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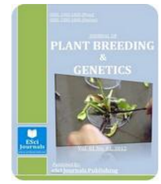

# MORPHOLOGICAL DIVERSITY OF ETHIOPIAN LINSEED (*LINUM USITATISSIMUM* L.) LANDRACE ACCESSIONS AND NON-NATIVE CULTIVARS

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**A B S T R A C T**

Understanding the genetic diversity of linseed (*Linum usitatissimum* L.*)* is important for the continued improvement of this crop as well as for its development in the agricultural system. Therefore, to generate adequate information on genetic diversity of linseed, 49 sample accessions collected from five regions of Ethiopia along with 15 cultivars were used in this study with the objectives of investigating the morphological diversity between and within germplasm. Experiment was conducted at Sinana Agricultural Research Center, South Eastern Ethiopia. Treatments were arranged in 8 x 8 simple lattice square design with two replications. The Agro-morphological data were subjected to the analysis of variance. Highly significant variation for all the characters except for number of seeds per capsule and biomass. Clustering pattern and correlation matrix among and within Ethiopian linseed landraces and non-native cultivars were discussed. Furthermore, there were ample variations between and within Ethiopian linseed landraces and non-native cultivars, implying high chances for current and future genetic improvements in which desirable traits could be incorporated to new cultivars.

**Keywords**: Genetic diversity, Correlation, linseed, variability, cluster analysis, morphology, yield.

## INTRODUCTION

Genetic diversity in a crop species can assist in the evaluation of germplasm collections as potential gene pools to improve the performance of cultivars. In fact, genetic diversity studies in linseed germplasm have been reported by different scientists over the past years. It is known that, genetic diversity can be measured as the number of different factors and their relative frequency at genus, species, population, individual, genome, locus and DNA base sequence levels (Kresovich and McFerson, 1992; Gaston, 1998; Kumar, 1999). However, the process of measurement needs to be iterative and dynamic because micro- and macro evolutionary changes will occur everywhere (Gaston, 1998). This study presents morphological genetic diversity in linseed/flax. Linseed (*Linum usitatissimum* L.) is an annual field crop that is largely grown in temperate climates (Mansby *et al*., 2000)and cool tropics including the highlands (>2500 meters above sea level) of Ethiopia. It is the second most important oil crop in the highlands of Ethiopia in terms of area and production (Adefris *et al*., 1992; Adugna, 2000).

Local populations of traditional cultivars provide a valuable resource for plant breeding as well as for the preservation of genetic diversity (Kölliker *et al*., 2003; *Abdul Rasheed et al., 2014*). The exploration, evaluation, and conservation *in situ* and *ex situ* of genetic diversity in natural populations is imperative to guarantee sustainable development (Nevo,1998). On the other hand, the enormous merits of the landraces coupled with the threat of genetic erosion indicates the importance of diversity study in the landraces, which is important to know the level of variability within the available collections under conservation and to plan future conservation practices of major priority (Adugna *et al*., 2006). Therefore, the experiment was conducted to study genetic diversity of Ethiopian linseed accessions collected from different Administrative Regions (ARs) of Ethiopia separately and with some non-native cultivars

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based on morphological characters as well as to generate baseline information on linseed diversity, which will value add for future linseed breeding program.

## MATERIALS AND METHODS

**Experimental Setup and Sampling Procedure:** Seeds(6g)of forty-nine linseed landrace accessions collected from five different administrative regions of Ethiopia were obtained from Institute of Biodiversity Conservation (IBC), Addis Ababa, Ethiopia. Administrative Regions (given in Fig. 1)*via.* Amhara, Oromia, SNNPR (Southern Nations Nationalities and Peoples of Ethiopia Region), Tigray, Somali with a total of 49 accessions were included in the study. Similarly, fifteen non-native cultivars (Table 1) were studied along with landrace accessions.

The genotypes were grown in 8 x 8 simple lattice design with two replications of 1.6 $m^2$ plot size (2 rows of 4m length spaced at 20cm) during *"Bona"* or *"Meher"* (August-December) Season in 2010/11. Randomization arrangement was done both within and between blocks and to minimize border effect. Seed rate was 25kg/ha as per the recommendation for the area. Fertilizer was applied with the rate of 23 kg/ha N and 23 kg/ha $P_2O_5$. Weeds were controlled by hand weeding once or as per needed. Five individual plants were randomly selected from each of the two replications and used for morphological diversity study. Mean values of temperature and rainfall of experimental site is given in Appendix Tables 1 and 2.

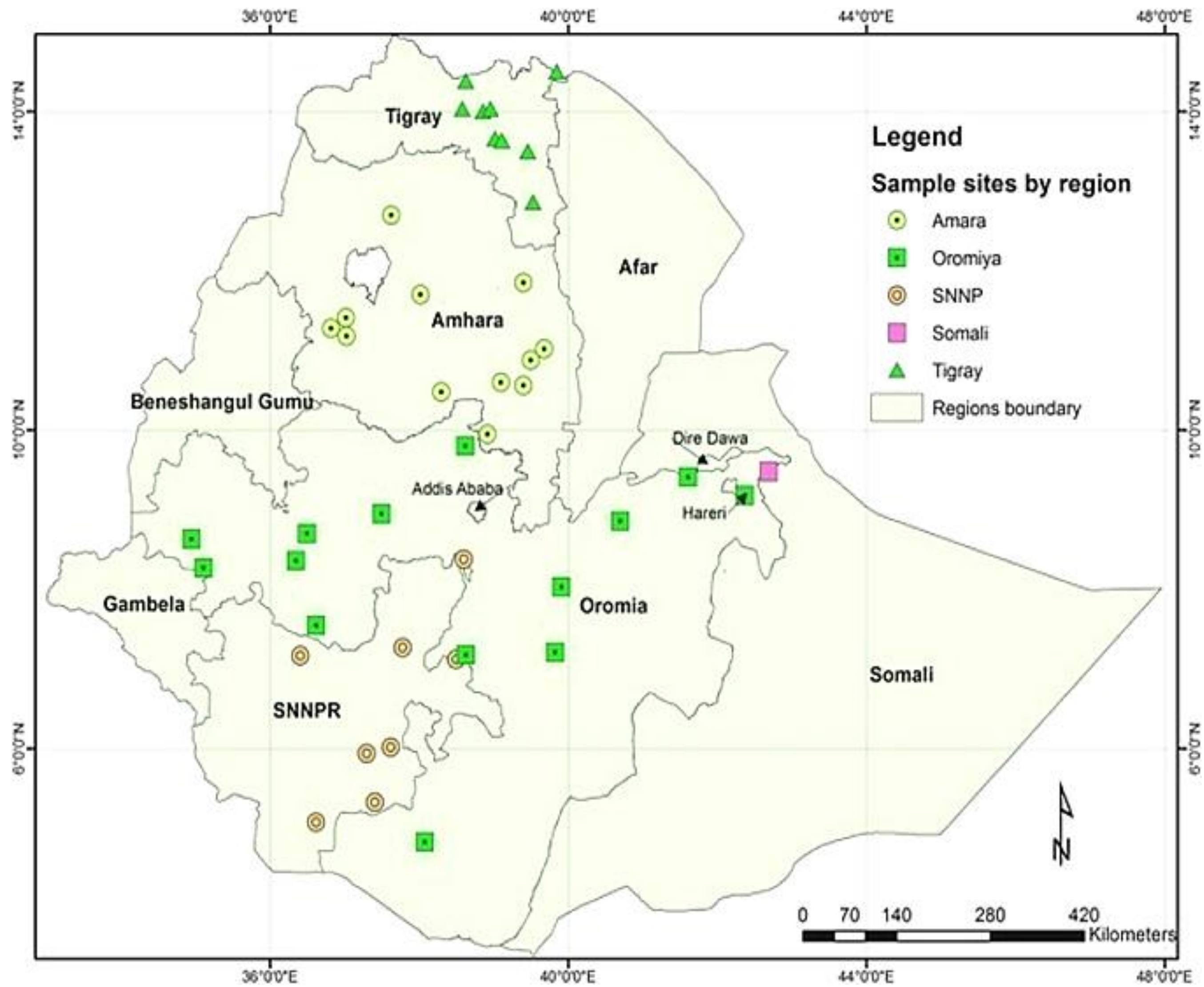


Figure 1. Map of Ethiopia showing the approximate areas of origin and collections sites of 49 linseed landraces accessions (NB: all boundaries are approximate and nothing to do with political borders).

Table 1. Passport data of linseed (*LinumusitatissimumL.*) non-native cultivars used in the study (2010/2011).

| List of non-native cultivars* | Background | Source/Origin |
|---|---|---|
| R12 D33C X CI 1525/P1/S1 | Non-native | Canada/USA |
| CI 1525 X R12-N27G/P1/S1 | ʺ | Canada/USA |
| CI 1525 X CDC 1747/P1/S1 | ʺ | Canada/USA |
| CI 1525 X R12 D33C/P1/S1 | ʺ | Canada/USA |
| R12- N27G X CI 1525/P1/S1 | ʺ | Canada/USA |
| CDC 1747 X CI 1652/SPS/1 | ʺ | Canada/USA |
| CI 1652 X R12 D33C/SPS | ʺ | Canada/USA |
| CI 1652 X R12-N27G/SPS1 | ʺ | Canada/USA |
| R12-N100 X CI 1525/SPS1 | ʺ | Canada/USA |
| OMEGA X CI 1525/B/3/M | ʺ | USA/Canada |
| CI 1652 X OMEGA/B/53/M | ʺ | Canada/USA |
| CI 1652 X CDC 1747/SPS1 | ʺ | Canada/USA |
| OMEGA X CI 1525/B/1 | ʺ | USA/Canada |
| PI – 523353 | ʺ | USA |
| CI 2698 X P136611 | Non-native | Canada /USA |

*Source: Holeta Agricultural Research Center (HARC).

**Data on Plant and Plot Basis:** Data was recorded on the phenotypic traits including days to flowering and maturity, plant height (cm), number of capsule per plant, number of seeds per capsule, Harvesting index was calculated, biomass (g), thousand seed weight (g), seed yield per plant (g), seed yield per plot (g/plot) and which is extrapolated to hectare basis (kg/ha).

**Statistical Analysis:** The mean value of the recorded data was subjected to analysis of variance (ANOVA), genetic divergence test, cluster distance and correlations for all characters was as per Gomez and Gomez (1984).Data were analyzed using SAS computer Software (2001), MSTATC (1991) and MINITAB (1996) using Least Significant Difference (LSD) at 1 and 5 percent levels of significance.

**Correlation Coefficient:** The coefficient of correlation at phenotypic level was tested for their significance by comparing the values of correlation coefficient with tabulated value at g-2 degree of freedom, where ‘g’ is number of genotypes.

However, the coefficients of correlations at genotypic level were tested for their significance using the formula described by Robertson (1959)as described below:

$$t = \frac{(rgxy)}{SErgxy}$$

**Genetic Divergence and Clustering Analysis:** Records on all traits were pre-standardized to means of zero and variances of unity before clustering to avoid bias due to differences in measurement scales (Manly, 1986). Clustering of accessions was performed by average linkage method and principal component analysis using the SAS software (SAS Institute, 2001). Points where local peaks of the pseudo F statistic join with small values of the pseudo $t^2$ statistic followed by a larger pseudo $t^2$ for the next cluster fusion were examined to decide the number of clusters. Genetic distances between clusters as standardized Mahalanobis’s $D^2$ statistics (1936)were calculated as:

$D^2_{ij} = (x_i - x_j)' \, cov^{-1} (x_i - x_j);$

Where, $D^2_{ij}$ = the distance between cases i and j; xi and xj = vectors of the values of the variables for cases i and j and $cov^{-1}$ = the pooled within groups variance-covariance matrix. The $D^2$ values obtained for pairs of clusters were considered as the calculated values of Chi-square ($X^2$) and were tested for significance both at 1% and 5% probability levels against the tabulated value of $X^2$ for ‘P’ degree of freedom, where P is the number of characters considered (Singh and Chaudhary, 1985).

**RESULTS AND DISCUSSION**

**Analysis of Variance (ANOVA):** The analysis of variance showed highly significant ($P< .01$) variation between the Ethiopian linseed landrace accessions and non-native cultivars for majority of the measured traits. Similarly, there was significant ($p < 0.05$) variation between germplasm in days to flowering, days to maturity, number of primary branches, seed yield per plot (gram/plot) that was extrapolated to seed yield per hectare as shown in the table no.2. On the other hand, there was non-significant variation were observed between seeds per capsule, biomass yield (gram/plot), and harvesting index.

The significant variation between the linseed materials for the measured agro-morphological traits indicates the presence of high degree of phenotypic diversity between the linseed materials and it implies the availability of great potential for improvement. Similar results were reported by Adugna (2002) for days to maturity, thousand seed weight and seed yield that showed significant variation among the tested germplasm. The present study also agrees with that of Tadele*et al*. (2010), which reported significant variations among yield and yield related traits of thousand seed weight, days to flowering, maturity and seed yield per plant.

**Range and Variability of Agro-morphological Traits Between and within Tested Cultivars:** Estimates of range and mean for all agro-morphological traits of Ethiopian linseed landraces and some non-native cultivars are presented in Table 3. The range of seed yield per plot varied from 156 to 472g. Out of the top 33 high yielding accessions, 16% were early maturing (138-140 days) and 84% were late maturing (141 to 150 days). Days to flowering varied from 69 days to 99 days. When genotypes are grouped based on these days to flowering, 64% were early (69 to 75 days) and 36 % were late flowering (76 to 99 days). There was a wide variability for days to maturity, the maximum days required to reach physiological maturity being 150 days against the minimum 138 days.

The range of capsule per plant was 27 to 93. This wide range indicated high variability for this trait among the evaluated germplasm. The range for seed yield per plant was 0.7g to 3.2g. Accessions 230816 that was obtained from Somali Region gave maximum seed yield per plant 3.2g (Table 3). The lowest seed yield per plant was for accession 13756 (0.7g), acquired from Oromia Region. Thousand seed weight varied from 2.6g to 7g, while harvest index ranged from 6.3 % to 38.7 %. Plant height (cm) ranged from 62 cm to 110 cm. Number of primary branches ranged from 3 to 6, whereas secondary branches varied from 12 to 42. It can be said, this variability among accessions and non-native cultivars revealed that the possibility and could be used as a source for linseed quality improvement program.

Similarly, Out of the top thirty-three high yielding cultivars, 30.3% were from Oromia Region and SNNP, 27.3% from Tigray and 12.1% from Somali region (Table 3). The maximum seed yield per plot was obtained by non-native cultivar CI-1652 X CDC 1747/SPS1 (472.3 g) (Tables3 and 4). Moreover, higher biomasses were also recorded by accessions 243810(2400g) and Acc. 238276 (2300g). The lowest seed yield and the lowest biomass yield were also obtained by accession 10067, which was collected from Amhara Region. Generally speaking, the Ethiopian linseed accessions were noted early maturing, shorter in plant height and small in seed size and the non-native cultivars were late maturing, taller in height, larger-seeded and relatively high oil yielder.

**Diversity of Tested Linseed Landraces and Non-native Cultivars:** Considering the samples collected from different Administrative Regions (ARs) as an independent population, samples from Oromia and SNNP Administrative Regions showed best mean values for seed yield per plot 305.3g and 298g), respectively. However, some of the accessions showed late maturing in the range of 71 to 77 days after planting. Similarly, linseed landraces collected from Somali Regional State showed better performance for number of capsules per plant (67.7), number of secondary branches (28.5) and late maturing (70-73 days after planting). On the other hand, samples collected from Southern Nations Nationalities and Peoples of Ethiopia (SNNP) showed relatively wider variation for harvesting index and number of seeds per capsule but lower biomass (1000 gram) as compared to samples collected from the rest. Samples from Tigray showed earliness and shorter in plant height (60 to 98 cm) and higher in thousand seed weight (5.2g). Samples from Amhara and Oromia were characterized by late maturity and tall plant height. Samples from Somali Regional States showed earliness and better in thousand seed weight. Samples collected from SNNPR were known by their high number of seeds per capsule. The overall performance of Ethiopian landraces, with the non-native cultivars was indicated in Table 3. Non-native cultivars showed better performance than Ethiopian landrace accessions on thousand seed weight, harvesting index and seed yield per plot. However, these non-native cultivars were late maturing and taller which leads susceptibility for lodging if they are exposed to fertile lands.

**Magnitude of Genetic Diversity and Cluster Analysis:** Clustering was done based on agro-morphological traits by Minitab Statistical Computer package. The data was standardized to a mean of zero and a variance of unity to avoid differences in scales used for recording data on the different characters before undertaking a series of multivariate analysis. Result of clustering parameters indicates the existence of considerable differences among Ethiopian linseed landraces and non-native cultivars (Figure. 2).

Table 2. Analysis of variance (ANOVA) for morphological traits of Ethiopian linseed landraces and some non-native cultivars (2010/2011).

| SOV (df) | DTF | DTM | PLH | CPPL | SPC | No. PB | No. SB | BM (g) | TSW (g) | HI | SYPPL (g) | SYPPLOT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replications (1) | 1.53 | 9.031 | 9.245 | 6917.82 | 6.57 | 1.12 | 586.5 | 894453.1 | 0.18 | 595.13 | 10.9 | 6434.03 |
| Cultivar (63) | 36.21* | 15.9** | 364.5** | 261.75** | 1.75ns | 0.91* | 79.7* | 172875.5ns | 2.09* | 123.6ns | 0.5ns | 14035.4** |
| Error (49) | 12.735 | 2.24 | 17.505 | 43.126 | 2.49 | 0.44 | 31.2 | 155422.5 | 0.154 | 85.5 | 0.19 | 1782.2 |
| CV (%) | 4.87 | 1.13 | 4.84 | 15.82 | 19.39 | 17.15 | 25.7 | 26.09 | 8.46 | 44.41 | 28.45 | 14.98 |
| LSD (5%) | 7.37 | 3.2 | 8.22 | 14.53 | - | 1.4 | 12.2 | - | 0.76 | - | - | 93.12 |

** Significant at P<.01 and * Significant at P=.05 ns= non-significant, numbers in brackets are degrees of freedom (df).

DTF = days to flowering; DTM = Days to maturity; PLH= plant height; CPPL = capsule per plant; SPC = seed per capsule; PB = primary branch; SB = secondary branch; BM = biomass; SYPP = seed yield per plant; SYPPLOT = seed yield per plot; TSW = thousand seed weight; HI = harvesting index.

Table 3. Mean, maximum and minimum values of agro-morphological parameters of Ethiopian linseed landrace accessions collected from administrative regions of Ethiopia (ARs) and non-native cultivars

| Region | | DTF | DTM | PLH | CPPL | SPC | PB | SB | BM | SYPP | TSW | HI | SYPPLOT | GYPHA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amhara | Min | 72.0 | 138.0 | 63.0 | 27.1 | 7.0 | 3.0 | 15.0 | 1200.0 | 0.9 | 3.3 | 11.0 | 156.0 | 975.0 |
| | Max | 85.0 | 149.0 | 107.0 | 64.6 | 10.0 | 4.0 | 41.0 | 2100.0 | 2.5 | 6.7 | 25.0 | 399.6 | 2497.0 |
| | Mean | 76.8 | 142.0 | 81.4 | 43.8 | 8.4 | 3.8 | 22.3 | 1808.3 | 1.6 | 4.2 | 16.0 | 245.1 | 1531.1 |
| Oromia | Min | 71.0 | 138.0 | 62.0 | 30.5 | 6.8 | 3.0 | 12.0 | 1300.0 | 0.7 | 2.6 | 15.0 | 188.8 | 1179.0 |
| | Max | 99.0 | 150.0 | 103.0 | 70.2 | 11.0 | 6.0 | 36.0 | 2300.0 | 2.4 | 5.5 | 33.0 | 447.8 | 2798.0 |
| | Mean | 76.3 | 141.8 | 82.9 | 48.2 | 8.0 | 3.7 | 21.7 | 1757.1 | 1.6 | 4.0 | 18.9 | 305.3 | 1907.7 |
| SNNP | Min | 71.0 | 138.0 | 69.0 | 34.5 | 7.8 | 3.0 | 16.0 | 1200.0 | 1.0 | 2.9 | 13.0 | 216.6 | 1353.0 |
| | Max | 86.0 | 142.0 | 88.0 | 53.5 | 10.0 | 4.0 | 35.0 | 2000.0 | 1.8 | 4.4 | 37.0 | 369.1 | 2306.0 |
| | Mean | 75.1 | 139.5 | 74.9 | 43.5 | 8.9 | 3.5 | 22.5 | 1530.0 | 1.4 | 3.5 | 21.0 | 298.4 | 1864.2 |
| Somali | Min. | 71.0 | 138.0 | 70.0 | 50.2 | 7.8 | 4.0 | 21.0 | 1000.0 | 1.5 | 3.8 | 14.0 | 180.0 | 1125.0 |
| | Max. | 77.0 | 144.0 | 93.0 | 93.2 | 9.2 | 5.0 | 33.0 | 1500.0 | 3.2 | 4.9 | 25.0 | 297.0 | 1855.0 |
| | Mean | 73.0 | 140.0 | 81.8 | 67.7 | 8.4 | 4.5 | 28.5 | 1275.0 | 2.4 | 4.2 | 17.5 | 244.7 | 1529.0 |
| Tigray | Min. | 69.0 | 138.0 | 60.0 | 37.1 | 6.2 | 3.0 | 22.0 | 1000.0 | 1.2 | 4.1 | 11.0 | 210.9 | 1318.0 |
| | Max. | 76.0 | 148.0 | 98.0 | 49.1 | 9.3 | 5.0 | 39.0 | 2400.0 | 2.4 | 6.5 | 24.0 | 444.3 | 2776.0 |
| | Mean | 71.4 | 139.8 | 78.3 | 40.6 | 7.9 | 3.8 | 26.1 | 1788.9 | 1.6 | 5.2 | 18.9 | 287.5 | 1796.2 |
| Non-native | Min. | 71.0 | 139.0 | 89.0 | 34.1 | 7.0 | 3.0 | 16.0 | 1100.0 | 1.6 | 4.4 | 19.0 | 276.6 | 1728.0 |
| | Max. | 77.0 | 142.0 | 109.0 | 53.1 | 8.5 | 4.0 | 34.0 | 1900.0 | 2.6 | 6.4 | 38.7 | 472.3 | 2951.5 |
| | Mean | 74.9 | 140.5 | 99.9 | 42.6 | 7.6 | 3.1 | 21.3 | 1473.3 | 1.9 | 5.7 | 27.1 | 401.8 | 2510.6 |
| Overall | Min | 69 | 138 | 62 | 27 | 6 | 3 | 12 | 1000 | 0.71 | 2.6 | 10.4 | 150 | 975.00 |
| | Max | 99 | 150 | 110 | 93 | 11 | 6 | 42 | 2400 | 3.24 | 6.7 | 38.7 | 472.25 | 2951.5 |
| Landrace $\bar{x}$ | | 75.5 | 141.0 | 79.8 | 56.1 | 8.6 | 4.2 | 26.6 | 1689.8 | 2.0 | 4.2 | 17.6 | 291.0 | 1818.8 |
| Non-native $\bar{x}$ | | 74.7 | 139.8 | 100.4 | 42.4 | 7.9 | 3.5 | 22.2 | 1473.3 | 1.9 | 5.8 | 23.3 | 338.6 | 2116.0 |
| Grand $\bar{x}$ | | 75.3 | 140.7 | 84.7 | 52.9 | 8.4 | 4.0 | 25.5 | 1639.1 | 2.0 | 4.6 | 18.9 | 302.2 | 1888.5 |

*DTF = days to flowering; DTM = Days to maturity; PLH= plant height; CPPL = capsule per plant; SPC = seed per capsule; PB = primary branch; SB = secondary branch; BM = biomass; SYPP = seed yield per plant; SYPPLOT = seed yield per plot; TSW = thousand seed weight; HI = harvesting index; SYPHA = seed yield per hectare, GM= Grand mean.

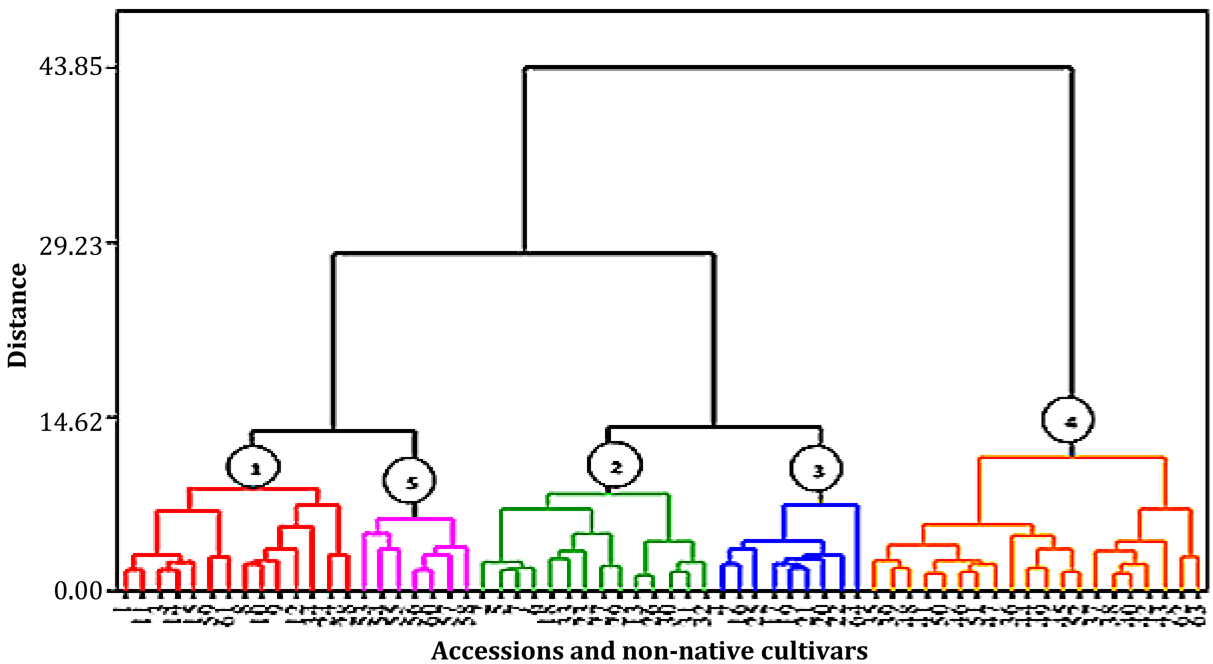


Figure 2. Dendrogram of forty-nine Ethiopian linseed landraces and fifteen Non-native cultivars developed by Ward's agglomerative hierarchical classification method based on Euclidian distance using mean of 13 agro-morphological characters.

**Cluster 1:** This cluster had of two accessions which were collected from SNNP, four from Amhara, six from Oromia Regions and two of them were non-native cultivars. Materials collected from ARs of Ethiopia had a common characteristic of early maturing with the highest number of primary and secondary branches and relatively higher number of capsule per plant and seed yield per plant. However, they were shorter in plant height. Similarly, non-native cultivars consisted in this cluster had high yield per plant, early maturing as compared to other non-native cultivars. Accordingly, the major contributing factors that had caused differentiation between the rests of the clusters were seed yield per plant and thousand seed weight.

**Cluster 2**: This cluster had a total of 14 landraces, four of them from Oromia, five from SNNPR, three from Amhara and one each from Tigray and Somali. The overall natures of these accessions were early maturing and more average yielder. However, materials from Tigray ARs were early maturing than any of the studied materials and had the highest capsules per plant, harvesting index and seed yield per plot. The major contributing factors that caused differentiation between the rests of the clusters were days to flowering, days to maturity and plant height.

**Cluster 3:** This cluster contained eight accessions (four from Amhara, three from Oromia and one from SNNPR) and one non-native cultivar. The peculiar feature of this cluster was the non-native cultivar showed high yielder than the Ethiopian landraces. On the other hand, the landraces were low yielder as compare to other accessions. This could be due to few number of capsules per plant and number of seeds per capsule. Similarly, the three materials collected from Oromia were late to flower, with the lowest seed yield per plant, lower harvest index and thousand seed weight. Generally, the major contributing factors that caused differentiation between the rests of the clusters were capsule per plant, biomass yield and days to flowering.

**Cluster 4:** This cluster holds 32% of the tested genotypes. Majority of the accessions collected from Tigray Region were grouped under this cluster. In this cluster, high yielding materials from all Regions were included *i.e.,* high yielder accessions from: Amhara (Acc. 243807), Tigray (Acc. 243810), SNNPR (Acc. 244809) Somali (Acc.231457) and Oromia region (Acc. 230822)]. Indeed, the major contributing factors that cause differentiation between the rests of the clusters was thousand seed weight, number of secondary branch and seed yield per plot.

**Cluster 5:** The last clustering groups consisted of five non-native cultivars and two landraces. They were characterized by late flowering and maturity but with next high yielder to those non-native cultivar found in cluster four. The characteristics of these cultivars were high number of capsules per plant, large-seeded and thick stems that may tolerate lodging if planted under fertile soils. The major contributing factors that had caused differentiation between the rests of the clusters were days to flowering, days to maturity, seed yield per plot.

**Divergence Analysis Based on morphological Characters of Ethiopian Linseed Landraces and Some Non-native Cultivars:** Summary of pair wise squared distance ($D^2$) among the five clusters are given in Table 5. Distance between agro-morphological characters. Considering the agro-morphological characters, the test of significant showed highly significant difference between the clusters' distance. Maximum distance was observed between cluster 4 and 5 ($D^2$ = 70.90), against the minimum, between cluster 1 and 2 ($D^2$ = 24.33). This suggests that such germplasm could be a good source of parents for improvements through hybridization and selection.

The tallest (mean height, 107 cm) genotypes were represented in cluster 1, whereas the shortest (62 cm) was included in cluster 2 that had fourteen accessions. Other tall (106 cm) varieties were grouped in cluster 5. Cluster 1 exhibited the early flowering, with 69 days for flowering. Similarly, early maturing germplasm were included in clusters such as cluster 1, 2 & 3. Genotypes classified under cluster 4 were relatively late maturing. The highest biomass with 2050.67 g per plot was found in cluster 3, whereas the minimum was recorded in cluster 2 with 760.25 g. Maximum seed yield per plot with 472.78 g per plot was exhibited in cluster 4.

Table 4. Cluster mean of forty-nine linseed landrace accessions and fifteen non-native cultivars for 13 morphological parameters

| Morphological traits | C1 | C2 | C3 | C4 | C5 | GM* |
|---|---|---|---|---|---|---|
| DTF | 73 | 76 | 83 | 74 | 78 | 75 |
| DTM | 139 | 141 | 146 | 142 | 144 | 141 |
| PLH (cm) | 75.0 | 100.0 | 85.0 | 97.0 | 93.0 | 85.0 |
| CPPL | 47.0 | 44.0 | 39.0 | 44.0 | 93.0 | 46.0 |
| SPC | 8.4 | 7.8 | 8.3 | 7.9 | 7.9 | 8.2 |
| PB | 4.1 | 3.5 | 4.3 | 4.0 | 5.0 | 4.0 |
| SB | 24.1 | 21.6 | 19.8 | 40.4 | 32.9 | 23.4 |
| BM (%) | 1630.0 | 1511.0 | 1944.0 | 1950.0 | 1000.0 | 1639.0 |
| SYPP (g) | 1.6 | 1.9 | 1.2 | 2.3 | 3.2 | 1.7 |
| YPPLOT (g) | 271.2 | 403.0 | 260.7 | 288.7 | 261.9 | 309.2 |
| TSW (g) | 4.1 | 5.6 | 3.8 | 6.6 | 4.3 | 4.6 |
| HI (%) | 17.0 | 27.1 | 13.5 | 14.9 | 26.2 | 19.6 |
| GYPHA (kg/ha) | 1695.0 | 2519.0 | 1629.0 | 1804.0 | 1637.0 | 1933.0 |

*GM = grand mean

Table 5. Pair wise generalized squared distances ($D^2$) among forty nine linseed landraces and 15 non-native cultivars in five clusters based on morphological characters

| Clusters | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|---|---|---|---|---|
| Cluster 1 | 24.33** | 27.68** | 44.12** | 67.17** |
| Cluster 2 | | 37.28** | 32.40** | 47.62** |
| Cluster 3 | | | 43.81** | 59.52** |
| Cluster 4 | | | | 70.90** |

$X^2$: ** Significant at P=.01 and * Significant at P=.05, ns= non-significant

**Correlation Coefficient among Morphological Characters of Ethiopian Linseed Landraces and Some Non-native Cultivars:** In this study as indicated on Table 6, seed yield per plot had positive and highly significant correlation coefficient with plant height (r=0.52), thousand seed weight (r= 0.45), capsule per plant (r=0.62) and biomass (r=0.41). On the other hand, seed yield per plot had non-significant association between days to flowering (r= 0.08) and days to maturity (r= 0.14). Similarly, harvest index had non-significant association with all agro-morphological parameters except with thousand seed weight (r= 0.40) and biomass (r= 0.45). Furthermore, biomass was positively and significantly associated with days to flowering (r= 0. 23), days to maturity and plant height (r= 0.3 and r= 0.27), respectively.

Table 6. Estimates of correlation coefficients agro-morphological characters of 11 traits in Ethiopian linseed landrace accessions and non-native cultivars.

| Variable | DTF | DTM | PLH | CPPL | SPC | PB | SB | BM | SYPP | SYPPLOT | TSW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DTM | 0.58** | | | | | | | | | | |
| PLH | 0.21* | 0.36** | | | | | | | | | |
| CPPL | -0.08ns | -0.11ns | -0.07ns | | | | | | | | |
| SPC | 0.08ns | -0.10ns | -0.19* | 0.12ns | | | | | | | |
| PB | -0.08ns | 0.01ns | -0.33** | 0.37** | 0.02ns | | | | | | |
| SB | -0.22* | -0.19* | -0.17ns | 0.39** | 0.01ns | 0.45** | | | | | |
| BM | 0.23** | 0.30** | 0.27** | 0.01ns | -0.09ns | -0.13ns | -0.03ns | | | | |
| SYPP | -0.11ns | -0.11ns | 0.16ns | 0.84** | 0.36** | 0.20ns | 0.36** | 0.02ns | | | |
| SYPPLOT | 0.08ns | 0.14ns | 0.52** | 0.67** | 0.29* | 0.29** | 0.22** | 0.41** | 0.10ns | | |
| TSW | -0.15ns | -0.03ns | 0.57** | -0.04ns | -0.21* | -0.22ns | 0.14ns | 0.09ns | 0.36** | 0.45** | |
| HI | -0.08ns | -0.13ns | 0.31ns | -0.06ns | -0.17ns | -0.33** | -0.21ns | -0.36** | 0.187ns | 0.60** | 0.40** |

DTF = days to flowering; DTM = Days to maturity; PLH= plant height; CPPL = capsule per plant; SPC = seed per capsule; PB = primary branch; SB = secondary branch; BM = biomass (g); SYPP = seed yield per plant (g); SYPPLOT = seed yield per plot (g); TSW = thousand seed weight (g); HI = harvesting index (%).

On the other hand, number of capsules per plant exhibited a positive association with seed yield per plant. This is an indication that plants bearing more number of capsules per plant can produce more seed yield plot. Thus, selection for capsule number alone may bring about a definite improvement in seed yield plot. Number of primary and secondary branches was positively and highly significantly correlated with seed yield plot. This suggests that more branch-prolific cultivars are likely to bear more yields. The positive and significant correlations noted between seed yield and number of primary and secondary branches, thousand seed weight and plant height were in agreement with the results reported by Tadele (2002). Similarly, Mahto and Mahto , 1998; Adugna *et al*., 2006) indicated positive and significant correlation of seed yield plot, plant height, number of primary branches, secondary branches and capsules per plant.

## CONCLUSION

In order to exploit the available genetic wealth, unraveling the information on the extent and nature of genetic diversity of linseed germplasm and the inter-relationships among characters that help formulate efficient scheme of multiple trait selection is required. To study morphological diversity and to generate baseline information, 49 Ethiopian linseed landraces collected from five administrative regions of Ethiopia and 15 non-native cultivars were investigated. From the study, linseed accessions collected from Ethiopia were highly variable for several traits; particularly presence of high yielder (yield per hectare) cultivars indicating the possibilities for genetic improvement of the crop through selection and cross breeding. The varying characters of the superior accessions have implications for further work. Thus, the variation for the different characters found in Ethiopian linseed landraces and non-native cultivars included in this study could be exploited and used in future linseed improvement programs.

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**APPENDIX**

Table 1. Mean monthly temperature (°C) of SARC (2007 - 2011)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 15.1 | 16.1 | 16.3 | 15.6 | 15.9 | 16.1 | 15.5 | 15.3 | 15.1 | 14.5 | 14.3 | 14.5 | 15.3 |
| 2008 | 15.2 | 16.4 | 16.7 | 10.6 | 15.7 | 15.8 | 15.1 | 15.0 | 14.7 | 14.5 | 14.0 | 13.8 | 14.8 |
| 2009 | 14.7 | 15.0 | 15.7 | 15.2 | 15.4 | 15.0 | 15.1 | 15.0 | 15.2 | 14.8 | 14.1 | 13.9 | 14.9 |
| 2010 | 14.6 | 15.3 | 15.9 | 15.3 | 15.5 | 15.8 | 15.6 | 15.2 | 15.1 | 15.0 | 14.8 | 15.0 | 15.3 |
| 2011 | 15.4 | 15.4 | 15.4 | 15.7 | 15.9 | 15.9 | 15.5 | 15.2 | 15.3 | 15.3 | 14.5 | 14.6 | 15.3 |
| Mean | 15.0 | 15.64 | 16 | 14.48 | 15.68 | 15.72 | 15.36 | 15.14 | 15.08 | 14.82 | 14.34 | 14.36 | 15.12 |

Source: Sinana Agricultural Research Center.

Table 2. Mean monthly rainfall (mm) of sinana agricultural research center (2007 - 2011).

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 16.8 | 71.4 | 54.3 | 179.5 | 131.5 | 86.2 | 62.5 | 110.0 | 139.5 | 129.4 | 23.4 | 35.4 | 1039.8 |
| 2008 | 0.0 | 6.2 | 49.1 | 286.3 | 108.6 | 94.6 | 167.1 | 172.4 | 152.8 | 122.4 | 103.2 | 0.0 | 1262.7 |
| 2009 | 9.7 | 0.0 | 28.4 | 274.8 | 275.8 | 119.8 | 98.3 | 164.3 | 239.3 | 126.3 | 139.2 | 0.0 | 1475.9 |
| 2010 | 49.9 | 0.0 | 31.3 | 207.1 | 142.9 | 49.6 | 58.0 | 89.2 | 136.2 | 44.2 | 44.3 | 86.1 | 938.8 |
| 2011 | 0.6 | 18.2 | 133.6 | 196.2 | 250.9 | 40.3 | 190.4 | 222.1 | 320.0 | 97.1 | 0.0 | 0.0 | 1469.4 |
| Mean | 15.4 | 19.2 | 59.3 | 228.8 | 181.9 | 78.1 | 115.3 | 151.6 | 197.6 | 103.9 | 62.0 | 24.3 | 1237.3 |

Source: Sinana Agricultural Research Center.