b), haricot bean (*Phaseolu vulgaris* L.) (Kebere et al., 2006), on barley (*Hordeum vulgare* L.) (Wondimu, 2010), on sorghum [*Sorghum bicolor (L.)* Moench] (Mihret et al., 2015) and on Teff [Eragrostis tef (Zucc.) Trotter] (Yifru and Hailu, 2005). However, there has been limited information generated on the genetic gain and morphological attributes for increased productivity, if there is any, attained through breeding on sorghum. Therefore, the current study was designed:

1. To determine the amount of genetic gain made over time in yield potential of lowland sorghum in Ethiopia
2. To identify the magnitude and direction of change in morphological and agronomic characters associated with genetic improvement in grain yield.
3. To investigate the correlations among yield and yield related traits of sorghum in Ethiopia.

MATERIALS AND METHODS

Description of the experimental sites

The trial was conducted at 2 sites, namely Sheraro (Tigray regional state) and Miesso (Harari regional state). Sheraro is suited at an altitude of 1028 m, above sea level. The area receives an average annual rainfall of 677 mm, with the average monthly maximum and minimum temperature of 32.9 and 18.8°C, respectively. The climate is typical of major sorghum producing regions of Ethiopia representing the dry lowlands. The second test site was Miesso, which is a substation of Melkassa Research Center located at an altitude of 1400 m located at a latitude of 9°23´N and longitudes 40°77´E. The area has a bimodal rainfall pattern and receiving an average annual rainfall of 763 mm, with the average monthly maximum and minimum temperature of 30.5 and 15.2°C, respectively. Generally, the two experimental sites do not differ considerably in their edaphic and climatic conditions.

Experimental materials

A total of 37 released varieties since 1976 by the national and regional research system and pipeline sorghum varieties and hybrids were used for this study. Sorghum genotypes (varieties) used for this study are presented in Table 1.

Experimental procedures and crop management

The test genotypes were laid using a randomized complete block design (RCBD) with 3 replications. Genotypes were randomly assigned to each of the experimental units for each of the testing site. Each plot has 11.25 m^2 areas which contained 3 rows of 5 m length. Spacing of 75 cm between rows and 15 cm between plants was used. The spacing between plots and blocks was 0.75 and 1.0 m, respectively. The experimental materials were planted in July 2016 at both locations. Phosphorus and nitrogen fertilizers were applied at the recommended rates of 46 kg P2O5 ha^{-1} and 50 kg nitrogen ha^{-1} in the form of diammonium phosphate and urea, respectively. DAP (diammonium phosphate) fertilizer was applied at time of planting, whereas urea was applied in split (half at planting and the other half at knee height). The plots were weeded as frequently as needed. Data were recorded on plot and plant basis on the train under consideration.

Statistical analysis

All measured parameters were subjected to analysis of variance (ANOVA) using PROCANOVA of SAS software version 9.0 (SAS institute, 2004) to assess the difference among the tested varieties in each location. The homogeneity of error variance between the two locations was tested by Bartlett 's test and combined analyses of variance was performed for the traits whose error mean squares

Table 1. List of genotypes used for genetic gain study in the lowland environment.

S/N	Variety	Pedigree	Year of variety release	Breeder/seed source
1	Gambella 1107	Gambella 1107	1976	MARC
2	76T1# 23	76T1# 23	1976	MARC
3	Seredo	Seredo	1986	MARC
4	Dink mash	Dink mash	1986	MARC
5	Meko	M-36121	1998	MARC
6	Abshir	P-9403	2000	MARC
7	Gobiye	P-9401	2000	SARC
8	Teshale	3443-2-op	2002	MARC
9	Yeju	Icsv-111 Inc	2002	SARC
10	Birhan	Key#8566	2002	SARC
11	Abuare	ICSV-1x (TSx135/4/2/3/1)	2003	SARC
12	Hormat	ICSV-1112 BF	2005	SARC
13	Macia	Macia	2007	MARC
14	Red Swazi	Red Swazi	2007	MARC
15	Raya	PGRC/EX 222878xKAT-369-1	2007	SARC
16	Miskir	PGRC/E 69441x KAT-369-1	2007	SARC
17	Girana-1	CR; 35XDJ1195X KAT-369-1	2007	SARC
18	Gedo-1	Gambella 1107x KAT-369-1	2007	SARC
19	Melkam	WSV-387	2009	MARC
20	ESH-1	P-9501AxICSR14	2009	MARC
21	ESH-2	ICSA21A xICSR50	2009	MARC
22	Mesay	MekoxGobye-2	2011	SARC
23	Chare	PGRC/E#222880	2011	DBARC
24	Dekeba	ICSR 24004	2012	MARC
25	Melkamash-79	Melkamash-79	2013	MARC
26	ESH-3	ICSA-15Xm-5568	2014	MARC
27	2005MI5064 (Argeti)	WSV387/P9404	2016	MARC
28	2005MI5065	WSV387/P9405	2016	MARC
29	PU209A/PRL021071	PU209A/PRL021071	2016	MARC
30	PU209A/PU304(ESH4)	PU209A/PU304	2016	MARC
31	ICSA15/AWN87	ICSA15/AWN87	2016	MARC
32	P9534A/Gambella1107	P9534A/Gambella1107	2016	MARC
33	Kari Metama-1	Kari Metama-1	2016	MARC
34	IESV23007DL	IESV23007DL	2016	MARC
35	P9511A/PRL020817	P9511A/PRL020817	2016	MARC
36	ETSC 300001	Teshale/B35//Teshale	2016	MARC
37	ETSC 300002	Teshale/E361//Teshale	2016	MARC

MARC= Melkassa Agricultural Research Center; SARC= Sirinka Agricultural Research Center, DBARC= Debrebirhan Agricultural Research Center.

were homogenous using PROC ANOVA procedure of SAS. Mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% of significance. Locations and replications within locations were considered random while the varieties were considered fixed effects. The following model was used for combined ANOVA:

$$Yijk = \mu + Gi + Lj + GLij + Bk(j) + Eijk$$

Where: Yijk = observed value of variety i in block k of location j, μ = grand mean, Gi = effect of variety I, Lj = effect of location j, Bk (j) = effect of block k in location j, GLij = the interaction effect of variety i with location j and Eijk = error (residual) effect of variety i in block k of location j. Linear regression analysis was used to calculate the genetic gain for each trait measured. The breeding effect was estimated as a genetic gain for grain yield and associated traits in sorghum improvement by regressing mean of each character for each variety against the year of release of that variety using PROC REG procedure.

The coefficient of linear regression gives the estimate of genetic gain in kg ha^{-1} $year^{-1}$ or in % per year (Evans and Fisher, 1999). For this study, the year of release was expressed as the number of years since 1976 for the varieties; the year when the first Sorghum variety was released. The relative annual gain achieved in the last 40 years (1976-2016) was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and

Table 2. The Average yields (kg/ha) of these 4 groups when tested at Sheraro and at Miesso and when averaged over the 2 locations.

Group of adaptation	Test		
	Sheraro	Miesso	Over Loc
Adapted to Sheraro	2848.0	1848.2	2348.1
Adapted to Miesso	2374.8	2587.3	2481.1
Widely adapted	2882.4	2695.1	2748.6
Un-adapted	2272.5	1870.2	2071.4

expressed as percentage.

RESULTS AND DISCUSSION

Performance of the genotypes

The difference between the 37 sorghum genotypes in the combined analysis was statistically significant for DTE, HWT, GFP, PW, GYHA, HI, GYPDAY and SGR (Table 4). The difference between the genotypes was significant at both locations for these traits except for DTE (Table 3). The average grain yield of all sorghum varieties was 2448.03 kg ha^{-1}, which ranged from 1861.2 kg ha^{-1} for 76T1#23 to 3190.3 kg ha^{-1}for P9534A/Gambella 1107 (elite genotype in NVT 2016). The recently advanced elite genotype P9534A/Gambella 1107 was the first best yielder (Table 8) among the 37 varieties. The superiority of the higher yielder variety, P9534A/Gambella 1107 represents 1152.7 kg ha^{-1} or 36.1% increment (Table 5) over the average of the first two older varieties (Gambella 1107 and 76T1#23) released in 1976.

The G x E interaction was highly significant for all traits except for DTF, DTM, FLW, NLPP and GL, indicating the inconsistency of performance of the genotypes over the 2 locations for most of the traits (Table 4). Due to the low G x E Mean square against which they were tested, the difference between the genotypes for DTF, DTM, FLW, NLPP and GL was significant. These five traits also had the lowest variance due to rank change (from 13 to 62 with mean variance of 45.4) (results not presented). For PHT, NTPP, FLL, PE, PL, and NSPP, the G x E interaction was significant, but did not mask the difference between the genotypes; mean square of genotypes was also significant, indicating the difference between the 37 genotypes. The variance of rank changes for these traits was also not very high and ranged between 39 and 86 with a mean of 64.7. Most of the interaction seems to be not that due to lack of correlation but due heterogeneity of variances and the performance over locations for PHT, NTPP, FLL, PE, PL, and NSPP is also relatively consistent. For the majority of the remaining traits, DTE, HWT, GFP, PW, TSW, GYHA, BYHA, HI, GYPDAY, BPR and SGR, where the G x E interaction was highly significant while the difference between genotypes was non-significant. For example, for HWA, GFP, GYHA, HI, and SGR, where the G x E was highly significant. The variance of ranks was high for these traits and ranged between 81 and 127 with mean of 101.5. There was large rank change of the varieties over the two locations for these traits. This means that some varieties performed best at Sheraro only while others performed best only at Miesso for this trait. For example, the 37 genotypes can be classified into four categories according to their adaptation (i) widely adapted genotypes with above-average grain yield at both locations (9, 16, 19, 21, 22, 27, 28,31, 32, 34 and 37), (ii) genotypes adapted to Sheraro (3, 4, 5, 7, 13, 14, 25, 26, 29 and 35), (iii) genotypes adapted to Miesso (8, 11, 12, 20, 23, 24, 33 and 36) and (iv) genotypes not adapted to any of the locations [(1, 2, 6, 10, 15, 17, 18 and 30) (Figure 1).

All the 11 highest yielding and superior genotypes were of 2000 and 2010s release (4th and 5th decades) (6 are advanced genotypes in the pipeline in 2016 and 5 were among those released in the 2000s). If we divide the 37 sorghum genotypes into 5 decades of release, that is, 1970s, 1980s, 1990s, 2000s and 2010s, mean grain yield of the 5 decades was 1872, 1846, 2095, 2190 and 2451 kg ha^{-1} (Table 5). Genotypes of the recent decade had a yield advantage of 607.1 kg ha^{-1} or 23.0% (Table 5). It can, therefore, be concluded that grain yield has been improved over the 40 years of the national sorghum improvement for the dry lowlands of Ethiopia. It is also interesting to note that the three varieties released in the second and third decades (1986 and 1998) still give high grain yield at Sheraro (Table 6). The following is the average yield of these four groups when tested at Sheraro, at Miesso and when averaged over the 2 locations

The 11 genotypes with narrow adaptation to Sheraro had a yield advantage of 473.2 Kg/ha (19.9%) over the mean of the 8 genotypes adapted to Miesso, when tested at Sheraro (2848.0 vs. 2374.8 Kg/ha, respectively). The 11 genotypes had a disadvantage of 739.1 Kg/ha (28.6%) as compared to the mean of the 8 genotypes specifically adapted to Miesso, when tested at Miesso (1848.2 vs. 2587.3 Kg/ha), respectively (Table 2). The widely adapted genotypes gave the highest yields at both locations and over both locations; however, their

Table 3. Mean squares, CV and R^2 for separate analysis of variance for seed yield and yield related traits in variety evaluated at Sheraro and Miesso in 2016 cropping season.

Trait[#]	Sheraro				Miesso			
	Variety (36)[$]	Mean	CV (%)	R^2	Variety (36)[2]	Mean	CV (%)	R^2
DTE	2.00***	6.60	9.47	0.72	0.59[ns]	6.06	10.41	0.43
DTF	66.64***	57.42	3.60	0.89	50.41**	71.56	6.65	0.53
DTM	88.99***	97.05	3.56	0.80	73.53***	107.64	3.50	0.73
PHT	3368.62***	182.86	10.54	0.82	73.53***	156.44	10.55	0.78
HWT	950.4***	5.51	7.56	0.74	526.65***	3.44	7.97	0.78
GFP	29.42***	39.63	8.97	0.54	41.43***	42.11	6.56	0.78
NTPP	0.08***	1.13	12.4	0.66	0 .04[ns]	0.89	18.04	0.44
NLPP	3.17 ***	10.29	9.45	0.63	1.92***	9.51	9.29	0.55
FLL	38.11***	40.13	3.80	0.89	34.20***	39.01	8.43	0.62
FLW	0.69[ns]	6.97	9.54	0.44	1.05***	6.15	10.13	0.59
PE	15.49***	5.41	15.98	0.91	5.29***	4.47	21.88	0.73
PL	33.21***	26.38	7.69	0.80	23.82***	25.95	7.99	0.74
PW	1.01**	8.01	9.82	0.45	4.13***	9.70	12.18	0.60
NSPP	1355769.2***	2718.99	7.39	0.94	1507233.28***	3186.00	19.28	0.67
TSW	34.52***	32.08	4.54	0.89	9.63***	24.26	5.24	0.75
GL	0.02***	2.61	2.99	0.66	0.03***	2.13	4.82	0.62
GYPH	324768.99***	2631.51	9.64	0.72	683676.66***	2264.55	11.33	0.84
BYPH	1578104.68**	8700.73	11.11	0.47	117.40***	38.43	14.63	0.65
HI	10.19[ns]	30.25	10.29	0.54	96.23**	55.23	15.30	0.41
GYPDAY	42.20***	27.21	10.22	0.73	57.29***	21.06	11.63	0.83
BPR	221.58***	89.53	11.87	0.50	518.14***	54.69	13.67	0.83
SGR	40.20***	66.73	16.43	0.45	57.29***	21.06	11.63	0.83

[$]= Numbers in parenthesis represent degrees of freedom, **, *, ns= Significant at P ≤ 0.01, significant at P ≤ 0.05, and non-significant respectively; CV= coefficient variance, R^2= determination coefficient, DTE= days to emergence, DTF= days to flowering, DTM= days to physiological maturity, PHT=plant height in cm, HWT=head weight tons per hectare, GFP= grain filling period (days), NTPP=number of productive tillers per plant, NLPP=number of leaves per plant, FLL=flag leaf length in cm, FLW=flag leaf width in cm, PE=panicle exertion in cm, PL=panicle length in cm, PW=panicle width in cm, NSPP=number of seeds per panicle, TSW=thousand seed weight in gram, GL=grain size in mm, GYPH= grain yield Kg per hectare, BYPH= above ground biomass yield Kg per hectare, HI=harvest index (%), GYPDAY= grain yield production per day (Kg ha-1 y-1day-1), BPR=biomass production rate (Kg ha-1y-1), and SGR=seed growth rate (Kg $ha^{-1}y^{-1}$).

advantage over both the Sheraro-adapted and Miesso-adapted genotypes is the highest when tested over both locations. They were superior to Sheraro-adapted genotypes by 1.2% at Sheraro, to Miesso- adapted genotypes by 4.2% at Miesso and by 17.1 and 10.8% to the two groups when tested over locations. This indicates the importance of testing the varieties across locations and over years to check their stability for use as reliable genetic materials for crop improvement in a specific location.

In this study, the result of significant interaction of variety by location for grain yield is in contrary to the finding of Hailu et al. (2009) who reported no variety x environment interaction for grain yield.

Genetic improvement in sorghum grain yield

Mean grain yields of varieties released in the years such as 1986, 1998, 2000, 2002, 2003, 2005, 2007, 2009, 2011,2012, 2013, 2014 and 2016 exceeded that of the average of the first released older varieties. Moreover, Seredo, Dinkmash by 300.2 kg ha^{-1}(12.84%), Meko by 587.0 kg ha^{-1}(22.36%), Abshir, Gobiye by 217.5 kg ha^{-1}(9.65%), Teshale, Yeju and Birhan by 408.8 kg ha^{-1}(16.71%), Abuare by 338.85 kg ha^{-1} (14.26%), Hormat by 457.2 $kgha^{-1}$ (18.33%), Macia, Red swazi and Raya by 194.23 $kgha^{-1}$ (8.70%) (Table 5). The least and highest increases were 194.3 kg ha^{-1} (8.71%) and 648.7 $kgha^{-1}$(24.15%), respectively, over varieties released in 1976 (Table 5). These indicated that there was a gradual increase in grain yield across years of release although this increment was not consistent over the years. For example; varieties 6. Abshir, released in 2000, 10. Birhan released in 2002, 15. Raya released in 2007 and 18. Gedo-1 released in 2007 was among the lowest yielding varieties. Among the advanced genotypes that were in the pipeline in 2016, genotype 30. PU209A/PU304 (ESH-4) was very low yielding (Table 5). This emphasizes the care that should

Table 4. Mean squares, CV and R^2 from combined analysis of variance for seed yield and other traits in varieties evaluated over two locations (Sheraro and Miesso) in 2016 cropping season.

Trait	Source of variation					
	Location (1) ++	Variety (36)	Location variety (36)	Mean	CV %	R^2
DTE	16.22***	1.53***	1.06***	6.33	9.85	0.66
DTF	11089.01***	101.52***	15.53^{ns}	64.49	5.71	0.89
DTM	6219.03***	150.86***	11.66^{ns}	102.35	3.51	0.87
PHT	38749.95***	3523.75***	1828.29***	169.65	10.65	0.83
HWT	237.83***	672.30***	804.70***	4.47	7.96	0.94
GFP	340.63***	40.63***	30.22***	40.87	8.34	0.65
NTPP	3.16***	0.08***	0.04**	1.01	14.90	0.69
NLPP	33.32***	3.88***	1.20^{ns}	9.90	9.39	0.63
FLL	69.82***	58.97***	13.35***	39.57	6.45	0.74
FLW	37.30***	1.30***	0.44^{ns}	6.56	9.88	0.62
PE	49.66***	14.92***	5.86***	4.94	18.92	0.87
PL	9.95 ^{ns}	41.77***	15.26***	26.17	7.79	0.77
PW	159.21***	2.98***	2.15***	8.86	11.26	0.70
NSPP	12104406.5***	2074565.45***	788437.15***	2952.50	1 5.38	0.79
TSW	3399.28***	22.70***	21.44***	28.17	4.82	0.95
GL	13.04***	0.05***	0.01^{ns}	2.37	3.84	0.93
GYPH	7473507.36***	559930.66***	448514.98***	2448.03	10.41	0.82
BYPH	427538713.9***	1269197.2**	12202251.7^{ns}	7312.98	12.38	0.81
HI	3544.01***	83.04***	63.00***	34.43	13.42	0.74
GYPDAY	2102.53***	55.48***	42.01***	24.14	10.88	0.85
BPR	66425.08***	176.50***	128.52^{ns}	72.23	12.73	0.86
SGR	8720.69***	481.12***	341.68***	60.96	14.18	0.78

++ = Number in parenthesis is degree of freedom, **, *** = Mean square of characters was significant at 0.05 and 0.01 respectively. CV= coefficient variance, R^2= determination coefficient, DTE=days to emergence, DTF = days to flowering, DTM=days to maturity, PHT=plant height(cm), HWT=head weight tons per hectare, GFP=grain filling period, NTPP= number of productive tillers per plant, NLPP=number of leaves per plant(main stem), FLL=flag leaf length (cm), FLW=flag leaf width(cm), PE=panicle exertion(cm), PL=panicle length(cm), PW=panicle width(cm), NSPP=number of seeds per panicle, TSW=thousand seed weight (gram), GL=grain length(mm), GYPH=grain yield kg per hectare, BYPH= Above ground biomass yield per hectare kg per hectare, HI=harvest index(%), GYPDAY=grain yield production kg per hectare per day, BPR= biomass production rate (kg per hectare per year), and SGR=seed growth rate (kg per hectare per year).

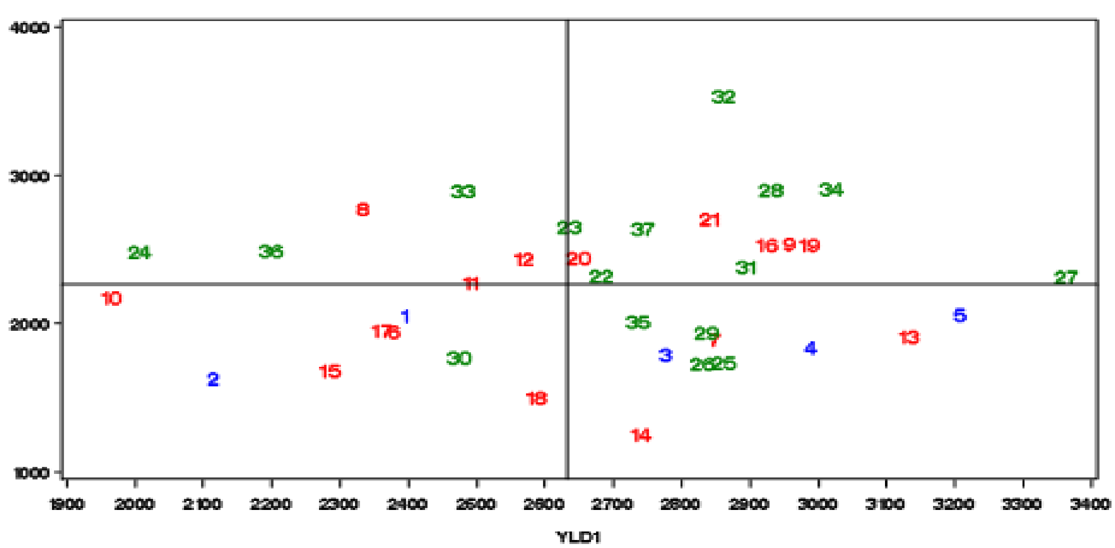

Figure 1. The yield (Yld1) at Sheraro (X) and Miesso (Y).

Table 5. Trends in genetic progress in grain yield for sorghum varieties over the average of the 1st older varieties (Gambella 1107 and 76t1#23) released in 1976.

Variety	Year	Mean yield	Increment over average of the 1st older varieties (1976s)	
		Kg ha^{-1}	Kg ha^{-1}	%
Gambella 1107	1976	2037.6	-	-
76T1#23	1976			
Seredo	1986	2337.8	300.2	12.84
Dinkmash	1986			
Meko	1998	2625.2	587.6	22.38
Abshir	2000			
Gobiye	2000	2255.01	217.41	9.64
Teshale	2002			
Yeju	2002	2446.5	408.9	16.71
Birhan	2002			14.25
Abuare	2003	2376.3	338.7	
Hormat	2005	2494.8	457.2	18.33
Macia	2007			
Red Swazi	2007			
Raya	2007	2233.65	194.23	8.70
Miski	2007			
Girana-1	2007			
Gedo-1	2007			
Melkam	2009			
ESH -1	2009	2688.26	648.67	24.15
ESH-2	2009			
Mesay	2011			
Chare	2011	2567.25	529.65	20.63
Dekeba	2012	2237.8	200.2	8.95
Melkamash-79	2013	2291.6	254.0	11.08
ESH-3	2014	2274.5	236.9	30.9
2005 MI5064	2016			
2005MI5065	2016			
PU209A/PRL021071	2016			
PU209A/PU304	2016			
ICSA15/AWN87	2016	2644.7	607.1	**23.0**
P9534A/Gambella 1107	2016		(1152.7)	(36.1) alone
Kari Metama 1	2016			
IEsV23007DL	2016			
P9511A/PRL020817	2016			
ETSC300001, TSC300002, ETSC300002E	2016			
ETSC300002	2016			
Total yield increment	1986--2016	2471.48	433.9	17.56

be taken in the process of variety release. The candidate advanced genotypes should be subjected to rigorous multi-environment and multi-season testing before release. When the candidates are tested only in one season over very few sites, the best ones (widely adapted high yielding genotypes) may be missed. For example, among the 11 elite advanced genotypes tested in 2016, only two (27) 2005MI5064 (Argeti) and (30) PU209A/PU304 (ESH-4)) were released, while genotypes 34. IESV23007DL and 36. ETSC 300001, that gave higher yield than varieties 27 and 30 (Figure 1) were missed from release and are testing in national variety trial (NVT). The average rate of increase in yield potential per year of release over the last 40 years period from the slope of linear regression was 12.2** kg ha^{-1} year^{-1} (Figure 2). Although there was

Table 6. Mean performance of characters from separate analysis of variance for sorghum varieties grown in the yield potential trial at Sheraro.

S/N	VAR	DTE	DTF	DTM	PHT	HWT	GFP	NTPP	NLPP	FLL	FLW	PE
1	Gambella 1107	5.33^{fg}	59.33^{bg}	101.33^{bc}	130.33^{k}	4.56^{lk}	39.67^{bf}	1.13^{ad}	10.83^{ac}	40.67^{ci}	6.33^{b}	1.33^{o}
2	76T1#23	5.33^{fg}	62.67^{b}	91.00^{jk}	141.67^{hk}	3.64^{m}	38.67^{bg}	0.93^{df}	8.50^{f}	41.57^{bh}	6.67^{ab}	5.33^{hk}
3	Seredo	5.67^{eg}	62.67^{b}	91.33^{ik}	132.33^{k}	5.07^{fl}	40.00^{bf}	1.23^{a}	8.67^{ef}	39.20^{el}	7.33^{ab}	5.00^{hl}
4	Dinkmash	6.67^{be}	49.67^{m}	99.67^{bf}	179.33^{dh}	6.22^{ac}	38.33^{cg}	0.93^{df}	10.50^{ac}	37.63^{im}	7.33^{ab}	2.67^{mo}
5	Meko	5.67^{eg}	62.00^{bc}	92.00^{hk}	222.33^{ac}	5.81^{ag}	39.33^{bf}	0.93^{df}	9.83^{ce}	38.75^{fl}	7.33^{ab}	3.33^{ln}
6	Abshir	5.00^{g}	61.67^{bc}	92.00^{hk}	227.00^{ab}	4.89^{hl}	36.33^{dg}	0.93^{df}	8.67^{ef}	44.60^{ab}	7.67^{ab}	6.67^{dh}
7	Gobiye	5.33^{fg}	61.67^{bc}	93.33^{fk}	201.67^{ae}	6.28^{ab}	38.67^{bg}	1.00cf	8.50^{f}	41.67^{bh}	7.00^{ab}	3.33^{ln}
8	Teshale	7.00^{ad}	61.67^{bc}	93.67^{ek}	135.33^{jk}	4.98^{gl}	36.67^{dg}	1.00cf	10.00^{bd}	33.33^{no}	7.00^{ab}	8.67^{b}
9	Yeju	6.67^{be}	61.33^{bd}	92.67^{gk}	137.33^{ik}	5.22^{el}	40.67^{bf}	0.93^{gf}	9.83^{ce}	36.97^{jm}	7.00^{ab}	6.00^{fi}
10	Birhan	8.00^{a}	61.33^{bd}	93.33^{fk}	188.33^{cf}	4.53^{lk}	40.00^{bf}	1.27^{a}	8.83^{df}	37.27^{im}	6.33^{b}	5.67^{gj}
11	Abuare	8.00^{a}	60.67^{be}	101.67^{b}	179.33^{dh}	5.81^{ag}	42.67^{ae}	1.23^{ab}	10.00^{bd}	40.40^{ci}	6.67^{ab}	3.00^{mn}
12	Hormat	6.00^{dg}	60.00^{bf}	94.33^{dk}	204.67^{ad}	5.54^{bi}	41.00^{bf}	1.03^{be}	10.50^{ac}	38.30^{hm}	7.00^{ab}	3.00^{mn}
13	Macia	7.00^{ad}	60.00^{bf}	96.33^{bk}	225.00^{ac}	5.66^{bi}	40.00^{bf}	1.03^{be}	9.67^{cf}	40.23^{dj}	8.00^{a}	4.33^{im}
14	Red Swazi	7.67^{ab}	59.67^{bg}	90.33^{k}	205.33^{ad}	4.62^{jl}	0.67^{bf}	1.00^{cf}	8.67^{ef}	36.10^{kn}	6.33^{b}	6.00^{fi}
15	Raya	5.00^{g}	74.00^{a}	123.00^{a}	218.33^{ac}	5.72^{ah}	49.00^{a}	1.17^{ac}	11.17^{ab}	42.75^{ae}	7.67^{ab}	7.33^{cf}
16	Miskir	6.67^{be}	59.00^{bg}	99.33^{bg}	133.67^{k}	5.04^{gl}	36.67^{dg}	0.97^{cf}	9.67^{cf}	38.97^{fl}	6.67^{ab}	5.00^{hl}
17	Girana -1	6.33^{cf}	58.33^{ch}	92.00^{hk}	218.33^{ac}	5.25^{el}	32.00^{g}	1.00^{cf}	10.67^{ac}	39.07^{fl}	7.33^{ab}	11.00^{a}
18	Gedo -11	6.67^{be}	58.00^{ch}	95.00^{bk}	172.00^{dj}	5.78^{ag}	34.33^{eg}	1.10^{ae}	10.67^{ac}	43.63^{ad}	7.33^{ab}	4.00^{jm}
19	Melkam	7.00^{ad}	57.33^{di}	100.33^{be}	202.00^{ae}	6.52^{a}	38.33^{cg}	1.03^{be}	10.17^{ac}	39.33^{el}	7.00^{ab}	2.00^{no}
20	ESH -1	7.00^{ad}	57.33^{di}	96.33^{bk}	143.67^{gk}	5.19^{el}	39.00^{bg}	1.00^{cf}	10.50^{ac}	40.87^{ci}	6.67^{ab}	8.00^{bd}
21	ESH-2	7.33^{ac}	57.33^{di}	94.33^{dk}	222.67^{ac}	5.19^{el}	40.33^{bf}	0.97^{cf}	9.67^{cf}	38.13^{hm}	6.67^{ab}	7.00^{cg}
22	Mesay	7.00^{ad}	57.00^{ei}	98.67^{bh}	166.67^{ek}	5.10^{el}	40.67^{bf}	1.03^{be}	10.83^{ac}	38.20^{hm}	7.67^{ab}	5.00^{hl}
23	Chare	7.00^{ad}	56.33^{fj}	100.33^{be}	238.00^{a}	6.07^{ad}	40.33^{bf}	1.03^{be}	9.83^{ce}	38.47^{gl}	6.67^{ab}	4.33^{im}
24	Dekeba	7.00^{ad}	55.67^{gk}	97.67^{bj}	150.67^{gk}	5.45^{ci}	42.00^{be}	1.03^{be}	9.50^{cf}	37.83^{im}	6.33^{b}	4.00^{jm}
25	Melkamash-79	6.00^{dg}	51.33^{lm}	99.00^{bg}	205.33^{ad}	5.39^{dj}	41.67^{be}	1.00^{cf}	9.50^{cf}	42.03^{ag}	6.67^{ab}	5.00^{hl}
26	ESH-3	7.67^{ab}	55.67^{gk}	94.67^{ck}	204.00^{ae}	5.57^{bi}	41.67^{be}	1.00^{cf}	9.50^{cf}	44.87^{ab}	7.33^{ab}	7.67^{be}
27	2005 MI5064	6.67^{be}	54.67^{hl}	98.33^{bh}	148.33^{gk}	5.04^{gl}	37.00^{cg}	0.81^{fg}	9.83^{ce}	41.67^{bh}	6.67^{ab}	2.67^{mo}
28	205MI5065	7.00^{ad}	54.00^{il}	96.33^{bk}	202.33^{ae}	5.90^{af}	36.67^{dg}	1.17^{ac}	9.50^{cf}	39.53^{ek}	6.67^{ab}	4.00^{jm}
29	PU209A/PRL021071	7.00^{ad}	53.67^{il}	99.33^{bg}	147.00^{gk}	6.31^{ab}	45.667^{ab}	1.07^{be}	8.50^{f}	45.27^{a}	7.33^{ab}	8.33^{bc}
30	PU209A/PU304	6.33^{cf}	53.33^{im}	96.33^{bk}	180.00^{dg}	5.93^{ae}	44.00^{ac}	1.00^{cf}	9.50^{cf}	44.03^{ac}	6.33^{b}	6.33^{eh}
31	ICSA15/AWN87	7.33^{ac}	63.33^{b}	102.33^{bg}	218.67^{ac}	5.30^{dk}	36.67^{dg}	1.00cf	10.83^{ac}	39.28^{el}	7.33^{ab}	6.33^{eh}
32	P9534A/Gambell1107	5.67^{eg}	53.00^{jm}	96.67^{bk}	174.67^{di}	5.33^{dk}	38.33^{cg}	0.97^{cf}	10.17^{ac}	39.27^{el}	6.67^{ab}	8.33^{bc}
33	Kari Mtama 1	6.67^{be}	52.67^{jm}	99.33^{bg}	197.67^{be}	4.83^{il}	42.00^{be}	0.67^{g}	10.33^{ac}	40.27^{dj}	6.33^{b}	5.00^{hl}
34	IESV23007DL	6.33^{cf}	52.33^{jm}	101.00^{bd}	149.33^{gk}	6.31^{ab}	39.33^{bf}	0.90^{ef}	11.33^{a}	34.93^{mn}	7.67^{ab}	4.33im
35	P9511A/PRL020817	7.67^{ab}	52.33^{jm}	95.00^{bk}	159.33^{fk}	6.34^{ab}	43.33^{ad}	0.967^{ef}	10.33^{ac}	42.23^{af}	7.00^{ab}	10.67^{a}
36	ETSC300001	7.33^{ac}	52.00^{km}	97.67^{bj}	172.00^{dj}	4.44^{l}	36.00$_{eg}$	0.97^{cf}	11.17^{ab}	30.73^{o}	6.33^{b}	6.00^{fi}

Table 6. Contd.

37	ETSC300002	6.33^{cf}	51.67^{km}	98.00^{bi}	231.33^{ab}	5.42^{cj}	38.67^{bg}	0.90^{ef}	10.17^{ac}	35.93^{ln}	7.67^{ab}	3.67^{km}
Grand mean		6.60	57.42	97.05	182.86	5.51	39.63	1.13	10.29	40.13	6.97	5.41
C.V (%)		9.47	3.60	3.56	10.54	7.56	8.97	12.42	9.45	3.80	9.54	5.98
R^2		0.72	0.89	0.79	0.82	0.74	0.54	0.66	0.63	0.89	0.44	0.91

S/N	VAR	PL	PW	NSPP	TSW	GL	GYPH	BYPH	HI	GYPDAY	BPR	SGR
1	Gambella 1107	24.33^{fj}	7.33^{bc}	2860.0^{gi}	32.83^{fk}	2.53^{fg}	2343.0^{gn}	8038.7^{cg}	30.97^{ad}	23.13^{gk}	80.23^{cf}	63.80^{ae}
2	76T1#23	24.00^{gj}	8.00^{ac}	1696.7^{r}	33.10^{ej}	2.50^{gh}	2062.7^{ln}	7371.2^{eg}	30.90^{ad}	22.70^{gk}	78.37^{df}	8.27^{ce}
3	Seredo	24.33^{fj}	9.33^{a}	2078.3^{nq}	36.10^{ad}	2.70^{bd}	2723.0^{bj}	9048.9^{ag}	30.47^{ad}	29.90^{ad}	101.40^{ac}	73.07^{ae}
4	Dinkmash	19.67^{k}	7.67^{bc}	3059.0^{eh}	36.27^{ad}	2.77^{ab}	2936.3^{af}	8897.8^{ag}	31.43^{ad}	72.23ae	29.50^{ae}	90.43^{af}
5	Meko	28.66^{be}	8.67^{ab}	2971.7^{fi}	33.10^{ej}	2.73^{ac}	3155.6^{ab}	10134.3^{a}	33.33^{a}	34.20^{a}	105.93^{a}	85.37^{a}
6	Abshir	28.00^{bg}	8.33^{ac}	3730.3^{b}	30.63^{km}	2.60^{dg}	2325.9^{hn}	7353.1^{fg}	30.20^{ad}	25.33^{dj}	77.90^{df}	59.93^{be}
7	Gobiye	28.33^{bf}	7.33^{bc}	2466.7^{jm}	33.43^{ei}	2.63^{cf}	2797.1^{bh}	8506.7^{ag}	29.80^{ad}	29.90^{ad}	90.13^{af}	63.77^{ae}
8	Teshale	26.67^{di}	8.33^{ac}	3049.7^{eh}	33.93^{dh}	2.63^{cf}	2281.5^{in}	8107.7^{bg}	27.83^{ad}	24.40^{dj}	84.07^{bf}	58.87^{be}
9	Yeju	25.00^{ej}	8.33^{ac}	2123.3^{mq}	28.50^{mn}	2.63^{cf}	2903.7^{af}	9089.4^{af}	29.80^{ad}	31.37^{ac}	98.76^{ad}	72.13^{ae}
10	Birhan	25.33^{ej}	7.00c	1955.3^{pr}	27.73^{no}	2.67^{be}	1920.0^{n}	8143.2^{bg}	28.57^{ad}	20.60^{ik}	83.83^{cf}	58.67^{be}
11	Abuare	25.33^{ej}	7.00^{c}	3394.3^{ce}	36.93^{ab}	2.70^{bd}	2447.4^{em}	7129.9^{g}	32.97^{ab}	24.03^{ej}	70.80^{ef}	57.27^{ce}
12	Hormat	25.67^{ej}	7.67^{bc}	2800.7^{gj}	30.87^{jm}	2.50^{gh}	2524.4^{dl}	9943.7^{ac}	26.03^{dc}	26.77^{ch}	103.73^{ab}	65.33^{ae}
13	Macia	27.00^{dh}	8.67^{ab}	3492.3^{bd}	32.10^{fk}	2.63^{cf}	3087.4^{ac}	8697.3^{ag}	33.37^{a}	32.13^{ac}	89.93^{af}	70.70^{ae}
14	Red Swazi	26.33^{di}	7.33^{bc}	2021.3^{or}	26.10^{op}	2.57^{eh}	2696.3^{bj}	9158.5^{af}	29.50^{ad}	29.90^{ad}	97.17^{ad}	66.20^{ae}
15	Raya	24.67^{ej}	8.33^{ac}	1857.0^{qr}	33.43^{ei}	2.57^{eh}	2240.0^{jn}	8000.0^{cg}	29.93^{ad}	18.17^{k}	70.03^{f}	52.63^{de}
16	Miskir	31.00^{ac}	7.33^{bc}	1815.7^{qr}	36.63^{ac}	2.53^{fh}	2880.0^{af}	9317.5^{ae}	29.43^{ad}	29.07^{ae}	94.17^{ad}	68.53^{ae}
17	Girana -1	27.67^{cg}	8.67^{ab}	1874.0^{qr}	30.70^{km}	2.63^{cf}	2317.0^{hn}	9403.5^{ad}	27.80^{ad}	25.10^{dj}	98.10^{ad}	75.00^{ac}
18	Gedo -11	28.33^{bf}	7.00^{c}	3412.0^{ce}	37.07^{ab}	2.67^{be}	2542.2^{dl}	8930.4^{ag}	29.13^{ad}	26.77^{ch}	92.47^{ad}	68.23^{ae}
19	Melkam	25.33^{ej}	8.67^{ab}	3119.7^{dh}	31.67^{hk}	2.50^{gh}	2942.2^{ae}	10017.8^{ab}	30.00^{ad}	29.40^{ae}	102.77^{ab}	80.93^{ab}
20	ESH -1	30.00^{ad}	8.00^{ac}	2647.3^{il}	24.80^{p}	2.47^{h}	2604.5^{ck}	8442.5^{ag}	31.00^{ad}	27.10^{ch}	86.30^{af}	63.20^{be}
21	ESH-2	24.67^{ej}	8.33^{ac}	2370.0^{ko}	35.27^{be}	2.57^{eh}	2797.0^{bh}	8423.7^{ag}	31.10^{ad}	29.70^{ad}	89.10	68.67^{ae}
22	Mesay	33.67^{a}	8.33^{ac}	2410.0^{kn}	37.77^{a}	2.60^{dg}	2637.0^{ck}	8369.4^{ag}	32.30^{ac}	26.77^{ch}	85.86^{af}	73.63^{af}
23	Chare	33.33^{a}	8.33^{ac}	2279.0^{lp}	28.70^{ln}	2.53^{fh}	2589.6^{ck}	9242.5^{af}	30.80^{ad}	73.53^{ad}	25.77^{di}	94.97^{ad}
24	Dekeba	31.67^{ab}	7.00^{c}	1983.3^{pr}	32.63^{fk}	2.70^{bd}	1961.5^{mn}	7499.3^{dg}	28.33^{ad}	50.83^{e}	20.07^{jk}	78.17^{df}
25	Melkamash-79	26.00^{ei}	8.67^{ab}	2941.0^{fi}	32.53^{fk}	2.53^{fg}	2817.8^{bh}	$9221.^{7af}$	30.57^{ad}	67.50^{ae}	28.47^{bf}	95.37^{ad}
26	ESH-3	30.00^{ad}	8.33^{ac}	2173.0^{mq}	31.67^{hk}	2.63^{cf}	2785.2^{bi}	9019.2^{ag}	30.70^{ad}	67.20^{ae}	29.60^{ae}	91.90^{ae}
27	2005 MI5064	28.00^{bg}	8.00^{ac}	2732.7^{hk}	32.00^{gk}	2.53^{fh}	3318.5^{a}	9677.0^{ac}	32.77^{ab}	85.53^{a}	33.73^{ab}	97.00^{ad}
28	205MI5065	23.33^{hk}	8.00^{ac}	3129.7^{dg}	32.13^{fk}	2.57^{eh}	2885.9^{af}	9080.5^{ag}	31.07^{ad}	78.73^{ac}	29.93^{ad}	95.17^{ad}
29	PU209A/PRL021071	25.00^{ej}	8.33^{ac}	3425.7^{ce}	32.17^{fk}	2.60^{dg}	2791.1^{bh}	8564.0^{ag}	31.90^{ad}	64.03^{ae}	28.33^{bf}	88.07^{af}
30	PU209A/PU304	23.33^{k}	7.67^{bc}	4874.3^{a}	33.20^{ej}	2.63^{cf}	2429.6^{fm}	8712.1^{ag}	29.43^{ad}	59.57^{be}	25.23^{dj}	89.93^{af}
31	ICSA15/AWN87	23.00^{hk}	7.67^{bc}	2735.0^{hk}	34.40^{cf}	2.60^{dg}	2850.4^{ag}	8522.1^{ag}	30.60^{ad}	67.13^{ae}	28.70^{ae}	80.47^{cf}

Table 6. Contd.

32	P9534A/Gambell1107	31.00ac	8.33ac	2902.0fi	32.83fk	2.77ab	2817.8bh	8190.6ag	32.20ad	64.30ae	29.17ae	84.33bf
33	Kari Mtama 1	22.67ik	8.00ac	3250.7cf	31.23ik	2.63cf	2435.6em	9449.9ad	25.93d	57.37ce	24.53dj	95.47ad
34	IESV23007DL	22.67ik	7.67bc	2812.7gj	24.37p	2.53fg	2974.8ad	8458.1ag	32.03ad	70.03ae	29.47ae	86.33af
35	P9511A/PRL020817	21.67jk	8.67ab	3558.3bc	30.93jl	2.53fh	2690.4bj	8448.4ag	30.53ag	61.97be	28.30bf	87.77af
36	ETSC300001	28.67be	7.67bc	2200.0mq	34.17dg	2.83a	2154.0kn	8744.7ag	26.83bd	61.07be	22.07hk	90.23af
37	ETSC300002	21.67jk	8.33ac	2400.0ko	25.17p	2.77ab	2699.3bj	8571.9ag	29.83ad	63.90ae	27.57cg	85.87af
Grand mean		26.38	8.01	2718.99	32.08	2.61	2631.51	8700.73	30.25	27.21	89.53	66.73
C.V (%)		5.41	9.82	7.3	4.54	9.64	9.64	11.11	10.29	16.43	10.22	11.87
R^2		0.80	0.45	0.94	0.89	0.72	0.72	0.47	0.35	0.45	0.73	0.50

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

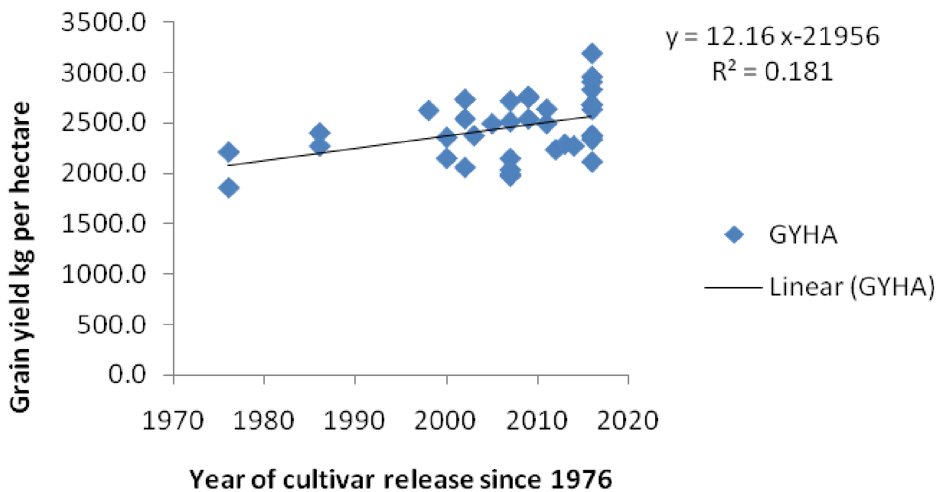

Figure 2. Relationship between year of cultivar release and grain yield over 2 locations.

significant G x E interaction, the direction of yield improvement was positive at both locations; 7.02 kg ha^{-1} year^{-1} at Sheraro and 17.3* kg ha^{-1} year^{-1} at Miesso.

Overall increase in grain yield over the older varieties was estimated to be 433.9 kgha^{-1} (17.56%) considering all varieties in the trial, whereas 1152.7 kgha^{-1} (36.1%) was obtained from variety P9534A/Gambella 1107 (Table 5). Hence, grain yield was found to increase substantially with the release of improved varieties (Figure 2). This agrees with the findings of Karmakar and Bhatnagar (1996) which reported a significant increase in grain yield of new soybean [*Glycine max* (L.) Merrill] cultivars over the older ones. Likewise, Mihret et al. (2015) reported that a significant increase in grain yield of new sorghum [Sorghum bicolor (L.) Moench] varieties over the early

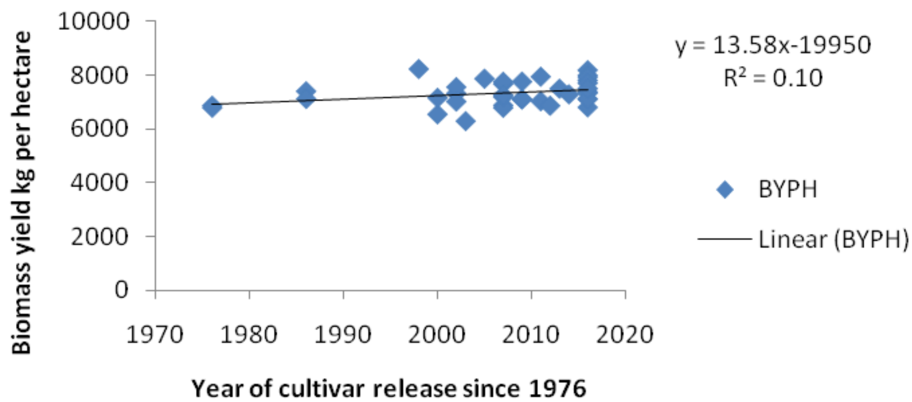

Figure 3. Relationship between the year of cultivar release and biomass yield at Sheraro and Miesso.

released cultivars. Similarly, Yifru and Hailu (2005) in tef [Eragrostis tef (Zucc.) Trotter], Tibebu (2011) in Chickpea (*Cicer arietinum* L.)., Kebere et al. (2006) in haricot bean (*Phaseolu vulgaris* L.) and Wondimu (2010) in food barley (*Hordeum vulgare* L.) who reported a substantial increment in grain yield of modern cultivars over the older ones.

There was no indication of a yield potential plateau in sorghum over the period studied indicating that the opportunity for breeders to further improve yields exists, and that continued progress towards that end may be expected. The average relative annual gain in grain yield of varieties since 1976 was 0.60% per year, or about 0.20% for the whole period of 40 years (Table 10). Present results indicated that plant breeders have made substantial progress for over the past 40 years in improving the yields of sorghum varieties in Ethiopia although; a yield fluctuation was occurring during the release of some of the varieties, Red Swazi (1991.1kg ha^{-1}) and Raya (1977.1kg ha^{-1}) released in (2007) showed yield reduction while, others showed a yield increment (Table 5).

Genetic improvement in biomass yield, harvest index and plant height

Mean biomass yields of varieties released in the years such as 1986, 1998, 2000, 2002, 2005, 2007, 2009, 2011, 2013, and 2016 exceeded that of the average of the first released older varieties. Moreover, Dinkmash by 431.8 kg ha-1(5.96%), Meko by 1400.1 kg ha-1(17.05%), Abshir, Gobiye by 20.3kg ha-1(0.30%), Teshale, Yeju and Birhan by 742.7kg ha-1(10.20%), Hormat by 1034.9 kgha-1 (13.18%), Macia, Red swazi and Raya by 430.8 kgha-1 (5.95%), Gedo, Melkam, ESH-1 &2 by 497.5 kgha-1 (6.81%), Messay, Chare by 6.58 kgha-1 (8.81%),Melkamash-79 by 669.6 kg ha^{-1} (8.95%), 2005MI504, 2005MI205 and ETSC300002 by 705.1 kg ha^{-1} (9.38%) (Table 9). The least and highest increases were 20.3kg ha-1(0.30%) and 1034.9 kgha-1 (13.18%, respectively, over varieties released in 1976 (Table 5). These indicated that there was a gradual increase in biomass yield across years of release although this increment was not consistent over years. The regression of the mean biomass yields of variety on the year of release indicated that there was 13.59** kg ha^{-1} year^{-1} average annual rate of increase (Figure 3). The increasing rate was 15.5 and 11.64*** kg ha^{-1} year^{-1} at Sheraro and at Miesso, respectively. There was positive significant trend of improvement in biomass over the last 40 years of sorghum improvement. The relative annual biomass yield increment in sorghum varieties was estimated to be 0.20% per year for the last 40 years (Table 10). The present result agrees with the findings of Daniel and Parzies (2011) in the study of genetic improvement of Sesame (*Sesamum indicum* L.) in Ethiopia. The authors reported higher biomass yield in recently developed varieties than in older ones. Similarly, Hailu et al. (2009) indicated that fodder yield of early-maturing soybean varieties can show a positive trend although not significant, the linear regression of fodder yield of variety means on year of release showed an increasing trend (22.81 kg ha^{-1} year^{-1}) during a 16 years period. Fano et al. (2016) also indicated that biomass yield in tef was greater in newer varieties and linearly related to variety age which positively and significantly correlated to grain yield. Contrary to these findings, Sinha et al. (1981) reported that breeding had failed to raise the biomass of wheat and the grain yield improvement was solely due to the result of higher harvest index and similarly, Wondimu (2010) reported a non-significant trend in biomass yield in food barley breeding program.

Although the difference between sorghum genotypes was statistically non-significant in the analysis due to the high G x E interaction, this difference was significant at Miesso. At this location, varieties released in the fourth and fifth decades had the highest harvest index (Table 7).

Table 7. Mean performance of characters from separate analysis of variance for sorghum varieties grown in the yield potential trial at Miesso.

S/N	VAR	DTE	DTF	DTM	PHT	HWT	GFP	NTPP	NLPP	FLL	FLW	PE
1	Gambella 1107	6.3^{ac}	70.7^{bc}	108.0^{ck}	137.0^{gk}	3.44^{cj}	40.0gm	1.00ac	10.3^{ad}	41.93^{ac}	5.0^{e}	5.7^{ac}
2	76T1#23	6.0^{ad}	69.7^{bc}	104.3^{fl}	125.7^{ik}	3.11^{gk}	48.0^{ad}	0.80^{be}	8.7^{df}	40.3^{af}	7.0^{ab}	3.3^{eh}
3	Seredo	6.3^{ac}	66.3^{cd}	101.3^{kl}	124.3^{ik}	3.02^{ik}	50.3^{ab}	1.00^{ac}	8.7^{df}	43.0^{a}	5.3^{de}	5.3^{ad}
4	Dinkmash	6.0^{ad}	70.0^{bc}	112.3^{be}	131.7^{hk}	3.35^{ck}	38.7^{jm}	0.73^{ce}	9.3 ^{bf}	26.8^{g}	6.3^{ad}	2.7^{gh}
5	Meko	6.0^{ad}	66.7^{cd}	102.0^{jl}	148.33^{fj}	3.05^{hk}	49.7^{ac}	0.87^{ae}	9.3^{bf}	40.9^{ae}	5.7^{ce}	2.0^{h}
6	Abshir	5.7^{bd}	70.7^{bc}	102.0^{jl}	139.7^{gk}	3.62^{bg}	41.7^{el}	0.93^{ad}	8.3^{ef}	39.4^{af}	6.3^{ad}	5.0^{ae}
7	Gobiye	6.7^{ab}	71.0^{bc}	103.3^{hl}	113.3^{k}	3.26^{ek}	45.3^{bg}	0.80^{be}	8.0^{f}	40.5^{af}	6.3^{ad}	4.3^{cg}
8	Teshale	5.0^{d}	68.7^{bc}	103.7^{gl}	162.0^{ei}	4.12^{b}	42.3^{el}	0.93^{ad}	9.3^{bf}	41.6^{ad}	5.3^{de}	5.7^{ac}
9	Yeju	6.0^{ad}	59.3^{d}	102.7^{il}	136.7^{gk}	3.56^{ci}	51.0^{a}	0.87^{ae}	9.7^{bf}	38.9^{af}	5.7^{ce}	4.3^{cg}
10	Birhan	6.7^{ab}	71.7^{bc}	106.3^{dl}	145.0^{fk}	3.23^{ek}	46.7^{af}	0.93^{ad}	8.3^{ef}	42.3^{ab}	6.0^{be}	3.7^{dh}
11	Abuare	6.7^{ab}	77.3^{ab}	111.7^{bf}	161.3^{ei}	3.08^{gk}	41.7^{el}	1.13^{a}	9.0^{cf}	39.9^{af}	6.7^{ac}	5.7^{ac}
12	Hormat	6.0^{ad}	67.3^{cd}	104.3^{fl}	153.3^{fj}	3.26^{ek}	42.7^{ek}	0.93^{ad}	9.3^{bf}	39.1^{af}	6.0^{be}	5.0^{ae}
13	Macia	6.0^{ad}	72.3^{bc}	106.3^{dl}	141.7^{gk}	2.90^{jk}	41.3^{fl}	0.80^{be}	8.7^{df}	38.6^{af}	7.3^{a}	4.3^{cg}
14	Red Swazi	6.0^{ad}	67.0^{cd}	100.3^{l}	114.3^{k}	2.85^{k}	47.0^{ae}	0.87^{ae}	8.3^{ef}	39.5^{af}	5.7^{ce}	3.3^{eh}
15	Raya	6.3^{ac}	84.7^{a}	125.0^{a}	190.3^{ae}	3.89^{bc}	35.3^{m}	1.00^{ac}	11.7^{a}	38.5^{af}	6.7^{ac}	6.0^{ac}
16	Miskir	5.7^{bd}	69.7^{bc}	109.3^{cj}	151.0^{fj}	3.26^{ek}	40.3^{gm}	0.73^{ce}	9.7^{bf}	43.7^{a}	6.3^{ad}	2.3^{h}
17	Girana -1	5.7^{bd}	76.0^{bc}	102.0^{jl}	190.3^{ae}	3.35^{ck}	37.7^{km}	0.87^{ae}	10.0^{ae}	38.5^{af}	6.7^{ac}	6.7^{a}
18	Gedo -11	5.7^{bd}	70.7^{bc}	105.0^{el}	169.7^{bg}	3.23^{ek}	37.0^{lm}	1.07ab	10.7^{ac}	43.0^{a}	6.3^{ad}	6.0^{ac}
19	Melkam	6.3^{ac}	74.3^{bc}	110.3^{ch}	156.3^{fj}	3.59^{ch}	40.0^{gm}	0.93^{ad}	9.7^{bf}	38.1^{af}	6.3^{ad}	3.3^{eh}
20	ESH -1	6.3^{ac}	71.7^{bc}	114.7^{bc}	146.0^{fk}	3.47^{ci}	40.0^{gm}	0.87^{ae}	9.3^{bf}	39.4^{af}	6.0^{be}	3.7^{dh}
21	ESH-2	6.0^{ad}	72.7^{bc}	104.3^{fl}	190.0^{ae}	3.76^{be}	40.0^{gm}	0.87^{ae}	9.0^{cf}	38.1^{af}	5.7^{ce}	6.3^{ab}
22	Mesay	6.7^{ab}	73.0^{bc}	109.0^{cj}	144.0^{fk}	3.35^{ck}	41.3^{fl}	0.93^{ad}	9.7^{bf}	43.7^{a}	6.7^{ac}	3.3^{eh}
23	Chare	5.7^{bd}	76.0^{bc}	113.3^{bd}	167.3^{cg}	3.62^{bg}	39.0^{im}	1.13^{a}	9.7^{bf}	37.9^{af}	6.7^{ac}	3.3^{eh}
24	Dekeba	5.7^{bd}	70.7^{bc}	109.0 ^{cj}	141.7^{gk}	3.17^{gk}	39.7^{hm}	0.80^{be}	9.7^{bf}	43.6^{a}	5.3^{de}	3.3^{eh}
25	Melkamash-79	6.3^{ac}	72.0^{bc}	109.0^{cj}	154.0^{fj}	3.88^{bc}	40.7^{gm}	0.87^{ae}	9.7^{bf}	34.1^{f}	6.7^{ac}	5.0^{ae}
26	ESH-3	6.7^{ab}	68.0^{bd}	104.7^{fl}	139.0^{gk}	3.05^{hk}	44.3^{di}	0.93^{ad}	9.0^{cf}	37.9^{af}	6.7^{ac}	5.0^{ae}
27	2005 MI5064	5.7^{bd}	74.7^{bc}	108.3^{ck}	169.3^{bg}	3.82^{bd}	41.7^{el}	0.67^{de}	9.7^{bf}	37.8^{af}	6.3^{ad}	3.0^{fh}
28	205MI5065	6.3^{ac}	74.7^{bc}	106.3^{dl}	212.3^{a}	3.73^{bf}	37.7^{km}	1.00^{ac}	9.7^{bf}	39.0^{af}	5.3^{de}	4.7^{bf}
29	PU209A/PRL021071	6.0^{ad}	73.7^{bc}	109.3^{cj}	131.0^{hk}	3.20^{fk}	44.0^{dj}	1.00ac	8.7^{df}	37.7^{af}	5.7^{ce}	5.0^{ae}
30	PU209A/PU304	6.0^{ad}	71.3^{bc}	107.0^{dl}	129.0^{ik}	3.32^{dk}	45.0^{ch}	0.87^{ae}	9.7^{bf}	39.2^{af}	6.3^{ad}	5.7^{ac}
31	ICSA15/AWN87	6.0^{ad}	77.3^{bc}	118.3^{b}	195.0^{ad}	3.44^{cj}	41.3^{fl}	0.87^{ae}	10.3^{ad}	36.3^{bf}	7.0^{ab}	5.3^{ad}
32	P9534A/Gambell1107	5.7^{bd}	71.3^{bc}	106.7^{dl}	198.7^{ac}	5.16^{a}	42.0^{el}	0.87^{ae}	10.0^{ae}	35.4^{cf}	5.3^{de}	6.0^{ac}
33	Kari Mtama 1	5.3^{cd}	73.3^{bc}	109.3^{cj}	175.3^{bf}	3.85^{bd}	40.0^{gm}	0.60^{e}	10.0^{ae}	43.4^{a}	6.0^{be}	2.3^{h}
34	IESV23007DL	6.0^{ad}	73.0^{bc}	111.0^{cg}	163.7^{dh}	3.59^{ch}	39.7^{hm}	0.87^{ae}	11.0^{ab}	35.0^{df}	6.7^{ac}	2.7^{gh}
35	P9511A/PRL020817	7.0^{a}	66.3^{cd}	104.3^{fl}	149.3^{fj}	3.02^{ik}	44.3^{di}	0.93^{ad}	9.3^{bf}	34.7^{ef}	6.0^{be}	6.3^{ab}
36	ETSC300001	6.7^{ab}	75.3^{bc}	107.7^{cl}	201.0^{ab}	3.35^{ck}	40.7^{gm}	0.87^{ae}	11.0^{ab}	34.6^{ef}	5.3^{de}	6.0^{ac}

Table 7. Contd.

37	ETSC300002	5.3^{cd}	72.7^{bc}	110.0^{ci}	189.7^{ae}	3.35^{ck}	40.0^{gm}	0.80^{bee}	9.7^{bf}	40.7^{af}	7.0^{ab}	3.7^{dh}
	Grand mean	6.06	71.56	101.69	156.44	5.51	42.11	0.89	9.51	39.01	6.15	4.47
	C.V (%)	10.41	6.65	3.5	10.55	7.97	6.56	18.04	9.29	8.43	10.13	21.88
	R^2	0.43	0.53	0.73	0.78	0.78	0.78	0.44	0.55	0.62	0.59	0.73

S/N	**VAR**	PL	PW	NSPP	TSW	GL	GYPH	BYPH	HI	GYPD	BPR	SGR
1	Gambella 1107	25.0^{dk}	9.3^{cf}	2675.0^{eh}	23.5^{el}	2.10^{ch}	2085.3^{em}	5656.8^{b}	38.17^{af}	19.30^{gm}	52.73^{b}	53.64^{ac}
2	76T1#23	26.7^{bh}	10.03^{ce}	2954.3^{df}	25.8^{af}	2.07^{dh}	1659.3^{mo}	6179.3^{ab}	35.57^{bf}	15.93^{lo}	57.83^{ab}	50.79^{bc}
3	Seredo	24.7^{ek}	7.3^{f}	1891.0^{fh}	22.3^{im}	2.03^{ei}	1822.2^{kn}	5721.8b	32.33^{df}	18.07^{in}	57.57^{ab}	37.26^{c}
4	Dinkmash	30.3^{ab}	9.7^{cf}	3552.3^{ae}	25.0^{bh}	2.23^{ae}	1869.6^{jn}	5304.7^{b}	38.67^{ae}	16.67^{ko}	47.23^{b}	53.80^{ac}
5	Meko	24.0^{gl}	9.3^{cf}	2711.0^{eg}	27.8^{a}	2.27^{ad}	2094.8^{em}	6288.9^{ab}	34.77^{bf}	20.60^{el}	59.47^{ab}	47.12^{c}
6	Abshir	28.7^{ae}	9.0^{cf}	3389.0^{be}	22.8^{gm}	2.33^{ab}	1977.4^{hn}	5706.7^{b}	38.93^{ae}	19.40^{gl}	52.80^{b}	54.28^{a}
7	Gobiye	28.3^{af}	8.7^{df}	4233.3^{ab}	23.5^{el}	2.20^{af}	1920.1^{in}	5776.6^{b}	35.67^{bf}	18.57^{hm}	54.97^{b}	45.24^{c}
8	Teshale	21.7^{km}	10.0^{ce}	3041.0^{bf}	25.5^{af}	2.13^{bh}	2803.0^{bc}	6507.1^{ab}	40.83^{ad}	27.10^{b}	61.03^{ab}	63.62^{ac}
9	Yeju	24.0^{gl}	9.0^{cf}	1568.3^{h}	24.2^{ck}	2.27^{ad}	2566.8^{be}	5993.4^{b}	43.73^{ab}	25.00^{be}	58.67^{ab}	54.97^{ac}
10	Birhan	26.0^{cj}	7.7^{ef}	3555.3^{ae}	25.2^{bg}	2.07^{dh}	2204.4^{dl}	5864.2^{b}	37.30^{af}	20.70^{el}	54.93^{b}	48.38^{bc}
11	Abuare	24.7^{ek}	9.0^{cf}	3211.7^{be}	22.7^{gm}	2.13^{bh}	2305.2^{ck}	5424.0^{b}	41.30^{ad}	20.67^{el}	49.50^{b}	54.19^{ac}
12	Hormat	24.3^{fl}	9.3^{cf}	2896.3^{df}	24.5^{ck}	2.20^{af}	2465.2^{bh}	5757.0^{b}	42.23^{ac}	23.60^{bg}	54.23^{b}	57.80^{ac}
13	Macia	27.7^{bg}	9.3^{cf}	3618.3^{ae}	25.2^{bg}	1.93^{hi}	1942.5^{in}	5029.1^{b}	39.67^{ad}	18.27^{in}	47.23^{b}	47.02^{c}
14	Red Swazi	25.3^{dk}	8.0^{ef}	2801.0^{eg}	21.2^{ln}	2.13^{bh}	1285.9^{o}	6154.4^{ab}	29.50^{ef}	12.80^{o}	58.50^{ab}	41.99^{c}
15	Raya	22.3^{im}	10.7^{bd}	1879.7^{fh}	27.2^{ab}	2.00^{fi}	1714.3^{lo}	5542.7^{b}	33.03^{cf}	13.73^{no}	47.43^{b}	48.06^{bc}
16	Miskir	26.3^{bi}	8.0^{ef}	2826.3^{eg}	25.0^{bh}	2.20^{af}	2560.1^{be}	6162.2^{ab}	41.07^{ad}	23.43^{bg}	56.33^{b}	62.62^{ac}
17	Girana -1	24.3^{fl}	11.3^{ac}	2721.7^{eg}	20.5^{mn}	2.20^{af}	1982.0^{gn}	4953.6^{b}	38.20^{af}	19.47^{fl}	46.37^{b}	50.50^{bc}
18	Gedo -11	26.7^{bh}	10.7^{bd}	3484.0^{be}	22.0^{kn}	2.13^{bh}	1534.8^{no}	5557.7^{b}	35.93^{bf}	14.63^{mo}	52.03^{b}	52.78^{ac}
19	Melkam	28.0^{ag}	12.3^{ab}	3086.7^{bf}	24.7^{cj}	2.20^{af}	2560.0^{be}	5468.4^{b}	42.40^{ac}	23.20^{bh}	50.70^{b}	58.79^{ac}
20	ESH -1	32.0^{a}	11.0^{bd}	3733.3^{ae}	25.8^{af}	2.07^{dh}	2477.6^{bg}	5724.6^{b}	41.93^{ad}	21.60^{dj}	50.63^{b}	60.20^{ac}
21	ESH-2	26.7^{bh}	9.7^{cf}	3920.3^{ae}	26.3^{ad}	1.87^{i}	2736.3^{bc}	5780.5^{b}	42.06^{ac}	26.30^{bd}	55.17^{b}	63.94^{ac}
22	Mesay	26.3^{bi}	9.3^{cf}	3798.0^{ae}	25.2^{bg}	2.10^{ch}	2355.6^{cj}	5659.5^{b}	39.73^{ad}	21.70^{dj}	52.73^{b}	60.30^{ac}
23	Chare	20.3^{lm}	10.7^{bd}	3043.7^{bf}	25.7^{af}	1.97^{gi}	2686.7^{bd}	6608.3^{ab}	39.33^{ad}	23.70^{bg}	59.73^{ab}	64.00^{ac}
24	Dekeba	29.7^{ac}	10.0^{ce}	3345.0^{be}	25.0^{bh}	2.17^{ag}	2514.1^{bf}	6201.0^{ab}	36.67^{af}	21.27^{ek}	55.13^{b}	56.33^{ac}
25	Melkamash-79	27.3^{bg}	9.7^{cf}	3610.3^{ae}	24.2^{ck}	2.37^{a}	1765.3^{ln}	5740.4^{b}	29.00^{f}	16.20^{lo}	53.60^{b}	40.62^{c}
26	ESH-3	29.0^{ad}	9.0^{cf}	3430.7^{be}	22.2^{jm}	2.10^{ch}	1763.8^{ln}	5524.0^{b}	39.13^{ad}	16.87^{jo}	50.83^{b}	53.82^{ac}
27	2005 MI5064	24.0^{gl}	9.7^{cf}	3766.3^{ae}	26.7^{ac}	2.10^{ch}	2345.7^{cj}	6657.9^{ab}	38.47^{af}	21.63^{dj}	60.13^{ab}	64.68^{ac}
28	205MI5065	23.0^{hm}	9.3^{cf}	2905.0^{df}	24.8^{bi}	2.03^{ei}	2930.4^{b}	6501.8^{ab}	46.13^{a}	27.63^{b}	61.77^{ab}	79.91^{a}
29	PU209A/PRL021071	28.3^{af}	9.0^{cf}	4205.3^{ac}	22.5^{hm}	2.17^{ag}	1970.3^{hn}	5013.3^{b}	37.33^{af}	18.07^{in}	46.67^{b}	44.27^{c}
30	PU209A/PU304	29.0ad	9.7^{cf}	4129.7^{ad}	24.8^{bi}	2.07^{dh}	1804.4^{kn}	5491.1^{b}	37.20^{af}	16.93^{jo}	51.60^{b}	51.11^{bc}
31	ICSA15/AWN87	27.7^{bg}	10.7^{bd}	2985.0^{cf}	26.0^{ae}	2.07^{dh}	2417.6^{ci}	6194.3^{ab}	35.23^{bf}	22.13^{ci}	54.43^{b}	57.91^{ac}

Table 7. Contd.

32	P9534A/Gambell1107	29.0^{ad}	10.7^{bd}	2761.7^{eg}	25.0^{bh}	2.17^{ag}	3562.9^{a}	7754.2^{a}	39.27^{ad}	33.37^{a}	72.23^{a}	75.62^{ab}
33	Kari Mtama 1	25.0^{dk}	10.0^{ce}	3376.3^{be}	23.8^{dk}	2.17^{ag}	2925.4^{b}	6373.2^{ab}	38.97^{ae}	26.73^{bc}	58.53^{ab}	63.70^{ac}
34	IESV23007DL	22.0^{jm}	9.3^{cf}	4739.7^{a}	24.3^{ck}	2.30^{ac}	2942.2^{b}	6186.2^{ab}	40.70^{ad}	26.50^{bc}	56.73^{b}	63.58^{ac}
35	P9511A/PRL020817	28.0af	9.7^{cf}	3625.3^{ae}	23.3^{fl}	2.07^{dh}	2047.4^{fm}	5745.7^{b}	36.30^{bf}	19.67^{fl}	54.10^{b}	51.04^{bc}
36	ETSC300001	19.7^{m}	9.7^{cf}	1648.0^{gh}	19.8^{n}	2.10^{ch}	2521.5^{bf}	6629.9^{ab}	38.83^{ae}	23.43^{bg}	61.70^{ab}	59.15^{ac}
37	ETSC300002	24.3^{fl}	13.3^{a}	2762.0^{eg}	23.5^{el}	2.10^{ch}	2668.4^{bd}	6399.0^{ab}	40.63^{ad}	24.27^{bf}	57.20^{b}	65.57^{ac}
Grand mean		25.95	9.70	3186.00	24.26	2.13	2264.55	5925.23	38.28	21.06	54.93	55.64
C.V (%)		7.99	12.18	19.28	5.24	4.82	11.33	14.29	12.48	21.06	13.76	25.09
R^2		0.74	0.6	0.67	0.75	0.62	0.84	0.39	0.46	0.83	0.42	0.40

First and last letter associated with a Variety. All letters between these two letters are also associated with the variety. DTE=days to emergence, DTF=days to flowering, DTM=days to physiological maturity, PHT= plant height (cm), HWT=head weight tons per hectare), GFP=grain filling period, NTPP= number of productive tillers, NLPP= Number of leaves per plant (main stem), FLL=flag leaf length(cm) FLW=flag leaf width(cm), PE= panicle exertion(cm), PL=panicle length(cm), PW=panicle width(cm), NSPP=Number of seeds per panicle, TSW=Thousand seed weight(gram), GL= grain length(mm), GYH = grain yield kg per hectare, BYH= biological yield kg per hectare, HI= harvest index in percent.

In combined analysis, the highest harvest index was recorded for varieties, 34(IESV23007DL) released in 2016 (42.0%), P9534A/Gambella 1107(41.6%) released in 2016, 21(ESH-2) (40.8%) released in 2009, and 19(Melkam) (38.6%) released in 2009 (Table 8).

Genotypes 1(Gambella1107) and 2(76T1# 23), which were released in 1976 had harvest index of 33.2 and 28.6% (Table 8), respectively; at Miesso higher harvest index is associated with higher grain yield. Harvest index was increased by 0.12% year^{-1} in the combined analysis (Figure 4). It was increased by 0.25%* at Sheraro, but declined by 0.059% at Miesso (Table 10); this is the consequence of the highly significant G x E interaction. The present finding is similar to the findings of Tafesse et al. (2011) that reported newer sesame varieties had high harvest index; harvest index was improved at an annual rate of 0.97% year^{-1} over a period of 47 years. Similarly, Wondimu (2010) showed that newer food barley varieties developed in Ethiopia had higher harvest index and the regression slope of the trait over years of release was 0.004. Jin et al. (2010) reported that harvest index increased significantly with year of release, averaging 0.40% per year, rising from 0.31 to 0.38 for soybean cultivars released from 1950 to 2006 in Northeast China. In the same way, yield potential improvement in bread wheat produced marked positive change in harvest index (0.42% year^{-1}) in Ethiopia (Amsal, 1994). In contrary, Fano et al. (2016) in tef, Kebere, et al. (2006) in haricot bean and Tamene (2008) in faba bean who have reported that harvest index was not steadily changed with the year of release of the varieties in the respective crops they investigated. Likewise, Era et al. (2009) also reported that soybean varieties did not show significant differences for harvest index over the period of the genetic improvement. Besides the increment in biomass, there was also a consistent gradual increment in plant height from the older to the newer varieties.

Genetic improvement in growth parameters

PHT was increased by 1.05*** cm year^{-1} (Figure 5). The same tendency was observed at Sheraro (0.90 cm year^{-1}) and at Miesso (1.20 cm year^{-1}). NTPP was reduced by 0.003* tillers plant^{-1} year^{-1} (Table 10). It was reduced by 0.005* and by 0.001 tillers plant^{-1} year^{-1} at Sheraro and at Miesso, respectively. PE was extended (increased) by 0.04* cm year^{-1}. This increment was 0.07* cm and 0.01 cm year^{-1} at Sheraro and at Miesso, respectively. PW was improved by 0.02* cm year^{-1} over the two locations. This improvement was 0.003 cm year^{-1} and 0.03* cm year^{-1} at Sheraro and at Miesso, respectively. There was a tendency for number of leaves plant^{-1} to increase over time. It increased by 0.01, 0.02* and 0.02 leaves plant^{-1} year^{-1}, at Sheraro, Miesso and over locations (Table 10).

PL and FLW had non-significant positive slope; there was a tendency to increase over time, but this increment was statistically non-significant. FLL remained unchanged over time, although there was a tendency of decrease in FLL at Sheraro and in the combined analysis.

A combined analysis averaged over both locations indicated that there was highly significant

Table 8. Mean values of different traits from combined analysis of variance for sorghum varieties in the yield potential trials at Sheraro and Miesso, 2016 cropping season.

S/N	Variety	Trait									
		DTE	DTF	DTM	PHT	HWT	GFP	NTPP	NLPP	FLL	FLW
1	Gambella 1107	5.8^{eg}	66.17^{bf}	104.7^{bf}	133.67^{lm}	4.98^{ac}	40.2^{di}	1.1^{ad}	10.8^{ac}	40.7^{ci}	5.7^{g}
2	76T1#23	5.7^{fg}	$61 .00^{fk}$	97.7^{jl}	133.67^{lm}	4.21^{jn}	43.8^{af}	0.9^{df}	8.5^{f}	41.6^{ah}	6.8^{ae}
3	Seredo	6.0^{dg}	58.83^{jl}	96.3^{kl}	128.33^{m}	4.04^{lo}	45.8^{ab}	1.2^{ab}	8.7^{ef}	39.2^{el}	6.3^{cg}
4	Dinkmash	6.3^{bf}	65.7^{bg}	107.3^{be}	155.50^{fl}	4.79^{ah}	38.5^{fj}	0.9^{df}	10.5^{ac}	36.8^{im}	6.5^{ae}
5	Meko	5.8^{eg}	59.67^{il}	97.0^{jl}	185.33^{bd}	4.43^{el}	44.8^{ad}	0.9^{df}	9.8^{ce}	38.8^{fl}	6.5^{bg}
6	Abshir	5.3^{g}	63.17^{ck}	97.0^{jl}	183.33^{be}	4.25^{in}	39.2^{ej}	0.9^{df}	8.7^{ef}	44.6^{ab}	7.0^{ad}
7	Gobiye	6.0^{dg}	62.83^{dk}	98.3^{il}	157.50^{fl}	4.77^{ah}	42.2^{ah}	1.0^{cf}	8.5^{f}	41.7^{bh}	6.7^{bf}
8	Teshale	6.0^{dg}	62.83^{dk}	98.7^{hl}	148.67^{hm}	4.55^{gl}	39.7^{ej}	1.0^{cf}	10.0^{bd}	33.3^{no}	6.2^{dg}
9	Yeju	6.3^{bf}	55.67^{l}	97.7^{jk}	137.00^{km}	4.39^{em}	43.3^{a}	0.9^{df}	9.8^{ce}	37.0^{jm}	6.3^{cg}
10	Birhan	7.3^{a}	62.50^{ek}	99.8^{fl}	166.67^{dj}	3.88^{no}	42.2^{af}	1.3^{a}	8.8^{df}	37.3^{im}	6.2^{dg}
11	Abuare	7.3^{a}	68.17^{bc}	106.7^{bd}	170.33^{di}	4.44^{el}	42.0^{ag}	1.2^{ab}	10.0^{bd}	40.4^{dj}	6.7^{bf}
12	Hormat	6.0^{dg}	60.33^{hl}	99.3^{gl}	179.00^{cg}	4.40^{el}	40.8^{ah}	1.0^{be}	10.5^{ac}	38.3^{hm}	6.5^{bg}
13	Macia	6.5^{af}	64.33^{bi}	101.3^{ek}	183.33^{be}	4.28^{hn}	43.8^{bh}	1.0^{be}	9.7^{cf}	40.2^{dj}	7.7^{a}
14	Red Swazi	6.8^{ad}	58.33^{kl}	95.3^{l}	159.83^{ek}	3.73^{o}	43.0ae	1.0^{cf}	8.7^{ef}	36.1^{kn}	6.0^{eg}
15	Raya	5.7^{fg}	79.33^{a}	124.0^{a}	204.33^{ab}	4.80^{ag}	38.5^{ag}	1.2^{ac}	11.2^{ab}	42.8^{ae}	7.2^{ac}
16	Miskir	6.2^{cg}	66.17^{bf}	104.3^{bg}	142.33^{jm}	4.15^{ko}	35.7^{fj}	1.0^{cf}	9.7^{cf}	39.0^{fl}	6.5^{bg}
17	Girana -1	6.0^{dg}	68.00^{bd}	97.0^{jl}	204.33^{ab}	4.23^{gn}	$37.^{17j}$	1.0^{cf}	10.7^{ac}	39.1^{fl}	7.0^{ad}
18	Gedo -11	6.2^{cg}	65.67^{bf}	100.0^{fl}	170.83^{dh}	4.50^{cl}	39.3^{ij}	1.1^{ae}	10.7^{ac}	43.6^{ad}	6.8^{ae}
19	Melkam	6.7ae	68.17^{bj}	105.3^{be}	179.17^{cf}	5.05^{ab}	39.5^{ej}	1.0^{be}	10.2^{ac}	39.3^{el}	6.7^{bf}
20	ESH -1	6.7^{ae}	64.50^{bi}	105.5^{be}	144.83^{jm}	4.33^{fn}	40.2^{ej}	1.0^{cf}	10.5^{ac}	40.9^{ci}	6.3^{cg}
21	ESH-2	6.7^{ae}	63.33^{bj}	99.3^{gl}	206.33^{ab}	4.47^{dl}	41.2^{ci}	1.0^{cf}	9.7^{cf}	38.1^{hm}	6.2^{dg}
22	Mesay	6.8^{ad}	65.50^{bg}	103.8^{bg}	155.33^{fl}	4222.2^{jn}	39.8^{bh}	1.0^{be}	10.8^{ac}	38.2^{hm}	7.2^{ac}
23	Chare	6.3^{bf}	68.00^{bf}	106.8^{bc}	202.6^{ac}	4.85^{ad}	39.7^{ei}	1.0^{be}	9.8^{ce}	38.5^{gl}	6.8^{f}
24	Dekeba	6.3^{bf}	63.17^{ck}	107.8^{b}	146.17^{im}	4.31^{fn}	43.3^{bh}	1.0^{be}	9.5^{cf}	37.8^{im}	5.8^{fg}
25	Melkamash-79	6.2cg	64.67^{bi}	104.0^{bg}	179.67^{cf}	4.64^{bk}	39.0^{ah}	1.0^{cf}	9.5^{df}	42.0^{ag}	6.7^{bf}
26	ESH-3	7.2^{ab}	60.50^{gk}	99.7^{fl}	171.50^{dh}	4.31^{fn}	39.5^{ag}	1.0^{cf}	9.5^{cf}	44.9^{ab}	7.0^{ad}
27	2005 MI5064	6.2cg	68.00^{bd}	103.3^{bh}	158.83^{fk}	4.43^{el}	38.3^{ej}	0.8^{fg}	9.8^{ce}	41.7^{bh}	6.5^{bg}
28	205MI5065	6.7^{ae}	67.17^{be}	101.3^{ek}	207.33^{ab}	4.81^{ae}	45.2^{hj}	1.2^{ac}	9.5^{cf}	39.5^{ek}	6.0^{eg}
29	PU209A/PRL021071	6.5^{af}	63.67^{bj}	104.3^{bg}	139.00^{km}	4.76^{bi}	44.5^{ac}	1.1^{be}	8.5^{f}	45.3^{a}	6.5^{bg}
30	PU209A/PU304	6.2^{cg}	61.83^{fk}	101.7^{dj}	154.50^{gl}	4.62^{bk}	39.0^{ad}	1.0^{cf}	9.5^{cf}	44.0^{ac}	6.3^{cg}
31	ICSA15/AWN87	6.7^{ae}	68.00^{bd}	104.3^{bg}	206.83^{ab}	4.37^{en}	40.7^{ej}	1.0^{cf}	10.8^{ac}	39.3^{el}	7.2^{ac}
32	P9534A/Gambell1107	5.7^{fg}	64.83^{bh}	101.7^{dj}	186.67^{ad}	5.24^{a}	41.0^{ci}	1.0^{cf}	10.2^{ac}	39.3^{el}	6.0^{eg}
33	Kari Mtama 1	6.0^{dg}	65.33^{bh}	104.3^{bg}	186.50^{ad}	4.34^{en}	39.5^{bh}	0.7^{g}	10.3^{ac}	40.3^{dj}	6.2^{dg}
34	IESV23007DL	6.2^{cg}	67.33^{be}	106.0^{be}	156.50^{fl}	4.95^{ad}	44.5^{ej}	0.9^{ef}	11.3^{a}	34.9^{mn}	7.2^{ac}
35	P9511A/PRL020817	7.3^{a}	59.00^{jl}	99.7^{fl}	154.33^{hl}	4.68^{bj}	38.5^{ae}	1.0^{cf}	10.3^{ac}	42.2^{af}	6.5^{bg}

Table 8. Contd.

36	ETSC300001	7.0^{ac}	68.50^{b}	102.7^{ci}	186.50^{ad}	3.90^{mo}	39.3^{gj}	1.0^{cf}	11.2^{ab}	30.7^{o}	5.8^{fg}
37	ETSC300002	5.8^{eg}	66.00^{bf}	104.0^{bg}	210.50^{a}	4.39^{em}	41.8^{ej}	0.9^{ef}	10.2^{ac}	35.9^{ln}	7.3^{ab}
	Grand mean	6.33	64.49	102.35	169.65	4.43	40.87	1.01	9.90	39.57	6.65
	CV (%)	9.85	5.71	3.51	10.54	8.04	8.34	14.90	9.39	6.45	9.88
	R^2	0.66	0.89	0.87	0.83	0.94	0.65	0.69	0.63	0.74	0.62

S/N	Variety	PE	PL	PW	NSPP	TSW	GL	GYPH	BYPH	HI	GYPDAY	BYPR	SGR
1	Gambella 1107	3.50^{ik}	24.7^{ik}	8.3^{dg}	2767.5^{ei}	28.2^{em}	2.3^{fh}	2214.2^{in}	6847.8^{ce}	33.17^{ch}	21.22^{hj}	65.88^{dg}	55.90^{gl}
2	76T1#23	4.33^{gi}	25.3^{hk}	9.0^{cf}	2325.5^{ij}	29.5^{ce}	2.3^{gi}	1861.0^{o}	6775.2^{ce}	28.58^{hi}	19.32^{j}	70.75^{bf}	44.06^{l}
3	Seredo	5.17^{eg}	24.5^{jk}	8.3^{dg}	1984.7^{j}	29.2^{cf}	2.4^{eg}	2272.6^{hn}	7385.4^{ae}	30.90^{fi}	23.98^{ei}	77.95^{ae}	52.72^{il}
4	Dinkmash	2.67^{k}	28.2^{ag}	8.7^{cg}	3305.7^{be}	25.1^{o}	2.5^{ad}	2403.0^{dk}	7101.2^{ae}	34.25^{ch}	23.08^{fi}	68.22^{bf}	62.68^{di}
5	Meko	2.67^{k}	26.3^{dk}	9.0^{cf}	2841.3^{di}	32.1^{a}	2.5^{ac}	2625.2^{bh}	8211.6^{a}	32.15^{ch}	27.40^{be}	86.02^{a}	61.09^{ei}
6	Abshir	5.83^{cf}	28.3^{af}	8.7^{cg}	3559.7^{bc}	28.0^{em}	2.5^{ab}	2151.6^{jo}	6529.9^{de}	33.47^{ch}	22.37^{gj}	68.07^{bf}	56.09^{gk}
7	Gobiye	3.83^{hk}	28.3^{af}	8.0^{eg}	3350.0^{bd}	27.1^{jn}	2.4^{cg}	2358.6^{fl}	7141.6^{ae}	33.67^{ch}	24.23^{di}	73.37^{ae}	57.32^{fk}
8	Teshale	7.17^{b}	21.7^{mo}	9.2^{be}	3045.3^{cg}	29.5^{ce}	2.4^{dg}	2542.2^{ci}	7307.4^{ae}	35.70^{ag}	25.75^{bg}	74.88^{ae}	64.71^{ci}
9	Yeju	5.17^{eg}	25.3^{hk}	8.7^{cg}	1845.8j	29.1^{ci}	2.5^{be}	2735.2^{bd}	7541.4^{ae}	37.55^{ae}	28.18^{ac}	78.28^{ae}	61.30^{ei}
10	Birhan	4.67^{fi}	25.5^{gk}	7.3^{cg}	2755.3^{ei}	26.8^{ko}	2.4^{eg}	2062.2^{ko}	7003.7^{ae}	31.25^{ei}	20.65^{ij}	71.50^{bf}	48.07^{kl}
11	Abuare	4.33^{gi}	25.0^{ik}	8.0^{eg}	3303.0^{be}	25.2^{o}	2.4^{cg}	2376.3^{el}	6277.0^{e}	38.42^{ad}	22.35^{gj}	59.37^{fg}	56.45^{gk}
12	Hormat	4.00^{gj}	24.8^{ik}	8.5^{eg}	2848.5^{ei}	30.7ac	2.5^{be}	2494.8^{cj}	7850.4^{ac}	34.13^{ch}	25.18^{ch}	80.27^{ab}	59.69^{ej}
13	Macia	4.33^{gi}	26.7^{dj}	9.0^{dg}	3555.3^{bc}	28.0^{em}	2.2^{hi}	2514.9^{ci}	6863.2^{be}	37.12^{af}	25.20^{bg}	68.95^{bf}	62.50^{di}
14	Red Swazi	4.67^{fi}	23.5^{kn}	7.7^{fg}	2411.2^{hj}	26.6^{lo}	2.4^{dg}	1991.1^{mo}	7656.5^{ad}	25.45^{i}	21.35^{hj}	81.57^{ab}	46.91^{kl}
15	Raya	6.67^{bc}	24.7^{ik}	9.5^{bd}	1868.3^{j}	26.7^{lo}	2.3^{gi}	1977.1^{no}	6771.4^{ce}	29.47^{gi}	15.95^{k}	54.67^{g}	47.13^{kl}
16	Miskir	3.67^{ik}	26.3^{dk}	7.7^{fg}	2321.0^{ij}	29.2^{cf}	2.4^{dg}	2720.0^{be}	7739.9^{ad}	36.37^{af}	26.25^{bf}	75.35^{ae}	71.75^{ae}
17	Girana -1	8.83^{a}	23.8^{jm}	10.0^{ac}	2297.8^{ij}	28.6^{dk}	2.4^{eg}	2149.5^{jo}	7178.5^{ae}	32.28^{dh}	22.28^{gj}	75.43^{ae}	62.50^{di}
18	Gedo -11	5.00^{eh}	25.7^{fk}	8.6^{cf}	3448.0^{bd}	26.4^{mo}	2.4^{df}	2038.5^{lo}	7244.1^{ae}	28.78^{hi}	20.70^{ij}	73.47^{ae}	57.82^{fk}
19	Melkam	2.67^{k}	29.5^{ac}	10.5^{ab}	3103.2^{cg}	30.9^{ac}	2.4^{bf}	2751.1^{bd}	7743.1^{ad}	38.55^{ac}	26.30^{bf}	75.03^{ae}	71.03^{ae}
20	ESH -1	5.83^{cf}	29.8^{ac}	9.5^{bd}	3190.3^{bg}	28.8^{dj}	2.3^{gi}	2541.0^{ci}	7083.5^{ae}	37.05^{af}	24.35^{di}	68.85^{bf}	64.80^{ci}
21	ESH-2	6.67^{bc}	27.5^{ci}	9.0^{cf}	3145.2^{cg}	25.6no	2.2^{i}i	2766.7^{bc}	7102.1^{ae}	40.75^{ab}	28.00^{ac}	72.40^{af}	69.12^{af}
22	Mesay	4.17^{gi}	25.8^{ek}	8.8^{cf}	3104.0^{cg}	30.2^{bd}	2.3^{eh}	2496.3^{cj}	7014.4^{ae}	36.47^{af}	24.23^{di}	68.38^{bf}	62.65^{di}
23	Chare	3.83^{hk}	21.8^{lo}	9.5^{bd}	2661.3^{fi}	31.7^{ab}	2.3^{gi}	2638.1^{bg}	7925.4^{ac}	34.38^{bh}	24.73^{ch}	75.22^{ae}	67.02^{cg}
24	Dekeba	3.67^{ik}	26.2^{dk}	8.5^{dg}	2664.2^{fi}	26.9^{ko}	2.4^{eg}	2237.8^{in}	6850.1^{ce}	33.25^{ch}	20.67^{ij}	64.57^{eg}	54.67^{hl}
25	Melkamash-79	5.00^{eh}	28.0^{bh}	9.2^{be}	3275.7^{bf}	29.2^{cg}	2.6^{a}	2291.6^{gn}	7481.1^{ae}	30.67^{fi}	22.33^{gj}	73.00^{ae}	55.86^{gl}
26	ESH-3	6.33^{bd}	29.5^{ac}	8.7^{cg}	2801.8^{ei}	27.4^{fn}	2.4^{cg}	2274.5^{hn}	7271.6^{ae}	31.88^{dh}	23.23^{fi}	74.30^{ae}	54.13^{hl}
27	2005 MI5064	2.83^{jk}	24.3^{jl}	8.8^{cg}	3249.5^{bf}	29.6^{ce}	2.3^{fh}	2832.1^{bc}	8167.5^{ab}	34.87^{bh}	27.68^{bc}	79.92^{ac}	53.67^{ad}
28	205MI5065	4.33^{gi}	28.3^{af}	8.7^{cg}	3017.3^{ch}	28.3^{el}	2.3^{eg}	2908.2^{ab}	7791.1^{ad}	38.43^{ad}	28.78^{ab}	77.77^{ae}	78.45^{ab}
29	PU209A/PRL021071	6.67^{bc}	30.8^{a}	8.7^{cg}	3815.5^{b}	27.3^{hn}	2.4^{eg}	2380.7^{el}	6788.6^{ce}	35.95^{ag}	23.20^{fi}	66.33^{cg}	53.67^{hl}
30	PU209A/PU304	6.00^{be}	30.3^{ab}	8.7^{cg}	4502.0^{a}	28.5^{dl}	2.3^{fh}	2117.0^{ko}	7101.6^{ae}	30.63^{fi}	21.08^{hj}	70.88^{bf}	48.47^{jl}

Table 8. Contd.

31	ICSA15/AWN87	5.83^{cf}	28.8^{ad}	9.2^{be}	2860.0^{di}	29.1^{ci}	2.3^{eh}	2634.0^{bg}	7358.2^{ae}	36.33^{af}	25.42^{bg}	71.20^{bf}	68.59^{af}
32	P9534A/Gambell1107	7.17^{b}	28.5^{ae}	9.5^{bd}	2831.8^{di}	29.1^{ci}	2.4^{cg}	3190.3^{a}	7972.4^{ac}	41.58^{a}	31.27^{a}	78.65^{ad}	79.79^{a}
33	Kari Mtama 1	3.67^{ik}	25.0^{ik}	9.0^{cf}	3313.5^{be}	29.1^{ch}	2.4^{dg}	2680.5^{bf}	7911.6^{ac}	36.05^{af}	25.63^{bg}	76.75^{ae}	65.77^{ch}
34	IESV23007DL	3.50^{ik}	20.8^{o}	8.5dg	3776.2^{b}	28.6^{dk}	2.5^{ab}	2958.5^{ab}	7322.1^{ae}	42.03^{a}	27.98^{ac}	69.75^{bf}	75.23^{ac}
35	P9511A/PRL020817	8.50^{a}	29.5^{ac}	9.2^{be}	3591.8^{bc}	27.3^{gn}	2.4^{eg}	2368.9^{el}	7097.0^{ae}	33.80^{ch}	23.98^{ei}	71.98^{bf}	54.30^{hl}
36	ETSC300001	6.00^{be}	21.17^{no}	8.7^{cg}	1924.0^{j}	22.1^{p}	2.3^{fh}	2337.8^{fm}	7687.3^{ad}	31.60^{ei}	22.75^{fj}	75.60^{ae}	61.23^{ei}
37	ETSC300002	3.67^{ik}	23.7^{kn}	10.8^{a}	2581.0^{gi}	27.2^{in}	2.3^{fh}	2683.8^{bf}	7485.5^{ae}	36.98^{af}	25.92^{bg}	72.72^{af}	68.54^{af}
Grand mean		4.94	26.17	8.86	2952.5	28.17	2.4	2448.03	7310.0	34.43	24.14	72.63	60.96
CV (%)		18.92	7.79	11.26	15.37	4.82	3.84	10.41	12.38	13.42	10.88	13.25	14.18
R^2		0.82	0.77	0.70	0.79	0.95	0.93	0.82	0.81	0.74	0.85	0.86	0.78

DTE=days to emergence, DTF=days to flowering, DTM=days to physiological maturity, PHT= plant height (cm), HWT=head weight tons per hectare), GFP=grain filling period, NTPP= number of productive tillers, NLPP= Number of leaves per plant (main stem), FLL=flag leaf length(cm) ,FLW=flag leaf width(cm), PE= panicle exertion(cm), PL=panicle length(cm), PW=panicle width(cm), NSPP=Number of seeds per panicle, TSW=Thousand seed weight(gram), GL= grain length(mm), GYH = grain yield kg per hectare, BYH= biological yield kg per hectare, HI= harvest index in percent.

($p \leq 0.01$) and significant difference among locations, varieties and location x variety interaction effect in plant height (Table 4). These highly significant differences observed among varieties for plant height agrees with different authors (Saleem et al., 2002; Fikru, 2004; Melese, 2005). Among those recently released varieties, minimum plant height was observed in genotypes "Seredo (128.0 cm), while, ETSC300002" advanced in 2016 (210.5 cm) exhibited maximum plant height. As it was estimated from regression of variety means against year of release, the annual rate of gain, 0.79 cm ha^{-1} $year^{-1}$ was different from zero (Table 12). This indicated that yield potential improvement program had markedly affected plant height. Similarly, Yifru and Hailu (2005) reported that plant height was higher for the modern tef varieties than the older ones, even though the relative genetic gain over the past 35 years of breeding, was low (0.4285 cm per year) and was not significantly ($p<0.05$) different from zero. Similarly, Amsal (1994) indicated that the newest varieties were significantly taller than the older ones but, it did not show relation with year of variety release. On the contrary, Donmez et al. (2001) reported that modern varieties showed significantly decreased plant height and reduced lodging in winter wheat varieties. Similar reports were presented by different researchers in different crops (Wondimu, 2010 in barley; Mihret et al., 2015 in sorghum, Kebere et al., 2006 in haricot bean).

Yield attributes

HWHA increased by 2.47 tones ha^{-1} $year^{-1}$. At Sheraro, it decreased by 5.06 tones ha^{-1} $year^{-1}$ while, at Miesso it increased by 10.0* tones ha^{-1} $year^{-1}$. NSPP increased significantly over the last 40 years by 13.7, 17.4* and 15.5* seeds $panicle^{-1}$ $year^{-1}$ at Sheraro, at Miesso and over locations, respectively. However, TSW was reduced by 0.01 g per thousand weight $year^{-1}$ at both locations and over locations, although this reduction was statistically not significant. Seed length (size) also reduced by 0.001, 0.0001 and 0.001 mm $year^{-1}$ at Sheraro, at Miesso and over locations (Table 10).

Location mean squares from combined analysis of variance were significant ($p \leq 0.05$) for panicle width, number of productive tillers per plant, number of seeds per panicle, grain length and thousand seed weight (Table 4). Likewise, Abebe (1985), Fikru (2004), Melese (2005) and Temesgen (2007), found significant difference in the above yield components traits among tested genotypes in different crops. The mean number of grain (seed) per panicle, panicle width, number of productive tillers per plant and grain length increased significantly over the 40 years period from 2546.50 to 2975.69 (an increase of 14.39%), from 8.67 to 8.84, from 1.03 to 1.04 and from 2.30 to 2.32, respectively. However, over the same period, thousand seed weight decreased from 28.82 to 28.13 cm (by 2.39%).

Generally, older varieties had lower number of grains per panicle and productive tillers than the newer and high yielding varieties. Similar trend was reported by Amasal (1994) who reported 0.438% grains gain in the number of grains per panicle. This difference is reflected in the linear regression coefficient that showed a significant

Table 9. Trends in genetic progress in biomass yield for varieties released in 1976, 1986,1998, 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2012, 2013,2014 and 2016 over the average of the 1st older varieties (Gambella 1107& 76t1#23) released in 1976.

Variety	Year	Mean biomass yield (kg/ha)	Increment over older varieties	
			kg/ha	%
Gambella 1107 76T1#23	1976	6811.5	-	-
Dinkmash	1986	7243.3	431.8	5.96
Meko	1998	8211.6	1400.1	17.05
Abshir	2000			
Gobiye	2000	683.0	20.3	0.30
Teshale	2002			
Yeju	2002	7284.2	742.7	10.20
Birhan	2002			
Abuare	2003	6277.0	-534.5	-8.52
Hormat	2005	7850.4	1034.9	13.18
Macia	2007			
Red Swazi	2007			
Raya	2007			
Miskir	2007			
Girana -1	2007	7242.3	430.8	5.95
Gedo -1	2009			
Melkam	2009			
ESH -1	2009			
ESH -2	2009	7309.0	497.5	6.81
Mesay	2011			
Chare	2011	7469.9	658.4	8.81
Dekeba	2012	6850.1	38.6	0.56
Melkamash-79	2013	7481.1	669.6	8.95
ESH-3	2014	7271.6	460.1	6.33
2005MI504	2016			
2005MI505	2016			
PU209A/PRL021071	2016			
PU209A/PU304	2016			
ICSA15/AWN87	2016	7516.6	705.1	9.38
P9534A/Gambella 1107	2016			
Kari Metama-1	2016			
IEsV23007DL	2016			
P9511A/PRL020817	2016			
ETSC300001	2016			
ETSC300002	2016			

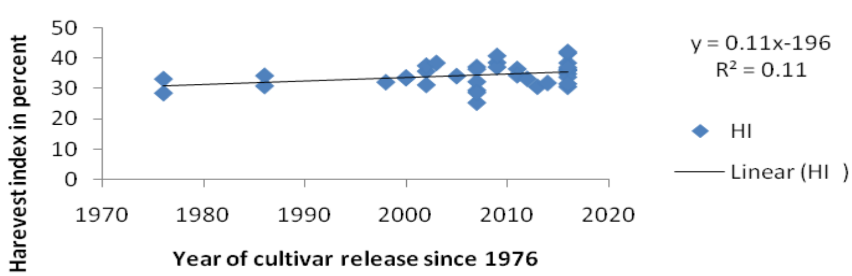

Figure 4. Relationship between the year of cultivar release and harvest index over 2 locations.

Table 10. Estimation 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 trait for each variety against the year of variety release since 1976.

Trait	Regression analysis for data of individual locations								Regression analysis for data combined over two locations			
	SHERARO				MEISO							
	Mean	RSQ	INTERC	B	Mean	RSQ	INTERC	B	Mean	RSQ	INTERC	B
DTE	6.6	0.31	-61.3*	0.03*	6.1	0.02	11.9	-0.002	6.33	0.22	-24.7*	0.02*
DTF	57.4	0.08	-61.8	0.06	71.6	0.21	-153.1**	0.11**	64.49	0.15	-107.5**	0.09**
DTM	97.1	0.17	-86.6	0.09**	107.6	0.14	-94.8	0.10	102.35	0.17	-90.7**	0.10**
PHT	182.9	0.20	-1618.0**	0.90**	156.4	0.64	-2247***	1.20***	169.65	0.60	-1932.3***	1.05***
HWHA	5509.5	0.06	15665.0	-5.06	3439.0	0.24	-16619.0**	10.0*	4474.47	0.04	-477.0	2.47
GFP	396.0	0.10	-24.8	0.03	42.1	0.25	270.4*	-0.11*	40.87	0.12	122.8	-0.04
NTPP	1.13	0.28	10.2*	-0.005*	0.89	0.02	2.71	-0.001	1.01	0.23	6.47*	-0.003*
NLPP	10.3	0.07	-17.5	0.01	9.5	0.25	-33.8**	0.02*	9.90	0.20	-25.6	0.02**
FLL	40.1	0.01	68.5	-0.01	39.0	0.001	31.8	0.004	39.57	0.00	50.11	-0.01
FLW	7.0	0.00	6.2	0.00	6.2	0.05	-8.4	0.01	6.56	0.03	-1.11	0.004
PE	5.4	0.34	-126.6*	0.07*	4.5	0.02	-12.9	0.01	4.94	0.27	-69.7*	0.04*
PL	26.4	0.18	-125.0**	0.08**	26.0	0.004	45.8	-0.01	26.17	0.05	-39.5	0.03
PW	8.0	0.01	2.4	0.003	9.7	0.28	-53.1**	0.03*	8.86	0.22	-25.4	0.02*
NSPP	2719.0	0.16	-24650.0**	13.68**	3186.0	0.30	-31683.0*	17.4*	2952.50	0.30	-28167.0*	15.5*
TSW	32.1	0.003	50.8	-0.01	24.3	0.01	41.5	-0.01	28.17	0.006	46.2	-0.01
GL	2.6	0.01	3.9	-0.001	2.1	0.004	3.0	-0.00	2.37	0.01	3.42	-0.001
GYHA	2632.0	0.12	-11470.0	7.03	2265.0	0.29	-32442.0*	17.3*	2448.03	0.41	-21956.0**	12.2**
BYHA	8701.0	0.08	-22476.0	15.54	5891.0	0.57	-86351.0**	11.6***	7312.98	0.46	-54413.0**	13.59**
HI	30.13	0.02	60.4	0.25	37.7	0.23	-268.0**	0.06*	34.27	0.20	-103.8**	0.07**
GYPDAY	27.2	0.05	-66.5	0.05	21.1	0.24	-261.2*	0.14	24.2	0.27	-164.0**	0.09*
BYPR	90.0	0.01	-49.8	0.07	54.8	0.48	-694.5**	0.37**	72 .4	0.23	-372.1	0.22*
SGR	65.1	0.06	55.15	0.005	51.7	0.22	-731.2**	0.39**	58.39	0.21	-338.0**	0.20**

**Red colored are significant at 15%.

($p \leq 0.05$) increase in number of grains per panicle with annual rate of gain of 429.19 or by 0.61% $year^{-1}$ as compared to the older variety for the last 40 years in Sorghum varieties improvement program (Table 12). Similarly, Demissew (2010) reported a linear regression of mean which is highly significant increment with a relative genetic gain of 0.61% $year^{-1}$ grain per panicle. Panicle length showed an increasing trend with years of variety release, which indicated that newer varieties had longer panicle length, higher number of productive tillers per plant and higher number of grains per panicle than the older ones. Linear regression of variety means against year of variety release showed significant ($p \leq 0.05$) increment trend in panicle length with relative annual genetic increment of 0.12% (Table 12). Similar reports were published for progress in seed length from soybean breeding in the USA during the period between 1902 and 1977 (Specht and Williams, 1984), in durum wheat improvement (Tafese, 2011) and chickpea breeding in Ethiopia (Tibebu, 2011).

Analysis of variance revealed highly significant

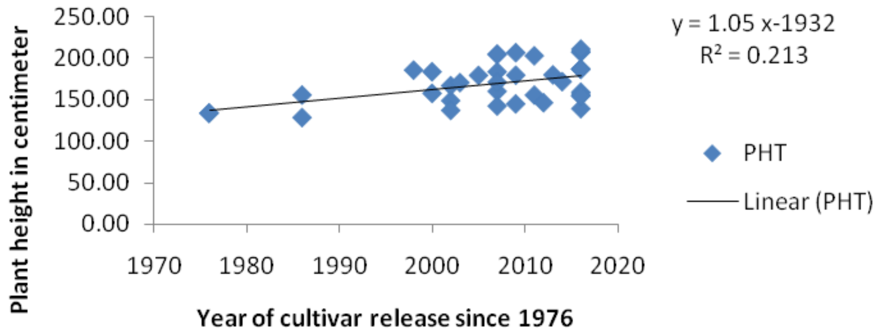

Figure 5. Relationship between the year of cultivar release and plant height over 2 locations.

differences among genotypes for 1000 seed weight. The values for 1000 seed weight ranged from 28.8 to 32.1 g with a mean value of 30.5 g. Accordingly, Meko (released in 1998) and mean of Gambella 1107 and 76T1#23 (oldest varieties) exhibited maximum and minimum 1000 seed weight of 32.1 and 8.82 g, respectively. In line with this, Tamene (2008) reported annual rate of genetic progress of 8 g thousand seed weight year^{-1} with relative genetic gain of 1.06 % in fababean. In the same way, Mihret et al. (2015) reported a significant increase in thousand seed weighs with a relative annual rate of gain was 0.94% year^{-1} over 39 year. However, a highly significant (P ≤ 0.01) decrease in thousand seed weight with a relative annual reduction of 0.96% was obtained in soybean varieties (Demissew, 2010). But Kebere et al. (2006) reported non-significant change in hundred seed weight of haricot bean varieties released between 1972 and 1998.

Results of the present study of the studied genotypes for Panicle width, which ranged from7.33 to10.83cm with mean value of 9.1 and coefficient of variations of 5.71. Highest Panicle width was depicted by genotype ETSC300002 (10.83 cm), while the lowest exhibited by Birhan (7.33 cm). Linear regression coefficient showed increment in Panicle width with annual rate of gain of 0.02*cm year^{-1} or by 0.004% year^{-1} relative increase as compared to the older varieties for the last 40 years in sorghum varieties improvement program (Table 12).

Phonological development traits (flowering and maturity)

The analysis of variance of the phonological traits at individual location revealed that there was significant difference (P ≤ 0.05) among varieties in days to flowering. DTE was increased by 0.03* and 0.02* days year^{-1} at Sheraro and over locations but was reduced by 0.002 days year^{-1} at Miesso. Days to flowering were increased by 0.06, 0.11 and 0.09 days year^{-1}, at Sheraro, Miesso and over locations. These changes were significant at 10% probability level. Days to maturity was also increased by 0.09, 0.10- and 0.10-days year^{-1} at Sheraro, Miesso and over locations and these changes were significant at 10% probability level. However, the grain filling period was decreased by 0.11* and 0.04 at Miesso and over locations, but was increased by 0.03 days year^{-1} at Sheraro (Table 10).

The regression analysis of days to flowering against the year of release indicated a significant annual genetic gain of 0.06 days y^{-1} at Sheraro and a 0.11 days year^{-1} gain at Miesso. In addition, days to physiological maturity showed a significant positive trend with the year of variety release in both locations (Table 10). The relative annual genetic gain since 1976 was found to be 0.11% (Sheraro) and 0.16% (Miesso) for days to flowering and 0.09% (Sheraro) and 0.09% (Miesso) for physiological maturity (Table 11).

A combined analysis of variance across the two test locations showed significant (p ≤ 0.01) differences among locations, among varieties and location by variety interaction for days to maturity (Table 4). In line with these results, Tigist (2003) and Ketema (2007) reported the presence of significant difference among genotypes for days to flowering. Most of the recently released varieties were the earliest in flowering and physiological maturity. Variety Raya (released in 2007) is the variety that took longer period (79 to 125) to flower and mature and the highest yielder "P9534A/Gambella1107 " is among the varieties that flower and mature early. This shift towards early maturity by decreasing the flowering and maturation time without significantly reducing the grain filling period is important to escape from terminal moisture stress in mid and low altitude areas. In the same way, Wondimu (2010) in barley, Tafese (2011) in sesame, Mihret et al. (2015) in sorghum and Tibebu (2011) in Desi type chickpea in Ethiopia reported a decrease in days to flowering. However, Hailu et al. (2009) observed insignificant yield increment with delayed flowering and maturity in soybean genotypes. Similarly, in a study on haricot bean and durum wheat in Ethiopia, Kebere et al. (2006) and Yifru and Hailu (2005) also reported a non-significant increase in days to maturity.

Table 11. Relative genetic gain (RGG) and correlation coefficients (corr.coe) for grain yield and different attributes in different sorghum varieties (in each location) during 2016 cropping season.

Trait	Sheraro		Miesso	
	Relative genetic gain (per year)	Correlation coefficient	Relative genetic gain (per year)	Correlation coefficient
Days to 50% emergence	0.57	-	-0.03	-
Days to flowering	0.11	0.12	0.16	0.31
Days to Maturity	0.09	0.21	0.09	0.6
Plant height (cm)	0.66	0.47	0.91	0.51
Head weight	-123.72	-0.13	0.31	0.17
Number of tillers per plant	-0.42	-0.51	-0.11	0.06
Panicle length	0.33	0.4	-0.04	-0.03
Panicle width	0.04	0.41	0.31	-0.41
Number of seeds per panicle	0.6	-0.07	0.62	0.48
Thousand seed weight (g)	-0.03	0.41	-0.04	-0.29
Grain length (mm)	-0.04	0.09	0	-0.3
Grain yield per hectare	0.32	0.31	0.92	0.57
Biomass yield per hectare	0.2	0.37	0.78	-0.25
Harvest index	-0.07	-0.02	0.47	0.29
Grain production per day	0.69	-0.05	0.8	0.01
Biomass production rate	0.06	0.26	0.66	-0.58**
Seed growth rate	0.01	0.26	0.88	0.4

Biomass production rate, seed growth rates and grain production per day

Biomass production rate, seed growth rate, and grain yield production per day showed significant ($p \leq 0.05$) difference among varieties in both locations. At Sheraro genotypes observed to produce the highest biomass production rate, seed growth rate and grain yield production per day of 90.0; 65.1, 27.2 kg $ha^{-1}day^{-1}$ at Sheraro and 54.8; 54.8, 21.1 kg $ha^{-1}day^{-1}$ at Miesso, respectively (Table 10). Low seed growth rate might be due to early termination of rain which caused lower biomass yield and grain yield. Most of the older varieties produced a higher biomass production rate, seed growth rate and grain yield production per day than the recent varieties at both locations. The relative annual gain of 0.13% per year for biomass production rate, 0.44% per year for seed growth rate and 1.80% for grain production per day (Table 12) was high, indicating that these characters were effectively and significantly improved as a result of the 40 years period of grain yield potential improvement. This agrees with the investigation of Kebere et al. (2006) on haricot bean and Fano et al. (2016) on tef. This data indicated that, biomass production rate; seed growth rate and grain production per day from the five decades of plant breeding and selection was increased by 11.61, 18.86 and 34.17%. The annual genetic gain as estimated from the regression coefficient was 0.22, 0.20 and 0.09 kg ha^{-1} day^{-1} $year^{-1}$ for biomass production rate, seed growth rate and grain yield production per day respectively (Table 10).

According to Kusmenoglu and Muehlbauer (1998), increased seed yield has been obtained through development of cultivars with shorter vegetative and generative growth periods, and greater rates of crop and seed growth. In agreement with the finding of the present study, Pedersen et al. (1998) and Demissew (2010) reported significant increase in seed growth rate in soybean. Similarly, Kebere et al. (2006), Tamene (2008) and Tibebu (2011) reported significant increase in seed growth rate and biomass production rates of haricot bean, fababean and chickpea varieties released in Ethiopia, respectively.

However, Wondimu (2010) showed that there was a significant increase only in seed growth rate in barley. In contrast, Yifru and Hailu (2005) observed non-significant increases in both seed growth rate and biomass yields of tef genotypes over 35 years of breeding and selection. From this, it can be concluded that substantial improvement was apparent in the rate of biomass production, seed growth rate and grain production per day due to grain yield improvement.

BYPR increased by 0.07, 0.37**, and 0.22 kg ha^{-1} day^{-1} at Sheraro, Miesso and over locations, for the last 40 years. GYPDAY also increased by 0.05, 0.14* and 0.09* kg ha^{-1} day^{-1} at Sheraro, Miesso and over locations. SGR increased by 0.14, 0.55** and 0.34 kg ha^{-1} day^{-1} at Sheraro, Miesso and over locations, respectively (Table 10). The highest improvements were achieved at Miesso.

Table 12. Relative genetic gain and correlation coefficients for grain yield and different attributes in different sorghum varieties (over locations) during 2016 cropping season.

Character	Relative genetic gain (% per year)	Correlation coefficients
Days to flowering	0.14	-
Days to maturity	0.1	0.81
Plant height	0.79	0.48
Head weight	0.67	0.32
Number of tillers per plant	-0.03	0.13
Panicle length	0.12	-0.19
Panicle width	0.23	0.32
Number of seeds per panicle	0.61	-0.07
Thousand seed weight	-0.03	-0.17
Grain length (size)	-0.04	-0.21
Grain yield per hectare	0.6	0.08
Biomass yield per hectare	0.45	-0.09
Harvest index	0.23	0.15
Grain production per day	1.8	-0.2
Biomass production rate	0.13	-0.52

Correlation analysis

Biomass yield, harvest index and plant height

The correlation coefficients of grain yield, thousand seed weight and biomass yield with all the traits studied are presented in Table 12. The results of correlation analysis indicated that grain yield showed a highly significant ($p \leq 0.01$) and positive association with biomass yield (r= 0.57***), harvest index (r=0.86***), grain yield production per day(r=0.94**), biomass production rate (r=0.37***), and seed growth rate(r=0.92***). Moreover, biomass yield showed significant positive correlation with biomass production rate (r=0.84***), grain yield production per day (r=0.61***) and seed growth rate(r=0.55***), but non-significant association with all other traits (Table 14) In agreement with the present study, Singh et al. (1990) on chickpea found that biological yield and harvest index had significant positive association with grain yield and therefore simultaneous selection for these two traits would lead to high seed yield. Conversely, Yifru and Hailu (2005) on tef, (Kebere et al., 2006) on haricot bean, Tamene (2008) on faba bean, 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. However, 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. The association between grain yield and plant height was positive (r=0.24). Different authors (Wondimu, 2010 on food barley and Jin et al., 2010 on soybean) found a significant correlation of grain yield and plant height. In contrary, 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, faba bean, and soybean respectively. 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 may serve as an index for identifying varieties with higher seed yield.

Yield components

Significant and negative correlation was observed between grain yield and number of tillers per plant, grain yield and panicle length, while the association of grain yields with panicle width, head weight and number of seeds per panicle were positive (Table 14). This indicates that these characters are important traits used as indirect selection criteria in breeding for improving grain yield in sorghum. Similar results were also reported by Saleem et al. (2002) in chickpea found that there was significant and negative association of grain yield with spike length. Likewise, Majumder et al., (2008); Degewione and Alamerew (2013) reported that positive and non-significant correlation of grain yield with number of kernel per spike and 1000 seed weight in chickpea.

Phonological traits

Days to flowering and days to maturity showed a non-significant and positive association (r = 0.08) and (r=0.03) with grain yield respectively (Table 14). This is in agreement with the investigation of Tibebu (2011) who reported a non-significant association of days to flowering and days to maturity with grain yield in chickpea. However, Singh et al. (1990) in chickpea, Hailu et al. (2009) and Demissew (2010) in soybean reported strong positive correlations of grain yield with days to flowering and days to maturity. In contrast, Fikru (2004), reported a negative association between days to flowering and days to maturity with grain yield in wheat. According to Amsal (1994) in wheat and Fano et al. (2016) in tef, days to flowering and days to maturity were association poorly with grain yield. Kebere et al. (2006) in haricot bean reported lack of correlation between grain yield and these phonological traits.

Productivity traits

Biomass production rate (r=0.37**), grain yield production per day (r=0.94**) and seed growth rate (r=0.92**) showed a highly significant (P ≤ 0.01) positive relation with grain yield (Table 14). This clearly showed that improvement in these traits was markedly concurrent with the yield improvement achieved in the past and can further be exploited in future breeding program. Similar results were reported by Kebere et al. (2006) in haricot bean and Demissew (2010) in soybean. Likewise, DeBruin and Pedersen (2009) found positive relation between grain yield and crop growth rate during seed set, seed growth rate, grain yield production per day. Moreover, positive correlation between grain yield with grain yield production per day and biomass production rate (Yifru and Hailu, 2005) on Tef were reported.

Yield components

Non-significant and negative correlation was observed between grain yield and plant height and grain filling period, while the association of grain yields with panicle length and panicle width was positive. This indicates that these characters are important traits used as indirect selection criteria in breeding for improving grain yield in sorghum. Similar results were also reported by Saleem et al. (2002) in chickpea found that there was significant and negative association of grain yield with spike length. Likewise, Majumder et al., (2008); Degewione and Alamerew (2013) reported that positive and non-significant correlation of grain yield with number of kernel per spike and 1000 seed weight in chickpea.

Phonological traits

Days to flowering and days to maturity showed a non-significant and positive association (r = 0.20) and (r=0.13) with grain yield respectively (Table 14). This is in agreement with the investigation of Fikru (2004), reported a negative association between days to flowering and days to maturity with grain yield in wheat, Tibebu (2011) who reported a non-significant association of days to flowering and days to maturity with grain yield in chickpea. However, Singh et al. (1990) in chickpea, Hailu et al. (2009) and Demissew (2010) in soybean reported strong positive correlations of grain yield with days to flowering and days to maturity. According to Amsal (1994) in wheat and Fano et al. (2016) in tef, days to flowering and days to maturity were association poorly with grain yield. Kebere et al. (2006) in haricot bean reported lack of correlation between grain yield and these phonological traits.

Productivity traits

Biomass production rate(r = 0.22NS) revealed a non-significant and negative association with grain yield, while grain yield production per day (r=0.92***) and seed growth rate (r =0.95***) showed a highly significant (P ≤ 0.01) and positive relation with grain yield (Table 14). This clearly showed that improvement in these traits was markedly concurrent with the yield improvement achieved in the past and can further be exploited in future breeding program. Similar results were reported by Kebere et al. (2006) in haricot bean and Demissew (2010) in soybean. Likewise, DeBruin and Pedersen (2009) found positive relation between grain yield and crop growth rate during seed set, seed growth rate, grain yield production per day. Moreover, positive correlation between grain yield with grain yield production per day and biomass production rate (Yifru and Hailu, 2005) on Tef were reported.

Stepwise regression analyses using grain yield as dependant variable and other traits independent variables indicated that, seed growth rate, harvest index, grain production per day and biomass yield production rate are traits which contributed to gain in grain yield. Particularly, 49% of the variation in grain yield was explained by seed growth rate and was the single most important trait that contributed most to the variation in grain yield among others, where as 27, 23 and 20% variation in grain yield were contributed by grain yield production per day, biomass production rate and harvest index respectively (Table 13). This illustrates that the improvement in grain yield was achieved by combination of different factors.

According to Wondimu (2010) results of a stepwise regression analysis of grain yield on selected yield components revealed that harvest index, biomass yield and seed yield per day altogether accounted for 46, 73 and 74% of the variation in grain production respectively. Amsal, (1994) also reported number of grains per meter square alone accounted for most of the variation (>68%) in grain yield while number of gains per meter square, 1000-seed weight, plant height, biomass yield collectively contributed for more than 93% variation in wheat grain yield. About 96% of the variation in

Table 13. Selection from stepwise regression analysis of mean grain yield as dependent variable and the other traits as independent variable.

Independent variable	Regression coefficient (b)	R^2 (%)
Harvest index	0.07**	0.20
Grain yield production per day	0.09*	0.27
Biomass yield production rate	0.22*	0.23
Seed growth rate	0.34**	0.49

**, All regression coefficients are significant at P≤0.015; *: All regression coefficients are significant at P≤0.05.

fababean grain yield was explained by economic (seed) growth rate, whereas economic growth rate, number of pods per plant, harvest index and biomass together accounted for 99% of the variation in grain yield (Tamene, 2008).

Conclusion

Regardless of considerable effort and devotion of resources, the magnitude of genetic progress from sorghum improvement made since its early inception and the associated traits of genetic improvement achieved so far from the same efforts from different years in a common environment have not been studied. Therefore, one set of yield potential experiment comprising 37 sorghum varieties were conducted in randomized complete block design with three replications at Sheraro and Miesso to determine the amount of genetic gain made over time in yield potential of sorghum varieties and to identify changes in morphological characters associated with genetic improvement in grain yield potential of sorghum varieties in Ethiopia. The analysis of variance for each location revealed wider variability (p<0.01) for all traits, except for days to emergence and number of productive tillers per plant, indicating wider possibility of selection for these traits. The combined analysis of variance across the two locations revealed that there were significant differences among the sorghum varieties due to genotype, location and genotype x location interaction for most of the traits.

The results from linear regression analysis showed that breeding has made significant improvement in grain yield potential of sorghum through consecutive release of new varieties over the past 40 years. The average grain yield of all sorghum varieties, averaged over the two locations was 2448.03 kg ha^{-1}, which ranged from 1861.0 to 3190.3 kg ha^{-1}. The superiority of the highest yielding variety, P9534A/Gambella1107 represents 1152.7 kg ha^{-1} or 36.13% increment over the average of the first two older varieties (Gambella1107 and 76T1#23) followed by IESV230007DL (2958.5 $kgha^{-1}$), 2005MI5065(2908.2 $kgha^{-1}$) and 2005MI5064 (Argeti) (2832.1 $kgha^{-1}$). Varieties derived from indigenous germplasm lines and from introduced (ICRISAT) advanced breeding lines yielded an average grain yield of 2644.7kg ha^{-1}, and exceeding the grain yield of older varieties by 607.1 kg ha^{-1} (30.9%). The average rate of increase in grain yield of sorghum varieties per year of release was 12.2 kg ha^{-1} (.60%). Generally, grain yield showed an increase from old to new varieties during the last five decades of sorghum breeding in Ethiopia. This implies that the grain yield potential of sorghum has not attained plateau in Ethiopia.

For the last 40 years of sorghum improvement, biomass yield increased significantly by 30.8 kg ha^{-1} (0.45%) $year^{-1}$. As the rate of biomass yield has been similar to that of yield gain, harvest index was also steadily modified with the year of release of a variety and there was no consistent gradual reduction in plant height from the older to the newer varieties. Linear regression analysis revealed that there was a significant improvement in most of yield attributes; PHT, NLPP, PE and PW which showed a significant increment and NTPP showed a reduction trend across the years of release. Like that of grain yield and harvest index, all productivity traits showed a highly significant increasing trend for the last 40 years of sorghum improvement program. On the contrary, corresponding to the decrease in flag leaf length, thousand seed weight, and grain length (size) showed a negative trend but not significantly different from zero. Unlike other crops, early maturing genotypes produce a higher seed yield than the late ones in most situations, because when days to maturity increases the phonology of the crops enters to the dry spell, which in turn leads to loss in yield.

Examination of yield components by a series of simple correlation indicated that grain yield was positively and significantly associated with biomass yield, head weight, thousand seed weight, grain production per day, biomass production rate and seed growth rate, whereas all other measured yield components showed non-significant association with grain yield.

Results of stepwise regression analysis indicated that harvest index, grain production per day biomass production rate and seed growth rate contribute most of the variation in grain yield of sorghum. Seed growth rate was by far contributing a lot, which accounted for 49% of the variation in grain yield. In the case of sorghum, the most recently released varieties showed higher grain yield.

Table 14. Correlation coefficients of mean values of yield and yield related traits of varieties represented in the study.

	YVR	DTF	DTM	PHt	HW	NTPP	PL	PW	NSPP	TSW	GL	GYPH	BYPH	HI	BPR	SGR	GYPD
YVR	1																
DTF	0.22^{ns}	1															
DTM	0.20^{ns}	0.81***	1														
PHt	0.46***	0.48***	0.20^{ns}	1													
HW	0.45***	0.32^{ns}	0.36**	0.31^{ns}	1												
NTPP	-0.24^{ns}	0.13^{ns}	0.14^{ns}	-0.07^{ns}	-0.05^{ns}	1											
PL	0.13^{ns}	-0.19^{ns}	-0.04^{ns}	-0.06^{ns}	0.29^{ns}	0.05^{ns}	1										
PW	0.27^{ns}	0.32^{ns}	0.22^{ns}	0.49***	0.39**	-0.31^{ns}	0.07^{ns}	1									
NSPP	0.8^{ns}	-0.07^{ns}	-0.06^{ns}	-0.06^{ns}	0.42**	-0.17^{ns}	0.47***	-0.02^{ns}	1								
TSW	-0.05^{ns}	-0.17^{ns}	-0.13^{ns}	-0.04^{ns}	0.16^{ns}	-0.19^{ns}	0.03^{ns}	0.26^{ns}	0.04^{ns}	1							
GL	-0.07^{ns}	-0.21^{ns}	-0.17^{ns}	-0.12^{ns}	0.24^{ns}	-0.17^{ns}	0.03^{ns}	-0.12^{ns}	0.13^{ns}	0.19^{ns}	1						
GYPH	0.43**	0.08^{ns}	0.03^{ns}	0.24^{ns}	0.56***	-0.36**	0.01^{ns}	0.27^{ns}	0.12^{ns}	0.33**	0.06^{ns}	1					
BYPH	0.32^{ns}	-0.09^{ns}	-0.19^{ns}	0.25^{ns}	0.21^{ns}	-0.42***	-0.20^{ns}	0.18^{ns}	-0.21^{ns}	0.45***	0.18^{ns}	0.57***	1				
HI	0.33^{ns}	0.15^{ns}	0.13^{ns}	0.17^{ns}	0.54^{ns}	-0.19^{ns}	0.11^{ns}	0.25^{ns}	0.25^{ns}	0.14^{ns}	-0.04^{ns}	0.86^{ns}	0.11^{ns}	1			
BPR	0.10^{ns}	-0.52***	-0.68***	0.07^{ns}	-0.06^{ns}	-0.37**	-0.13^{ns}	0.01^{ns}	-0.16^{ns}	0.41**	0.23^{ns}	0.37**	0.84***	-0.04^{ns}	1		
SGR	0.41**	0.27^{ns}	0.05^{ns}	0.37**	0.52***	-0.35**	-0.06^{ns}	0.35**	0.09^{ns}	0.25^{ns}	0.04^{ns}	0.92***	0.55***	0.80***	0.33^{ns}	1	
GYPD	0.33**	-0.20^{ns}	-0.30^{ns}	0.17^{ns}	0.42***	-0.38**	0.04^{ns}	0.19^{ns}	0.12^{ns}	0.36***	0.12^{ns}	0.94**	0.61***	0.77***	0.58**	0.85***	1

This clearly indicated that grain yield was improved consistently as year of release considered.

Ethiopia is known for wide genetic base of sorghum which is a potential for developing improved varieties targeting high yield, disease resistance and other quality traits. However, this huge potential is not yet exploited due to lack of strong breeding program that enable collection, characterization, evaluation and identification of desirable traits for genetic improvement. The Ethiopian sorghum national breeding program was dependent mostly on material introduction from other countries such as Zimbabwe (SAFGRAD) and India (ICRISAT). Moreover, the existing conventional breeding scheme is time taking, laborious and the desirable traits are masked by environmental effect. Hence, the use of modern tools aid to know genetic makeup of different varieties that can be used effectively for breeding and conservation program.

Finally, it should be emphasized that data generated from an experiment conducted for one season may not be sufficient enough to measure the average improvement over the last 40 years. Therefore, similar experiments conducted over many years and over many locations are preferred to make reliable recommendations. But data collected herein from two locations and one season may be used as the base line for yield potential experiments for several years.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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