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Research article

Genetic Gain in Lowland Sorghum [*Sorghum Bicolor* (L.) Moench] Varieties in Ethiopia

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Abstract

Information on genetic progress achieved over time from a breeding program is absolutely essential to develop effective and efficient breeding strategies. Twelve lowland sorghum [*Sorghum bicolor* (L.) Moench]varieties developed by Haramaya University, Melkassa and Sirinka Agricultural Research Centers from 1976 to 2009 along with one local check (farmers' variety, Rufe), were to estimate the amount of genetic gain made over time in yield potential of lowland sorghums in Ethiopia and, thereby, identify changes in morpho-physiological characters associated with genetic improvement in grain yield. The varieties were evaluated in a randomized complete block design at Melkassa and Mieso Agricultural Research Center experimental field. Over 39 year period represented by the regression analysis demonstrated an increase in estimated average annual rate in grain yield potential of 27.4kg ha^{-1} $year^{-1}$ with an annual relative genetic change of 0.85% yr^{-1}. Increasing trends along variety release years were also evident for thousand kernel weight and grain filling rate. Biomass yield, biomass production rate, harvest index, and head weight non-significantly positive trend whereas, the other parameters revealed negative non-significant trends in association with grain yield over the past improvement period. Grain yield was positively and significantly correlated with biomass yield, biomass production and grain filling rate, thousand kernel weight and head weight. Stepwise regression analysis revealed that grain filling rate, grain filling period and biomass production rate was the most important characters, which greatly contributed to the variation in grain yield among the varieties.

Key words: Genetic improvement, grain yield, stepwise regression, thousand kernel weight

INTRODUCTION

Sorghum[*Sorghum bicolor* (L.) Moench] is the fifth important crop in the world among cereals following wheat, rice, maize and barley in terms of both area and production [8, 13]. However, in Ethiopia, ranks third after teff in total production and third after teff and maize in area harvested. The area under sorghum in 2012 was estimated annual production of 3.6 million tons and average yield of 2.01 tons/ha[7]. It is the major crop in drought stressed lowland areas that cover 66% of the total arable land in the country [26]. Sorghum is an important food crop in Ethiopia where it is widely grown in the highlands, lowlands and semi-arid regions of in Ethiopia[2, 26]; especially in moisture stressed parts where other crops can least survive.

The importance of sorghum for food security in the drought prone areas, the development of early maturing, drought escaping varieties have been a main focus of breeding programs in Ethiopia[14,22]. A number of lines, segregating generations and/or accessions and introductions, have been evaluated annually at different sites representing major sorghum production systems to improve the productivity of sorghum. The first improved highland sorghum variety Alemaya-70 was released by Haramaya University in 1970, whereas the first lowland sorghum variety, Gamebella 1107, was released by Melkassa Agricultural Research Center in 1976. A total of twenty-six sorghum varieties (under production) were released by Melkassa and Sirinka Agriculture Research Centers between 1976 and 2010 for lowland, intermediate and highland areas of Ethiopia. Most of the sorghum varieties that were released were from exotic sources, and only three (Gambella 1107, Chiro (Co11#4) and Chelenko ETS 1176) are selections from landraces[24].

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 suggest on future selection direction to facilitate further improvement [1]. Progress made in genetic yield potential and associated traits produced by different crops improvement program and the benefits obtained have been evaluated and documented in different countries, including Ethiopia and it is concluded that genetic improvement in those crops have produced modern cultivars with improved yield potential [1,3,4,32].

Sorghum variety development in the lowland parts of the country has focused on selection of early maturing varieties that can escape drought with reasonable yields. For the last nearly half a century, a number of early open-pollinated sorghum varieties were developed and released for these areas [5]. In Ethiopia, apart from some comparative observations in variety trials by breeders and results of field demonstrations and popularization programs by different stakeholders, where a few varieties might be tested together under common environments, studies on the magnitude of genetic gain from breeding efforts are very limited. Among a few studies in Ethiopia include studies on wheat [3, 4], haricot bean [18], barley [32] and on Teff [33]. However, the genetic gains of sorghum varieties released for adaptation to lowland areas and traits which have conferred yield improvement over time have not been studied in Ethiopia. Thus, this study was carried out to estimate the amount of genetic gain made over time in yield potential of lowland sorghums in Ethiopia and, thereby, identify changes in morpho-physiological characters associated with genetic improvement in grain yield.

MATERIALS AND METHODS

The sorghum yield experiment was conducted under rain fed condition at two sites, namely Melkassa (in East Shewa) and Mieso (in West Hararghe Zone). Melkassa Agricultural Research Centre (MARC) of the Ethiopian Institute of Agricultural Research (EIAR) is found near Awash Melkassa(altitude of 1500 m.a.s.l., latitude 8º30´N and longitudes 39º21´E). The average monthly maximum and minimum temperature are 24.8^0C and 14.0^0C, respectively. The area is categorized as dry semiarid and has a well-drained sandy loam soil with an average annual rainfall of 763mm [29]. Mieso Research, substation of Melkassa Research Center (altitude of 1400 m.a.s.l., latitude 9º23´N and longitudes 40º77´E). The climatic is typical of major sorghum producing regions of Ethiopia (i.e., average annual rainfall is 693 mm, average monthly minimum 15.2^0C, and average maximum temperature 30.5^0C). The area is categorized as arid agro-climatic zone and the soil is dominantly vertisol.

Thirteen sorghum varieties (released between 1976 and 2009 by Haramaya University, Sirinka and Melkassa Agricultural Research Centers and a local variety, "Rufe" of Melkassa) released for lowland areas, were used for the experiment (Table 1). The varieties were grown at the two sites (Melkassa and Mieso) during 2011/12 main cropping season.

Table 1. Description of sorghum varieties used for the experiment

No	Varieties Names	Year of release	Breeder/ Maintainer	Pedigree	Altitude (m.a.s.l.)	Seed color
1	Rufe(local)	Pre-1970	-	-	-	Brown
2	Gambella 1107	1976	HU/MARC	Gambella 1107	≤ 1650	White
3	76 T1 #23	1979	MARC	76T1 #23	≤ 1650	White
4	Meko-1	1997	MARC	M-36121	≤ 1650	White
5	Abshir	2000	SARC	P-9403	1450-1850	White
6	Gubiye	2000	SARC	P-9401	1450-1850	White
7	Teshale	2002	SARC	3443-2-0P	1450-1850	White
8	Yeju	2002	SARC	ICSV 111Inc	1450-1850	White
9	Abuare	2003	SARC	90MW 5353	1450-1850	White
10	Hormat	2005	SARC	ICSV-1112BF	1450-1850	White
11	Misker	2007	SARC	PGRC/E#69441XP-9401	1450-1850	White
12	Girana-1	2007	SARC	CR:35XDJ1195XN-13	1450-1850	White
13	Melkam	2009	MARC	WSV-387	≤ 1650	White

HU-Haramaya University, MARC-Melkassa Agricultural Research Center (MARC), SARC-Sirinka Agricultural Research Center (SRARC)

The experiment was laid out in a randomized complete block design with three replications. Gross plot area was $18.75m^2$ and consisted of 5rows of 5m in length. The seed rate used was as per the recommendation for the area (5kg ha^{-1}). The spacing between rows and plants within row was 0.75 m and 0.15m, respectively. The three middle-rows, with net plot of $11.25m^2$, were considered for collection data. Nitrogen and phosphorus fertilizer were applied in the form of urea (46% N) and DAP (18% N and 46% P_2O_5) at the rate of 50kg/ha and 100kg/ha, respectively. DAP fertilize was applied at time of planting, whereas urea was applied in the form of split application, i.e. at planting and knee height stage after sowing. Hand weeding was practiced as frequently as needed. Insect pests (shoot fly and stem borer) were controlled with chemicals (Lambda Cyhalothrin) at the rate of 0.3 liters ha^{-1}, while diseases were not occurred in the area during the growing season.

Grain and biomass yield, head weight, number of productive tillers, plant height and phonological parameters (days to flowering, days to physiological maturity) were measured from three central rows of each plot. While, grain filling and biomass production rate, grain filling period and harvest indices were calculated from the measured parameters. Thousand kernel weights the weight of and averaged thousand randomly taken grains from each harvestable plot.

Analysis of variance for each location and combined analysis of variance over locations were done following the standard procedure given by Gomez and Gomez (1984).Mean separation was carried out using Duncan's multiple range test (DMRT) at 5% level of significance. The breeding effects were estimated as a genetic gain for grain yield and associated agronomic traits in sorghum improvement program by regressing mean of each character for each variety against the year of release of the variety. The relative gain achieved over the year of release period for traits under consideration were determined as a ratio of genetic gain to the corresponding mean value of local variety and was expressed as percentage. Correlation coefficients between traits were calculated using means of each variety. To determine those variables that contributed much for yield variation among varieties, stepwise regression analysis was carried out on the varietal mean.

RESULTS AND DISCUSSION

Test for homogeneity of variance was carried out to determine the validity of the individual experiment and thereafter, combined analyses of variance were performed. Table 2 indicates combined analysis of variance across the two locations showed highly significant (P< 0.01) differences among the varieties for all the traits. Location effects were also highly significant for days to flowering, days to maturity, thousand kernel weights, biomass yield, biomass production rate, harvest index and head weight. However, the interaction effect was significant only for days to flowering, days to maturity, grain filling period, grain filling rate, grain yield, and number of productive tillers (Table 2).

Table 2. Mean squares of growth and phonological parameters, yield and yield components of thirteen lowland sorghum varieties grown over two locations (Melkassa and Mieso)

Traits	Mean Squares				
	Loc (1)++	**Variety (12)**	**Var*Loc(12)**	**Pooled Error(48)**	**CV%**
Days to Flowering	560.01**	266.43**	17.37**	1.16	1.43
Days to Maturity	620.51**	243.05**	11.85**	2.38	1.37
Plant Height	149.82^{ns}	6143.59**	127.15^{ns}	76.64	4.68

Head Weight	13352.07**	219.79**	49.34^{ns}	84.51	9.86
N. Productive Tiller	0.115^{ns}	30.84**	2.59**	0.87	14.49
1000 K/Weight	363.14**	83.94**	4.99^{ns}	3.82	6.86
Grain Filling Period	1.55^{ns}	32.76**	9.11**	2.19	3.97
Grain Filling Rate	0.83^{ns}	1062.4**	288.94**	131.42	10.1
Grain Yield	23220.2^{ns}	1697581.9**	355039**	123912.9	8.35
Biomass Yield	120924610**	35157555**	7105598.7^{ns}	3851597.8	12.19
Biomass P/Rate	4224.35**	2462.81**	459.81^{ns}	295.26	12.01
Harvest Index	269.77**	48.70**	15.40^{ns}	10.69	12.20

++ = numbers in parenthesis are degrees of freedom.*, ** = Mean squares of characters were significant at probability of 0.05 and 0.01, respectively. **Abbreviation;** Loc-Location, Var-variety, N-Number, P-Production, K-Kernel

Growth Parameters

Plant height had negatively non-significant (P>0.05) trend on year of release; the average annual genetic gain and annual relative percentage gain of -0.39 cm $year^{-1}$ and -0.16% per year were recorded, respectively (Table 6). Significantly higher biomass yield was produced by the recently released varieties, Horemat (17,819 kg ha^{-1}), Girana-1 (17,925 kg ha^{-1}), Misker (19,719 kg ha^{-1}) and Melkam (20,442 kg ha^{-1}) relative to the local check and other improved varieties (Table 7).The mean above ground biomass yield ranged from 12,615 kg ha^{-1} for ‘Abuare’ to 20,442 kg $ha^{-1}$for ‘Melkam’. The recently released variety, ‘Melkam’, produced significantly highest biomass yield. Varieties with higher grain yield also had higher biomass yield. The regression of the mean biomass yields of sorghum variety on the year of release indicated average annual rate of increase by 53.7kg ha^{-1} (Fig. 1.). Hence, biomass yield showed a positively non-significant trend. Similarly, in maize hybrids from different eras only a slight positive trend (non-significant) toward increased fodder was found to accompany the increased grain yield potential [8]. However, [19] found that yields of whole-plant maize forage increased in cultivars that ranged in era from 1930 to 1998. Table 6 show that the relative biomass annual yields gain was estimated to be 0.33% per year for the 39 years. Present finding is less than biomass yield gains (1.0%) for maize forage [20]. Conversely, [9] found no trend in maize fodder weight per plant.

Production Rates

The result indicated that biomass production rate over 39 years of sorghum breeding increased by 22.6%. According to Grifford et al. (1984), biomass production rate is related to light interception and the conversion efficiency of intercepted light to photosynthetic products. This indicated that recent cultivars might have gained more photosynthetic efficiency than the local and oldest varieties. The regression of the mean biomass production rate of sorghum variety on the year of release indicated average annual rate of increase by 0. 72 kg ha^{-1} day^{-1} with the relative annual genetic gain was also 0.58% yr^{-1} (Table 6). This revealed that biomass production rates exhibited an increasing trend (although a non-significant) over 39 years period of sorghum breeding. This is also true in teff, where a non-significant increase in biomass production rate[33].

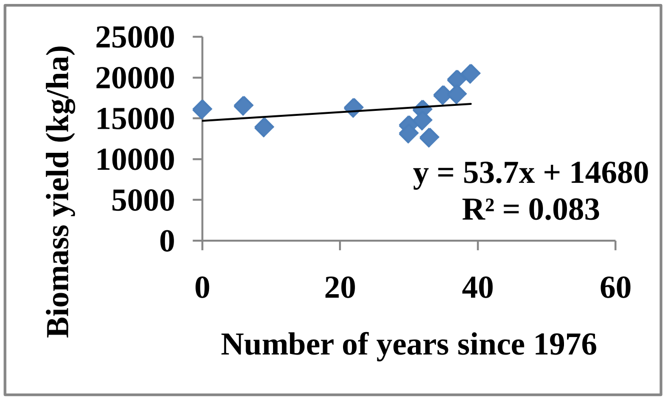

Fig. 1. Relationship between the number of years since cultivars were released and biomass yield (kg ha^{-1})

Annual genetic gain for grain filling rate as estimated from the regression coefficient was 0.78 kg ha^{-1} day^{-1} with the relative annual genetic gain of 0.87% yr^{-1} (Table 6). Linear regression coefficient indicated that grain filling rate showed a positive and significantly ($P \leq 0.01$) different from zero with year of release of the varieties. Similarly, on barley reported that there was a significant increase in seed growth rate [32].

Phenological Parameters

Table 3 shows the improved varieties took shorter number of days to attain flowering and physiological maturity stages than the local variety, Rufe. On average, the varieties tended to flower and mature later for (92.7, 128.8) than other improved varieties. The regression analysis of days to flowering against the year of release indicated a non significant negative annual genetic gain of 0.21 days $yr^{-1}$and the relative annual genetic gain reduction was 0.23% yr^{-1}. Days to physiological maturity also showed non-significant negative trend, 0.23 days yr^{-1} with the relative annual genetic gain of 0.18 yr^{-1} (Table 6). However, a non-significant increase in days to physiological maturity reported in teff [33].

Table 3. Phenological and Growth parameters of thirteen lowland sorghum varieties grown over locations

Variety[a]	Phenological and Growthparameters						
	DTF	DTM	GFP	PH	GFR	BYH	BPR
Rufe	92.67a	128.8a	36.2de	241.58a	89.2f	16065cde	124.4cde
Gamebella 1107	80.67b	119.17b	38.5bc	203.03c	102.8def	16516cd	138.5bcd
76 T1 #23	65.5i	103.17h	37.5bcd	151.2ef	106.1cde	13865ef	134.4cde
Meko-1	69.17h	111de	41.8a	179.8d	109cde	16263cde	146.5bc
Abshir	75.5de	110.17ef	34.7e	142.5fg	102.8def	14126def	128.1cde
Gubiye	76.5cd	108.67f	32.2	134.6g	119.9bc	13116f	120.7de
Teshale	75.17de	114.3c	39.2b	220b	116bcde	16039cde	140.1bcd
Yeju	68.5h	105.3g	36.8cd	184d	118bcd	14708def	139.3bcd
Abuare	73.3f	111.17de	37.8bcd	159.8e	101.5ef	12615f	113.3e
Hormat	71.3g	110.67de	39.3b	207.3c	115bcde	17819bc	161.1ab
Misker	75.5de	112.5d	37cd	208.5c	129.9ab	19719ab	174.5a
Girana-1	74.67e	111.17de	36.5d	198.4c	130ab	17925bc	160ab

Melkam	77.5c	114.5c	37cd	199.08c	135.3a	20442a	178a
Mean	**75.09**	**112.4**	**37.27**	**186.9**	**113.46**	**16093.65**	**143.04**
CV (%)	**1.43**	**1.37**	**3.97**	**4.68**	**10.1**	**12.19**	**12.01**

[a]Varieties are listed in chronological order from the oldest to the recent
Abbreviations: DTF- Days to Flowering, DTM- Days to Physiological Maturity, GFP-Grain Filling Period (days), PH- Plant Height (cm), GFR- Grain Filling Rate (kg/ha/day) ,BYH- Biomass Yield (kg/ha), BPR-Biomass Production Rate (kg/ha/ day)

Grain Yield

Table 4 showed the mean grain yield over the two locations was higher for the recently released varieties, Melkam (5004.5 kg ha^{-1}), Misker (4806 kg ha^{-1}) and Girana^{-1}(4749 kg ha^{-1}), than the yield mean grain for the local variety, Rufe (3221.6 kg ha^{-1}).The average grain yields of varieties released in 1970's, 1990's, 2001's and after 2005's was 3945 kg ha-^{1}, 3703.7 kg ha^{-1}, 4216.9 kg ha^{-1}and 4770.6 kg ha^{-1}, respectively over the two locations(Table 4). Increases in grain yield of improved varieties over the local variety, Rufe, were 18.3, 13.1, 23.6 and 32.5% for the varieties released in 1970's, 1990's, 2001's and after 2005's, respectively, were obtained(Table 5).The grain yield increment of sorghum varieties derived from introduction over that of derived from local collection (Gamebella 1107) was 375.7 kg ha^{-1} (Table 5). This indicates that the varieties developed from introduced germplasm contributed to the genetic improvement of the yield potential of sorghum varieties over the past 39 years.

Table 4. Yield and yield components of thirteen lowland sorghum varieties grown over locations

Variety[a]	Yield and yield components		
	GYH	TKW	HI
Rufe	3221.6f	19.1e	20.4f
Gamebella 1107	3955de	27.1cd	24ef
76 T1 #23	3935de	27.0cd	28.5abcd
Meko-1	4562abc	33.3a	28.6abcd
Abshir	3568.6ef	26.8d	25.7bcde
Gubiye	3838.8e	25.4d	29.4abc
Teshale	4494bc	30.6b	28.4abcd
Yeju	4318.8cd	33.1a	29.9ab
Abuare	3838e	27cd	30.7a
Hormat	4523bc	30.5b	25.4cde
Misker	4806ab	30.1b	25.4cde
Girana-1	4749abc	29.4bc	27abcde
Melkam	5004.5a	30.9ab	24.8de
Mean	**4216.5**	**28.49**	**26.79**
CV (%)	**8.35**	**6.86**	**12.20**

[a]Varieties are listed in chronological order from the oldest to the recent
Abbreviations: GYH-Grain Yield per Hectare (kg/ha), TKW-Thousand Kernel Weight (g) and HI- Harvest index

Table 5. Average grain yield of sorghum varieties released over four periods and increment over the local variety, Rufe

Varieties	**Year of Release**	**Average Grain Yield (kg/ha)**	**Grain yield increment over Local variety, Rufe**	
			kg/ha	**%**
Rufe	Pre1970's	3221.6	-	-
Gamebella 1107 76 T1 #23	1970's	3945	723.4	18.3
Meko-1 Abshir Gubiye	1990's	3703.7	482.1	13.1
Teshale Yeju Abuare	2001's	4216.9	995.3	23.6
Hormat Misker Girana-1 Melkam	After 2005's	4770.6	1549.1	32.5
			Increase over local collection	
Local collection derived		**3955.0**	**-**	**-**
Introduction derived		**4330.7**	**375.7**	**8.7**

The results showed that there was substantial improvement in grain yield of sorghum through breeding over the past 39 years. Hence, average rate of increase in grain yield potential per year of release over the 39 year period was 27.4 kg ha^{-1} (Fig. 2).This rate of yield improvement was lower than 65-77 kg ha^{-1} yr^{-1} in maize hybrids [10, 11]. The relative annual genetic gain in grain yield potential of sorghum varieties was also 0.85% yr^{-1}.The relative annual genetic gain in the present study was less than what had been reported by other researchers, such as Miller and Yilma (1984) (1.6% yr^{-1}) and Unger and Baumhardt (1999) (1.2% yr^{-1}).

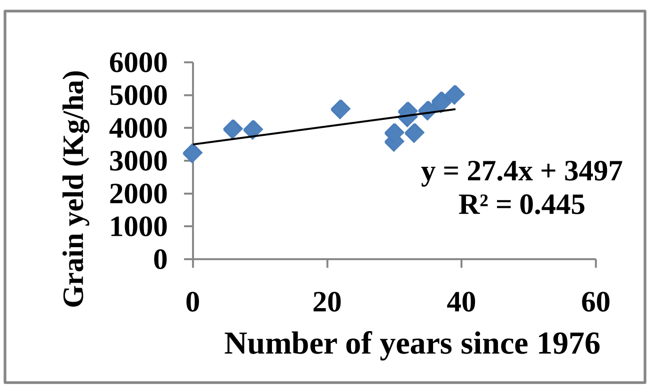

Fig.2. Relationship between the numbers of years since cultivars were released and grain yield (kg ha^{-1}).

Table 6. Estimation of mean values, regression coefficients (b) of various agronomic traits, the annual relative genetic gain (RGG), coefficient of determination (R^2) and intercept at Melkassa and Mieso

Parameters	Mean	b	R GG (% yr^{-1})	R^2 (%)	Intercept
Days to Flowering	92.67	-0.21	-0.23	17.0	80.67
Days to Maturity	128.8	-0.23	-0.18	21.9	118.39
Plant Height	241.58	-0.39	-0.16	2.6	197.0
Head Weight	93.3	0.07	0.08	2.6	91.2
N. of P/Tillers	13.0	-0.07	-0.54	13.6	8.2
1000 Kernel Weight	19.1	0.180*	0.94	39.19	23.72
Grain Yield/Hectare	3221.6	27.35*	0.85	44.59	3497.03
Biomass Yield/Hectare	16065	53.70	0.33	8.3	14680
Biomass P/Rate	124.4	0.72	0.58	21.4	123.9
Grain Filling Period	36.2	-0.02	-0.06	8.6	37.7
Grain Filling Rate	89.2	0.78**	0.87	58.7	92.9
Harvest Index	20.4	0.10	0.49	19.3	24.2

b= regression coefficient
*, **= Significant at probability level of 0.05 and 0.01, respectively.

Yield Components

In sorghum, yield is a complex trait similar to any other crops. Hence, there is a need to concentrate on the component traits of yield such as head weight, thousand kernel weight, harvest index, number of productive tillers and other traits because some of these component traits may have simple inheritance. The information on the genetic gain analysis of these component traits would be helpful to choose appropriate breeding strategy for yield improvement Local variety ‘Rufe’ and ‘Meko-1’ had the lowest and highest thousand kernel weight, respectively. Comparing the varieties, Meko-1 had the highest (33.3g) thousand kernel weight, followed Yeju (33.1g), Melkam (30.9g), Teshale (30.6g), Hormat (30.5g) and Misker (30.1g) (Table 4).

The estimated annual rate of genetic gain in thousand kernel weights due to genetic improvement was 0.18g per thousand kernels per year (Fig. 3).Generally, rate of gain in thousand kernel weight of the sorghum variety showed significant increment over release period. The relative annual rate of genetic gain was estimated to be 0.94% per year over 39 years (Table6).

The mean harvest index of the varieties under current studies showed increase trend for the corresponding improvement of grain yield of the new variety; improved varieties have high harvest index compared to the local variety, Rufe. Regression analysis of mean harvest index showed a positively non-significant (P > 0.05), there was 0.10 per year of release of the varieties (Table 6). Generally, harvest index showed a positive trend of change with year of release of the varieties. The progress occurred at annual rate of 0.49% for the last decades which indicated breeding for increased genetic yield potential attributed to improved dry matter partitioning capacity.

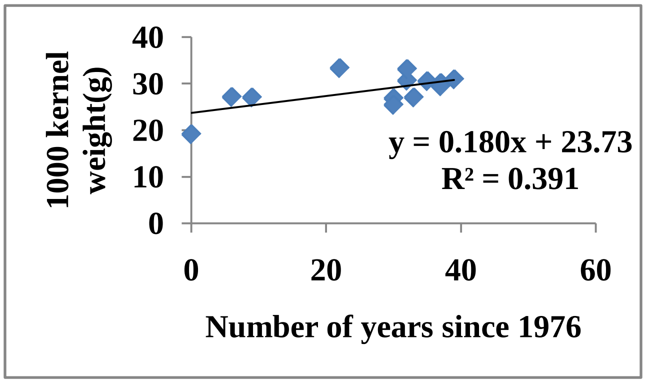

Fig. 3. Relationship between the number of years since cultivars were released and thousand kernel weight (g).

Association of Grain Yield and Morphological Traits

Table 7 showed grain yield was positively and significantly correlated with biomass yield (r= 0.73**). Similarly, [33] on teff found positive association between grain yield and biomass yield. Conversely, [3] found that no relation between grain yield and biomass yield on bread wheat. Plant height had positively non-significant (P>0.05) association with grain yield (Table 7).Similarly, [19] found that grain yield was positively correlated with plant height in sorghum, while, Singh and Chand (2003) evaluated and found no correlation between plant height and grain yield in sorghum. Biomass production (r = 0.87**) and grain filling rate(r = 0.87**) also had highly significant positive correlation with grain yield (Table 7).All of these positively related traits had contributed to the present grain yield progress obtained in recently released sorghum varieties. The association between grain yield and the phenological traits (days to flowering and physiological maturity) was negative and non-significant (P>0.05) (Table 7). [6]In sorghum indicated that grain yield per plant was negatively correlated with flowering.

Association of Grain Yield and Yield Related Traits

Table 7 indicated grain yield highly significant positive correlation with thousand kernel weight (r= 0.82**) and head weight (r= 0.73**). This is in agreement with the funding of [12] in sorghum there was a significant high positive correlation between grain yield and head weight (r= 0.976), grain yield and thousand kernel mass (r= 0.522). Similarly, [17, 18] found a positive correlation with grain yield with the thousand kernel weight. [28] indicated that among the yield components panicle dry weight had showed significant positive association with grain yield. A strong positive correlation of maize yield and thousand kernel weights have been also reported [21].

Table 7. Correlation coefficients (r) between traits studied over two locations (Melkassa and Mieso)

Traits	YoR	DTF	DTM	PH	NPT	HW	TKW	GYH	BYH	BPR	GFP	GFR
YOR	-											
DTF	-0.44	-										
DTM	-0.48	0.94**	-									
PH	-0.17	0.53	0.71**	-								
NPT	-0.38	0.72**	0.77**	0.78**	-							
HW	0.19	0.14	0.33	0.69**	0.39	-						
TKW	0.67*	-0.73**	-0.59*	-0.05	-0.50	0.40	-					
GYH	0.69**	-0.43	-0.30	0.25	-0.15	0.73**	0.82**	-				
BYH	0.29	0.19	0.30	0.66*	0.35	0.89**	0.33	0.73**	-			
BPR	0.47	-0.14	-0.04	0.44	0.09	0.82**	0.56*	0.87**	0.94**	-		
GFP	-0.03	-0.29	0.06	0.42	0.06	0.53	0.51	0.40	0.29	0.29	-	
GFR	0.76**	-0.32	-0.38	0.03	-0.20	0.50	0.62*	0.87**	0.61*	0.77**	-0.10	-
HI	0.46	-0.78**	-0.80**	-0.64*	-0.65*	-0.39	0.51	0.19	-0.53	-0.27	0.04	0.22

* = Significant at probability of 0.05, ** = Significant at probability of 0.01
Abbreviations: YoR-Year of Release ,DTF- Days to Flowering (day), DTM- Days to Physiological Maturity (day), PH- Plant Height (cm), NPT- Number of Productive Tillers (Number), Head Weight (g), TKW-Thousand Kernel Weight (g),GYH-Grain Yield per Hectare (kg/ha), BYH- Biomass Yield per Hectare (kg/ha), BPR-Biomass Production Rate (kg/ha/day),GFP-Grain Filling Period (days), GFR- Grain Filling Rate (kg/ha/day) and HI- Harvest index per plot.

Table (7) indicates harvest index (r=0.19) showed non-significant positive correlation with grain yield. Whereas, in sorghum hybrids reported harvest index has shown a significant positive association with grain yield[25]. In addition, gain in grain yield of durum wheat was strongly related to harvest index[4].

Stepwise regression analysis revealed that grain filling rate (75.5%), grain filling rate and grain filling period (99.8%), and grain filling rate, grain filling period and biomass production rate together (99.9%) was the most important character, which greatly contributed to the variation in grain yield among the varieties. However, 85% of the genetic gain in grain yield of maize was attributed by the increased total dry matter accumulation[30].

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REFERENCES

1. Abeledo, L. G., Calderini, D. F. and Slafer, G. A.,. Genetic improvement of barley Yield potential and its physiological determinants in Argentina (1944-1998). Euphytica, 130, 2003, 325-334.

2. Adugna Abdi, Endashaw Bekele, Zemede Asfaw, and Awgechew Teshome. Patterns of morphological variation of sorghum (*Sorghum bicolor* (L.) Moench) landraces in qualitative characters in North Shewa and South Welo, Ethiopia. Hereditas, 137, 2002, 161-172.

3. Amsal Tarekegne, Turner, D. G. and Getinet Gebeyehu. Improvement in yield of bread wheat cultivars released in Ethiopia from 1949 to 1987. African Crop Sci. J.3 (1), 1995a, 41-49.

4. Amsal Tarekegne, Turner, D.G., Tesfaye Tesemma and Getinet Gebeyehu. Improvement in durum wheat yield and associated effects on morpho-physiological characters. African Crop Sci.J. 3(4), 1995b, 433-442.

5. Asfaw Adugna. Assessment of yield stability in sorghum. Ethiopia. African Crop Sci. J. 15(2), 2007, 83-92.

6. Choudhari, S. D., 1992. Heterosis in high energy sorghum. *Journal of Maharashtra Agricultural Universities*, 17: 28-29.

7. CSA (Central Statistical Agency). Central Statistical Agency. Agricultural sample survey (2013), report on area and production for major crops (private peasant holdings, main season), Addis Ababa, Ethiopia.

8. Doggett, H. Sorghums 2nd ed. Longman. Scientific and Technical. New York, IDRC, Canada. 512, 1988.

9. Duvick, D. N., Plant breeding, an evolutionary concept. Crop Sci., 36, 1996, 539-548.

10. Duvick, D. N., Smith, J. S. C. and Cooper, M., Long-term selection in a commercial hybrid maize breeding program. Plant Breeding Review 24, 2004, 109-151.

11. Duvick, D. N., Genetic progress in yield of United States Maize [*Zea mays* (L.)]. Iowa State University, Ames, IA, US. Maydica, 50, 2005, 193-202.

12. Ezeaku I. E. and Mohammed S. G., Character association and path analysis in grain sorghum. African J. of Biot., 5 (14), 2006, 1337-1340.

13. FAOSTAT(Food and Agriculture Organization Statistics). Published Online at: http://www.faostat. fao. org/. 2011, Accessed on January, 2012.

14. Firew Mekbib. Farmer and formal breeding of sorghum (*Sorghum bicolor* (L.) Moench) and the implications for integrated plant breeding. Euphytica, 152, 2006, 163-176.

15. Gomez, K. A. and Gomez, A. A., Statistical procedure for agricultural research 2nd ed. John and Wiley and Sons Inc., 1984, 680p

16. Grifford, R. M., Thorne, J. H., Hitz, W.D. and Giaquinta, R.T, Crop productivity and photo-assimilate partitioning. Sci., 225 (4664), 1984, 801-808.

17. Kadam, G. N., Gadakh, S. R. and Awari, V. R., Physiological analysis of rabi sorghum genotypes for shallow soil. J. of Maharashtra Agricultural Universities, 27 (3), 2002, 274 -276.

18. Kebere Bezaweletaw, Ketema Belete and Stripichitt P., Genetic gain in grain yield and associated agronomic traits in haricot bean [*Phaseolu vulgaris* (L.)].Kasetsart J., (Natural Sci.) 40, 2006, 835-847.

19. Khizzah, B. W. and Miller, F. R.,. Correlations between sorghum components of drought resistance and various agronomic characters at four locations. Sorghum News letter 33, 1992, 54.

20. Lauer, J. G., Forage yield and quality of corn cultivars developed in different eras. *Crop Sci*. 41, 2001, 1449-1455.

21. Lee, E. A. and Tollenaar, M., Physiological basis of successful breeding strategies for maize grain yield. Crop Sci. 47(3), 2007, 202-215.

22. McGuire, S., Getting genes: rethinking seed system analysis and reform for sorghum in Ethiopia. PhD Thesis,Wageningen University,Wageningen. 2005.

23. Miller, F. R. and Yilma Kebede. Genetic contributions to yield gains in sorghum, 1950 to 1980. In: Fehr WR (ed) Genetic contributions to yield gains of five major crop plants. Crop Science Society of America Special Publication. American Society of Agronomy, Madison, Wisconsin, 1984.

24. MoARD (Ministry of Agriculture and Rural Development). Animal and Plant Health regulatory directorate, crop variety register. Issue No.13, 2010.

25. Muchow, R. C., Comparative productivity of maize, sorghum and pearl millet in a semi-arid tropical environment. Yield potential. Field Crops Research, 20(3), 1989, 207-219.

26. Richard, R. A. and Jorgensen, R. S., Plant genetics and genomics: Crops and Models Springer Science Business Media, LLC, 233 Spring Street, New York, NY 10013, USA, 2008.

27. Singh, P. K. and Chand, P., Evaluation of sorghum (*Sorghum bicolor* L.) genotypes for drought tolerance. Indian J. of Dry land Agricultural Research and Development 18(1), 2003, 92-94.

28. Sriram, N. and Rao, J. S., Physiological parameters influencing sorghum yield. Indian J. of Agricultural Sci.53, 1983, 641-649.

29. Tesfaye Tesso, Alemu Tirfessa and Hussein Mohammed. Association between morphological traits and yield components in the durra sorghums of Ethiopia. Hereditas, 148(3), 2011, 98-109.

30. Tollenar, M., Genetic improvement in grain yield of commercial maize hybrids grown in Ontario from 1959 to. 1988. Crop Sci. 29, 1989, 1365-1371.

31. Unger, P. W. and Baumhardt, R. L.,. Factors related to dry land grain sorghum yield increases: 1939 through 1997, Agronomy J., 91, 1999, 870-875.

32. Wondimu Fekadu. Assessment of genetic improvement in grain yield potential, malting quality and associated traits of barley [*Hordeum vulgare* (L.)] in Ethiopia. An M.Sc. Thesis Presented to the School of Graduate Studies of Haramaya University, 2010, 111p.

33. Yifru Teklu and Hailu Tefera. Genetic improvement in grain yield potential and associated agronomic traits of teff (*Eragrostis tef*). Euphytica, 114: 2005, 247-254.