Ethiop. J. Agric. Sci. 24:79-98: (2013)

AMMI Analysis of Yields and Oil Content in Some Linseed *(Linum usitatissimum* L.*)* Genotypes in South and Central Ethiopia

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Abstract

*Linseed (***Linum usitatissimum** *L.) is important to the Ethiopian farmers in terms of its various home uses generating potential in both domestic and foreign markets. One of the major linseed production constraints in the country is the lack of high yielding and high oil content varieties. This experiment was conducted at Hossaina, Kokate, Dida-Midore and Holeta to assess the genotype-by-environment interaction (GEI) among the varieties for yield and oil content. The experiment was carried out using nine released out and three pipeline varieties with a local cultivar. The analysis of variance of AMMI exhibited a very highly significant (P ≤ 0.001) variation due to varieties and locations for grain yield, oil content and oil yield, but GEI was significant for oil content and oil yield and not for grain yield indicating that the stability of the genotypes over the range of locations tested. The genotypes CI-1652, Tolle, Kassa-2, CI-1525, Jeldu, and Kulumsa-1 for oil content and the genotypes Kassa-2, Jeldu and CI-1525 for oil yield formed the first adaptive group with high mean and IPCA1 closer to zero IPCA1 indicating that they were the most stable and had wider adaptability across the studied environments. The AMMI selections for oil content and yield per environment included Kassa-2 in all the four locations; Jeldu in Holeta and Kokate; Kulumsa-1 in Dida-Midore, Hossaina and Kokate; CI-1525 in Holeta and Hossaina; Dibannee in Hossaina for both oil content and oil yield but in Kokate only for oil yield.*

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 Ethiopia, small-scale farmers have been producing it without applying any chemicals (fertilizers, herbicides, pesticides) and with minimum inputs (Adugna, 2000).

In Ethiopia, linseed is usually cultivated in higher elevations where frost is a threat for other oil seeds such as noug and gomenzer. Linseed is a major oil seed and rotation crop for barley in high elevation areas of Arsi, Bale, Gojam, Gonder, Wello, Shewa and Wellega (Getinet and Nigussie, 1997). Thirteen percent of the Ethiopian oilseed production comes from linseed. Ethiopia is the fifth world producer of linseed, but its export contribution to the world market is negligible (Wijnands *et al.,* 2009). The crop is primarily grown for food, but some proportion of it goes for generating cash for the farmers (Adefris *et al.*, 1992). According to Central Statistical Authority (CSA, 2008) report, in Ethiopia 176,750 ha of land was covered with linseed and the annual production was estimated to be 1,714,900 quintals in the year 2008.

In Ethiopia, research on linseed was commenced in the early 1960's at the then Debrezeit Research Station, but, systematic research 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. Efforts of breeding for edible oils have led to the development of low linolenic fatty acid varieties and some efforts are also underway at Holeta (Adugna *et al.*, 2004).

Plant breeders invariably encounter GEI when testing crop varieties across a number of environments (Kaya *et al.,* 2002). Depending upon the magnitude of the interactions or the differential genotypic responses to environments, the varietal rankings can differ greatly across environments. Assessing any variety or agronomic treatment without including its interaction with the environment is incomplete and thus limits the accuracy of yield estimates (Crossa, 1991).

Kaya *et al. (*2002), defined the AMMI model as a hybrid analysis that incorporates both the additive and multiplicative components of the two-way data structure. Romagosa and Fox (1993), also reported the powerfulness of the model, providing a scale for principal component analysis (PCA) scores which allows estimation of specific GEI terms, and for its ability to extract genotype and environment main effects.

The objective of this investigation was to analyze the pattern of GEI for yields and oil content potential as well as other related agronomic traits of 13 genotypes by Additive Main Effects and Multiplicative Interaction (AMMI) model.

Materials and Methods

Experimental Sites

The experiment was conducted at four locations during the main cropping season of 2009 under rainfed condition at Kokate, Hossaina, Dida-Midore, and Holeta testing sites. The first three sites are located in South Nations, Nationalities and Peoples Region (SNNPR). Holeta, which is located in West Shoa of Oromia Region and were included for comparison due to its significance on a centre of excellence. It is also one of the potential areas for linseed production in the country. The description of geographical coordinates, altitude, soil and climatic conditions of the testing sites is given in Table 1.

Table 1. Description of the study locations

Trial site	Latitude	Longitude	Alt. (masl)	Soil			Rainfall (mm)		Temp. (^{0}C)	
				Type	Texture	pH	Annual	From months of Planting to maturity	min.	max
Kokate	06^0 49' 18''	037^0 44' 56''	2161	D.nitosols	clay	5.6	1376	673.1	13.5	25.3
Hossaina	07^0 34' 04"	037^0 51' 22"	2306	Nitosols	Clay-loam	5.5	1153	708.5	10.3	23.0
Dida-M	08^0 00' 39"	038^0 31' 53"	1876	Luvisols	Clay-loam	5.9	783	344.1	NA	NA
Holeta	08^o 58'	38^o 14'	2400	Nitosol	NA	4.9	929.3	588.6	6.1	22.4

NA = data is not available, Temp. = temperature, Alt. = altitude, min. = minimum, max.= maximum, Dida-M = Dida-Midore, D. nitosols = Dystric nitosols
Source: National Meteorology Agency Awassa Branch Office, South Bureau of Agricultural and Rural Development, Hawassa and Holeta Agricultural Research Centers.

Experimental Materials

The experiment consisted of 13 varieties. Seven of them (CI-1525, CI-1652, Chilalo, Belay-96, Kulumsa-1, Berene and Tolle) were nationally released by Holeta Agricultural Research Center (HARC) 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) from HARC and one local cultivar were also included. The genotypes and their origin, year of release/registration and seed color are presented in Table 2.

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

No.	Genotype	Origin	Year of Release /Registration	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	Pipeline	Brown
11	Kasa-1	PGRC/E 10306 x Chilalo/1/A	Pipeline	Brown
12	Kasa-2	PGRC/E 10306 x Chilalo/Y/3	Pipeline	Yellow
13	Local cultivar	Local Cultivar	--------	Brown

Field Experiment

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 the respective locations, i.e. on 3, 18, 23 and 30 July, 2009 at Holeta, Hossaina, Kokate and Dida-Midore, respectively.

The gross plot size was 4.8 m^2 (6 rows each 4 m long) and the harvestable plot area was 3.2 m^2 (4 rows of 0.2 m apart with 4 m length) leaving one empty row between plots. The spacing 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. The seed rate was 25 kg/ha. Weeding was carried out using weeding as required to keep the experimental sites weed free during the growth period of the crop. All data were collected from the four middle rows in all locations.

Laboratory Analysis

Laboratory analyses for oil and moisture contents as well as other data were carried out according to the standard procedures for each experimental unit.

Moisture content (%): Moisture content was determined using oven method by drying 25 g of well-cleaned sample of seeds from each plot at 130^0 C for two hours. The actual moisture content of fresh seeds of each sample during weighing was determined identified by converting the difference of fresh and dry weights to percentage. The correction factor was calculated as:

$$\text{Moisture \%} = \frac{100 - \text{recorded moisture \%}}{100 - \text{required moisture (7\%)}}$$

Then the adjusted grain yield of each plot was obtained multiplying the fresh plot yield in g/plot by the correction factor and finally converted to kg/ha.

Oil content (%): Oil content was analyzed using a wide line nuclear magnetic resonance (NMR) method. Twenty-two grams of clean seed samples from each plot were oven-dried at 130^oC for 2 hrs and then were analyzed by NMR with reference to the set standard at Holetta Research Centre, Ethiopia.

Statistical Analysis

Analysis of variance for each location and combined analysis over locations was done following the standard procedures using SAS software version 9.0 (SAS Institute, 2004). Mean separation was done using Duncan's multiple range test (DMRT) at 0.05, 0.01and 0.001 probability level. The additive main effects and multiplicative interaction (AMMI) stability model was calculated using GenStat 9th ed. The AMMI model for the average yield, Yij, over replicates of the i^{th} variety in the j^{th} environment Anandan *et al.* (2009) was:

$$Y_{ij} = \mu + G_i + E_j + {}^n\Sigma\, \lambda_k\, \alpha_{ik}\, \gamma_{jk} + \epsilon_{ij}$$

Where, Y_{ij} is the yield of the i^{th} variety in the j^{th} environment; μ is the grand mean; Gi and Ej are the variety and the environment deviations from the grand mean, respectively; λ_k is the eigenvalue of the PCA axis k; α_{ik} and γ_{jk} are the variety and environment principal component scores for axis k; n is the number of PCA axes considered and ϵ_{ij} is the residual term which includes the experimental error.

The additive part of the AMMI model (μ, Gi and Ei) was estimated from an analysis of variance and the multiplicative part (λ_k, α_{ik}, and γ_{jk}) was from a principal component analysis. The interaction between any variety and environment was estimated by multiplying the score for the interaction principal component axis (IPCA) of a variety by an environment IPCA score (Van, O. *et al.*, 1993).

Results and Discussion

Grain Yield Performance

Combined ANOVA across locations revealed highly significant difference ($P \leq 0.01$) among genotypes (varieties) and the environment (locations) for grain yield (Table 4). Tadele (2002); Adugna and Labuschagne (2003b); Erena (2003); and Adane (2008) also reported significant differences among varieties for their mean grain yields of linseed across locations.

There was significant difference ($P \leq 0.05$) among the genotypes, at Dida-Midore and at Hossaina for grain yield (Table 3). The grain yield performance of the genotypes ranged from 776.96 kg/ha for local cultivar at low yielding environment, Dida-Midore, to 1773.4 kg/ha for Dibannee at high yielding environment, Hossaina, (Table 5). At Dida-Midore, the grain yield ranged from 776.96 kg/ha for the local cultivar to 1186.88 kg/ha for kassa-2 while at Hossaina it ranged from 1070.6 kg/ha for Geregera to 1773.4 kg/ha for Dibannee.

At Holeta, the highest yielder, Jeldu, gave significantly higher yield than the local cultivar with grain yield advantage of 421.3 kg/ha (41.1%). This variety was already released in 2010 for high lands of West-Shewa and other similar main agro-ecological zones (MoARD, 2010), confirming its superior yield performance under Holeta condition (Table 5).

Among the varieties, Kasa-2 (the promising line) ranked first in grain yield and showed significant difference from local cultivar, Geregera, Tolle, and Chilalo with yield advantages of 349.69 kg/ha (34.82%), 277.49 kg/ha (25.78%), 246.36 kg/ha (22.24%), and 185.99 kg/ha (15.92%), respectively.

Table 3. Mean square values, CV (%) and means of grain yield, oil content and oil yield of the varieties against the trial locations

Traits	Source of variation	DF	Mean Squares (MS)			
			Kokate	Dida-Midore	Hossaina	Holeta
GY	Variety	12	40815.5ns	61363**	200621.9*	70229.1ns
	Rep	3	333266.1**	174413.2**	32260.2ns	72309.7ns
	Error	36	22037.1	16213.8	93107.2	40164
	Mean		**1133.99**	**1024.16**	**1458.29**	**1283.97**
	CV (%)		13.09	12.43	20.92	15.61
OC	Variety	12	4.89**	6.01**	3.99**	5.04**
	Rep	3	10.29**	12.19**	1.17**	1.19*
	Error	36	0.458	0.431	0.26	0.309
	Mean		**35.99**	**34.65**	**36.14**	**38.08**
	CV (%)		1.88	1.89	1.40	1.46
OY	Variety	12	8261.8**	10715.2**	34266.7**	14186.3*
	Rep	3	48832.9**	32181.6**	6547.2ns	10054.4ns
	Error	36	2815.7	2226.1	12436.5	5592.7
	Mean		**409.02**	**356.91**	**528.60**	**489.46**
	CV (%)		12.97	13.22	21.10	15.28

ns = nonsignificant, * = significant at P ≤ 0.05, ** = significant at P ≤ 0.01, and *** = significant at P ≤ 0.001 probability level. GY= grain yield, OC = oil content, OY = oil yield

Table 4. Combined across locations mean square values of the genotypes, environments (locations), GxE interactions, blocks within locations, error, and means and CV% of the traits

Source of variation	Degrees of freedom	Mean squares and CV%			
		Grain yield	Oil content	Oil yield	Remarks
Genotypes (G)	12	195357**	18.3***	40614***	
Environment (E)	3	1846375***	103.6***	312267***	
GxE	36	59224ns	0.56*	8939*	
Block (loc)	12	153062***	6.21***	24404***	
Error	144	42881	0.36	5767.8	
CV%		16.90	1.66	17.03	

*ns = nonsignificant, * = significant at P ≤ 0.05, ** = significant at P ≤ 0.01, and *** = significant at P ≤ 0.001 probability level.*

Table 5. Mean grain yield (kg/ha) of 13 varieties grown at four locations during 2009 cropping season

No	Variety	Kokate	Dida-Midore	Hossaina	Holetta	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	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

Oil Content and Yield Performances

The combined analysis of variance across the four locations showed that the varieties differed highly significantly ($P \leq 0.01$) in performance of both traits (oil content and yield) (Table 4). There was also highly significant difference among locations. Erena (2003) and Adugna et al. (2004) also reported similar significant variation among varieties for oil content and oil yield. However, Adane (2008) showed that there was significant difference for oil yield but not for oil content and Tadele (2002) indicated nonsignificant difference among linseed varieties for oil content.

Differences among varieties were significant ($P \leq 0.05$) at all locations for both oil content and oil yields (Table 3). The oil content ranged from 30.97% for the local cultivar at Dida-Midore to 39.55% for Kassa-2 at Holeta (Table 6). Adane (2008) also indicated that the range of oil content was about 35.1% for the lowest oil containing cultivar at low yielding environment to about 39.7% for the highest containing cultivar at high oil containing environment.

Dida-Midore was characterized by lower rainfall during the months from planting to maturity (344 mm) compared with the other locations (Table 1). Wijnands *et al.* (2009) indicated that high temperatures and low rainfall during flowering and seed set lead to lower grain yield and oil content.

The varieties varied in their combined mean oil content performance across the locations ranging from 33.3% for local cultivar to 37.45% for Kassa-2 (Table 6). Similarly, Adugna *et al.* (2004) reported a range of oil content from 29-36% for 60 linseed accessions at Holeta. Erena (2003) also indicated the range for oil content from 26.5 to 33.45% and for oil yield from 9.33 to 428.5 kg/ha (1.68 to 77.13 g/1.8 m^2) at Kulumsa. Wijnands *et al.* (2009) also indicated the oil content ranging from 35% to 42%.

Table 6. Means of oil content of 13 varieties grown at four locations during 2009/10 cropping season

No	Variety	Kokate	Dida-Midore	Hossaina	Holeta	Mean
1	Local cultivar	33.34f	30.97e	33.77g	35.12e	33.30 f
2	CI-1525	36.52abc	35.13abc	36.95abc	38.74ab	36.83bc
3	CI-1652	37.06ab	35.37abc	36.76bcd	38.73ab	36.93 b
4	Chilalo	36.44abc	33.92d	36.11de	38.45bc	36.23 d
5	Belay-96	35.08e	34.72bcd	35.29f	37.33d	35.61 e
6	Geregera	34.93e	34.43cd	35.23f	36.93d	35.38 e
7	Berene	35.25de	34.64bcd	35.54ef	37.64cd	35.78 e
8	Tolle	36.18abcd	34.95abcd	36.25cde	38.33bc	36.43dc
9	Kulumsa-1	37.10a	35.57ab	37.55a	38.56b	37.20ab
10	Dibanne	35.98bcde	35.97a	36.76bcd	38.24bc	36.38cd
11	Jeldu	36.93abc	35.12abc	36.57bcd	38.78ab	36.85bc
12	Kassa-1	35.91cde	35.17abc	36.06de	38.65b	36.44cd
13	Kassa-2	37.17a	35.97a	37.13ab	39.55a	37.45 a
Mean		35.99	34.65	36.14	38.08	**36.21**
R^2		0.844	0.875	0.848	0.852	0.923
CV%		1.88	1.89	1.40	1.45	1.66

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 7. Mean oil yield (kg/ha) of 13 varieties grown at four locations during 2009/10 cropping season

No	Varieties	Kokate	Dida-Midore	Hossaina	Holeta	Mean
1	Local cultivar	314.09 c	241.38e	429.41de	359.79c	336.17 g
2	CI-1525	427.57ab	371.88abc	615.05abcd	557.20a	492.93ab
3	CI-1652	422.34ab	377.11abc	602.96abcd	465.94abc	467.09abcd
4	Chilalo	431.80ab	286.37de	462.15bcde	522.66ab	425.75def
5	Belay-96	367.05bc	387.23abc	481.03abcd	537.22ab	443.13bcde
6	Geregera	365.53bc	363.08abc	376.57e	418.14bc	380.83fg
7	Berene	391.93abc	372.15abc	482.50abcde	475.87abc	430.61cde
8	Tolle	376.13bc	310.34cde	486.95abcde	446.40abc	404.95ef
9	Kulumsa-1	445.94ab	390.01ab	632.85ab	474.10abc	485.72abcd
10	Dibanne	470.16 a	350.75abcd	651.56a	472.73abc	486.30abcd
11	Jeldu	467.76 a	345.45bcd	592.59abcd	560.23a	491.51abc
12	Kassa-1	396.41abc	416.01ab	439.03cde	527.22ab	444.67bcde
13	Kassa-2	440.59ab	428.15a	619.16abc	545.54a	508.36a
Mean		409.02c	356.91d	528.60a	489.46b	**446.00**
R^2		0.708	0.737	0.490	0.499	0.711
CV%		12.97	13.22	21.10	15.28	17.03

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

Genotype × Environment Interaction for Grain Yield, Oil Content and Oil Yield

The GEI showed significant difference ($P \leq 0.05$) for oil content and oil yield but not for grain yield (Tables 8, 10, 11 and 13). Nonsignificant GEI for grain yield may indicate the stability of the genotypes over the range of locations tested as suggested by Misra *et al.* (2009).

Table 8. Additive main effects and multiplicative interaction (AMMI) analysis of variance for grain yield

Sources	df	SS	MS	F	% Explained
Treatments	51	10015484	196382**	4.58	**55.56**
Gentype (G)	12	2344293	195358**	4.56	13.00
Environments (E)	3	5539123	1846374**	12.06	30.73
Reps within Env.	12	1836739	153062**	3.57	**10.19**
G x E	36	2132069	59224 ns	1.38	11.83
Error	144	6174796	42881		**34.25**
Total	207	18027019	87087		

ns = nonsignificant, * = significant at $P \leq 0.05$ and ** = significant at $P \leq 0.01$ probability level.

The AMMI analysis for grain yield revealed that the locations, genotypes and GEI accounted for 30.73, 13.00 and 11.83% of the total SS of the model, respectively (Table 8). The larger proportion of the environments (locations) indicated that the environments were diverse, with large differences among environmental means, causing most of the variations in grain yield. Similarly, Adugna and Labuschagne (2003b) indicated that year by location and location variability was found to be dominant sources of interactions for linseed in Ethiopia. Adane (2008) on linseed also reported that the larger portion of the sums of squares was due to environment, denoting the significant influence of the environment. In this study, because of non significant MS of GEI, the IPCA component part of the grain yield is not analyzed.

Oil Content Stability Analysis

The AMMI analysis of variance showed that the sum of squares due to genotypes, environments and GEI were significant indicating broad range of diversity existed among environments, genotypes and their interaction (Tables 10 and 11). The significance exhibited by GEI indicated that the genotypes interacted differentially in localities tested.

The analysis of AMMI model showed that most of the total SS of the model for oil content were attributed to environmental effects (45.92%) and the rest to genotypic (32.36%) and the interaction term (2.97%) (Table 10), indicating that there was greater influence of the environments on the performance of oil content of linseed varieties under investigation. This was in agreement with the findings of Taye *et al.* (2000), Kaya *et al.* (2002), Alberts (2004), and Solomon *et al.* (2008) who found greater influence of the environments on the performance of traits.

The multiplicative variance of the treatment sum of squares due to GEI was partitioned into IPCA1, IPCA2, and IPCA3 variation (Tables 11). About 66.17, 23.38, and 9.95% of the interaction sum of squares were explained by IPCA1, IPCA2, and IPCA3, respectively.

The first principal component factor showed a highly significant difference ($P \leq 0.01$) and captured a high contribution to the interaction sum of squares, while the second and the third components together accounted for 33.33%, which was almost half of the first principal component with non significant difference (Table 11). Therefore, the latter two principal component axes did not help to predict validation observations and thus the interaction of the genotypes with the environments was predicted by only IPCA1. This is in agreement with the reports of Romagosa *et al.* (1996) who showed that, among the principal component analyses, the IPCA1 captured the highest and significant part. However, Gauch and Zobel (1996); Annicchiarico (2002) and Solomon *et al.* (2008) recommended that the most accurate models for AMMI analysis were the first two principal components.

The scatter of genotypes' points in the AMMI 1 biplot (Table 9 and Figure 1) showed four adaptive groups of genotypes for oil content. The genotypes CI-1652, Tolle, Kassa-2, CI-1525, Jeldu, and Kulumsa-1 formed the first adaptive group with high mean accompanied with relatively closer to zero IPCA1 scores, indicating that they are the most stable across the studied environments. Anandan *et al.* (2009) and Misra *et al.* (2009) also described that genotypes with IPCA1 scores near zero had little interaction across environments, while those with large IPCA 1 scores, either positive or negative direction were highly interactive.

Except Tolle, all the other five genotypes from the first adaptive group were included in the first four AMMI selections of genotypes per environment (Table 12). Genotype Kassa-2 was the top ranking variety in its oil content at three environments (Holeta, Kokate, and Dida-Midore). Among the above mentioned first adaptive group with high mean oil content, genotypes CI-1652, Jeldu, and Kulumsa-1 showed moderately positive interaction which is similar sign with Holeta indicating that the attribution to the higher oil content and adaptability of these genotypes at this location. Crossa *et al.* (1991) and Nimbalkar *et al.* (2004) reported similar signs of IPCA 1 score for both genotype and environment imply positive interaction and thus it attributes to higher yield of genotype at that particular environment.

Table 9. The genotype and location means and scores for the first 3 AMMI components (IPCA1, IPCA2 and IPCA3 scores) of oil content and oil yield

	Oil content				Oil yield			
Genotype	Mean yield	IPCA1	IPCA2	IPCA3	Mean yield	IPCA1	IPCA2	IPCA3
Local cultivar	33.30	0.6991	0.2472	-0.0827	336.2	1.2491	0.5401	-1.9737
CI-1525	36.83	0.1181	0.1093	-0.2111	492.9	2.4339	-2.3354	4.3360
CI-1652	36.93	0.0269	-0.2264	0.4567	467.1	3.9644	3.0311	0.1941
Chilalo	36.23	0.6077	-0.4373	0.0191	425.7	-2.3073	-7.4459	-3.1814
Belay-96	35.61	-0.5780	0.0763	0.0495	443.1	-4.6482	-0.3053	4.7890
Geregera	35.38	-0.4893	0.2716	0.1635	380.8	-6.4410	3.7839	-4.0927
Berene	35.77	-0.3970	0.0062	-0.1261	430.6	-2.5449	1.6468	-0.3842
Tolle	36.43	-0.0844	-0.0711	0.0069	404.9	0.1880	-0.4067	-0.8843
Kulumsa-1	37.19	0.1574	0.5741	0.2782	485.7	4.9958	3.2452	-0.4500
Dibanne	36.38	0.2285	0.3218	-0.3711	486.3	7.1727	0.4821	-2.4730
Jeldu	36.85	0.1455	-0.2671	0.2614	491.5	1.9784	-5.1795	0.0021
Kassa-1	36.4	-0.3223	-0.3175	-0.3386	444.7	-7.3965	1.1859	0.7666
Kassa-2	37.45	-0.1123	-0.2873	-0.1058	508.4	1.3556	1.7578	3.3514
Mean	36.21	-------	-----	------	446.0	----	-----	-----
Locations								
Kokate	35.99	0.5379	-0.2273	0.6236	409.0	0.3013	-2.4421	-8.0287
Dida-Midore	34.65	-1.1364	0.1420	0.1313	356.9	-6.7200	8.4333	0.9431
Hossaina	36.14	0.4806	0.7542	-0.2683	528.6	12.4058	1.1709	2.7825
Holeta	38.08	0.1179	-0.6689	-0.4866	489.5	-5.9871	-7.1621	4.3031

The genotypes Dibannee and Kassa-1 formed the second adaptive group having moderately higher oil content than the combined mean and exhibiting almost medium absolute value of IPCA1 score but with opposite interaction signs; the former having positive (0.2285 score), while the latter negative (-0.3223 score) (Table 9 and Figure 1). Genotypes Berene, Geregera, and Belay-96 were grouped as the third adaptive group with lower mean than the combined mean and with the highest magnitude of negative interaction (Figure 1) and were in the same quadrant (quadrant III) with Dida-Midore which is the lowest oil containing environment.

The local cultivar and Chilalo formed another adaptive group, showing the highest IPCA1 scores and lower mean oil content with higher positive interaction effect. These genotypes were closer to environments Kokate and Hossaina in AMMI 1 biplot, indicating that the specific adaptability to these environments (Table 9 and Figure 1). Misra *et al.* (2009) reported that a genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment and is therefore best suited to that environment.

Table 10. Sum of squares (SS) of the 3 traits for 13 linseed varieties grown at four locations during 2009/10 cropping season

No	Trait	Sources of variation and their sum of squares (SS)					% Contributed		
		Environment (3)	Genotype (12)	GxE (36)	Error (144)	Total (207)	L	G	LxG
1	OC	310.81**	219.05**	20.11 *	52.35	676.85	45.92	32.36	2.97
2	OY	936799**	487362**	321797*	830557	2869364	32.65	16.99	11.21
3	GY	5539124**	2344282**	2132071^{ns}	6174795	18027019	30.73	13.00	11.83

Values in parenthesis indicate degrees of freedom (df)
*ns = nonsignificant, * = significant at P ≤ 0.05 and ** = significant at P ≤ 0.01probability level. OC = oil content (%), OY = oil yield (kg/ha), GY = grain yield (kg/ha)*

Table 11. Additive main effects and multiplicative interaction (AMMI) analysis of variance for oil content

Sources	df	SS	MS	% Explained
Treatment	51	550.0	10.78**	81.26
Environments	3	310.8	103.60**	45.92
Reps within Env.	12	74.5	6.21**	11.01
Genotype	12	219.0	18.25**	32.36
G x E interaction	36	20.1	0.56*	2.97
IPCA 1	14	13.3	0.95**	66.17
IPCA 2	12	4.7	0.39ns	23.38
IPCA 3	10	2.0	0.20ns	9.95
Error	144	52.4	0.36	7.74
Total	207	676.8	3.27	

ns = nonsignificant, * = significant at P ≤ 0.05 and ** = significant at P ≤ 0.01 probability level.

The AMMI1 biplot and AMMI analysis of variance indicated that the four environments (locations) were scattered grouping Kokate and Hossaina in one category with relatively larger absolute IPCA 1 score (0.5379) for Kokate and (0.4806) for Hoassina (Table 9 and Figure 1), showing a larger interaction and high discrimination among varieties and the lower oil content than the combined mean. However, varieties Kassa-2, Kulumsa-1, CI-1652, and Jeldu were better adapted to Kokate environment.

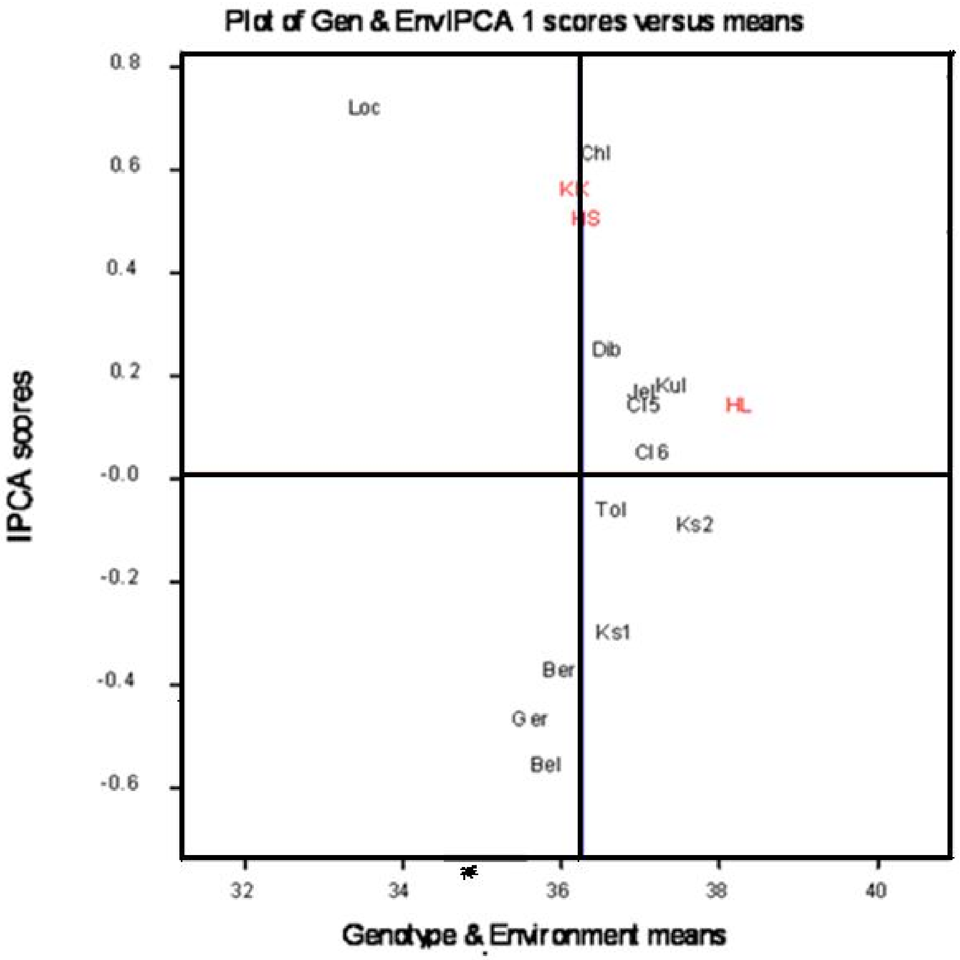

Figure 1. AMMI biplot of IPCA1 versus oil content means
Where * mark just below the bottom horizontal line, indicates the position of location Dida-Midore which was outlier with oil content mean 34.65% and IPCA 1 score -1.1364.
For locations HS = Hossaina, KK = Kokate, HL = Holeta, , and for genotypes Dib = Dibannee, Kul = Kulumsa-1, C16 = CI-1652, C15 = CI-1525, Jel = Jeldu, Ks2 = Kassa-2, Ks-1 = Kassa-1, Loc = Local cultivar, Tol = Tolle, Chl = Chilalo, Ber = Berene, Bel = Belay-96, ger = Geregera

Hossaina was more favorable for the genotypes Kulumsa-1, Kassa-2, CI-1525, and Dibannee. Holeta showed the smallest absolute IPCA1 score (0.1179) indicating that it had the least interaction across genotypes and low discrimination among genotypes. This environment was more conducive particularly for genotypes Kassa-2, Jeldu, CI-1525, and CI-1652. Dida-Midore exhibited the largest absolute IPCA 1 score (-1.13638) indicating that it had highest discrimination and large interaction across genotypes (Table 9 and Figure 1).

Table 12. The first four varieties of AMMI selections for oil content per environment

No	Environment (location)	Mean (%)	AMMI1 score	The four selected varieties according to their rank per location			
				1st	2nd	3rd	4th
1	Dida-Midore	34.65	-1.1364	Kassa-2	Kulumsa-1	CI-1652	Kassa-1
2	Holeta	38.08	0.1179	Kassa-2	Jeldu	CI-1525	CI-1652
3	Hossaina	36.14	0.4806	Kulumsa-1	Kassa-2	CI-1525	Dibannee
4	Kokate	35.99	0.5379	Kassa-2	Kulumsa-1	CI-1652	Jeldu

The first four varieties of AMMI selections for oil content per environment included Kassa-2 in all the four locations; Jeldu for Holeta and Kokate; Kassa-1 for only Dida-Midore; Kulumsa-1 for Dida-Midore, Hossaina and Kokate; Dibannee for only Hossaina; CI-1525 for Holeta and Hossaina; and CI-1652 for Dida-Midore, Holeta and Kokate (Table 12).

Oil Yield Stability Analysis

The AMMI analysis of variance for oil yield of 13 varieties under study at four locations showed genotypes and environments differed highly significantly ($p < 0.01$). Moreover, GxE interaction was also significant ($P \leq 0.05$) (Tables 10 and 13), indicating broad range of diversity existed among environments, genotypes and their interaction.

Most of the total SS were attributed to environmental effects (32.65%) and the rest to genotypic (16.99%) and the interaction (11.22%), indicating that the environments were diverse and there was greater influence of the environments on the performance of oil yield of linseed varieties under the study (Table 13). Results from AMMI analysis exhibited that the first principal component analysis (IPCA 1) of the interaction captured 68.64% of the interaction SS showing a highly significant ($P \leq 0.01$) interaction. The second and the third components were nonsignificant that explained 20.93% and 10.43%, respectively. Therefore, the interaction of the varieties with the environments was predicted by IPCA1 only.

The scatter of the varieties in the AMMI 1 biplot for oil yield (Table 13 and Figure 2) showed four adaptive groups of varieties. The varieties Kassa-2, Jeldu, and CI-1525 formed an adaptive group with high mean 508.36, 491.51, and 492.93 kg/ha, respectively, accompanied with moderate positive interaction, indicating that they were the most stable across the environments under study. These genotypes were also included in the first four genotypes of AMMI selections for oil yield per environment, Kassa-2 being selected for all the four experimental sites (Table 14).

Genotypes CI-1652, Kulumsa-1, and Dibannee formed another adaptive group having moderately higher mean and high positive interaction, while the third group which included Chilalo, Berene, and Belay-96 had moderately higher negative interaction and lower mean oil yield than the grand mean. Kassa-1 and Geregera formed the fourth adaptive group with high negative interaction and lower oil yield than the grand mean (Table 9 and Figure 2).

Table 13. Additive main effects and multiplicative interaction (AMMI) analysis of variance for oil yield

Sources	df	SS	MS	F	% Explained
Treatments	51	1745975	34235**	5.94	60.85
Genotype	12	487370	40614**	7.04	16.98
Environments	3	936802	312267**	12.80	32.65
Reps within Env.	12	292846	24404**	4.23	10.20
G x E Interaction	36	321802	8939*	1.55	11.22
IPCA 1	14	220893	15778**	2.74	68.64
IPCA 2	12	67341	5612ns	0.97	20.93
IPCA 3	10	33569	3357ns	0.58	10.43
Error	144	830558	5768		28.94
Total	207	2869379	13862		

ns = nonsignificant, * = significant at P ≤ 0.05 and ** = significant at P ≤ 0.01 probability level.

The remaining two genotypes, Tolle and local cultivar, scattered separately in the biplot, differentially from each other as well as from the other genotypes both in mean and interaction effects, the former having almost negligible positive interaction and lower mean while the latter with relatively low positive interaction and exclusively the lowest mean oil yield.

The AMMI 1 biplot and AMMI analysis of variance also indicated that the four environments were scattered among the four quadrants. Locations Hossaina and Kokate had positive IPCA 1 score, Hossaina being with the highest score (12.40575) and significantly differed from all the others (Table 9 and Figure 2). Locations Holeta and Dida-Midore had high negative IPCA1 score, -5.987 and -6.772, respectively.

Table 14. The first four varieties of AMMI selections for oil yield per environment

No	Environment (location)	Mean (kg)	AMMI1 scores	The four selected varieties according to their rank per location			
				1st	2nd	3rd	4th
1	Dida-Midore	356.91	-6.720	Kassa-2	Kassa-1	Kulumsa-1	Belay-96
2	Holeta	489.50	-5.987	Jeldu	CI-1525	Kassa-2	Belay-96
3	Hossaina	528.60	12.406	Dibannee	Kulumsa-1	Kassa-2	CI-1525
4	Kokate	409.02	0.301	Dibannee	Jeldu	Kulumsa-1	Kassa-2

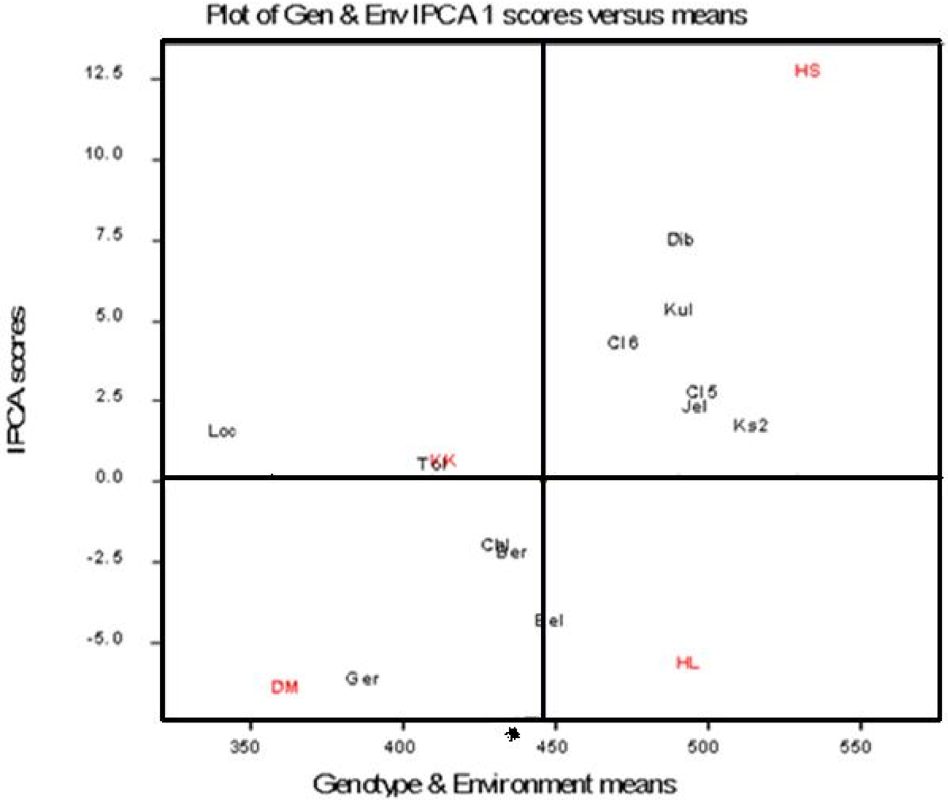

Figure 2. Plot of genotype and environment IPCA1 scores versus oil yield means.

N.M. The genotype Kasa-1 with IPCA1 score -7.3965 and mean oil yield 444.7 kg/ha is disappeared because it was outlier. Its position is marked *below the bottom horizontal line just near the bottom of the combined means (middle vertical line). For locations HS = Hossaina, KK= Kokate, HL = Holeta, DM = Dida-Midore, and, for varieties Dib = Dibannee, Kul= Kulumsa-1, C16 = CI-1652, C15 = CI-1525, Jel = Jeldu, Ks2 = Kassa-2, Loc = Local variety (local cultivar), Tol = Tolle, Chl = Chilalo, Ber = Berene, Bel = Belay-96, Ger = Geregera and *= represents Kassa-1 which was outlier

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