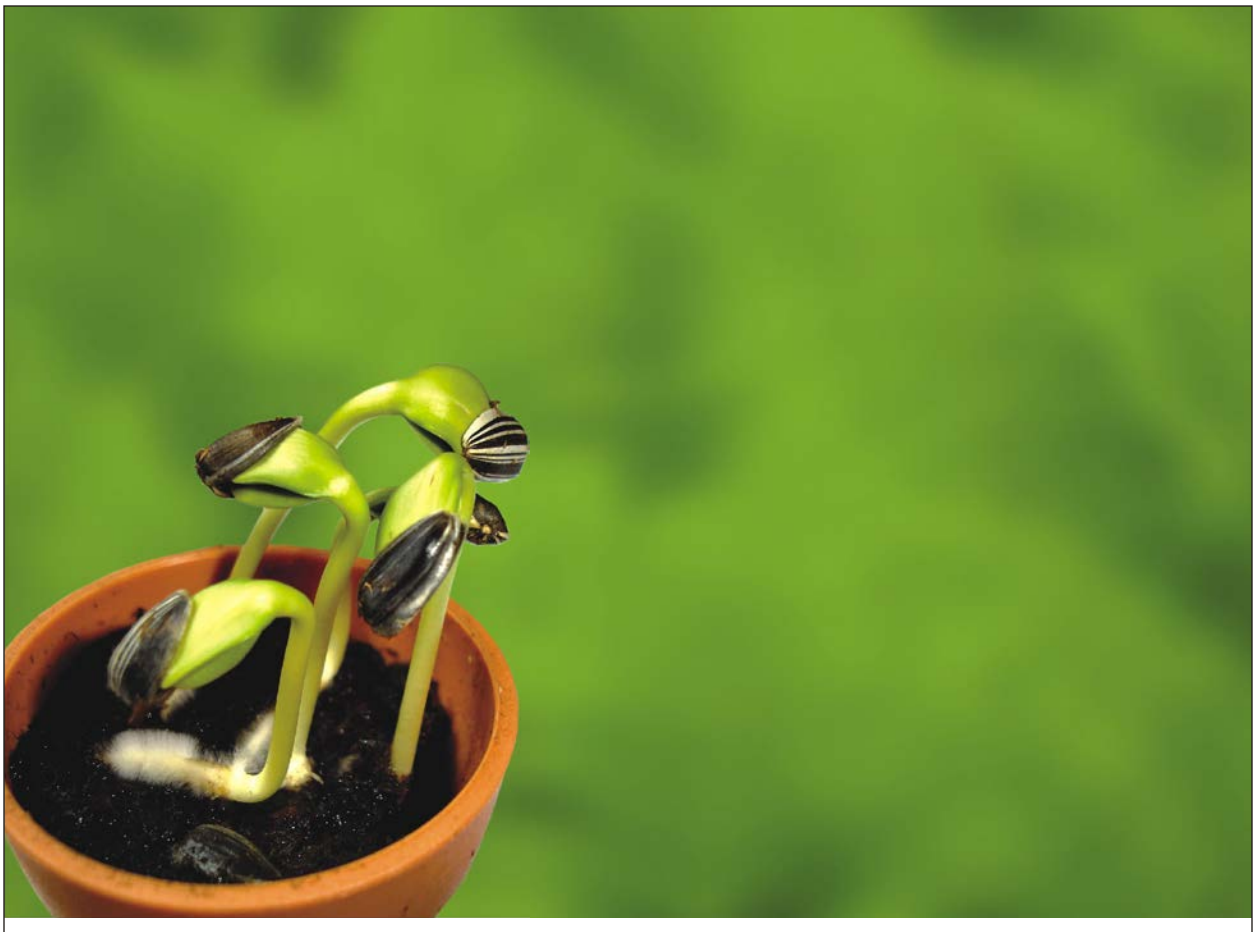

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# Study on Genotype X Environment Interaction of Seed Yield, Oil Content, Fatty Acid Profile and Stability Analysis of Yield Related Trait in Linseed (*Linum usitatissimum* L.) in North Western Ethiopia

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## ABSTRACT

Linseed (*Linum usitatissimum*), or common flax, is a useful plant that has been cultivated for thousands of years. Its oil is rich in omega-3 fatty acids, especially Alpha-Linolenic Acid (ALA) (C18:3) that was beneficial for heart disease, inflammatory bowel disease, arthritis and a variety of other health conditions. Nine linseed (*Linum usitatissimum* L.) genotypes were evaluated in randomized complete block design with three replications during 2011 main cropping season at six locations to determine the pattern of genotype by environment interaction of yield and yield related traits to identify the most stable linseed genotypes for wide and/or narrow adaptations. Combined analysis of variance (ANOVA) indicated significant variations among environments and among genotypes, indicating the existence of variability among the tested genotypes. Debark was the most suitable environment for seed yield, oil content, oil yield and most important fatty acid alpha-linolenic acid. Genotype by Environment Interaction (GEI) was statistically significant only for days to flowering, days to maturity and seed per capsule, indicating the importance of stability analysis. Additive main effect and multiplicative interaction (AMMI) stability analysis in this study selected Kulumsa-1 as stable genotypes for seed per capsule. Linseed adapts to North West Amhara Region, Ethiopia although differences were observed among genotypes. According to the combined analysis of variance for seed yield, oil content, oil yield and alpha-linolineic acid variety Kulumsa-1 can be used for wider cultivation to the North West Amhara Region, Ethiopia.

**Key words:** Genotype by environment interaction, linseed, stability, AMMI

## INTRODUCTION

Linseed (*Linum usitatissimum*), or common flax, is a useful plant that has been cultivated for thousands of years. It is grown for both of its fiber and its seeds. The fiber from its stems is used to make linen cloth, while linseed oil is derived from its seeds. Flax seeds are also edible and contain important nutrients. Linseed oil is rich in omega-3 fatty acids, especially alpha-linolenic acid (C18:3) that was beneficial for heart disease, inflammatory bowel disease, arthritis and a variety of other health conditions. It also contains a group of chemicals called lignans that play a significant role in the prevention of cancer. Ethiopia is considered to be the secondary center of diversity, and now the 5th major producer of linseed in the world after Canada, China, United States and India (Wakjira, 2007). Linseed has long history of cultivation by smallholders, exclusively for its oil in the traditional agriculture of Ethiopia (Belayneh and Nigussie, 1988). It is usually cultivated in higher elevations where frost is a threat for other oil seed crops. It is a major oil seed and second most important oil crop after noug seed (*Guizotia abyssinica* Cass.) in Ethiopia. The crop performs best

in altitudes ranging from 2200-2800 masl; but it is also found in areas as low as 1200 masl and as high as 3420 masl. It is an important rotational crop for cereals and pulses in Ethiopia.

Linseed requires cool temperature during its growing period for better yield. It grows well within temperature ranges of 10-30°C but it performs best between 21-22°C. It prefers dry and sunny weather with well-distributed moderate rain over the growing season (Getinet and Nigussie, 1997). Optimum soils for flax are well drained but moisture retentive and medium to heavy textured, such as clay loams and silty clays. The soil should be of a fine tilth and not prone to crusting. Flax will not perform well on soils with pH less than 5 or above 7 and is sensitive to soil salinity (Wakjira, 2007).

Worldwide, linseed total area harvested during the year 2010 was 2218625 ha; with production of 1922759 tons, average yield of 866.6 kg $ha^{-1}$ and linseed oil production of 613944 tons (FAO, 2012). In Africa, linseed total area harvested during the year 2010 was 153431 ha; with seed production of 166690 tons, average yield of 1086.4 kg $ha^{-1}$ and linseed oil production of 52009 tons (FAO, 2012). In Ethiopia, its total area during the year 2008 was 180872.7 ha; with the total production of 156079 tons and average yield of 0.863 tons $ha^{-1}$ (CSA, 2008). In Ethiopia linseed is produced mostly for edible oil. But the remains after oil extraction are used for animal feed (Getinet and Nigussie, 1997). So far several varieties of linseed have been released in Ethiopia by national and regional research institutions (MoARD, 2007).

It is commonly observed that the relative performance of different genotypes varies in different environments, i.e., there exists genotype-environment interaction. Presence of significant genotype by environment interaction due to the differential response of varieties in different environments represents a major challenge to plant breeders to fully understand and obtain the genetic control of variability (Luthra and Singh, 1974). In this case, measuring and understanding the Genotype by Environment Interaction (GEI) should be an essential component of variety evaluation. One of the main reasons of growing varieties in multilocations is to estimate their stability (Freeman, 1973) as selection of superior varieties is mainly based on their yield potential and stable performance over a wide range of environments (Crossa *et al.*, 1989).

An understanding of the genetic and environmental basis of genotype by environment interaction is of fundamental importance in plant breeding (Crossa *et al.*, 1999). Mean seed yield is an important criterion for the selection of superior varieties in the absence of GEI. However, a stability analysis is necessary when GEI is significant and its contribution to the total sums of squares is higher than that of genotypes contribution. Successful linseed cultivars must perform reliably in yield and other agronomic traits over wide range of environments (Diepenbrock *et al.*, 1995).

In Ethiopia, there are only few studies reported on the genotype by environment interaction and stability of linseed varieties in the past. One study by Adugna and Labuschagne (2002) indicated that year by location and location variability was found to be dominant sources of interactions for linseed in Ethiopia. But further investigation on GEI and stability of linseed in Ethiopia is crucial to accumulate more scientific evidences for any anticipated changes like climatic irregularities. To date, little information is available on this crop and its adaptation pattern, especially under Northwestern Ethiopian conditions. Keeping this in view, the present study was conducted to examine the pattern of GEI of yield and yield related traits; to identify the most stable linseed variety for wide and/or specific adaptations.

## MATERIALS AND METHODS

Nine released linseed genotypes (CI-1525, CI-1652, Chilallo, Belay-96, Geregera, Berene, Tole, Kulumsa-1 and Geldu) were evaluated at six different locations during 2011 main cropping season.

Table 1: Brief description of experimental sites

| Location | Altitude (m) | Soil type | Annual rainfall (mm) | Average temperature | | Global positions | |
|---|---|---|---|---|---|---|---|
| | | | | Min (°C) | Max (°C) | Latitude | Longitude |
| Adet | 2240 | Nitosol | 1119.1 | 9.4 | 34.1 | 11°16` N | 37°29` E |
| Dabat | 2620 | Cambisol | 740.4 | NA | NA | 13°39` N | 37°85` E |
| Debark | NA | Nitosol | 1349.8 | 6.3 | 23.2 | 13°7` N | 37°53` E |
| Debretabor | 2630 | Luvisol | 1522.1 | 7.5 | 24.7 | 11°89`N | 38°9E |
| Lai-Gaint | 3156 | Nitosol | 886.5 | 6.4 | 20.0 | 11°43`N | 38°28E |
| Merawi | 1960 | Nitosol | 1063.4 | 11.8 | 28.4 | 11.4° N | 37° E |

Ethiopian Metrological Agency, Bahir Dar branch, NA: Data not available

The detailed information about locations is presented in Table 1. Randomized Complete Block Design (RCBD) with three replications was used throughout the testing locations. Each experimental plot had six rows of 5 m length and 20 cm spacing between rows. A seed rate of 45 kg $ha^{-1}$ was used by hand drilling the seeds in the rows. Fertilizers rates of 50/30 kg $ha^{-1}$ DAP and Urea respectively was used for all sites and applied fully at time of planting. Planting was carried out from mid to the end of June 2011 following the farmers' practice. All other recommended agronomic and cultural practices were carried out for all the plots uniformly. Twenty different data were collected from the middle four rows. Combined analyses of variance over locations were done using AGROBASE 20 software 2000.

## RESULTS AND DISCUSSION

Combined analysis of variance (not presented) showed highly significant variations among environments for all characters considered except plant height and among genotypes across all locations for days to flower, days to maturity, plant height, thousand seed weight, oil content, palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, tiller per plant and capsule per plant, indicating the existence of variability among the tested genotypes. Significant variations among locations for days to flower, days to maturity, seed per capsule, branch per plant and capsule per plant and among genotypes for days to flower, days to maturity, plant height and thousand seed weight were also reported by Adugna and Labuschagne (2003). Significant variation among genotypes for oil content was also reported by Wakjira *et al.* (2004). Ahmed and Ahmed (2012) in sesame; Patil *et al.* (1999) in safflower and Choferie (2008) in linseed reported significant differences between genotypes for days to flowering and days to maturity. Berti *et al.* (2010) also reported significant differences between genotypes for oil content and stearic, oleic and linolenic acid in linseed. Similarly, Gabiana (2005) reported significant differences between genotypes for oleic, linoleic and linolenic acid in linseed. Significant genotype by environment interaction was observed only for days to flower, days to maturity and seed per capsule. Similarly, significant GEI for days to flower and days to maturity was also reported by Adugna and Labuschagne (2003) and Choferie (2008). It agrees with the finding that yield and agronomic traits are influenced by genotypes, environment factors and the interaction between genotype and environment (Adugna and Labuschagne, 2003; Wakjira *et al.*, 2004; Choferie, 2008; Berti *et al.*, 2010; Gunasekera *et al.*, 2006; Mostafa and Ashmawy, 1998).

**Analysis of variance (ANOVA):** The analysis of variance of seeds per capsule of nine genotypes tested in six environments is presented in Table 2 and 3. The analysis revealed that linseed

Table 2: Additive main effects and multiplicative interaction analysis of variance for seeds per capsule of the genotypes across environments

| Source | DF | SS | MS | Explained (%) |
|---|---|---|---|---|
| Total | 161 | 346.050 | | |
| Environments | 5 | 183.316 | 36.663** | 52.97 |
| Reps within Env. | 12 | 46.072 | 3.839 | |
| Genotype | 8 | 3.601 | 0.450 | |
| Genotype× Env. | 40 | 46.469 | 1.162* | 13.42 |
| IPcA 1 | 12 | 35.633 | 2.969** | 76.68 |
| IPcA 2 | 10 | 5.660 | 0.566 | 12.18 |
| IPcA 3 | 8 | 3.427 | 0.428 | 7.37 |
| IPcA 4 | 6 | 1.727 | 0.288 | 3.72 |
| IPcA 5 | 4 | 0.022 | 0.005 | 0.05 |
| Residual | 96 | 66.592 | 0.694 | |

*, **Significant at 5 and 1%, respectively, Env: Environments, DF: Days to flower, SS: Sum of square, MS: Mean sum of square

Table 3: Mean seed yield (kg ha$^{-1}$), Thousand Seed Weight (TSW), oil content (%), oil yield (kg ha$^{-1}$), seed per capsule and fatty acid profiles of 9 linseed genotypes tested at 6 locations in the GEI study (2011-12)

| Genotypes | SY | TSW | OC | OYH | SPC | Palmitic | Stearic | Oleic | Linoleic | Linolenic |
|---|---|---|---|---|---|---|---|---|---|---|
| CI-1525 | 1000.26 | 5.33 | 40.83 | 407.95 | 7.06 | 5.74 | 4.72 | 15.17 | 14.44 | 58.79 |
| CI-1652 | 985.12 | 5.44 | 40.83 | 403.47 | 7.44 | 5.80 | 4.80 | 15.22 | 14.46 | 58.60 |
| Chilallo | 1067.25 | 5.28 | 40.44 | 432.19 | 7.22 | 5.92 | 4.69 | 15.52 | 14.62 | 58.03 |
| Belay-96 | 1050.13 | 5.39 | 39.89 | 418.30 | 7.50 | 5.95 | 4.78 | 15.29 | 14.51 | 58.28 |
| Geregera | 1043.57 | 6.00 | 39.50 | 412.36 | 7.33 | 6.04 | 4.55 | 16.29 | 14.80 | 56.76 |
| Berene | 1066.38 | 5.44 | 40.06 | 427.41 | 7.06 | 5.93 | 4.72 | 15.16 | 14.49 | 58.43 |
| Tole | 1076.83 | 5.72 | 40.44 | 436.65 | 7.22 | 5.92 | 4.78 | 15.30 | 14.49 | 58.19 |
| Kulumsa-1 | 1086.48 | 5.50 | 41.28 | 448.06 | 7.39 | 5.85 | 4.65 | 15.28 | 14.57 | 58.30 |
| Geldu | 1073.42 | 5.50 | 40.28 | 430.21 | 7.22 | 5.90 | 4.64 | 15.38 | 14.62 | 58.32 |
| Mean | 1049.94 | 5.51 | 40.40 | 424.07 | 7.27 | 5.89 | 4.70 | 15.40 | 14.55 | 58.19 |
| CV (%) | 17.12 | 6.03 | 1.42 | 17.16 | 11.45 | 1.51 | 2.98 | 1.84 | 0.90 | 0.64 |
| LSD(0.05) | - | 0.22 | 0.38 | - | 0.55 | 0.15 | - | 0.49 | - | 0.64 |
| | | ** | ** | | ** | * | | ** | | ** |

*, **Significant at 5 and 1%, respectively. SY: Seed yield (kg ha$^{-1}$), TSW =1000- Seed weight (g), OC: Oil content (%), OYH: Oil yield (kg ha$^{-1}$), SPC: Seeds per capsules and fatty acid profiles

genotypes were significantly ($p<0.01$) affected by Environments (E) and Genotype by Environment Interaction (GEI). The main effects of Environments (E) and Genotype by Environment Interactions (GEI) accounted for 52.97 and 13.42% of the total variation in G×E data for seeds per capsule. High variability among environments and genotypes existed both in the main and interaction effects for seeds per capsule. Potential environments for seed per capsule were distributed in the 4th quadrant (Lai-Gaint), and in the 1st quadrant (Adet, Debark, Debretabor and Merawi), whereas the low potential environment Dabat (B), was distributed in the 2nd quadrant (Fig. 1). Environments A (Adet), C (Debark), D (Debretabor), E (Lai-Gaint) and F (Merawi) gave above average mean seed per capsule, while location B (Dabat) gave below average (Fig. 1). Locations A (Adet), C (Debark), D (Debretabor) and F (Merawi) were in the same quadrant (I) for seed per capsule and hence they discriminated between the genotypes in much similar ways, while location E (Lai-Gaint) differed from these high potential environments hence discriminated between the genotypes in different way.

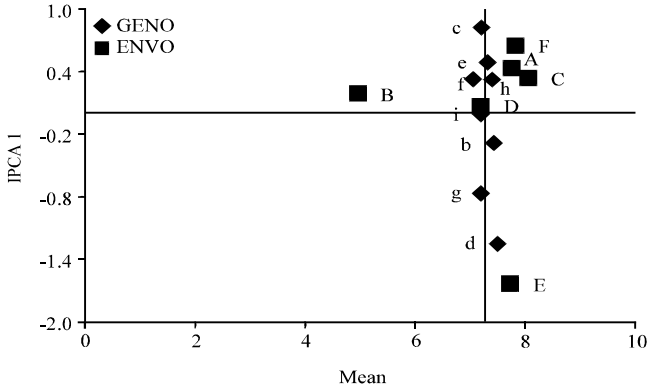


Fig. 1: AMMI biplot of mean seed per capsule and the first Principal Component Axis (PCA) 1 scores of 9 linseed genotypes at six environments in 2011, Genotypes plotted as a, b, c ... and environments as A, B, C..., a: CI-1525, b: CI-1652, c: Chilallo, d: Belay-96, e: Geregera, f: Berene, g: Tole, h: Kulumsa-1, i: Geldu, A: Adet, B: Dabat, C: Debark, D: Debretabor, E: Lai-Gaint, F: Merawi

Table 4: Environment means of seed per capsule and their EIPC1 and EIPC2 scores of six locations for the 9 linseed genotypes

| | Seed per capsule | | |
|---|---|---|---|
| Environment | EIPCA1 | EIPCA2 | Mean |
| Adet | 0.4274 | -0.0323 | 7.78 |
| Dabat | 0.1820 | 0.4025 | 4.96 |
| Debark | 0.3446 | -0.9909 | 8.07 |
| Debretabor | 0.0555 | 0.1644 | 7.22 |
| Lai-Gaint | -1.6447 | 0.0075 | 7.74 |
| Merawi | 0.6354 | 0.4489 | 7.85 |

Location E (Lai-Gaint) had the highest interaction with the genotypes, followed by F (Merawi) and A (Adet) because they had higher EIPC1 scores for seed per capsule (Table 4).

Genotypes CI-1652 (b), Belay-96 (d), Tole (g) and Geldu (I) had positive interaction with the potential environment, Lai-Gaint (E), while these genotypes had negative interaction with the potential environments, Adet (A), Debark (C), Debretabor (D), Merawi (F) and with the low potential environment, Dabat (B) for seed per capsule. Genotypes CI-1525 (a), Chilao (c), Geregera (e), Berene (f) and kulumsa-1 (h) had positive interaction with the potential environments, Adet (A), Debark (C), Debretabor (D), Merawi (F) and with the low potential environment, Dabat (B), while these genotypes had negative interaction with the potential environment, Lai-Gaint (E), for seed per capsule (Table 5).

Varieties Geldu, CI-1652 and kulumsa-1 had absolute IPCA1 scores very close to zero for seed per capsule. CI-1652 and kulumsa-1 had also mean seed per capsule above average and these were the most stable varieties across location (Table 5).

When biplot interaction for the AMMI2 model (Fig. 2) is considered, genotypes Geldu, CI-1652, Kulumsa-1 and CI-1525 were the most stable varieties for seed per capsule; while Geregera and Berene were moderately stable for seed per capsule. On the other hand, genotypes Chilalo, Belay-96 and Tole were found unstable for seed per capsule.

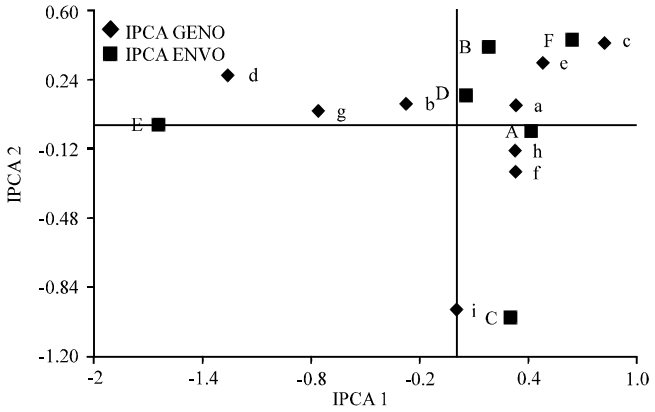


Fig. 2: Biplot of Principal Component Analysis axis (PCA) 1 against principal component analysis axis (PCA) 2 for seed per capsule of 9 linseed genotypes at six environments in 2011, Genotypes plotted as a, b, c ... and environments as A, B, C... a: CI-1525, b: CI-1652, c: Chilallo, d: Belay-96, e: Geregera, f: Berene, g: Tole, h: Kulumsa-1, i: Geldu, A: Adet, B: Dabat, C: Debark, D: Debretabor, E: Lai-Gaint, F: Merawi

Table 5: Scores of genotypes and locations to the first interaction principal component axis for days to flowering, days to maturity and seed per capsule

| Parameters | Designation | DF | DM | SPC |
|---|---|---|---|---|
| **Genotypes** | | | | |
| CI-1525 | a | 0.5070 | 0.7458 | 0.3283 |
| CI-1652 | b | 0.6653 | -0.7610 | -0.2753 |
| Chilallo | c | -0.3475 | 0.5313 | 0.8222 |
| Belay-96 | d | 0.7029 | 1.8062 | -1.2484 |
| Geregera | e | -0.7469 | -0.8383 | 0.4837 |
| Berene | f | 0.7100 | -1.1031 | 0.3323 |
| Tole | g | -1.5142 | -0.0614 | -0.7624 |
| Kulumsa-1 | h | 1.2322 | -1.0606 | 0.3203 |
| Geldu | i | -1.2087 | 0.7411 | -0.0008 |
| **Environments** | | | | |
| Adet | A | -1.5659 | 0.9140 | 0.4274 |
| Dabat | B | 0.4429 | 0.7076 | 0.1820 |
| Debark | C | 2.0726 | -0.6674 | 0.3446 |
| Debretabor | D | -0.8189 | -2.3463 | 0.0555 |
| Lai-Gaint | E | -0.1776 | 0.8009 | -1.6447 |
| Merawi | F | 0.0469 | 0.5912 | 0.6354 |

SPC: Seed per capsule, DF: Days to flower, DM: Days to maturity

## CONCLUSION

Generally, the present study entails the presence of significant variations among environments and among genotypes for most of the characters, indicating the existence of variability among the tested genotypes. Linseed adapts to Northwest Amhara region, Ethiopia, although differences were observed among genotypes for days to flowering, days to maturity, plant height, thousand seed weight, capsule per plant, and oil content and composition. Seed yield was above 1700 kg $ha^{-1}$ for some environments and genotypes, indicating the high seed yield potential of some environments

in Northwest Amhara region, Ethiopia. Debark was found to be the most suitable environment for seed yield, oil content, oil yield and most important fatty acid alpha-linolenic acid. According to the combined analysis of variance for seed yield, oil content, oil yield and alpha-linolineic acid variety Kulumsa-1 can be used for wider cultivation to the to Northwest Amhara region, Ethiopia.

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