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ABSTRACT

Grain yield, oil content and other related traits of linseed (*Linum usitatissimum* L.) have been improved in the country over the last 25 years through breeding and other improved production techniques. The objective of this study was to estimate the genetic progress made in improving grain yield, oil content and associated traits. The experiment was conducted at Hossaina, Kokate, Dida-Midore and Holeta in 2009/10. A randomized complete block design with four replications was used. Nine released cultivars from 1984 to 2009, three pipeline varieties, and one local cultivar were used as testing materials. Among many others, the major traits that were analyzed in this study include grain and oil yields, oil content, thousand seeds weight, number of capsules per plant and seeds per capsule. Regression of trait means against the year of release indicated that thousand seeds weight and number of capsules per plant exhibited significant ($P \leq 0.05$) changes while the others being nonsignificant since 1984. However, dramatic and highly significant ($P \leq 0.01$) progress was observed in major traits such as grain and oil yields, oil content and thousand seeds since 1992 and furthermore since 1997. The estimated rates of increases per year were 4.33, 9.78 and 10.45 kg ha^{-1} for grain yield, 2.01, 4.59 and 5.00 g ha^{-1} for oil yield, 0.05, 0.10 and 0.12% for oil content, 0.033, 0.057 and 0.06 g for thousand seeds weight and 0.11, 0.15 and 0.18 capsules per plant since 1984, 1992 and 1997, respectively. These significant and linear genetic gains showed that there is no indication of a yield plateau for linseed breeding in Ethiopia. Therefore, the effort should be strengthened and continued to achieve more progresses in these and other relevant traits.

Key words: Genetic gain, economic importance, traits, pipeline, yield plateau.

INTRODUCTION

Linseed (*Linum usitatissimum* L.) is a traditional crop in Ethiopia and it is the second most important oil crop in production after noug (*Guizotia abyssinica* CASS) in the higher altitudes (Adugna and Adefris, 1995). In the country, it is usually cultivated in higher elevations where frost is a threat for other oil seeds such as niger seed (noug) and Ethiopian mustard (gomenzer). Linseed is a major oil seed and rotation crop for barley in high elevations of Arsi, Bale, Gojam, Gonder, Wello, Shewa and Wellega (Getinet and Nigussie, 1997).

Wijnands *et al.,* (2009) stated that 13% of the Ethiopian oilseed production is linseed and Ethiopia is the fifth world producer of linseed, but is negligible as exporter on the world market. It has been grown primarily for food and to generate cash for the farmers either on local markets or by exporting abroad (Adefris *et al.*, 1992).

Linseed oil has 45-65% of unique alpha-linolenic fatty acid (an essential omega 3 fatty acid), which has beneficial effects on health and the auto immune system (Payne, 2000; Moris, 2005). It is also consumed in various forms of soups, soft drinks and with porridges, cooked potatoes, etc. Hence, linseed has been cultivated in Ethiopia for its seed and oil, but the use as a fiber crop is very limited (Adugna *et al.*, 2004).

Due to the result of the high content of α-linolenic acid in linseed oil, it is used industrially for manufacturing paints, stains, inks, lacquers, varnishes, linoleum, etc. However, this character of linolenic acid that readily oxidizes and produces off-flavor (rancidity) has limited the use of linseed oil for edible purposes, particularly for cooking oil. In order to overcome this problem, "Linola" and "Solin" edible oil cultivars were developed in Australia and Canada, respectively (Adugna *et al.*, 2004).

The knowledge of changes associated with advances in crop productivity is essential for understanding yield–limiting factors and developing strategies for further improvement (Donmez *et al.,* 2001). After conducting an experiment on genetic improvement for yield and fertility of alfalfa cultivars representing different eras of breeding, Holland and Bingham (1994) concluded that genetic improvement in alfalfa has produced modern cultivars with improved forage yield potential and increased ratios of cross to self-fertility. Information about changes associated with advances in crop breeding is essential for understanding yield-limiting factors and developing new strategies for future breeding programs (Bogale *et al.,* 2015).

Periodic evaluation of genetic improvement of crop cultivars 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. Evaluation of cultivars from different eras in a common environment is the most direct of the several methods that have been used to estimate breeding progress (Cox *et al.,* 1988). Genetic improvement can be studied either by estimating level of genetic advance from a single or a series of selection cycles made at a time or from a long-term breeding effort made by a breeding program (Johanson *et al.,* 1955; Allard, 1960; Waddington *et al.,* 1986). Battenfield *et al.,* (2013) also stated that analysis of breeding progress can be conducted by studying a set of historical cultivars over multiple locations and years, or by comparing historical yield data with a standard over time.

In Ethiopia, research on linseed was commenced in the early 1960's at the then Debrezeit Research Station. However, systematic research on linseed was initiated during 1970's which led to the release of high yielding, agronomically suitable and disease resistant improved varieties in the 1980's (Adefris *et al*., 1992). As a result of existence of genetic variability for various economic traits, breeders tried to develop promising linseed varieties and many varieties were released for production so far.

Regardless of considerable resources allocation to linseed improvement there were no studies conducted to determine the progress in genetic gain in grain yield and oil content potential and related agronomic traits in the country. Hence, this experiment was initiated to fill this gap. The objective of the study was therefore, to estimate the genetic gain made in improving grain yield, oil content and associated traits of linseed.

MATERIALS AND METHODS

Experimental Sites and Materials

The experiment was conducted at four locations namely Kokate, Hossaina, Dida-Midore, and Holeta testing sites during the main cropping season of 2009 under rain fed condition. The first three sites are located in South Nations, Nationalities and peoples Region (SNNPR) under Hawassa and Areka Research Centers of South Agricultural Research Institute (SARI). Holeta is under Ethiopian Institute for Agricultural Research (EIAR) and is located in Oromia Region. The description of geographical coordinate, altitude, soil and climatic conditions of the testing sites is given in Table 1.

The experiment consisted of 13 varieties. Seven of them (CI-1525, CI-1652, Chilalo, Belay-96, Kulumsa-1, Berene and Tolle) were nationally released and the other two (Geregera, and Dibannee) regionally released from Adet and Sinana Agricultural Research Centers, respectively. Three pipeline varieties (Jeldu, Kassa-1, and Kassa-2) and one local cultivar were also included (Table 2). Among the nine released varieties, CI-1525 and CI-1652 were introduced from Europe before 1984 (Table 2).

Table 1: Description of the study locations

No	Trial site	Altit. (masl)	Soil			Rainfall amount (mm)		Temp. (^{0}C)	
			Type	Texture	pH	Annual	From Planting to maturity	min.	max
1	Kokate	2161	D.nitosols	clay	5.6	1376	673.1	13.5	25.3
2	Hossaina	2306	Nitosols	Clay-loam	5.5	1153	708.5	10.3	23.0
3	Dida-M	1876	Luvisols	Clay-loam	5.9	783	344.1	NA	NA
4	Holeta	2400	Nitosol	NA	4.9	929.3	588.6	6.1	22.4

Where NA = data is not available, Temp. = temperature, Altit. = altitude, RF = rainfall, N = north, E = east, min. = minimum, max.= maximum, yrs' = years', Dida-M = Dida-Midore, D. nitosols = Dystric nitosols
Source: National Meteorology Agency Hawassa Branch Office, South Bureau of Agricultural and Rural Development, Hawassa and Holeta Agricultural Research Centers

Table 2: The origin, year of release, and seed color of the tested linseed varieties

No.	Variety	Origin	Year of release	Seed Color
1	CI-1525	Introduced from Europe	1984	Brown
2	CI-1652	Introduced from Europe	1984	Brown
3	Chilalo	PGRC/E 200482/12 (SPS from Arsi; Chilalo)	1992	Brown
4	Belay-96	IAR/Li/124 x CI-25249(3)/4	1997	Brown
5	Geregera (R7-20D)	Introduced from Canada in 1989	1999	brown
6	Berene	PGRC/E 013627	2001	Brown
7	Tolle	CI-2698 x PGRC/E 13611/B	2004	Brown
8	Kulumsa-1	Chilalo/16 (SPS from Chilalo variety)	2006	Brown
9	Dibannee	CI-1525 x CDC 1747/21	2009	Brown
10	Jeldu	CI-1652 x Omega/23/A	In pipeline	Brown
11	Kasa-1	PGRC/E 10306 x Chilalo/1/A	In pipeline	Brown
12	Kasa-2	PGRC/E 10306 x Chilalo/Y/3	In pipeline	Yellow
13	Local cultivar	local cultivar	Pre-1984	Brown

Experimental Design and Procedures

The treatments were laid in a randomized complete block design with four replications. The experimental materials were planted according to the recommended dates of planting for each location, i.e. on 3 July at Holeta, 18 July at Hossaina, 23 July at Kokate, and 30 July 2009 at Dida-Midore. Each plot consisted of six rows of 4 m long and 1.2 m width (4.8 m^2) with spacing of 0.2 m between rows by leaving one empty row between plots. Distance between blocks was 1.5 m. Fertilizer was applied at planting in the form of diammonium phosphate (DAP) and urea at the recommended rates of 23:23 kg ha^{-1} N/P_2O_5 by incorporating with the soil before drilling the seeds. The seed rate was 25 kg ha^{-1}. Weed control was done by hand weeding and the sites were kept weed free during the growth period of the crop. All data were collected from the four middle rows in all locations.

Laboratory analysis for oil and other parameters were carried out according to the standard procedures for each treatment. Oil content was analyzed using a wide line nuclear magnetic resonance (NMR) method. Twenty-two g of clean seed samples from each plot were oven-dried at 130^{o}C for 2 hrs and then were analyzed by NMR with reference to the set standard at Holeta Agricultural Research Centre, Ethiopia.

In this study, linseed breeding program in Ethiopia was divided into three eras based on the changes brought about in the progresses of breeding:

i. Since 1984, the period in which high yielding, agronomically suitable and disease resistant improved varieties introduced and recommended.
ii. Since 1992, the period in which elite landraces began to be released and
iii. Since 1997, the period in which intra-specifically hybridized varieties began to be released.

Data Collection and Statistical Analysis

Data were collected on plot basis for all characters under investigation. Analysis of variance for each location and combined analysis over locations was done using the mean values of the recorded data following the standard procedures of SAS software version 9.0 (SAS Institute, 2004). Mean separation was subjected to Duncan's multiple range test (DMRT) at 0.05, 0.01 and 0.001 probability levels.

The annual rate of gain and changes produced in agronomic and physiological characters were estimated by regressing the mean value of each character for each variety against the year of release of the variety. The relative gains achieved over the 25 years period, in different traits were determined as the genetic gain to the corresponding mean values of the oldest variety (farmers' cultivar) and expressed as a unit value per year.

RESULTS AND DISCUSSION

The combined analysis of variance showed that there is highly significant (P≤ 0.01) differences among the locations for all characters and among genotypes for days to flowering, days to maturity, grain filling period, plant height, number of seeds capsule^{-1}, oil content, oil yield, thousand seeds weight and grain yield. However, nonsignificant differences for stand percent, primary and secondary branches, and number of capsules per plant (Table 3) were observed.

Grain yield performance of the varieties ranged from 776.96 kg ha^{-1} for local cultivar at low yielding environment, Dida-Midore, to 1773.4 kg ha^{-1} for Dibannee at high yielding environment, Hossaina. Varieties Kassa-1, Berene, Chilalo, Tolle, Geregera, and local cultivar did not exceed the grand mean (1225.10 kg ha^{-1}) across locations (Table 4). Among the varieties under the test, Kassa-2 which was very recent (the promising line) and that was derived from intra-specific hybridization ranked first in grain yield, oil content and oil yield. It also showed highly significant difference from local cultivar with yield advantage of 349.69 kg ha^{-1} (34.82%) in grain yield (Table 5). Similarly, Donmez (2001) in yield of winter wheat in the Great Plains, Fufa et al., (2005) in hard red winter wheat cultivars and Fikre *et al.*,(2012) in groundnut varieties reported that unlike modern cultivars, older cultivars were low yielding and the most recently released varieties had significantly exceeded the older ones in their grain yields.

In the current study, genotype x location interactions were not significant for grain yield, thousand seeds weight, number of capsules per plant, number of seeds per capsule and number of primary and secondary branches; indicating a similar response of different genotypes to environmental changes.

Table 3: Mean squares (MS) and degrees of freedom (df) for the combined analyses of variance of the characters for the 13 linseed cultivars over the four test locations

No	Character	Sources of variations, their degrees of freedom and significance levels of mean squares					mean	CV%
		Location (L) (3)	Reps within L (12)	Genotype (G) (12)	LxG (36)	Error (144)		
1	DtF	5763.87**	5.24*	124.18**	8.44**	2.84	67.69	2.49
2	DtM	14784.10**	23.8**	11.92**	11.20**	4.56	135.96	1.57
3	GFP	2464.67**	23.7**	106.44**	106.4**	6.53	68.27	3.74
4	PHT	3988.58**	130.7**	825.04**	30.84**	16.89	77.97	5.27
5	StP	1297.24 **	231.9**	76.68 ns	86.99*	52.34	76.85	9.41
6	PBr	151.02**	19.2**	2.63 ns	1.95 ns	1.68	7.24	17.91
7	SBr	2195.77**	36.7**	6.12 ns	5.91 ns	5.14	11.30	20.05
8	CPP	3920.58**	95.3**	58.52 ns	33.73 ns	33.08	27.93	20.59
9	SPC	9.94 **	5.2**	2.26**	0.92 ns	0.63	7.37	10.74
10	OC	103.60**	6.2**	18.25**	0.56*	0.36	36.21	1.66
11	OY	312266.6**	24404**	40613.5**	8938.8*	5767.8	446.00	17.03
12	TSW	4.21**	0.2 ns	5.08**	0.09 ns	0.10	5.37	5.97
13	GY	1846375**	153062**	195357**	59224 ns	42880.5	1225.1	16.90

*, **: indicate significant at 5 and 1% probability levels respectively. ns: not significant, DtF: days to flowering, DtM: days to maturity, GFP: grain filling period, PtH: plant height (cm), StP: stand percent, PBr: primary branches, SBr: secondary branches, CPP: capsules per plant, SPC: seeds per capsule, OC: oil content (%), OY: oil yield (kg ha^{-1}), TSW: thousand seed weight (g), GY: grain yield (kg ha^{-1})

Note: numbers in parentheses indicate degrees of freedom for each source of variation

Table 4: Mean grain yield (kg ha^{-1}) of 13 varieties grown at four locations

No	Variety	Kokate	Dida-Midore	Hossaina	Holeta	Varieties' Mean
1	local cultivar	939.5c	776.96d	1275.5abc	1025.2 b	1004.28 e
2	CI-1525	1169.7abc	1057.66ab	1661.2ab	1439.0a	1331.88ab
3	CI-1652	1139.5abc	1063.91ab	1645.9ab	1201.8ab	1262.80abc
4	Chilalo	1185.1abc	844.14cd	1282.0abc	1360.7a	1167.98bcd
5	Belay-96	1044.3bc	1112.89a	1363.1abc	1439.3a	1239.90abcd
6	Geregera	1047.3bc	1055.39ab	1070.6c	1132.6ab	1076.48de
7	Berene	1112.5abc	1073.21ab	1353.5abc	1265.8ab	1201.25abcd
8	Tolle	1038.4bc	882.97bcd	1343.3abc	1165.8ab	1107.61cde
9	Kulumsa-1	1200.5ab	1093.21ab	1682.8ab	1236.3ab	1303.21ab
10	Dibanne	1307.0 a	1012.34abc	1773.4 a	1238.4ab	1332.78ab
11	Jeldu can	1267.7ab	978.13abc	1620.1ab	1446.5a	1328.10ab
12	Kassa-1	1106.0abc	1176.41a	1218.3bc	1363.6a	1216.08abcd
13	Kassa-2	1184.1abc	1186.88a	1668.0ab	1376.8a	1353.97a
Mean		1133.99	1024.1	1458.29	1283.97	1225.10
R^2		0.652	0.683	0.428	0.423	0.657
CV%		13.09	12.43	20.92	15.61	16.90

Means followed by a common letter within a column are not significantly different according to Duncan's multiple range test at 0.05 probability level

Table 5: Year of release and means over all locations for six traits of 13 linseed varieties

Varieties	Year of release or register	Grain yield (Means)	Oil yield (Means)	OC (Means)	TSW (Means)	CPP (Means)	SPC (Means)
		Kg/ha		%	G	Number	
Local cultivar	----	1004.28	336.17	33.3	3.60	24.0	7.61
CI-1525	1984	1331.9	492.9	36.8	5.46	26.6	7.78
CI-1652	1984	1262.8	467.1	36.9	5.51	27.5	7.05
Chilalo	1992	1168.0	425.7	36.2	5.23	28.8	7.49
Belay-96	1997	1239.9	443.1	35.6	5.34	28.8	6.90
Geregera	1999	1076.5	380.8	35.4	5.70	24.6	6.92
Berene	2001	1201.3	430.6	35.8	5.25	28.7	7.39
Tolle	2004	1107.6	404.9	36.4	5.54	27.5	7.40
Kulumsa-1	2006	1303.2	485.7	37.2	5.43	29.3	8.13
Dibanne	2009	1332.8	486.3	36.4	5.83	30.0	7.54
Jeldu	Promising	1328.1	491.5	36.9	5.74	29.6	7.24
Kasa-1	Promising	1216.1	444.7	36.4	5.46	27.7	7.53
Kasa-2	Promising	1354.0	508.4	37.5	5.73	30.0	6.83
Significance level		***	***	***	***	Ns	***
CV%		16.90	17.03	1.66	5.97	20.59	10.74
Changes in traits per year	Since 1984	4.15ns	2.01ns	0.05ns	0.033*	0.11*	-0.003ns
	Since 1992	9.54**	4.59**	0.10***	0.057***	0.15*	-0.003ns
	Since 1997	10.20**	5.00**	0.12***	0.06***	0.18**	-0.002ns

Where ns = nonsignificant, *, **, *** = Significantly different from zero for change per year and from each other for genotypes at the 0.05, 0.01 and 0.001 levels of significance, respectively. CPP = number of capsules per plant, SPC = number of seeds per capsule, TSW = thousand seeds weight

Genetic Gains in Some Selected Traits

In this study, six relevant traits (grain and oil yields, oil content, thousand seeds weight, number of capsules per plant and number of seeds per capsule) were selected and analyzed for their estimated rate of changes per year. Among these traits; thousand seeds weight and number of capsules per plant revealed significant differences at 5% probability level. But, all of the remaining four traits brought about non-significant changes per year during the period of the first era i.e. since 1984 (Table 5).

However, since 1992 and 1997, except the number of seeds per capsule, all the other five traits showed highly significant ($P \leq 0.01$) progresses and maintained linearly with year of release. Similarly, Abeledo *et al.* (2003) indicated that most cereals exhibited a trend to a relatively low yield increases during much of the first half of the 20th century followed by a rapid rate of yield gains, due to both genetic and managements, during the second half. Ribeiro *et al.,* (2008) also reported that the significant increment of number of pods plant^{-1} yr^{-1} but no alteration for the number of seeds pod^{-1} yr^{-1} in some seasons of the test period.

Gains in grain and oil yields

The combined mean grain yield increased from 1004.3 kg ha^{-1} for local cultivar to 1353.9 kg ha^{-1} for Kasa-2 and that of oil yield from 336.2 for local cultivar to 508.4 kg/ha Kassa-2 with very highly significant difference ($P \leq 0.001$) among the overall means of the genotypes under the test (Table 5).

In the first era (since 1984), the relative rate of genetic gains in grain and oil yields (4.15 and 2.01 kg ha^{-1}yr^{-1}, respectively) of the modern cultivars over that of the older ones was non-significant (Table 5, figures 1a and 2a). This could be due to CI-1525, one of the most stable and high yielder, introduced oldest variety, which might be intra-specifically hybridized in Europe before being introduced to Ethiopia. Tamene (2008) also reported the lower and minimal genetic progress in faba bean breeding since the late 1970s could be attributed to the exceptionally stable and better adaptation of one of the oldest faba bean variety, CS20DK. Adugna and Labuschagne (2004) reported that the Ethiopian collections of linseed had smaller seeds and lower oil contents than the exotic ones.

When the varieties developed since 1992, regressed against the year of release; have shown an estimated average annual rate of highly significant ($P \leq 0.01$) increase in grain and oil yields of about 9.54 and 4.59 kg ha^{-1}yr^{-1}, respectively (graph is not shown). This progressive linseed breeding also continued to the next era (since 1997) achieving highly significant estimated annual gain of 10.20 kg ha^{-1} yr^{-1} grain and 5.00 kg ha^{-1} yr^{-1} oil yields (Table 5, figures 1b and 2b). In the same manner, Yifru (1998) in tef in Ethiopia; Abeledo *et al.* (2003) in barley in Argentina and Kebere (2006) in haricot bean in Ethiopia reported the significant average rate of increases per year of release.

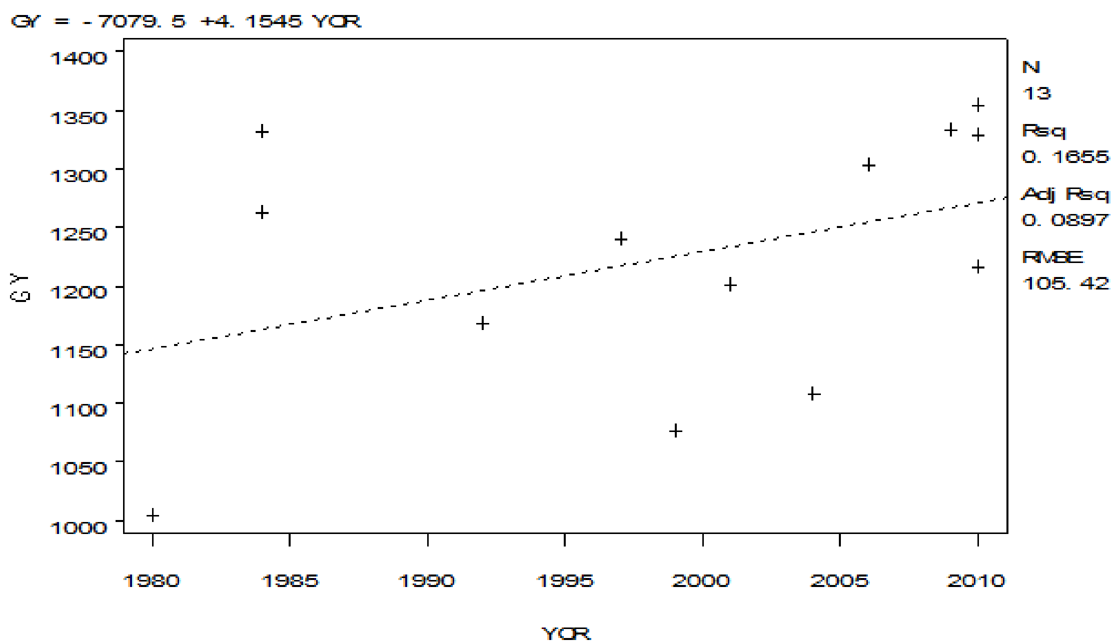
The grain and oil yields level of the varieties increased progressively over years of releases, showing that there was no indication for a yield plateau in linseed breeding in the country. This assessment is in agreement with the findings of Cox *et al.* (1988) in hard red winter wheat, Ustun *et al.,* (2001) in soybean, Edme´ *et al.,* (2005) in sucrose content of sugarcane breeding program in Florida and Wondimu (2010) in food barley in Ethiopia;- reported that no evidence of a yield plateau was found and the genetic improvement has not reached this stage. Conversely, Waddington *et al.* (1986) reported that genetic improvement in bread wheat (*Triticum aestivum* L.) reached the yield plateau in Northwest Mexico.

The varieties under this study were also categorized into four groups according to their period of release within a decade i.e. 1980s, 1990s, 2000s and pipeline varieties (2010s) to analyze the averaged mean rate of changes of the traits over the local cultivar. The varieties introduced and registered in 1980s gave grain and oil yields increment of 293.07 kg (29.18%) and 143.83 kg (42.78%), respectively, over the local cultivar exhibiting remarkably higher yields than the successive two decades (Table 6).

However, the promising lines which are considered and expected to be released in 2010, yielded higher than the preceding two decades with grain yield increment of 295.12 kg (29.39%) and oil yield increment of 145.36 kg (43.24%) over the local cultivar, indicating that the linear genetic progress of the breeding effort from 1990s to 2010s. The most distinguishable genetic gain in modern varieties of linseed in Ethiopia may be due to the focus on intra-specific hybridization to create genetic variability among the elite lines of the crop. Similarly, Yilma (1991) reported that with conventional breeding methods such as selection and progeny testing and variety crossing, genetic progress has utilized a lot of local germplasms. Likewise, most of the increase in soybean yield (Ustun *et al.* 2001), has come via genetically related elite by elite parent crosses.

Table 6: Comparison of the increments of grain and oil yields of the varieties released in 1980's, 1990's, 2000's and candidates in pipe line with local cultivar

No	Variety	Period of release	Mean yield (kg/ha)		Increment over the local cultivar			
					Grain yield		Oil yield	
			Grain	Oil	Difference Kg/ha	Increase %	Difference Kg/ha	Increase %
1	Local C.	Pre-1984	1004.28	336.17	---	---	---	---
2 3	CI-1525 CI-1652	1980's	1297.35	480.0	293.07	29.18	143.83	42.78
4 5 6	Chilalo Belay-96 Geregera	1990's	1161.47	416.53	157.19	15.65	80.36	23.90
7 8 9 10	Berene Tolle Kulumsa-1 Dibannee	2000's	1236.23	451.88	231.95	23.10	115.71	34.42
11 12 13	Jeldu Kasa-1 Kasa-2	In pipeline (2010's)	1299.40	481.53	295.12	29.39	145.36	43.24



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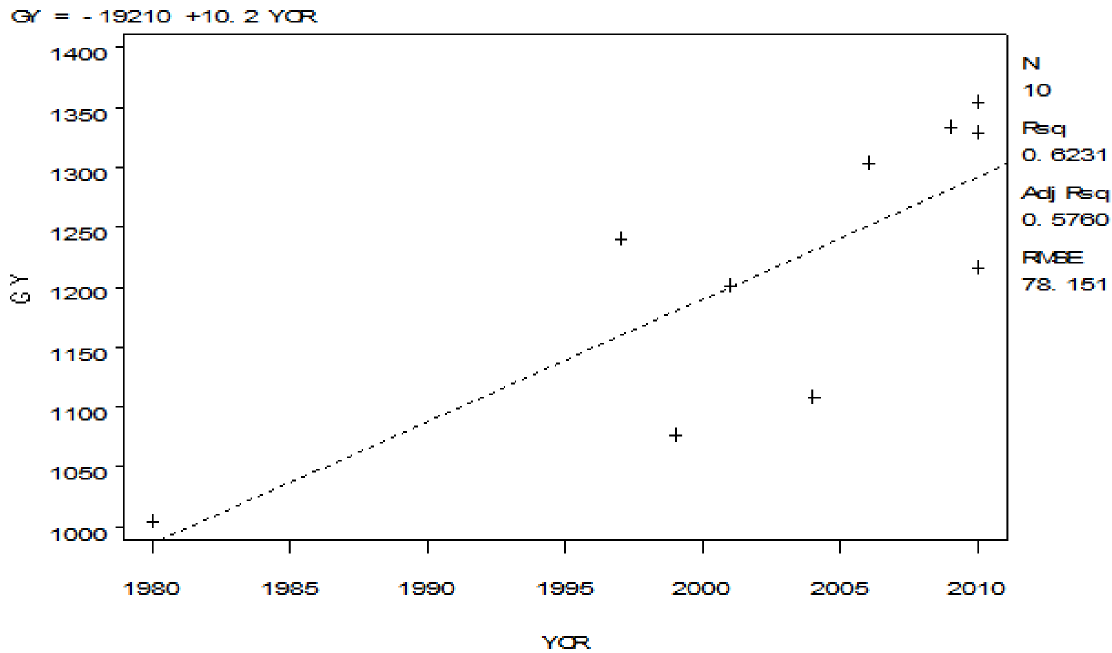
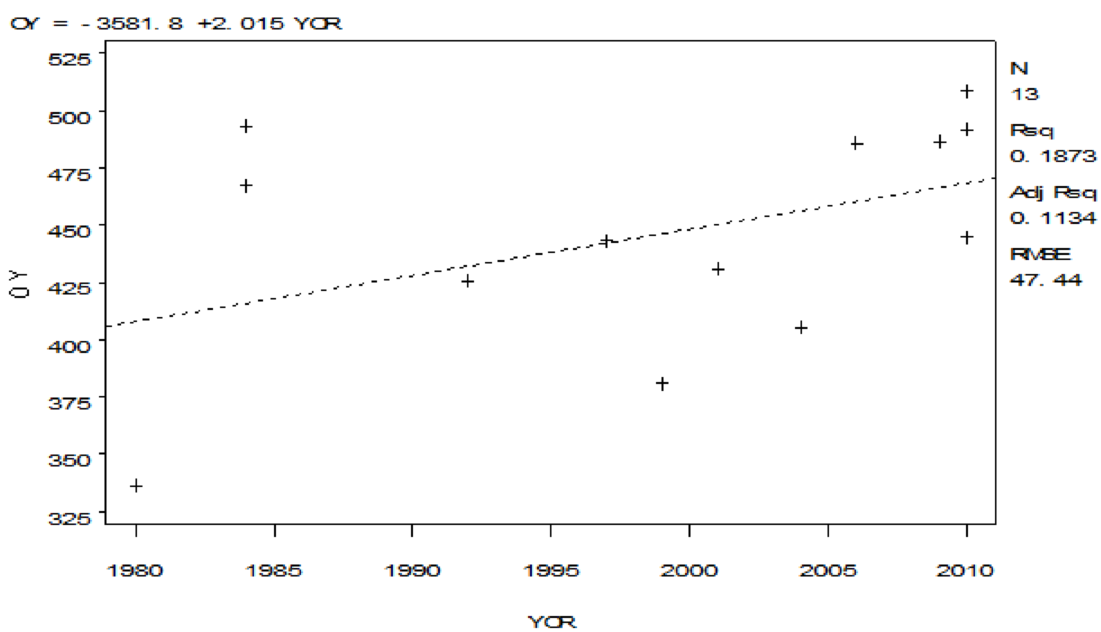


B

Figure 1: Relationship between mean grain yield (kg ha^{-1}) of the varieties and their year of release/register since 1984 (a) and since 1997 (b) Where Gy = grain yield (kg ha^{-1}), YOR = year of release



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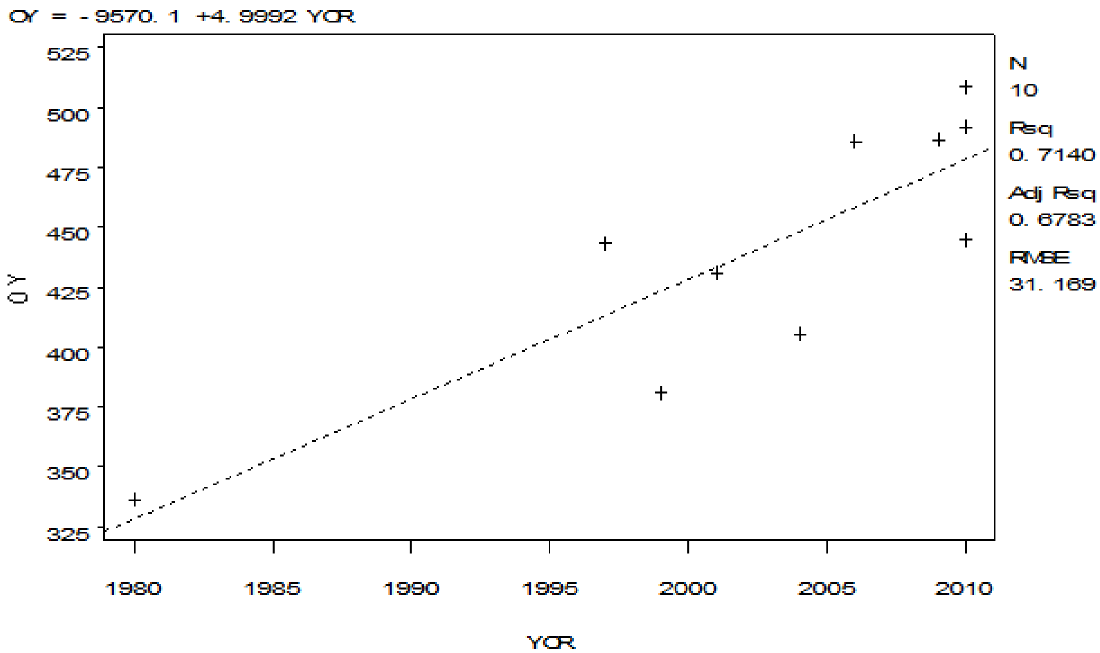

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Figure 2: Relationship between mean oil yield (kg ha^{-1}) of the tested varieties and their year of release since 1984 (a) and since 1997 (b) Where YOR = year of release, Oy = oil yield (kg ha^{-1})

Gains in oil content and thousand seeds weight

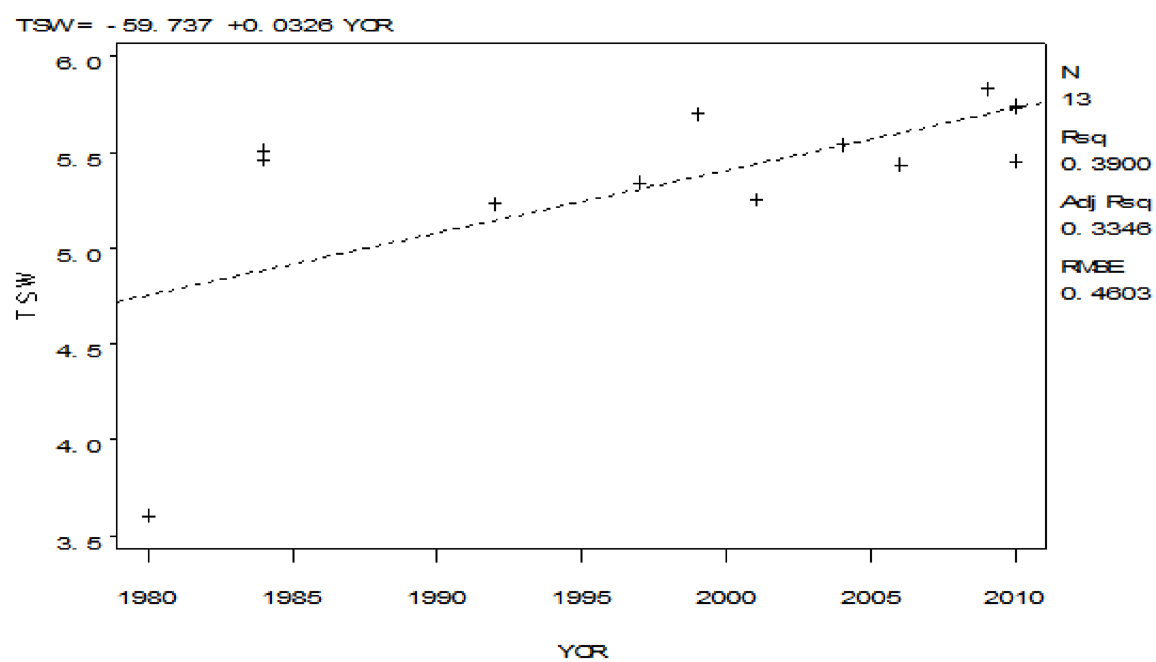
The linear regression of thousand seeds weight against years of release showed that there was continuous significant progress in increasing of weight exhibiting the estimated relative genetic gain of 0.033 g yr^{-1} since 1984 (Table 5 and Fig. 3a), 0.057 g yr^{-1} since 1992 (figure is not shown) and 0.06 g yr^{-1} since 1997 (Table 5 and Fig. 3b). Likewise, Wych and Rasmusson (1983) in malting barley; Cox *et al.* (1988) in hard red winter wheat; Amsal (1994) in durum wheat and Ortiz *et al.* (2002) in 2-row Nordic spring barley found that thousand seed weight of modern varieties were heavier than the older ones. In the contrary, Austin *et al.* (1980), in winter wheat, Waddington *et al.* (1986) in the yield potential of bread wheat adapted to Northwest Mexico; Yifru (1998) in tef, Brancourt-Hulmel *et al.* (2003) in winter wheat and Wondimu (2010) in food barley reported that modern varieties were not significantly heavier than the old varieties in thousand seeds weight.

The relative rate of gains per year of release of varieties developed since 1984 for oil content (0.05% yr^{-1}) was not significant (Table 5 and Fig. 4a). Nevertheless, the progress of genetic gains in varieties developed over years of release for this trait since 1992 and 1997 were very highly significantly ($P \leq 0.001$) different from zero with an estimated annual rate of increase about 0.10% since 1992 and 0.12% since 1997 (Table 5 and Fig. 4b).

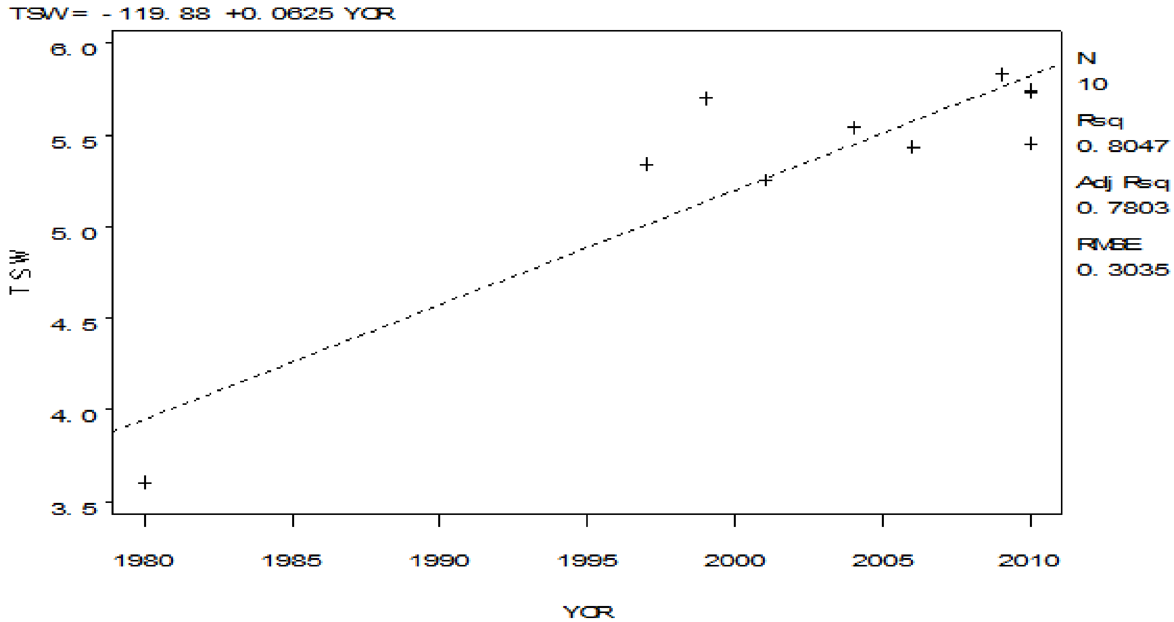
The averaged oil content and thousand seeds weight of the varieties registered in the decade 1980s showed higher progressive changes than that of 1990s and 2000s. But, there was consistent and linearly continuous increment since 1990s and 2000s as well as in the pipelines (2010s) (Table 7). When the average oil content within each decade compared with local cultivar, there were advantages of 10.66, 7.30, 9.46 and 10.90% in 1980s, 1990s, 2000s and in pipeline varieties, and in that of thousand seeds weight, there were 52.50, 50.56, 53.33 and 56.67% weight increments in 1980s, 1990s, 2000s and in pipeline varieties (2010), respectively. Similarly, Tamene (2008) indicated that the genetic progress obtained in faba bean breeding since the late 1970s was minimal, but there was progress in varieties released in the 1990s and since the year 2000 as well as those that were promising lines.

Table 7: Comparison of oil content and thousand seeds weight increases of varieties released/registered in 1980's, 1990's, 2000's, and the pipelines with the local cultivar

No	Varieties	Year of release	Mean		Increase over the local cultivar			
					Oil content		Thousand seeds weight	
			OC (%)	TSW (g)	Difference (%)	Increase (%)	Difference (g)	increase (%)
1	Local cultivar	Pre-1984	33.30	3.60	---	---	---	---
2 3	CI-1525 CI-1652	1980s	36.85	5.49	3.55	10.66	1.89	52.5
4 5 6	Chilalo Belay-96 Geregera	1990s	35.73	5.42	2.43	7.30	1.82	50.56
7 8 9 10	Berene Tolle Kulumsa-1 Dibannee	2000s	36.45	5.51	3.15	9.46	1.92	53.33
11 12 13	Jeldu Kasa-1 Kasa-2	Pipeline	36.93	5.64	3.63	10.90	2.04	56.67

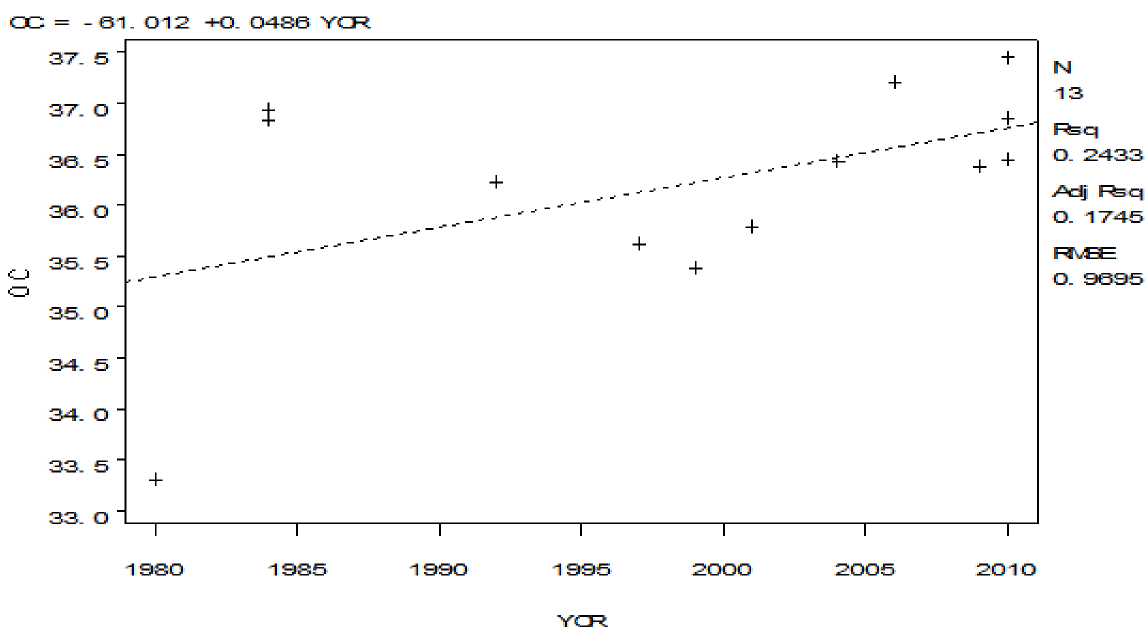


A

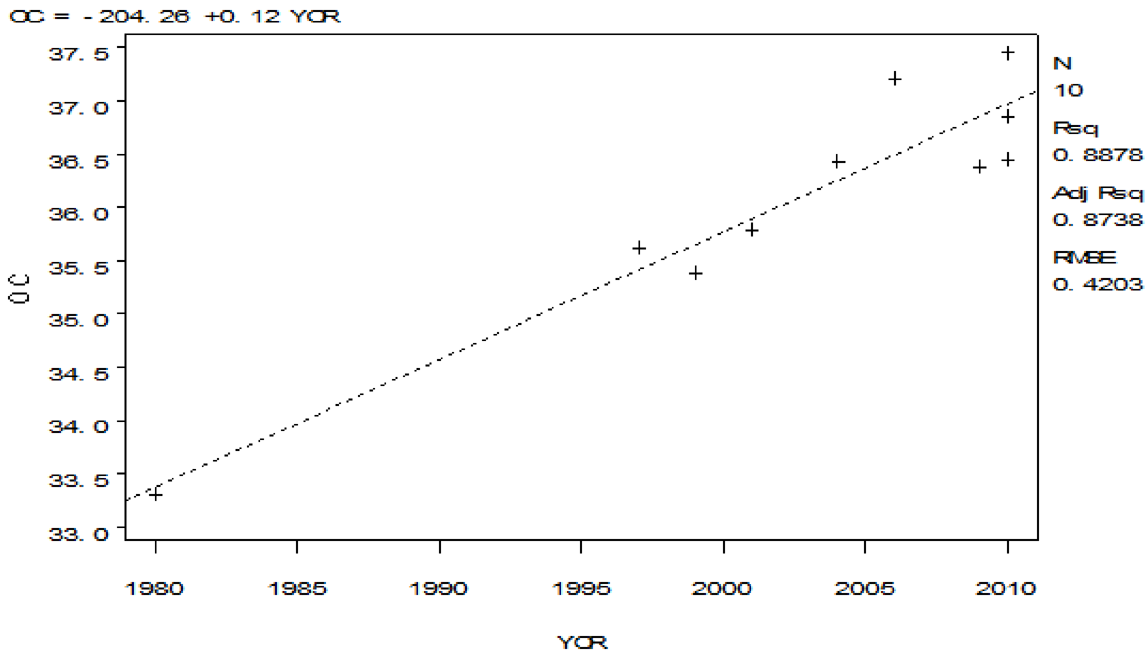


B

Figure 3: Relationship between mean thousand seeds weight (g) of the tested varieties and their year of release since 1984 (a) and since 1997 (b) Where YOR = year of release, TSW = thousand seeds weight



A



b

Figure 4: Relationship between mean oil content (%) of the tested varieties and their year of release since 1984 (a) and since 1997 (b) Where YOR = year of release, OC = oil content (%)

CONCLUSION

In the first era (since 1984), the relative rate of genetic gains in grain and oil yields, and in oil content (4.15 and 2.01 kg $ha^{-1}yr^{-1}$, and 0.05% yr^{-1}, respectively) of the modern cultivars over that of the older ones was non-significant. This could be due to CI-1525, one of the most stable and high yielder, introduced oldest variety, which might be intra-specifically hybridized in Europe before being introduced to Ethiopia.

However, when the varieties developed since 1992, regressed against the year of release; have shown an estimated average annual rate of highly significant ($P \leq 0.01$) increase in grain and oil yields, oil content, thousand seeds weight and significant ($P \leq 0.05$) increase in number capsules per plant of about 9.54 and 4.59 kg $ha^{-1}yr^{-1}$, 0.10%, 0.057 g, 0.15 capsules yr^{-1}, respectively. This progressive linseed breeding also continued to the next era (since 1997) achieving highly significant estimated annual gain of 10.20 and 5.00 kg $ha^{-1}yr^{-1}$, in grain and oil yields, 0.12% in oil content, 0.06 g in thousand seeds weight, and 0.18 capsules yr^{-1} in number capsules per plant.

The varieties introduced and registered in 1980s exhibited remarkably higher grain and oil yields than the successive two decades over the local cultivar. Nevertheless, the promising lines which are considered and expected to be released in 2010, yielded higher than the preceding two decades with grain yield increment of 295.12 kg (29.39%) and oil yield increment of 145.36 kg (43.24%) over the local cultivar. Similarly, the averaged oil content and thousand seeds weight of the varieties registered in the decade 1980s showed higher progressive changes than that of 1990s and 2000s, but there was consistent and linearly continuous increment since 1990s and 2000s as well as in the pipelines (2010s); indicating that the linear genetic progress of the breeding effort from 1990s to 2010s.

The average annual rate of progressive increasing level of the traits of these varieties over years of releases, showed that there was no indication for a yield plateau in linseed breeding in the country. Therefore, it is advisable and recommendable that the productivity of linseed can be increased by developing varieties through conventional and some latest progressive (recommended) breeding technologies.

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