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VARIATION AND ASSOCIATION ANALYSES ON MORPHOLOGICAL CHARACTERS OF LINSEED (*LINUM USITATISSIMUM* L.) IN ETHIOPIA

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ABSTRACT: Morphological studies of linseed (*Linum usitatissimum* L.) of Ethiopia were undertaken in this study on 56 accessions collected from 10 administrative regions (former regions) classified into seven altitude classes. The seeds were planted during 2001 growing season in Bale-Goro "wereda" using randomized complete block design (RCBD) on three replications with the aim of investigating the morphological diversity in the accessions. Over the entire accession, except seed number per boll, all the characters showed significant variation. However, regional groups of linseed accessions showed insignificant variations only for secondary branches number per plant (SBP), days to flowering (DTF) and days to maturity (DTM) among themselves, and altitudinal groups of linseed accessions only for seed number per boll (SNB) and days to flowering (DTF). The analysis for coefficient of variation and cluster analysis showed that accessions from Gojam and Tigray were less diversified. About 53% of the total associations showed significant correlation and out of this 71% of the correlations were with the positive significant correlation coefficients. Cluster analysis indicates that accessions collected from the two extremes of altitude classes have variations for the studied traits. It is only Tigray Region that did not contribute member accession to cluster III, whereas Gondar and Bale regions contribute member accessions to 80% of clusters. Factor analysis showed that of the total variation (73.86%) 30.04% and 27.29% were accounted for by first and second principal components, respectively. The highest Shannon diversity index (0.322±0.039) was recorded for boll size and Shannon diversity index for overall pooled mean was 0.223±0.063.

Key words/phrases: Cluster/factor analysis, diversity index, linseed accessions, morphological characters, variation/association

INTRODUCTION

Linseed (*Linum usitatissimum* L.) is a member of the family Linaceae containing about 300 species distributed in 25 genera. The genus *Linum* L. has about 200 species including *L. usitatissimum* L. (Friedt *et al.*, 1996; Friis, 2000). *L. usitatissimum* L. is a self-pollinated species with less than 1% outcrossing although, up to 40% outcrossing was observed (Seegeler, 1983). The suggested developmental or biological relationships among the different varieties of *L. usitatissimum* L., is that the procumbent linseeds probably appeared first, and then came the erect types followed by the dual-purpose forms and finally the fiber types (Durrant, 1976). Vavilov (1951) reported that linseed is one of the crops with high diversity in Ethiopia. Moreover, this author showed that Ethiopia, with the Central Asiatic, Near Eastern and Mediterranean diversity centre, is in the place for the origin of linseed.

All the seed, the straw and the chaff of linseed have different use values. The seed is used to extract oil for both cooking and industrial uses (Durrant, 1976; Berhanu Abegaz Gashe and Desta Hamito, 1983; Seegeler, 1983; Dubey, 1990; Friis, 2000). However, its high content in linolenic acid gives it poor quality as edible oil. On the other hand because of its higher linolenic acid linseed seed oil is with high quality as industrial oil (Hiruy Belayneh, 1983; Seegeler, 1983). The oil cake is used as animal feed (Hiruy Belayneh *et al.*, 1981; Shelemew W/Mariam, 1985). The roasted and pounded seed is used to make the component of different traditional food items (Seegeler, 1983; Mulatu Geleta, 2001). In addition to its food and industrial use values, the seed has different medicinal values (Elder and Rathmann, 1962;

Mulatu Geleta, 2001). The fibers produced from the straw are used to make linen cloth, very strong thread (Hill, 1952; Seegeler, 1983; Friis, 2000), gloves, footwear, netting and sports gear (Durrant, 1976).

Genetic and morphological improvements of crops for drought tolerance, high yield, resistance to insect pests and diseases are the main components of agricultural improvement that could be achieved by utilizing the biological diversity of a given species (Melaku Worede, 1988). Plant genetic resources with highest potential for genetic diversity are represented primarily by landraces, wild relatives of cultivated species and wild/weedy species (Monti, 1992). More specifically in the gene pools genetic resources conservation involves description of variation and association for morphological traits, particularly agro-morphological characteristics of direct interest to users (Bretting and Widerlechner, 1995; Karp *et al*., 1997).

Ethiopian crops made important contributions in genetic diversity and the need to conserve its genetic stocks have been stressed several times (Harlan, 1969; Endeshaw Bekele, 1983). However, although quantitative estimates of genetic diversity are prerequisite for genetic conservation strategy there was no quantitative estimate on the magnitude of Ethiopian crops genetic diversity until 1983 (Endeshaw Bekele, 1983). Similarly, although it is believed that studies on heritable phenotypic traits, genetic markers and ethnobotanical studies are essential for conservation activities such studies were not carried out on linseed in Ethiopia, except on agronomic characters and very limited ethnobotanical information (Westphal, 1975; Seegeler, 1983; Shelemew W/Mariam, 1985; Hiruy Belayneh *et al*., 1990; Mulatu Geleta, 2001). A study was, therefore, carried out to fill the gaps in ethnobotanical information as well as in morphological and biochemical data on Ethiopia linseed. This paper is particularly devoted to the study of the diversity, variability and associations of morphological characters of linseed in Ethiopia using gene bank accessions/collections.

DESCRIPTION OF THE EXPERIMENTAL STUDY AREA

The study was conducted at Bale-Goro at Addis Alem Mana on Institute of Biodiversity Conservation and Research (IBCR/E) site, which is located at 07°01′ N and 040°23′ E, in the Oromia Region. Addis Alem Mana is 482kms from Addis Ababa via Shashemenee and Robe to Goro town. It is located at 2130masl. The site has two crop-growing seasons, "Meher" (main rainy season) and "Belg" (small rainy season). Based on the data obtained from National Meteorological Services Agency of Ethiopia (NMSAE), at Meleyu Station (within 3km from the study site) the annual average rainfall in the recent nine years, 1993–2001, was 1304.09 mm. The minimum and maximum annual rainfalls were 941.9 mm for the 1994–year and 1569.8 mm for the 1997-year, respectively. The monthly minimum rainfall was 18.9 mm in December and the maximum was 236.3 mm in October. Monthly average rainfall for the growing season during this study was 100.14 mm. But the rainfall was recorded only for the first three months. Based on the data recorded from Goro station that is about 9km from the study site, the monthly average temperature in nine years, 1993–2001, was 17.86°C whereas the maximum and the minimum temperatures were 28.9 and 4.37°C in February and December, respectively.

MATERIALS AND METHODS

Seed materials were obtained from the IBCR, collected from Shewa, Gondar, Arsi, Bale, Gojam, Wello, Hararghe, Gamogofa, Wellega and Tigray (Table 1). The demarcation of these regions is based on the division for former Administrative Regions and indicated/used by Hedberg and Edwards (1989) in "Flora of Ethiopia Vol. 3". The seed source altitude ranges from 1480 to 3190masl and within this range, taking the maximum possibility to include all the ten regions 56 accessions were selected. Seven altitude classes were made using the formulae:

$K = 1 + 3.32\log_{10}{}^{n}$ and $i = \text{Range}/K$ (Agarwal, 1996);

Where i = class interval width, K = number of classes and n = sample size.

The number of cluster was determined using Toit *et al.* (1986) method:

$$g = \frac{n}{10}; \text{ where } g = 1, 2, 3, \ \ , k \text{ clusters;}$$

n = the number of accessions; and

k usually is the largest integer smaller than $\frac{n}{10}$.

The experiment was laid out in a randomised complete block design (RCBD) with three replications in a single row. The size of each block, row, and spaces between rows and between blocks were 2.00m x 22.40m, 0.20m x 2.00m, 0.20m and 2.00m, respectively. Based on the recommendation from IAR (1985) seeds were planted with 25kg/ha seeding rate over the 0.20m x 2.00m area on October 4, 2001 (corresponding to the "Meher" planting season) on the field that was ploughed twice before planting. Seeds were covered with sufficiently moist soil and days to flowering and maturity were counted starting from the sowing date. There was no application of fertilizers. Weeding was performed twice manually. Following the descriptor for *L. usitatissimum* L. obtained from IBCR the following morphological characters were recorded: plant height, 1000-seed weight, primary branches number per plant, secondary branches per plant, boll number per plant, seed number per boll, seed number per plant, seed weight per plant, days to flowering and days to maturity. Seven plants per row and twenty-one plants per accession with a total of (21 x 56) 1176 plants were selected using systematic sampling. Each plant was taken at 30cm distance on a row: i.e., plants at readings of 0cm, 30cm, 60cm, 90cm, 120cm, 150cm, and 180cm on the measurement, to evaluate morphological characters both within and between accessions.

Qualitative morphological characters: seed colour with four classes: brown, light brown, beige and yellow; boll size with three classes: large, medium and small; flower colour with four classes: blue, light blue, purple blue and white; and seedling stem colour with two classes: violet and green were scored. Boll size was measured using caliper with mm unit and the distribution was determined using scattered plot technique. From the scattered plot three patterns were used as distributions for large, medium and small boll sizes. Seeds from the above twenty-one plants from each accession were germinated in the IBCR Biotechnology Laboratory and seedling stem colours were scored from visual observation.

Statistical analysis

The analysis of mean, correlation, principal components, and cluster analysis by SPSS software (SPSS, 1999), and Chi-square test by MSTATC software (Bricker, 1991) were done. The diversity index on the qualitative morphological characters for the accessions, regional and altitude classes were determined using Shannon diversity index $(H), i.e. H = -\sum P_i * inP_i$; where P_i is the proportion of the total number of plants per acccession in the i^{th} class and n is the number of phenotypic classes for a given trait. Each value of H was divided by its maximum value, ln n, in order to keep the values between zero and one (denoted as H' as used by Yemane Tsehaye and Fassil Kebebew, 2002).

RESULTS AND DISCUSSION

Coefficient of variation (CV)

As can be seen in Table 2 the least CV over the entire accession is from PH (1.02 %) whereas the highest CV is from SWP (33.03%) (Gomez and Gomez, 1984) concluded that in field experiments for rice the acceptable CV for PH would be about 3%. Hence, although the CV for precision varies greatly with the characters measured and type of plant the above CV for linseed PH showed high precision in the measure of plant height.

Accessions collected from Gojam were with the least CV (Table 3) for about 33.3% of the quantitative morphological characters. That is accessions from Gojam were less variable. Comparisons among altitudinal classes of accessions fro CVs (Table 4) showed that accessions from altitude class 1 (= 1700 m) were with the highest CVs for PH, SNB, DTF and DTM. Accessions from altitude class 2 (1701–1950 m) were with the highest CVs for TSW and PBP. In general, the highest CVs for 60% of the traits were from the accessions collected from altitude classes 1 (= 1700 m) and 2 (1701–1950 m). This indicates that these linseed accessions tend to be highly variable towards the lowest altitude classes than to the highest altitude classes.

Mean values

Accessions collected from Arsi showed the highest mean value (Table 3) for PH. Accessions collected from Tigray showed the highest mean values for TSW and SWP. The highest mean values for DTF, DTM and SNB were from accessions collected from Gondar. As Wuletaw Tadesse (1999) reported, DTF and DTM in this region showed similar results in grasspea (*Lahyirus sativus* L.) populations. Accessions from Gojam showed the highest mean value for SNP but the least mean value TSW. Tigray and Gojam were similar with the results reported by Seegeler (1983) for TSW. The highest mean value for PBP, SBP and BNP were from the accessions collected from Hararghe.

Table 1. Source regions and altitudes for the sample accessions.

S. No.	Accession No.	Region/Origin	Locality*	Altitude
1	13511	Arsi	Shirka	2800
2	13655	Arsi	Tena	3190
3	216891	Arsi	Jeju	2050
4	231252	Arsi	Guna	2330
5	232215	Arsi	Jeju	1610
6	236998	Arsi	Limu and Bilbila	2565
7	13528	Bale	Gololcha	2060
8	13538	Bale	Gasera	1520
9	13543	Bale	Raytu	2570
10	230025	Bale	Nensebo	1830
11	237931	Bale	Adaba	2350
12	237934	Bale	Dinsho	2800
13	13656	Gamogofa	Chencha	2710
14	13657	Gamogofa	Konso	2000
15	211477	Gamogofa	Konso	1780
16	211478	Gamogofa	Konso	1560
17	225801	Gamogofa	Kemba	2650
18	13566	Gojam	Dembecha	2040
19	13567	Gojam	Dega Damot	2810
20	212747	Gojam	Yilma and Densa	2340
21	13684	Gojam	Banja	2570
22	13685	Gojam	Dega Damot	1880
23	10162	Gondar	Dabat	2575
24	13522	Gondar	Fogera	1840
25	13624	Gondar	Lay Gayint	3000
26	13674	Gondar	Gonder Zuriya	2390
27	212751	Gondar	Farta	2800
28	214249	Gondar	Debark	3009
29	223327	Hararghe	Achar	2130
30	13637	Hararghe	Goro guta	2880
31	208664	Hararghe	Kunta chele	2540
32	230817	Hararghe	Jarso	2370
33	230821	Hararghe	Bedeno	1700
34	230824	Hararghe	Deder	2510
35	10100	Shewa	Addis Alem	2350
36	13502	Shewa	Baso and werena	2810
37	13599	Shewa	Bereh	2510
38	212518	Shewa	Mama Bidir	3110
39	236846	Shewa	Baso and werena	3150
40	236850	Shewa	Aberhu Neyo	2800
41	237590	Shewa	Alaba	1900
42	219963	Tigray	Adi Abeyti	1850
43	223227	Tigray	Aubah and Saisa	2570
44	223231	Tigray	Genta	2360
45	235167	Tigray	Tseda Amba	2060
46	13658	Wellega	Gobu Seyo	1890
47	13662	Wellega	Gidarkiremu	2090
48	13666	Wellega	Jima Genet	2340
49	13753	Wellega	Dale and Sadi	1680
50	13622	Wello	Guba Lafto	2100
51	13692	Wello	Were Ilu	2850
52	13711	Wello	Legambo	3070
53	13719	Wello	Tenta	3100
54	13725	Wello	Tehuledere	2560
55	13734	Wello	Tehuledere	2000
56	237491	Wello	Kalu	1480

* Local name is given at former "woreda" level.

Table 2. Mean, Std., Min., Max and CV for 56 linseed accessions.

Parameter	Characters*									
	PH	TSW	PBP	SBP	BNP	SNB	SNP	SWP	DTF	DTM
Mean	51.97	4.09	4.54	19.83	60.89	6.99	423.02	1.71	81.65	127.95
Std.	9.67	0.91	1.82	4.74	18.29	0.85	126.15	0.56	8.21	11.01
Min.	27.98	2.68	2.00	10.67	29.25	4.43	203.46	0.78	61.00	98.00
Max.	75.45	6.08	9.00	30.67	96.30	8.56	728.65	3.21	94.67	153.00
CV, %	1.02	3.75	17.96	10.26	8.43	18.07	19.21	33.03	2.33	6.59

*PH=plant height, TSW=1000-seed weight, PBP= primary branches per plant, SBP= secondary branches per plant, BNP= boll number per plant, SNB = seed number per boll, SNP= seed number per plant, SWP = seed weight per plant, DTF = days to flowering and DTM = days to maturity.

Table 3. Mean, Std, Range and CV of quantitative morphological characters by regions.

Region	No of Acce.	Parameter	Character									
			PH	TSW	PBP	SBP	BNP	SNB	SNP	SWP	DTF	DTM
Shewa	7	Mean	49.45	3.80	4.90	15.19	55.38	7.49	414.52	1.56	84.62	130.86
		Std.	5.10	0.66	2.08	4.41	16.20	0.51	27.61	0.54	6.07	9.79
		Range	15.33	1.53	5.66	12.33	43.52	1.44	330.32	1.59	15.95	29.05
		CV	10.33	17.35	42.34	29.05	29.24	6.86	30.78	34.66	7.19	7.45
Gondar	6	Mean	55.95	4.15	3.17	19.17	45.95	7.74	350.79	1.42	86.78	136.17
		Std.	8.27	0.97	1.11	5.45	21.90	0.51	152.17	0.55	7.80	13.31
		Range	25.50	2.38	3.00	15.00	56.00	1.29	92.23	1.41	18.36	28.81
		CV	14.78	23.42	35.01	28.42	47.67	6.59	43.38	38.50	8.96	9.70
Arsi	6	Mean	57.90	4.54	4.05	20.61	65.27	6.39	407.72	1.78	84.00	128.83
		Std.	9.61	0.88	2.30	1.16	23.94	1.13	140.69	0.45	5.65	5.15
		Range	22.59	2.69	6.00	3.00	56.35	2.80	393.18	1.28	14.24	12.39
		CV	16.59	19.48	56.78	5.64	36.67	17.66	34.51	25.10	6.77	4.00
Bale	6	Mean	56.43	4.43	5.11	17.55	59.62	7.03	417.69	1.84	74.94	119.11
		Std.	15.48	0.65	2.08	4.27	19.73	1.36	161.67	0.78	8.90	11.81
		Range	46.85	1.48	5.67	10.67	57.06	3.66	436.73	2.03	21.65	30.32
		CV	27.43	14.69	40.77	24.31	33.09	19.41	38.70	42.49	11.87	9.95
Gojam	5	Mean	49.74	3.40	5.29	23.40	80.54	7.53	608.20	2.10	82.47	127.27
		Std.	7.83	0.73	1.43	2.58	11.41	0.33	95.16	0.70	4.80	2.26
		Range	18.74	1.88	3.45	7.00	23.19	0.74	196.05	1.70	11.98	5.88
		CV	15.74	21.61	26.96	11.01	14.16	4.40	18.72	33.54	5.80	1.73
Wello	7	Mean	47.53	3.71	4.90	22.90	58.14	6.87	392.25	1.48	83.48	133.00
		Std.	9.13	0.51	1.42	3.60	18.25	0.77	100.69	0.55	11.23	16.97
		Range	23.34	1.14	4.66	8.00	50.64	2.30	284.37	1.61	29.40	44.55
		CV	19.20	13.83	28.98	16.71	31.39	11.24	25.67	37.29	13.35	11.90
Hararghe	6	Mean	51.63	3.96	6.00	24.00	66.99	6.45	426.56	1.68	86.39	131.45
		Std.	7.60	0.49	1.88	5.91	11.40	0.74	40.12	0.22	7.85	11.32
		Range	20.00	1.18	5.66	14.00	32.10	1.93	109.00	0.62	22.32	32.40
		CV	14.71	12.33	31.39	24.64	17.10	11.54	9.40	12.87	9.07	8.57
Gamogafa	5	Mean	49.73	3.84	3.67	17.67	63.91	6.83	433.82	1.66	80.27	125.40
		Std.	10.75	0.92	1.51	4.44	17.04	0.70	113.70	0.55	2.16	2.43
		Range	23.83	2.20	3.67	11.00	41.01	1.72	281.53	1.28	4.32	5.35
		CV	21.62	24.03	41.21	25.14	26.66	10.22	26.21	32.43	2.63	1.93
Wellega	4	Mean	55.36	4.10	2.83	20.17	52.87	7.02	370,18	1.55	78.91	124.83
		Std.	13.40	1.58	0.43	3.01	10.49	0.79	71.81	0.77	2.45	3.94
		Range	27.24	3.15	1.00	6.33	22.83	1.81	148.72	1.79	5.16	8.59
		CV	24.10	38.65	15.18	14.93	19.84	11.19	19.40	49.59	3.11	3.04
Tigray	4	Mean	45.29	5.34	4.83	17.50	63.66	6.78	433.59	2.23	68.00	115.50
		Std.	4.93	1.07	1.73	2.44	15.69	0.32	109.84	0.15	1.98	2.90
		Range	10.78	2.30	3.66	5.33	32.46	0.69	245.75	0.32	4.10	7.03
		CV	10.84	19.93	35.75	13.95	24.64	4.67	25.33	6.66	2.76	2.16

For character codes see Table 2.

Accessions collected from altitude class 1 (= 1700 m) (Table 4) showed the least mean values for PH, SNP and DTM but the highest mean values for BNP and SNP. This indicates that linseed accessions from low altitudes adapt to mature early using the available short cycle of moisture. Accessions collected from altitude class 7 (= 2951 m) were with the least mean value for TSW, but with maximum SNB. This is in agreement with the finding by Seegeler (1983) that the SNB tends to be inversely correlated with seed size and TSW, and the smallest seeds are found in areas with the high rainfall.

TSW is used as important estimator for the productivity of linseed varieties (Banwal *et al*., 1971 and Chowdhuti, 1972; both cited in Seegeler, 1983). Similarly, Endeshaw Bekele (1996) reported that mean values are useful to determine variations within and between populations. Therefore, linseed accessions from Gojam and those from the highest altitude are relatively less productive than the accessions from other regions and altitude classes, respectively. Accessions from lowest altitude class took 77 and 44, and from highest altitude class, 89 and 51 days to flowering, and from flowering to maturity, respectively. This could be due to positive effect of longer growing season on growth. Maturing in the rainy season decreases the oil content and causes seed decay in linseed (Seegeler, 1983). Therefore, adapting to longer flowering and maturity time in higher altitudes characterized with longer rainy season is advantageous for linseed to flower and mature towards the end of the rainy season.

Analysis of Variance (ANOVA)

ANOVA on the quantitative morphological characters over the entire accession (Table 5), regional groups and altitude groups (Table 6) were determined. ANOVA over the entire accession (Table 5) showed highly significant differences for the mean values among accessions for all characters, except for SNB. The character that showed significant difference among blocks (replication) was DTF. ANOVA for the mean values of linseed accessions between regions (Table 6) showed significant differences for the mean values of SBP, DTF and DTM. The same analysis between altitude classes showed significant differences for the mean values of SNB and DTF. Therefore, the variation was stronger within a region and an altitude class than between regions or altitude classes. This low variation between regions can be explained in terms of the environmental heterogeneity of each region.

Table 4. Mean, Std, Range and CV of quantitative morphological characters by altitude classes.

Altitude Class in m	No. of Acce.	Parameter	Characters code									
			PH	TSW	PBP	SBP	BNP	SNB	SNP	SWP	DTF	DTM
1. = 1700	6	Mean	46.91	4.25	4.72	20.17	76.56	5.87	449.62	1.86	77.22	121.50
		Std.	16.22	1.05	1.62	4.49	16.01	1.12	121.69	0.52	8.41	11.97
		Range	47.47	2.55	4.33	12.67	38.88	2.89	371.04	1.28	23.28	32.58
		CV	34.58	24.62	34.41	22.25	20.19	19.10	27.06	27.72	10.93	9.84
2. 1701–1950	7	Mean	50.02	3.72	4.90	19.19	63.02	7.04	447.47	1.61	78.90	123.33
		Std.	6.67	1.14	2.48	4.73	12.14	0.67	113.35	0.42	4.91	4.83
		Range	20.14	3.34	7.00	11.33	33.53	1.54	302.11	1.08	14.43	12.39
		CV	13.34	30.66	50.52	24.66	19.27	9.56	25.33	25.82	6.15	3.89
3. 1951–2200	9	Mean	51.51	4.09	4.52	21.00	62.81	6.81	424.00	1.74	76.67	122.78
		Std.	12.79	1.02	2.04	4.45	16.40	0.59	96.05	0.59	7.20	8.62
		Range	39.57	2.89	5.66	15.00	54.21	1.89	290.29	1.81	18.91	28.17
		CV	24.83	24.94	45.13	21.19	26.09	8.66	22.65	33.92	9.27	5.63
4. 2201–2450	8	Mean	55.13	4.64	4.64	18.54	51.54	7.32	375.79	1.70	83.62	131.17
		Std.	7.17	0.90	1.75	5.04	19.87	0.70	156.12	0.55	8.97	11.83
		Range	19.00	2.72	5.12	15.00	63.13	2.10	506.03	1.47	25.30	34.41
		CV	13.00	19.49	43.26	27.16	38.55	9.67	41.54	32.54	10.74	9.00
5. 2451–2700	10	Mean	49.68	4.42	4.73	21.87	64.81	6.86	448.86	1.99	80.70	126.60
		Std.	8.11	0.62	1.51	4.82	20.84	0.82	163.40	0.77	9.11	9.62
		Range	23.19	1.86	4.67	15.67	58.50	2.58	490.38	2.22	28.20	35.24
		CV	16.33	13.91	31.80	22.03	32.16	11.98	36.40	38.94	1.12	7.63
6. 2701–2950	9	Mean	56.72	4.00	3.89	19.59	55.76	7.48	406.25	1.62	85.33	130.07
		Std.	8.86	0.64	1.40	4.98	17.04	0.76	102.76	0.49	6.14	9.83
		Range	23.55	1.90	3.34	14.33	49.22	2.61	312.17	1.60	16.67	29.25
		CV	15.61	15.86	36.09	25.40	30.56	10.17	25.29	30.05	7.19	7.53
7. =2951	7	Mean	52.40	3.32	5.14	17.57	54.57	7.58	413.16	1.34	89.00	140.24
		Std.	5.12	0.63	2.38	4.99	19.04	0.39	140.75	0.39	6.42	11.49
		Range	14.67	1.91	5.66	12.33	48.15	1.07	328.41	1.06	16.03	24.64
		CV	9.76	18.94	46.36	28.37	34.90	5.20	34.07	29.08	7.21	8.09

For character codes see Table 2.

Table 5. Mean squares for quantitative morphological traits of 56 linseed accessions.

Source of variation	Character									
	PH	TSW	PBP	SBP	BNP	SNB	SNP	SWP	DTF	DTM
Replication (df = 2)	0.79	0.01	1.30	9.24	29.77	1.15	3434.53	0.09	110.97**	138.34
Accession (df = 165)	280.8**	2.47**	10.06**	67.31**	1003.48**	1.93	47746.53**	0.95**	209.93**	462.85**
Error (df = 167)	0.28	0.02	0.66	4.14	26.34	1.60	6604.85	0.13	3.63	70.94

** stands for 0.01 and * for 0.05 level of significances; df = degree of freedom; for Character codes see Table 2.

Table 6. Mean squares for quantitative morphological traits of linseed within and between regions and altitude groups.

Characters	ANOVA by regions		ANOVA by altitude classes	
	Source of variation		Source of variation	
	Between groups	Within a group	Between groups	Within a group
PH	98.07	92.71	86.40	94.46
TSW	1.40	0.71	1.48	0.74
PBP	5.33	2.98	1.62	3.47
SBP	51.98**	16.66	17.81	23.01
BNP	468.50	308.30	484.89	316.10
SNB	1.19	0.64	2.22**	0.55
SNP	24860.58	14165.25	6029.24	17125.94
SWP	0.346	0.312	0.345	0.314
DTF	157.22**	49.40	155.73*	56.18
DTM	365.69**	112.92	177.96	139.14
Degree of freedom (df)	9	46	6	49

For Character codes see Table 2.

Correlation

As indicated in Table 7 PH, SNB, DTF and DTM were with positive significant correlations with each other. TSW was with significant negative associations with PBP, DTF and DTM, but with significant positive associations with SWP. Shelemew W/Mariam (1985) reported similar results for the association between TSW and PH, PBP, SBP and SNB. Lin and Nelson (1988) working on determinate soya bean also showed that delayed flowering increased plant height.

Positive correlations could result from the presences of common genetic elements or microenvironments (or both) that control the characters to the same direction. Positive significant correlation due to effect of genes can be the result of the presence of strong coupling linkage between their genes or the characters may be the result of pleiotropic genes that control these characters in the same direction (Kearsey and Pooni, 1996).

The negative significant associations for TSW with PBP, DTF and DTM could be explained in that the available resources were used up in the production of profuse vegetative growth for longer time at the expense of material production that should be stored in the seeds. An alternative explanation is that different genes or pleiotropic genes that have dominance on the characters may control the characters in different directions (Kearsey and Pooni, 1996). Therefore, desiring to develop a cultivar having higher TSW simultaneously with these traits could be achieved in difficulty.

Cluster analysis

After standardizing each value measured for the quantitative characters into *z score*, using the average linkage between groups method, cluster analysis for the entire accessions was made (Fig. 1). The entire accessions were divided into two general groups, G_A and G_B i.e. G_A with 51 and 5 member of accessions, respectively. The marker morphological characters that grouped the entire accession into the first two groups are TSW, DTF and DTM. Clusters under G_A (I, II, and III) are with lower mean value for TSW but higher values for DTF and DTM and the reverse is true for clusters under G_B (IV and V). Accession 13538, collected from Bale at altitude 1520m, formed one independent cluster, cluster V. The accession was with the least mean values for PH, SNB, DTF and DTM, and the seeds were twin-seeded. The average seed weight (TSW = 5.08g) of these twin-seeded seeds was above the average weight (TSW = 4.09g) of the seeds of the whole sample accessions. Therefore, Cluster analysis revealed that accession 13538 would have specific position in the classification of these linseed accessions.

Except Tigray, all the regions contributed member accessions to cluster III, a cluster consisting about 50% of the total sample accessions. Gondar, Bale and Arsi regions contributed member accessions to three and four clusters whereas the rest regions contributed only to two clusters. Sixty percent of G_B member accessions were from Tigray and 75% of the accessions from this region remained being the member of one cluster, cluster IV. This may hint at the presence of genetic similarity among the accessions and that they are different from the other regional groups of accessions.

Table 7. Correlations between the quantitative morphological characters.

Char.	PH	TSW	PBP	SBP	BNP	SNB	SNP	SWP	DTF	DTM
PH	------									
TSW	0.261	------								
PBP	-0.175	-0.301*	------							
SBP	0.029	-0.008	0.407**	------						
BNP	-0.218	-0.100	0.387**	0.408**	------					
SNB	0.404**	-0.243	-0.050	-0.119	-0.297*	------				
SNP	-0.082	-0.208	0.387**	0.372**	0.905**	0.117	------			
SWP	0.134	0.474**	0.119	0.313*	0.736**	-0.052	0.747**	------		
DTF	0.362**	-0.353**	0.000	-0.023	-0.300*	0.403**	-0.167	-0.369**	------	
DTM	0.329*	-0.374**	-0.003	-0.056	-0.272	0.358**	-0.149	-0.344**	0.866**	------

** = Correlation is significant at the 0.01 level and * at the 0.05 level. For Character codes see Table 2.

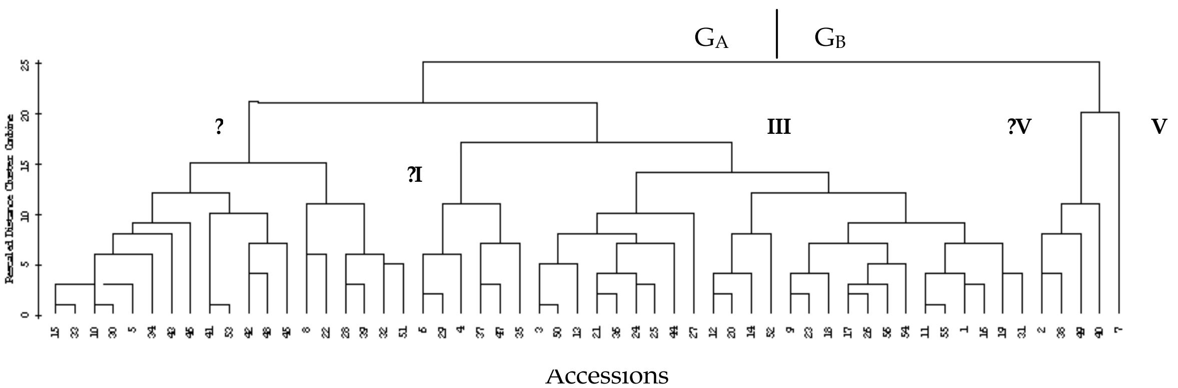

Fig. 1. A dendrogram from quantitative morphological characters using average linkage between groups for 56 accessions.

All the accessions from altitude classes 6 (2701–2950m) and 7 (≥2951m) moved together into one group, GA, up to the final stage of clustering. Moreover, 71.4% of the accessions from altitude class 7 (≥2951m) were grouped under one cluster, cluster III. Similarly 66.57% of the accessions from the other extreme altitude class, class 1 (≤ 1700m) were grouped into one cluster, cluster I. But the range for the highest percentage of accessions number contributed to one cluster by each of the rest altitude classes was from 44.44% to 62.5 %. This shows that accessions from the two extreme altitude classes may have great genetic differences. Franco *et al.* (1997) reported that cluster analysis groups genetically similar populations in to one core subset.

Principal component (PC) analysis

As indicated in Table 8, the first three PCs accounted for 73.86% of the total variation. Chatfield (1995) explained that factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of variables and can also aid in the selection of better genotypes.

In Table 9, under PC 1 the highest weight or load for the common factor is from SNP, which accounts for about 19.32% of the variation accounted for by PC 1. Under PC 2 the highest load is from DTM, which accounts for about 19.95% of the variation accounted for by PC 2. The first three largest factors under PC 1 were the productivity factor. The first two largest factors under PC 2 were the phonological factors. These phonological factors, DTM and DTF, are the first two agronomic characters used as the main criteria for evaluation to release and register a variety (Abbas, 2001).

Linseed diversity

The morphological variation in Ethiopian linseed landraces was estimated (Table 10) by the Shannon-Weaver Diversity Index for both regional and altitudinal groups based on qualitative characters. Brown, light brown, beige and yellow; large, medium and small; blue, light blue, purple blue and white; and violent and light green classes of traits were recorded for seed colour, boll size, flower colour and seedling stem colour, respectively.

Table 8. Eigenvalues for the first three PCs and the distribution of the cumulative variance accounted for by these PCs on different characters among the three PCs.

	Initial Eigenvalues			Extraction Sum of Squared Loadings			Rotation Sums of Squared Loadings		
PC	Total	% of Varia.	Cum %	Total	% of Varia.	Cum %	Total	% of Varia.	Cum %
1	3.49	34.94	34.49	3.49	34.94	34.49	3.00	30.04	30.04
2	2.24	22.39	57.33	2.24	22.39	57.33	2.73	27.29	57.33
3	1.65	16.54	73.86	1.65	16.54	73.86	1.77	17.73	73.86

Table 9. The first two PCs extracted from the principal component matrix after Varimax rotation for 10 quantitative characters of 56 linseed accessions.

Variable	SNP	BNP	SWP	SBP	PBP	DTM	DTF	SNB	PH	TSW
PC 1	0.942	0.898	0.787	0.599	0.533	-0.183	-0.153	0.020	0.012	-0.750
PC 2	-0.121	-0.285	-0.145	0.198	-0.208	0.858	0.854	0.717	0.673	-0.242

*PH=plant height, TSW=1000-seed weight, PBP= primary branches per plant, SBP= secondary bra nches per plant, BNP= boll number per plant, SNB = seed number per boll, SNP= seed number per plant, SWP = seed weight per plant, DTF = days to flowering and DTM = days to maturity.

Table 10. Shannon's mean diversity index values by region, altitude class and entire accession.

A. By region						
Region	No. of Acce.	Seed colour	Boll size	Flower colour	Seedling stem colour	Mean
Shewa	7	0.24±0.08	0.47±0.13	0.28±0.68	0.14±0.10	0.28±0.07
Gondar	6	0.16±0.09	0.24±0.17	0.16±0.40	0.12±0.12	0.17±0.03
Arsi	6	0.27±0.07	0.40±0.09	0.37±0.83	0.13±0.08	0.29±0.06
Bale	6	0.36±0.11	0.35±0.13	0.13±0.49	0.05±0.05	0.22±0.08
Gojam	5	0.12±0.07	0.04±0.04	0.17±0.55	0.09±0.09	0.11±0.03
Wello	7	0.28±0.09	0.27±0.10	0.30±0.63	0.21±0.14	0.27±0.02
Hararghe	6	0.24±0.08	0.24±0.08	0.26±0.80	0.16±0.10	0.22±0.02
Gamogofa	5	0.17±0.10	0.51±0.06	0.29±0.56	0.00±0.00	0.24±0.12
Wellega	4	0.22±0.08	0.24±0.13	0.09±0.50	0.00±0.00	0.14±0.06
Tigray	4	0.46±0.09	0.46±0.15	0.06±0.49	0.00±0.00	0.24±0.13
B. By altitude class						
Altitude class	No. of Acce.	Seed Colour	Boll Size	Flower colour	Seedling stem colour	Mean
= 1700	6	0.23±0.07	0.14±0.08	0.43±0.04	0.22±0.11	0.26±0.06
1701–1950	7	0.19±0.08	0.20±0.10	0.09±0.07	0.04±0.04	0.20±0.08
1951–2200	9	0.19±0.06	0.43±0.08	0.34±0.12	0.00±0.00	0.24±0.09
2251–2450	8	0.29±0.07	0.18±0.07	0.31±0.10	0.15±0.10	0.23±0.04
2451–2700	10	0.24±0.06	0.31±0.09	0.14±0.06	0.09±0.06	0.20±0.05
2701–2950	9	0.20±0.07	0.53±0.12	0.22±0.08	0.16±0.10	0.28±0.09
= 2951	7	0.31±0.08	0.24±0.11	0.06±0.07	0.04±0.04	0.16±0.07
Overall	**56**	**0.24±0.03**	**0.30±0.04**	**0.22±0.03**	**0.10±0.03**	**0.22±0.06**

Boll size shows the highest (0.32±0.03) mean diversity index value whereas seedling stem colour shows the lowest (0.10±0.03) mean diversity index value. The first three regions with the highest mean diversity indices pooled over traits are Arsi (0.29±0.06), Shewa (0.28±0.07) and Wello (0.27±0.02). On the other hand Gojam (0.11±0.03), Wellega (0.12±0.06) and Gondar (0.17±0.03) were with the lowest pooled mean diversity indices. Accessions collected from Gamogofa, Wellega and Tigray were monomorphic (0.00±0.00) for seedling stem colour. Altitude class 6 (2701–2950m) was with the highest (0.28±0.09) mean diversity index pooled over traits, whereas altitude class 7 (=

2951m) was with the least (0.16±0.07) mean diversity index pooled over traits. Accessions collected from altitude classes 2 (1701–1950m) and 7 (= 2951m) were almost monomorphic for flower colour. Analysis of variance for the mean diversity indices showed that there is no significant difference between the regional groups of linseed accessions for all the characters. As it can be seen from Table 11, the only character that shows significant variation between altitudinal groups at 5% level of significance was flower colour. The Chi-square tests (Table 12) showed that the variation is random within each region and altitude class than between regions and between altitude classes.

When multiple comparisons for the variables are made between regional groups of linseed accessions using LSD (least significant difference), accessions from Tigray showed significant differences with accession collected from Gondar, Gojam and Gamogofa for seed colour. Accessions from Gojam showed significant difference with accessions collected from Shewa, Arsi, Gamogofa and Tigray for boll size at the 0.05 level of significance.

When multiple comparisons for the variables are made between altitude groups of linseed accessions using LSD altitude class 6 (2701–2950) showed significant differences with altitude classes 1 (=1700), 2 (1701–1950), 4 (2201–2450) and 7 (=2951) for boll size. Altitude class 1 (=1700) with altitude classes 2 (1701–1950), 5 (2451–2700) and 7 (=2951); altitude class 2 (1701–1950) with altitude classes 1(=1700) and 3 (1951–2200); altitude class 5 (2451–2700) with altitude class 1(=1700); altitude class 7 (=2951) with altitude classes 1(=1700), 3 (1951–2200) and 4 (2201–2450) showed significant differences for flower colour at the 0.05 level of significance. This confirms that most altitude groups of linseed accessions are significantly variable for flower colour.

However, the mean diversity indices for the accessions from the South and Southwest are relatively higher than the mean diversity indices for those from the northern part of Ethiopia. Similar trends for finger millet (*Eleusine coracana* L. Gaertn. subsp. coracana [Poeceae]) (Yemane Tsehaye and Fassil Kebebew, 2002) and for "Teff" (*Eragrostis tef* (Zucc. (Trotter)) (Endeshaw Bekele, 1996) were reported. According to Endeshaw Bekele (1996) the migration effect of the people from the central and northern part of Ethiopia into the South carrying their seed stocks with them, and the presence of diversified and wetter habitats in the South could be the possible reasons for the occurrence of high mean diversity indices from the South. Indeed, the longer a species has been in an area, the greater the time it had to accumulate genetic variability.

Table 11. Mean squares for qualitative morphological traits of linseed within and between regions and altitude groups.

Characters	ANOVA by regions		ANOVA by altitude classes	
	Source of variation		Source of variation	
	Between groups	Within a group	Between groups	Within a group
Seed colour	0.027	0.043	0.017	0.043
Boll size	0.084	0.084	0.165	0.074
Flower colour	0.046	0.068	0.132*	0.056
Seedling stem colour	0.029	0.052	0.064	0.052
Degree of freedom (df)	9	46	6	49

Table 12. The Chi-Square test for qualitative morphological traits among linseed accessions.

	Seed colour	Boll size	Flower colour	Seedling stem colour
Chi-Square	75.750**	131.607**	162.571**	164.286**
df	16	16	14	5

CONCLUSION

The Investigation on quantitative characters variability and association for 56 linseed accessions collected from different administrative regions (former) and altitude classes in Ethiopia indicated the presence of high diversity in Bale and Gondar regions and low diversity in Gojam region. Accessions from Gojam were also with the least pooled mean diversity index for qualitative characters. In general linseeds from Gojam, Wellega and Tigray relatively have low diversity. Both cluster and Shannon-Weaver Diversity Index analyses showed that accessions collected altitude class 7 (=2951m) are with the least variation. Based on factor analysis, which effectively selected out important traits from the whole characters, the first two agronomic characters used as the main criteria for evaluation to release and register a variety are found to be the factors under PC 2 as phonological factors. Germplasm collection programmes for *ex situ* conservation and selecting sites for *in situ* conservation for linseed priority attention needs to be given to the Bale and Gondar regions. In addition to the regions with high mean diversity indices, the North and North-western parts of Ethiopia need prior attention for germplasm collection programme.

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