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Genetic Gain in Grain Yield Potential and Associated Traits of Sesame (Sesamum indicum L.)

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Abstract
A yield potential experiment was conducted with eleven sesame varieties developed by the then Ethiopian Lowland Oil Crops Research Program from 1960s to 2007 along with one local variety. The objectives were to understand the genetic gain made in grain yield potential and to assess changes produced on morphological traits associated with genetic yield potential improvement. The varieties were evaluated in a randomized complete block design (RCBD) with three replications in 2010 main cropping season under irrigation and rainfed conditions at Melka Werer Agricultural Research Center and Mieso experimental testing sites, respectively. The analysis of variance revealed significant differences among varieties for all investigated traits. The over all increase in grain yield of improved varieties over the local variety was estimated to be 150.3 kg ha^{-1} (26.03%). Based on the regression analysis, the estimated average annual rate of increase in grain yield potential was 9.55 kg ha^{-1} year^{-1} with an annual relative genetic change of 1.24 % year^{-1}. Harvest index and seed yield per plant showed significant and non significant increase with respective annual genetic gains of 3.00 and 0.57% respectively, while biomass yield, plant height, and number of capsules per plant showed insignificant decrease of 0.64, 0.10 and 0.17% per annum respectively. Days to flowering and days to maturity decreased non significantly by 0.33 and 0.26%, while seed growth rate and seed yield per day increased significantly by 1.35 and 1.74% per annum, respectively. Absence of plateau indicated the potential for further progress in grain yield in sesame. Correlation analysis indicated that grain yield was positively correlated with harvest index, plant height, seed yield per plant, number of capsule per plant, capsule length, thousand seed weight, seed growth rate and seed yield per day while, biomass yield, number of branches per plant, days to flowering, days to maturity and capsule filling period were negatively correlated with yield. The stepwise regression analysis showed that seed yield per plant greatly contributed to the variation among the varieties in grain yield. Improvement for high grain yield potential in sesame occurred over the past 47 years was ,due to grain yield improvement efforts. However, the improvement was also associated with paralleled increase in harvest index, plant height, seed yield per plant, number of capsule per plant, capsule length, thousand seed weight, seed growth rate and seed yield per day.
Keywords: Ethiopia**,** Harvest index**,** Seed yield**,** Yield components**,** Yield gain.

INTRODUCTION

Sesame (*Sesamum indicum L.)* is a valuable crop for Ethiopia both for local uses and export market. Ethiopia is the 6th major sesame producing country in the world and has an export share of 5.1%. There are around 21 countries that are major importers of sesame from Ethiopia. In 2008, Ethiopia exported about 109,000 tons of sesame worth 175,490,000 USD. The total area under sesame is estimated at 277,992 ha and production is about 2,167,407 quintals and productivity is about 780 kg ha^{-1} (Wijnands, 2009). A suitable production area of sesame in Ethiopia has been indicated as areas with an altitude between 750 to 1600 m.a.s.l. with an average temperature of 27^{0}C. Sesame is used in a wide range of applications. The most important are: edible oil, confectionary, biscuit, and bakery industry**,** tahini industry, halva industry, sesame flour, sprouts of sesame seed and pharmaceutical ingredients (Nayar and Mehra, 1970). Despite its high economic importance, the average productivity of sesame is low as compared to other oilseeds due to lack of high yielding cultivars, resistant to major insect pests and diseases and shattering problem. Since sesame has been treated as less input intensive crop, the role of breeding for improved varieties has been considered as promising approach (Ashri, 1988). Documentation of the contribution of plant breeding to a given crop yield improvement and evaluation of the past gains are useful for identifying areas with potential for further enhancement and for planning a future breeding program (Waddington *et al.*, 1986). Evans (1993) also advocated that an understanding of changes produced by crop breeding on grain yield and its determinants is important to evaluate the efficiency of past improvement work on the advances in genetic grain yield potential, and to define future selection criteria to facilitate further progress. Progress made in genetic yield potential, and associated changes in morphophysiological attributes produced by genetic improvement and benefits obtained thereof have been documented in different crop in different countries (Fehr, 1984, Perry and D'Antuono, 1989; Austin *et al.,* 1980, 1989) by comparing old and modern varieties. In Ethiopia, genetic gain studies were conducted on different crops to determine the progress made in improving grain yield potential and associated changes in morphological characters (Amsal, 1994; Yifru and Hailu, 2005; Kebere *et al*, 2006; Wondimu, 2010). Despite, the devotion of considerable resources to sesame improvement, studies which have been conducted to determine the genetic progress made in improving grain yield potential and associated changes in morphological characters during the past breeding endeavors are virtually absent with in Ethiopia. Therefore, estimating the progress made in yield potential and changes in morphologicalcharacters resulting from the past improvement of sesame, and examining the possibilities of future progress were felt crucially important areas of research on sesame. Hence, the present study was undertaken with the following objectives:

1. To estimate the amount of genetic gain made in grain yield potential.
2. To determine changes produced by genetic improvement on associated morphological traits.

METHODOLOGY

An experiment was conducted at Melka Werer Agricultural Research Center (WARC) and Mieso testing site during the main cropping season of 2010 under irrigated and rainfed conditions respectively. Werer Agricultural Research Center (WARC) is located in the Middle Awash Valley, 50km north-east of the town of Awash on the way to Aseb. It is located at latitude $9^0$16N', longitude $40^0$9'E, and at altitude of 740 meters above sea level. It receives an annual rainfall of 650mm (http://WWW.fallingrain.com/World/ET/45/Melka Werer.html), Accessed in June 2010. Mieso is located on the main road between Adama and Chiro towns. The rain fall is very erratic and estimated to be between 400mm and 600mm. Its altitude is 1450 m.a.s.l. The latitude and longitude of the site is $9^0$20'N and $40^0$59'E respectively (NMSA, 1996). The study was executed using 11 sesame (ten and one) varieties released by both Werer and Sirinka Agricultural Research Centers respectively between 1976-2007 and one local check (Werer local) obtained from Werer Research Center (Table 1). The experiment was laid down in Randomized Complete Block Design (RCBD) with three replications. Each treatment was planted to a plot area of 3.2 m^2 consisting four rows of 2m long spaced 0.4m apart between rows, 0.4m between plots and 1.5m between blocks. Hand weeding and other cultural practices were done as per recommendation.

Table 2. Sesame varieties used in the experiment.

Name of Variety	Year of release	Research Center	Yield (kg ha^{-1})
Werer local	Pre-1960s		
Kelafo-74	1976	WARC/EIAR	300
T-85	1976	WARC/EIAR	500
E	1978	WARC/EIAR	300
S	1978	WARC/EIAR	400
Mehado-80	1989	WARC/EIAR	400
Abasena	1990	WARC/EIAR	400
Adi	1993	WARC/EIAR	600
Argane	1993	WARC/EIAR	500
Sarkamo	1993	WARC/EIAR	600
Tate/BSC-003	2000	WARC/EIAR	914
Ahadu	2007	SrARC/ARARI	1050

Source: MoARD, 2009

Data were recorded on Days to 50% flowering: Days to 90% maturity: Capsule filling period: Seed yield per plant: Number of capsules per plant: Capsule length: Number of branches per plant: Plant height: Thousand seed weight: Seed yield: Biomass yield: Harvest index and the following two traits were calculated as indicated below.

$$\text{seed yield per day} = \frac{\text{seed yield per day}(\frac{kg}{ha})}{\text{days to physiological maturity}}$$

$$\text{seed growth rate}(\frac{\frac{kg}{ha}}{day}) = \frac{\text{seed yield }(\frac{kg}{ha})}{\text{days to capsule filling period}}$$

To evaluate the differences among the varieties, all measured variables were subjected to analysis of variance using SAS software version 9.00 (Anonymous, 2002). Linear regression analysis was used to calculate the genetic yield potential gain for each trait considered in the study. The breeding effect was estimated as a genetic gain for grain yield and yield related traits in sesame improvement by regressing mean of each character for each variety against the year of release of that variety(0-47 years) using PROC REG procedure. the year of release was determined as the number of years since 1960, the period when coordinated sesame improvement program started. Calculation was done as follows.

$$\text{Annual rate of gain}(b) = \frac{\text{CovXY}}{\text{VarX}}$$

Where: Cov =covariance,
Var = variance,
X = the year of variety release,
Y = the mean value of each character for each variety

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

RESULTS AND DISCUSSION

Grain Yield Performance of the Varieties

Significant difference was observed among tested varieties in both locations for all traits except plant height and number of branchs per plant at Melka Werer (Appendix Table 3) revealing that the varieties tested were highly variable. The mean values for grain yield of all sesame varieties represented in the yield potential trial ranged from 584.2 for E to 1815.8 kg ha^{-1} for Tate with an average yield of 995.13 at Melka Werer while, at Mieso it ranged from 240.8 for Argane to 875.2 kg ha^{-1} for Tate with an average yield of 509.8 kg ha^{-1}(Appendix Table 1). At Melka Werer grain yield potential was showed significantly higher than Mieso. The relative low yield of Mieso may be partly attributed to extended erratic rain fall.

The result of combined analysis of variance showed significant mean square values among the 12 genotypes in the source of variation such as location (L) and variety (V) for all the investigated characters (Table 2). Mean squares of locations were significantly ($P< 0.05$) different for all parameters. Varieties were also markedly ($P< 0.05$) different from each other for all characters.

Mean squares of variety by location interaction effects were significant for most of the characters except for number of branches per plant, number of capsule per plant, capsule length, plant height and seed yield per plant. 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, which reported no variety × environment interaction was observed for grain yield. Significant mean squares values in these characters indicated that there existed differences in performance among the test varieties, locations and variety by location interaction for most of the traits. The annual rate of gain in yield potential was estimated from linear regression of mean grain yields of varieties on year of release expressed as the number of years since 1960s, the period when coordinated sesame breeding program started. Empirical experimental evidence of gains in sesame yield showed that at an average rate of increase in yield potential per year of release over 47 years period from the slope of linear regression shown in the graph was 9.550 kg ha^{-1} (Figure 2a). If estimation is made from equation Y= 9.550 X + 535.4, the estimated grain yield at initial year (1960) was 535.4 kg ha^{-1} compared with 657.1 kg ha^{-1} at 16 years (1976) and 586.1 kg ha^{-1} at 18 years (1978). Separate regression analysis for annual gain for the period from 1976 to 2007 and from 1978 to 2007 was 11.28 kg ha^{-1} $year^{-1}$ (Figure 2b) and 12.8 kg ha^{-1} $year^{-1}$ (Figure 2c) respectively. The average rate of increase in yield potential per year of release (estimated from the slope of the graph (Figure 2a) was 9.55 kg ha^{-1} $year^{-1}$ and it was significantly different from zero ($p≤0.05$) (Table 3**)**.There was no indication of a yield potential plateau in sesame over the period studied indicating that the opportunity for breeders to further improve sesame yields exists, and that continued progress towards that end may be expected**.** The average relative annual gain in grain yield of sesame varieties since 1960 was 1.65% per year, or about 58.28% for the whole period of 47 years (Table 6). Present results indicated that the plant breeders have made substantial progress for over the past 47 years in improving the yields of sesame varieties in Ethiopia although; a yield fluctuation was occurring during the release of some of the varieties. Mean values of different characters of sesame varieties over two locations are shown in (Table 4). This experiment showed that mean grain yield potential ranged from 456.7kg ha^{-1} for S to 1345.5 kg ha^{-1} for Tate/BSC-003 sesame varieties. The average mean grain yield of all varieties over both locations was 752.5kg ha^{-1} (Table 4). The second recently released variety, Tate showed significantly ($p≤0.05$) higher grain yield than all varieties tested in the trial, it exceeded the local variety, and the first released cultivar Kelafo-74 by 133% and 40% respectively (Table 4).

Table 3. Combined analysis of variance over locations for grain yield and yield related character of sesame varieties grown in the yield potential trials at Melka Werer and Miesso.

	Mean squares (MS)						
Trait	Location (1))[y]	Variety (11)	Loc x Var. (11)	Error (46)	Mean	CV (%)	R^2
GY	17821117.69(1.56)*	181171.80(0.13)*	181206.95(0.02)*	10619.53(0.003)	497.61(2.82)++	20.7(0.96)	0.98(1.96)
BY	44533203.12*	4776258.68*	683771.31*	324032.4	3258.68	17.47	0.88
HI	1.17*	0.01*	0.01*	0.0005	0.13	17.44	0.98
PH	85724.22*	504.55*	154.23ns	114.92	105.39	10.17	0.95
SY	29.85*	12.27*	0.56ns	0.9002	5.47	17.35	0.81
NC	3895.50*	271.96*	166.10ns	85.33	41.89	22.05	0.69
CL	1.88*	0.17*	0.02ns	0.024	2.33	6.69	0.79
NB	2.88*	1.66*	0.25ns	0.549	3.44	21.51	0.49
TSW	1.31*	0.55*	0.13*	0.065	2.74	9.31	0.75
SGR	4985.17(1.84*	24.52(0.10)*	24.53(0.03*	3.258(0.003	8.32(1.05	21.69(0.96	0.97(5.53)
SYD	1601.82(2.35*	12.02(0.12)*	12.02(0.02)*	1.053(0.003	4.72(0.77	21.75(0.96	0.97(7.31)
CFP	304.22*	362.60*	355.74*	3.441	60.97	3.04	0.98
DF	3280.50*	190.42*	87.23*	0.853	52.67	1.75	0.99
DM	5582.72*	825.21*	142.96*	2.07	113.64	1.27	0.99

BY-Biomass yield (kg ha^{-1}); CFP-Capsule filling period; CL-Capsule length(cm);DTF-Days to flowering;DTM-Days to maturity.++=Figures in parenthesis are transformed values, based on natural logarithmic scale of transformation. GY-Grain yield (kg ha^{-1});HI- Harvest index(%);NB- Number of branches per plant; NC-Number of Capsule per plant; ns- non significant; SGR- Seed growth rate; * Significant difference at (P< 0.05); SYD-Seed yield per day; SYP-Seed yield per plant; TSW- Thousand seed weight; y = Numbers in parenthesis represent degrees of freedom;

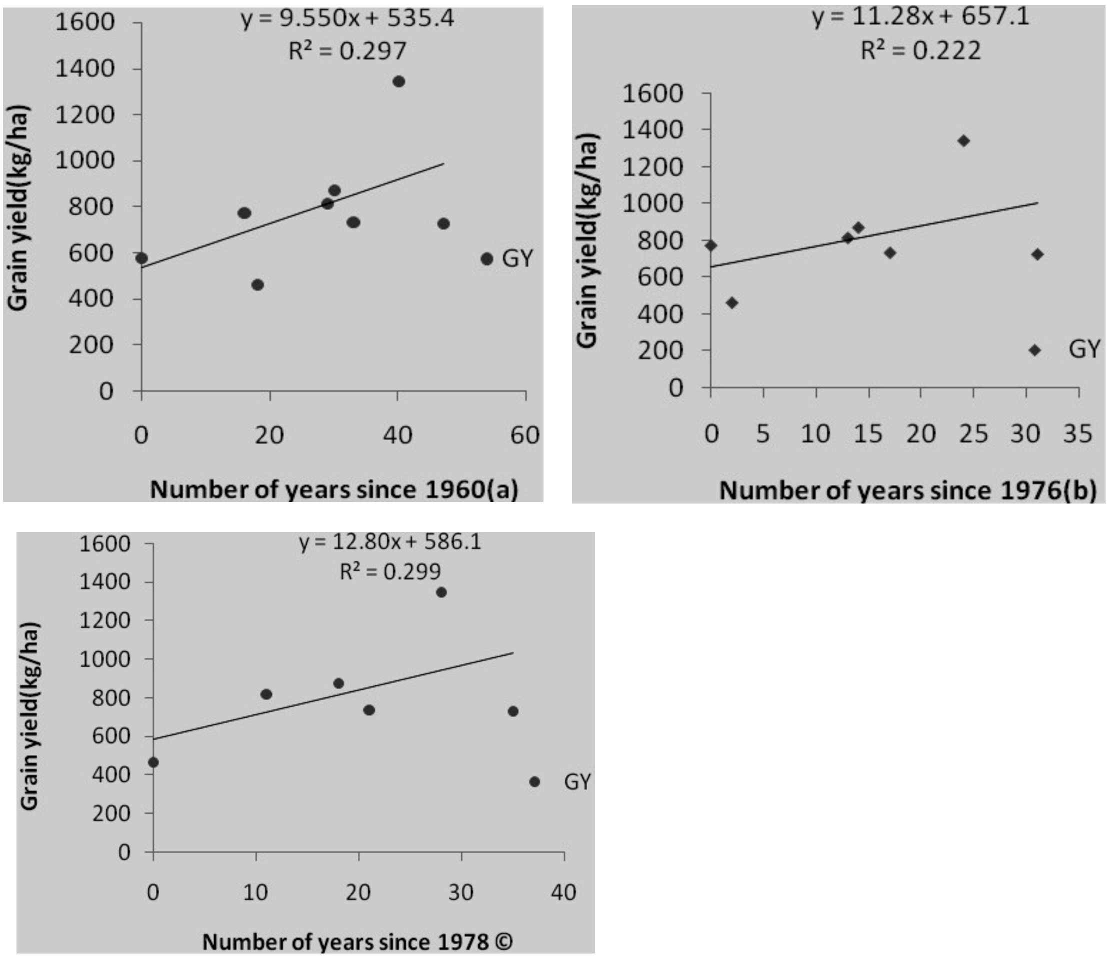

Figure 2. Relationship between mean grain yield of sesame varieties and its year of release (expressed as the number of years since 1960 (the year when coordinated sesame improvement program started) (a), since 19 76 (the year when the first improved varieties were released) (b), since 1978 (the year when variety E and S were released) (c).

Table 4. Estimation of mean values, coefficients of determination (R^2) and regression coefficient (b) of various morphological traits from linear regression of the mean value of each character for each variety against the year of release for that variety

Character	1960-2007			1976-2007			1978-2007		
	Mean	R^2	b	Mean	R^2	b	Mean	R^2	b
GY	752.5	0.3	9.55	768.43	0.22	11.29	766.8	0.3	12.81
BY	3258.7	0.33	-34.59	3062.51	0.09	10.81	3094.91	0.08	9.7
HI	0.2	0.43	0.003	0.25	0.08	0.002	0.24	0.19	0.002
PH	105.4	0.08	-0.11	104.5	0.13	0.16	104.42	0.37	0.27
SY	5.5	0.11	0.03	5.48	0.1	0.05	5.5	0.09	0.04
NC	41.9	0.05	-0.09	40.99	0.12	0.18	40.68	0.32	0.28
TSW	2.3	0.58	0.02*	2.78	0.36	0.01	2.82	0.09	0.01
CL	3.4	0.31	0.004	2.36	0.001	-0.0003	2.36	0.22	0.003
DTF	52.7	0.4	-0.22	51.61	0.01	0.02	51.97	0.01	0.02
DTM	113.6	0.36	-0.46	111.47	0.002	-0.03	112.03	0.003	-0.03
NB	2.7	0.06	-0.01	3.41	0.0002	0.001	3.42	0.0003	-0.001
CFP	61	0.18	-0.24	59.86	0.01	-0.05	60.07	0.01	-0.05
SGR	12.5	0.34	0.13	12.77	0.19	0.13	12.7	0.3	0.16
SYD	6.8	0.3	0.08	7.02	0.11	0.06	6.96	0.18	0.08

BY-Biomass yield(kg ha^{-1}); *=b value is significantly different from zero at probability level of 0.05, CFP-Capsule filling period; CL-Capsule length(cm) ; DTF-Days to flowering; DTM-Days to maturity; GY-Grain yield (kg ha^{-1}); HI- Harvest index(%); NB-Number of branches per plant; NC-Number of Capsule per plant; PH - Plant height; SGR- Seed growth rate; SYD- Seed yield per day,SYP-Seed yield per plant; TSW-Thousand seed weight.

The average grain yield of varieties released in 1960,1976s, 1978s, 1989s, 1990s, 1993, 2000 and 2007 were 577.5, 775.75, 464.4, 817.1, 873.2, 736.26, 1345.5 and 727.8kg ha^{-1}, respectively (Table 5). These indicate a gradual increase in grain yield of mean of individual varieties across locations even if, there is no a parallel growth pattern with year of release of the varieties. This is in agreement with the findings of Amsal (1994) in Wheat, Yifru and Hailu (2005) in Tef, Kebere *et al.* (2006) in haricot bean and Wondimu (2010) in food barley who found substantial increases in grain yield of modern cultivars over the older ones. The least and highest increases were 150.3 kg ha^{-1} (26.03%) and 768 Kg ha^{-1} (132.99%) for the variety released in 2007 and 2000, respectively, over the farmers' local variety, Werer local. Hence, grain yield increased substantially with the release of improved varieties. This was in agreement with the findings of Yifru and Hailu (2005) in tef, Kebere *et al.* (2006) in haricot bean and Wondimu (2010) in barley which reported a significant increase in grain yield of new cultivars over the older ones.

Biomass Yield, Harvest Index and Plant Height

The combined analysis of variance showed that recent varieties were not significantly different from the oldest ones for their biomass yield (see Table 2). The regression of the mean biomass yields of sesame variety on the year of release indicated that there was -34.59 kg ha^{-1} $year^{-1}$ average annual rate of decrease (Table 6). This was significantly lower than zero, revealing that there was a negative trend from the old to the modern varieties in biomass yield. The relative annual biomass yield reduction in sesame varieties was estimated to be -0.64 % per year for the 47 years (Table 7). The present result was in agreement with the findings of Amsal, (1994) on bread wheat and durum wheat and Wondimu (2010) reported non significant trend in biomass yield in food barley breeding. Contrary to these findings, in the study of genetic improvement of haricot bean in Ethiopia reported higher biomass yield in recently developed haricot bean variety than the older ones Kebere *et al.* (2006). Similarly, Hailu *et al.*(2009) indicated that fodder yield of early-maturing soybean varieties can show a 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 the 16 years period. Yifru and Hailu (2005) also indicated that biomass yield in tef was greater in newer varieties and linearly related to variety age and positively and significantly correlated to grain yield. It was shown from analysis of variance that varieties were markedly ($P \leq 0.05$) different from each other in harvest index. Improved varieties established relatively high harvest index compared to the local variety. Harvest index was better for both the new varieties (Ahadu by 10% or more and for the second resent variety Tate by 30%) as compared with the oldest varieties (Table 4). Similarly, linear regression coefficient indicated that harvest index was positively and significantly different from zero ($P \leq 0.05$) with year of release of the varieties (Table 7).

The average rate of increase in harvest index for the periods 1960-2007, 1976-2007 and 1978-2007 was 0.003, 0.002 and 0.002 $year^{-1}$ respectively (Table 3) and the progress occurred at annual rate of 2.97% increase for the last 47 years. In line with this result, Wondimu (2010) revealed that newer food barley varieties developed in Ethiopia, showed higher harvest index with regression slope of 0.004. In the same way, yield potential improvement in bread wheat and durum wheat produced marked positive change in harvest index (0.42% to 0.54% year^{-1}) in Ethiopia Amsal, (1994). The present finding was contrary to the findings of Yifru and Hailu(2005) in tef, Kebere *et al.*(2006) in haricot bean and Tamene (2008) in faba bean have found that harvest index was not steadily changed with the year of release of the varieties in the respective crops they investigated. Despite the reduction in biomass, there was a non-consistent gradual reduction in plant height from the older to the newer varieties. A combined analysis averaged over both locations indicated that the newest variety, Ahadu was relatively shorter than the older variety (Table 4). As it was estimated from regression of variety means against year of release, the annual rate of gain, -0.1cm ha^{-1} year^{-1} was not different from zero (Table 6). This implied that yield potential improvement program did not markedly affect plant height. On the contrary Yifru and Hailu (2005) indicated that plant height was higher for the modern tef varieties than the older ones, eventhoue 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 can not showed relation with year of variety release. In line with this result, Wondimu (2010) found that Significant ($P<0.05$) negative trend on year of release from regression line with an average annual genetic gain of - 0.39 cm (-0.33%) year^{-1} in barley. Kebere *et al.*(2006) also found that a non-consistent gradual reduction in plant height from the older to the newer varieties of haricot bean.

Table 5. Mean values of different characters from combined analysis of variance for sesame varieties grown in the yiel potential trials at Melka Werer and Mieso.

Variety	Character								
	GY	BY	HI	PH	DTF	DTM	CFP	SGR	SYD
Werer local	577.5(2.73)^{fg}	5416.7^{a}	0.1^{e}	115.2^{ab}	64.3^{a}	137.5^{a}	73.2^{b}	9.6(0.89)^{d}	4.6(0.60)^{f}
Kelafo-74	960(2.95)^{b}	2916.7^{de}	0.3^{ab}	110.1^{bc}	49^{f}	106.2^{fg}	57.2^{e}	16.5(1.20)^{a}	9.2(0.93)^{b}
T-85	591.5(2.74)^{fg}	2916.7^{de}	0.2^{d}	99.6^{cd}	51de	111.7^{d}	60.7^{d}	9.7(0.96)^{d}	5.4(0.69)^{ef}
E	472.1(2.65)^{g}	2604.2^{de}	0.2^{d}	96.5^{cd}	52.2^{bc}	107.5^{ef}	55.3^{ef}	8.6(0.91)^{d}	4.5(0.62)^{f}
S	456.7(2.63)^{g}	2395.8^{e}	0.2^{d}	94^{d}	53^{b}	108.5^{e}	55.5^{ef}	8.3(0.88)^{d}	4.3(0.59)^{f}
Mehado-80	817.1(2.88)^{cd}	3333.3^{cd}	0.2^{cd}	100.9^{cd}	47^{g}	108.8^{e}	61.8^{d}	13.2(1.09)^{b}	7.8(0.84)^{c}
Abasena	873.2(3.10)^{bc}	4479.2^{b}	0.2^{d}	127.2^{a}	64.2^{a}	132.7^{b}	68.5^{e}	14(1.21)^{b}	6.8(0.99)^{cd}
Adi	663.5(2.92)^{ef}	2500^{e}	0.3^{bc}	105.9^{bcd}	49^{f}	103.5^{h}	54.5^{f}	12.1(1.09)^{bc}	6.5(0.80)^{cde}
Argane	551.2(2.81)^{fg}	2812.5^{de}	0.2^{d}	98^{cd}	50.3^{e}	106.3^{fg}	56^{ef}	10.3(1.07)^{cd}	5.6(0.80)^{def}
Sarkamo	994.1(2.66)^{b}	2854.2^{de}	0.3^{a}	106.2^{bcd}	50.5^{ed}	105.3^{g}	54.8^{ef}	17.9(0.91)^{a}	9.6(0.63)^{ab}
Tate	1345.5(2.98)^{a}	3750de	0.4^{a}	108^{bcd}	50^{def}	127.2^{c}	77.2^{a}	17.2(1.24)^{a}	10.7(0.6)^{a}
Ahadu	727.8(2.85)^{de}	3125^{cde}	0.2^{cd}	103.1^{bcd}	51.5^{cd}	108.5^{e}	57^{e}	12.7(1.10)^{b}	6.8(0.82)^{cd}
Mean	752.5(2.82)	3258.7	0.2	105.4	52.7	113.6	61	12.5(1.05)	6.8(0.77)
CV (%)	14.2	17.5	19.5	10.2	1.8	1.3	3	15.1	15.4
R^2	0.9	0.9	0.8	0.95	0.99	0.99	0.98	0.93	0.94

BY=Biomass yield (kg ha^{-1}); CFP=Capsule filling period; DTF= Days to flowering; DTM=Days to maturity; + = Figures in parenthesis are transformed values, based on natural logarithmic scale of transformation. GY=Grain yield (kg ha^{-1}); HI=Harvest index (%); PH= plant height, SGR=Seed growth rate; SYD= Seed yield per day.

Table 6. Average grain yield (Kg ha-1) of sesame varieties and average increment of the newest varieties over the older variety.

Variety	Year of release	Average grain yield	Increment over local variety	
			Kg ha^{-1}	%
Werer local	Pre-1960s	577.5	_	_
Kelafo-74 T-85	1976	775.75	198.25	34.33
E S	1978	464.4	_	_
Mehado-80	1989	817.1	239.6	41.49
Abasena	1990	873.2	295.7	51.2
Adi Argane Sarkamo	1993	736.27	158.77	27.49
Tate/BSC-003	2000	1345.5	768	132.99
Ahadu	2007	727.8	150.3	26.03

Phenological Development

Combined analyses of variance indicated that there were significant ($P\leq0.05$) differences among varieties for days to flowering and days to physiological maturity (Table 4). Mean days to flowering of all varieties represented in the study was 53 days (Table 4). From the combined analysis of variance it was observed that there was a significant variety by location interaction for days to flowering (Table 2). The earliest variety for days to flowering was Mehado-80 followed by Adi and Kelafo-74, while the older variety Werer local and Abasena takes maximum days to flowering. Mean days to physiological maturity of varieties was 114 days, averaged over both locations (Table 4). Relatively the recently released varieties scored the lower days to maturity compared to the older varieties, but the variety Adi stand first in maturity in earliness (Table 4). Similarly in days to flowering, there was a significant ($p \leq 0.05$) difference between variety by location interaction (Table 2).

Table 7. The annual relative genetic gain and correlation of characters with grain yield of sesame varieties represented in the yield potential trial.

Character	Relative genetic gain (% $year^{-1}$)	Correlation coefficient
GY	1.65	1
BY	-0.64	-0.23
HI	3.00	0.77*
PH	-0.10	0.15
SY	0.57	0.65
NC	-0.17	0.29
CL	0.83	0.47
NB	0.19	-0.79*
TSW	-0.34	0.29
DTF	-0.33	-0.42
DTM	-0.26	-0.31
CFP	-0.33	-0.16
SGR	1.35	0.90*
SYD	1.74	0.80*

BY-Biomass yield(kg ha^{-1});CFP-Capsule filling period; CL-Capsule length(cm) ; DTF-Days to flowering; DTM-Days to maturity; GY-Grain yield (kg ha^{-1}); HI- Harvest index(%); NB-Number of branches per plant; NC-Number of Capsule per plant; PH -Plant height; *=r value is significantly different from zero at probability level of 0.05, SGR- Seed growth rate; SYD- Seed yield per day,SYP-Seed yield per plant; TSW-Thousand seed weight.

Like plant height, the regression analysis indicated a negative regression coefficient in days to flowering was 0.22. However, this value was not significantly different from zero (Table 6). This insignificant reduction occurred due to early flowering character of some recently released varieties such as Mehado-80 and Adi (Table 4). Hence, the change in days to flowering was not associated with the time of release of the varieties. The relative annual change of physiological maturity was found to be low, -0.46% per year (Table 6). The estimated annual rate of changes (-0.46%) was in opposite direction with that of days to flowering (Table 6). Similar to days to flowering, a negative annual relative change of 0.24 % per year was achieved for capsule filling period (Table 6). This made clear that the change in capsule filling period was not paralleled with the release of improved variety regardless of some recently released varieties possessed longer period

Yield Components

Mean seed yield per plant of sesame varieties, averaged over both locations, was 5.5g per plant (Table 7). Combined analysis of variance, across both test sites, indicated a non significant variety by location interaction for seed yield. The variety Tate produced the highest seed yield per plant followed by Mehado-80, Sarkamo and Kelafo-74. While the varieties E and S produced the lowest yield. Estimated annual gains of seed yield per plant of varieties, over the 47 years period, was 0.03g and it was not significantly ($p \leq 0.05$) different from zero (Table 3). Similar to seed yield per plant, number of capsule per plant also showed non significant values in the variable variety X location interaction (Table 2). The mean value of number of capsule per plant estimated from the combined analysis ranged from 29 for S to 51.7 for Werer local with an average value of 41.9. The varieties Werer local, Tate and Kelafo-74 produced a relatively high number of capsules per plant than all varieties. Estimated annual gains for this trait since 1960 was non significant ($p \leq 0.05$) (Table 6). The traits capsule length and number of branches per plant also showed a non significant mean squares value in the variable variety by location interaction (Table 2). Mean capsule length and number of branches per plant of sesame varieties, averaged over both locations were 2.3 and 3.4 respectively (Table 7). The varieties Adi and Abasena had the highest capsule length and number of branches per plant respectively. The recently released variety Ahadu produced high number of branches per plant next to Abasena. Estimated annual gains of capsule length and number of branches per plant of sesame varieties, over the 47 years period, were 0.004 and -0.01 and this value was not significantly ($p \leq 0.05$) different from zero (Table 3) with an annual relative genetic gain of 0.2 and -0.19% respectively (Table 6). Unlike the above yield components, thousand seed weight showed a significant (p≤0.05) value in the variable variety by location interaction (Table 2). The combined analysis of variance showed that the mean values of thousand seed weight of sesame varieties ranged from 2.3 for Kelafo-74 to 3.2 for Ahadu and Mehado-80 with an average value 2.7 of over both locations. The relative annual genetic gain of -0.34% was produced for thousand seed weight (Table 6). The estimated annual gain of thousand seed weight, over the period of 47 years was 0.02 and it has shown non significant gain of the recent varieties over the older varieties (Table 3).

Table 8. Mean values of yield components of sesame varieties combined over locations

Variety	Character				
	SY	NC	CL	NB	TSW
Werer local	5.3[cd]	51.7[a]	2.1[f]	3.9[ab]	2.4[cd]
Kelafo-74	6.2[cb]	48.8[a]	2.5[ab]	3.3[abcd]	2.3[d]
T-85	4.6[de]	36[bc]	2.3[cde]	3.4[abc]	2.9[b]
E	3.6[e]	33.2[bc]	2.4[bcde]	3.4[abcd]	2.8[b]
S	3.6[e]	29[c]	2.2[def]	3.7[abc]	2.6[bc]
Mehado-80	7[b]	40[abc]	2.2[cdef]	3.4[abcd]	3.2[a]
Abasena	5.1[cd]	43.6[ab]	2.2[ef]	4.3[a]	2.4[cd]
Adi	4.3[de]	42[ab]	2.7[a]	2.7[cd]	2.8[b]
Argane	5.1[cd]	44.1[ab]	2.4[bcde]	3.2[bcd]	2.6[bc]
Sarkamo	6.9[b]	44.2[ab]	2.4[bcd]	2.4[d]	2.9[b]
Tate	8.4[a]	49.5[a]	2.4[bc]	3.6[abc]	2.9[b]
Ahadu	5.5[cd]	40.5[abc]	2.3[cde]	4.1[ab]	3.2[a]
Mean	5.5	41.9	2.3	3.4	2.7
CV (%)	17.4	22.1	6.7	21.5	9.3
R^2	0.81	0.69	0.79	0.49	0.75

CL=Capsule length (cm); Means followed by a common letter within a column weren't significantly different at p=≤0.05, according to Duncans' s Multiple Range Test, NB=Number of branches per plant;NC=Number of capsule per plant; SYP=Seed yield per plant; TSW=Thousand seed weight.

Seed Growth Rate and Seed Yield per Day

Both seed growth rate and seed yield per day increased significantly (p≤ 0.05) with the annual rates of genetic gain by 0.13 and 0.08 kg ha^{-1} $year^{-1}$, respectively (Table 3). Moreover, the relative annual gain of 1.35% per year for seed growth and 1.74% per year for seed yield per day (Table 6) were high, indicating that these characters were effectively and significantly improved due to the 47 years period of grain yield potential improvement. This was in agreement with the investigation of Kebere *et al*.(2006) on haricot bean, Yifru and Hailu (2005) on tef. Mean seed growth and seed yield per day of sesame varieties, averaged over both locations, were 12.5 and 6.8 respectively (Table 4). Similar to phenological traits, seed groth rate and seed yield per day also showed a significant (p≤0.05) value for the variable variety by location interaction (Table 2). The varieties Sarkamo and Tate produced the highest seed growth rate and seed yield per day respectively (Table 4).

Functional Relationship among Yield and Yield Related Traits

The combined data over the two locations showed that harvest index (r=0.77), seed growth rate (r=0.90) and seed yield per day (r=0.80) had significant positive correlation with grain yield at (p ≤0.05) (Table 8), revealing that progress in sesame improvement with respect to these traits was substantial while the association was negative with number of branches per plant(r=0.79). It showed positive but non-significant association with plant height (r=0.11), number of capsule per plant (r=0.49), capsule length (r=0.22) and thousand seed weight (r=0.07). With regard to positive correlation, similar results are in concurrence with the results of Sumathi and Muralidharan (2007) and Engin *et al*., 2010. Similarly, (Amsal, 1994) reported that no relation between grain yield and biomass yield and positive association between grain yield and harvest index on bread wheat. Similar results were found by Engin *et al*. (2010) that plant height; number of capsule per plant and thousand seed weight have positive correlation with seed yield. The traits biomass yield (r=-0.23), number of branches per plant (r=-0.79) and days to flowering (r=-0.42), days to maturity (r=-0.31) and capsule filling period (r=-0.16) showed negative correlation with grain yield. The negative correlation between grain yield (Table 8) and these characters observed in the present study was in contrary with the findings of Sumathi and Muralidharan (2007) and Engin *et al*. (2010) which reported positive association in sesame. Biomass yield showed significantly positive correlation with plant height, number of capsules per plant, days to flowering, days to maturity and capsule filling period and a positive association with seed yield per plant and number of branches per plant and a non significant negative association with harvest index, capsule length, thousand seed weight, seed growth rate and seed yield per day. The traits capsule length, seed growth rate and seed yield per day showed significantly positive correlation with harvest index. Capsule length showed a negative correlation with plant height, number of branches per plant, days to flowering, days to maturity and capsule filling period. The negative correlation with days to flowering is significant. In contract it shows a non significant positive correlation with number of capsule per plant, seed yield per plant and 1000 seed weight. The character plant height showed significantly positive correlation with number of capsule per plant and days to maturity and also positive correlation with seed yield per plant, number of branches per plant, days to flowering, capsule filling period, seed growth rate and seed yield per day. The traits capsule length and thousand seed weight were negatively correlated without a significant value. Sumathi and Muralidharan (2007) also indicted similar finding that plant height showed significantly positive correlation with number of capsule per plant, days to flowering, days to maturity. A positives correlation of plant height with seed yield per plant, number of capsule per plant and number of branches per plant reported by (Engin *et al*., 2010) in sesame accessions. In this study a positive significant correlation was recorded between seed yield per plant with number of capsule per plant, capsule length, thousand seed weight, days to maturity, capsule filling period, and a significant association with seed growth rate and seed yield per day. With regard to positive correlation similar results were reported by Ofosuhene and Yeboah (2010) with plant height and number of capsule per plant. Number of capsule per plant was positively correlated with all investigated characters except capsule length and thousand seed weight but the correlation is not statistically significant. A negative and significant correlation of capsule length with days to maturity and capsule filling period was observed. Most of the traits showed a positive association with number of branches per plant except seed growth rate and seed yield per day but none of them was statically significant. This contradicts with the results of Ofosuhene and Yeboah (2010) who found that significant association with plant height and number of capsule per plant. Thousand seed weight is negatively and significantly associated with days to flowering and negatively with days to maturity. Days to flowering is positively and significantly associated with days to maturity. The present study indicated that, the selection based on the characters such as, harvest index, seed yield per plant and seed yield per day would be effective for the development of superior sesame variety through breeding. Stepwise regression analyses (Table 9) using grain yield as dependant variable indicated that, harvest index and seed yield per plant were traits which contributed to gain in grain yield. Particularly, 84% of the variation in grain yield of sesame was explained by seed yield per plant, 12% by harvest index and 96% was contributed altogether by harvest index and seed yield per plant. This illustrates that the improvement in grain yield was achieved by combination of different factors.

Table 9. Estimates of correlation coefficient among morphological characters of sesame varieties means represented in the study.

Character	GY	BY	HI	PH	SY	NC	CL	NB	TSW	DTF	DTM	CFP	SGR	SYD
GY	1													
BY	-0.23	1												
HI	0.77*	-0.52	1											
PH	0.15	0.78*	-0.17	1										
SY	0.65	0.16	0.69	0.24	1									
NC	0.29	0.79*	0.06	0.92*	0.55	1								
CL	0.47	-0.68	0.79*	-0.16	0.22	-0.13	1							
NB	-0.79*	0.44	-0.56	0.09	-0.24	0.08	-0.44	1						
TSW	0.29	-0.43	0.45	-0.53	0.44	-0.33	0.13	0.0001	1					
DTF	-0.42	0.78*	-0.75*	0.65	-0.42	0.45	-0.63	0.38	-0.72*	1				
DTM	-0.31	0.93*	-0.4	0.74*	0.18	0.76	-0.51*	0.48	-0.51	0.74*	1			
CFP	-0.16	0.78*	-0.08	0.6	0.51	0.76	-0.30*	0.42	-0.24	0.38	0.91*	1		
SGR	0.90*	-0.19	0.92*	0.16	0.85*	0.4	0.59	-0.56	0.39	-0.54	-0.16	0.12	1	
SYD	0.80*	-0.2	0.93*	0.07	0.90*	0.36	0.59	-0.46	0.44	-0.62	-0.13	0.21	0.98*	1

BY-Biomass yield(kg ha^{-1});CFP-Capsule filling period; CL-Capsule length(cm);*=correlation coefficients were significant at the P≤ 0.05, DTF-Days to flowering; DTM-Days to maturity; GY-Grain yield (kg ha^{-1}); HI-Harvest index(%); NB-Number of branches per plant; NC-Number of Capsule per plant; PH -Plant height; *=r value is significantly different from zero at probability level of 0.05, SGR- Seed growth rate; SYD- Seed yield per day,SYP-Seed yield per plant; TSW-Thousand seed weight.

According to Wondimu (2010) results of a stepwise regression analysis of grain yield on selected yield components revealed that harvest index, biomass yield and harvest index altogether and biomass yield, harvest index and seed yield per day accounted for 46% , 73% and 74% of the variation in grain yield respectively.

Table 10. Summary of selection from stepwise regression analysis of mean grain yield of sesame as dependant variable on independent variable.

Independent variables	Regression coefficient (b)	R^2	VIF
Seed yield per plant	0.65**	0.84	1
Harvest index	0.43**	0.12	1.71

** All regression coefficients are significant at P≤0.05; VIF: variance inflation factor

According to Yifru and Hailu (2005) results of a stepwise regression analysis of grain yield on selected yield components revealed that biomass yield accounted for 56.7% of the variation in grain yield. Amsal (1994) also reported number of grain per meter square alone accounted for most of the variation (>68%) in grain yield while number of gain 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 faba bean grain yield was explained by economic growth rate (grain sink filling rate), whereas economic growth rate, number of pod per plant, harvest index and biomass together accounted for 99 % of the variation in grain yield (Tamene 2008). Kebere *et al*. (2006) also found that biomass contributed 82.7% of variation in grain yield in haricot bean.

CONCLUSIONS

Oils crop in general and sesame crop in particular play a great role in improving household's food security, increasing income for the local population and export earnings for the country. Despite the high production potential and the economic importance of the crop, sesame producers particularly small scale farmers did not economically much benefited from its production. Low production and productivity, which is mainly associated with poor adoption of improved technologies and poor marketing system, was among the major problems. Sesame is a valuable crop for Ethiopia both for local uses and export market, and it is currently growing in area of production. As part of the effort to make it popular and enhance its productivity, the then Ethiopian Lowland Oil Crops Research Program successively released new varieties since 1976. Evaluating the progress in improving crop cultivars achieved by such a program is useful,both as a demonstration of the importance of plant breeding to the public and as a way of identifying traits or target environments that may require increased efforts by breeders. Thus, with an objective to estimate the amount of genetic gain in grain yield potential and yield associated traits of sesame genotypes produced by variety improvement, a yield potential experiment comprising 12 genotypes was conducted at Melka Werer Agricultural Research Center (WARC) and Mieso testing site using a randomized complete block design with three replications in 2010 main croop season. During the period 1960 to 2007, substantial progress was made in improving the grain yield potential of sesame. Moreover, changes occurred on the associated morphological characters parallel to varietal release. The present study revealed that the genetic yield potential improvement of sesame over the last 47 years was associated with paralleled increases in harvest index, seed yield per plant, seed growth rate and seed yield per day as these traits were strongly correlated with grain yield and the year of varietal release. Sesame grain yield has increased from 577.5 kg ha^{-1} to 1345.5 kg ha^{-1}. Yield increment of improved varieties over the farmers' variety was 768 kg ha^{-1}. Based on regression of mean grain yield versus the number of years elapsed since 1960 (when coordinated sesame breeding started), since 1976 (when Kelafo-74 released) and since 1978 (when E and S released), yield gain has risen at an average rate of 9.55 kg ha^{-1} (1.65%), 11.29 kg ha^{-1} (1.95%) and 12.81 kg ha^{-1} (2.22%) per year of release respectively. Generally,sesame breeding has been successful in increasing grain yield potential consistently across years since 1960 through 2007,signifying that there was no indication of yield potential plateau during this period. Moreover, significantly increasing parallel trend to variety release was also observed for thousand seed weight and grain yield, harvest index, seed yield per plant, capsule length, seed growth rate and seed yield per day also show increasing trend, but not statistically significant. On the contrary, regression of biomass yield, number of capsule per plant, number of branches per plant, days to flowering, days to physiological maturity, capsule filling period and reduced plant height on time of release of varieties showed negative trend though their slopes were not significantly different from zero. Stepwise regression analysis indicated that seed yield per plant was the most important character accounting for 84% of the variation in gain yield.

Changes in grain yield may be interpreted at one level as due to changes in seed yield per plant. In this study, changes in sesame yield potential were strongly correlated with harvest index, seed yield per plant, seed growth rate and seed yield per day indicating progressive improvement in these traits were successful in developing varieties and selection of these characters might have good impact on grain yield. Moreover, grain yield was positively associated with plant height, number of capsule per plant, capsule length and thousand seed weight. In conclusion, absence of plateau indicated the potential for further progress in grain yield. Finally, the data generated in one season can be used as a baseline though it may not be comprehensive enough as a data found over many seasons and locations. Hence, it is suggested that other yield potential experiments need to be conducted in more locations and seasons under both controlled and uncontrolled management conditions.

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