CORRELATION AND PATH COEFFICIENT ANALYSIS AMONG SEED YIELD TRAITS AND OIL CONTENT IN ETHIOPIAN LINSEED GERMPLASM

TADELE TADESSE[1], HARJIT SINGH[1] and BULCHA WEYESSA[2]

[1]Sinana Agricultural Research Center, P.O. Box 208 Bale-Robe Ethiopia; Tel: +2510911967286; E-mail: tadeleta20@yahoo.com. [2]Holeta Agriculture Research Center, P.O. Box 32

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ABSTRACT

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Keeping in view the lack of information on genetic diversity in the Ethiopian linseed germplasm and need to study associations among seed yield, yield related traits and oil content in this crop, the present investigation was undertaken on 81 geographically diverse Ethiopian accessions of linseed. Theses accessions were evaluated at the Agricultural Research Center, Sinana, and on farmers' field at Robe during 2001/2002 cropping season. Seed yield per plot was significantly associated with seed weight, seed yield per plant, harvest index and biomass at both locations. However, at Sinana, plant height and oil content were also significantly associated with seed yield per plot. Path coefficient analysis for seed yield per plant at Sinana indicated that number of capsules per plant and biomass are good indicators of seed yield per plant. At Sinana, plant height, harvest index, number of primary branches and tillers per plant had high positive direct effect at genotypic level but to use these traits for indirect selection, negative association of harvest index with plant height, number of primary branches and tillers per plant has to be taken care of through simultaneous selection with appropriate weightage to the pair of traits. Path analysis indicated that harvest index and biomass were the main determinats of yield per plot at both Sinana and Robe. Analysis over locations also supported that harvest index and biomass are the main determinant of yield per plot. Seed weight was found to be an important trait in indirect selection for oil content.

Keywords: Correlation, Path coefficient, direct effect, indirect effect, Linseed

INTRODUCTION

Linseed, *Linum usitatissimum* L. (n=15), also called flax, is an important oilseed crop which belongs to the family linaceae having 14 genera and over 200 species. Linseed is the only widely grown and economically important species. It is believed that this crop species may have originated from *Linum angustifolium* Huds (n=15), native to the Mediterranean region. The genus Linum has both cultivated and wild species. The wild species have little economic value. Almost all the species are annual herbs and some are shrubs *Linum usitatissimum* L. is the only species with non-dehiscent or semi-dehiscent capsules suitable for modern cultivation of the family linaceae (Getinet and Nigussie, 1997). *Linum usitatissimum* L. is one of the oldest plant species cultivated for oil and fiber (Lay and Dybing, 1989). The crop is predominantly self pollinated, but out crossing (less than 2%) occasionally results from insect activity (Dillman, 1928).

Ethiopia is considered to be the center of diversity for linseed (Vavilov, 1926). The principal linseed growing regions in Ethiopia are located at altitudes between 1800 and 2800m, although it occasionally grows at altitudes as low as 1680m or as high as 3430m (CSO, 1984). Arsi, Bale, Chercher Mountains, Eastern Welega, Eastern Gojam, Tigray, Eriterea and southeast Welo, and Shewa are the major areas of production where frost is a problem for other oilseed crops such as noug (*Guizotia abyssiniccacass*) and Ethiopian mustard (*Brassica carinata A.Braun*). Linseed is a major oilseed and rotation crop for barley in higher elevations of Arsi, Bale, Gojam, Gonder, Wello, Shewa and Welega parts of Ethiopia. High yields of wheat, barley and tef can be obtained following linseed (Getinet and Nigussie, 1997).

Linseed has been a traditional oilseed in Ethiopia for many centuries. In terms of area and production, it occupies the second position among the oilseed crops next to noug. The area under this crop is about 73, 000 ha with an average yield of 400-500 kg/ha (CSO, 1984). The crop is traditionally grown on marginal and sub-marginal lands with minimum frequency of plowing and no weeding (Adefris *et al.*, 1992). Inspite of low productivity, Ethiopian land races of linseed possess economically important traits such as more number of capsules/plant, high seed weight, resistance to most of the diseases, high number of tillers/plant.

Selection is an integral part of a breeding program by which genotypes with high productivity in a given environment could be developed. However, selection for high yield is made difficult because of its complex nature. Yield per unit area is the end product of components of several characters, which are polygenic in inheritance and thus are highly influenced by environment. Therefore, only little progress could be made over a long span of time through direct selection for yield. Indirect selection through yield components has been proved more effective (Ford, 1964). This selection criterion takes into account the information on interrelationship among agronomic characters, their relationship with grain yield as well as their direct influence on grain yield. Nevertheless, selection for yield *via* highly correlated characters becomes easy if the contribution of different characters to yield is quantified using path coefficient analysis (Dewey and Lu, 1959).

Knowledge of the extent and pattern of variability, particularly of genetic variability present in a population of a given crop is absolutely essential for further improvement of the crop. Similarly, information on the extent and nature of interrelationship among characters help in formulating efficient scheme of multiple trait selection.

Besides this, knowledge of the naturally occurring diversity in a population helps to identify diverse groups of genotypes that can be used for hybridization program. In Ethiopia, the information on these aspects in linseed is very scarce. Therefore, there is a need to generate information on interrelationships of yield and yield related traits among linseed genotypes. Keeping this in view, the present study was intended to study associations among yield, yield related traits and oil content in linseed.

MATERIALS AND METHODS

The experiment was carried out at two locations. One of the experimental sites was at research farm of Sinana Agricultural Research Center, Oromia Agriculture Research Institute, and the other at a site in the farmer's field near Robe town, in the highlands of bale, Ethiopia. The experiment was conducted at each location on vertisol clay loam soil under rain fed conditions during the meher season (August-January) of 2001/2002 cropping season. Sinana Research Center (7^o N latitude and 40^oE longitude; and 2400m a.s.l.) is located 463 km south east of Addis Ababa and East of Robe, the capital of Bale zone. The other location is located 45-km from Sinana and about 5 km from Robe in the Southwest direction.

Eighty-one geographically diverse populations of linseed collected from different part of the country were used for this study (Annexure 1, Table 1). In this investigation, 9 x 9 simple lattice design with two replications was used. Each experimental plot consisted of two 4m long rows with inter-row spacing of 20-cm. Seeding rate was applied at the rate of 25 kg/ha and fertilizers were applied at the rate of 23/23 kg/ha $N/P_2O_{5.}$ Weeds were controlled by hand. Data are collected on both plot and plant basis.

Phenotypic (r_p) and Genotypic (r_g) correlation coefficient

Correlation coefficient (r): Phenotypic correlation, the observable correlation between two variables, which includes both genotypic and environmental effects, and genotypic correlation, the inherent association between two variables were estimated using the standard procedure suggested by Miller *et al*. (1958). Covariance analysis between all pairs of the variables followed the same form as the variance. Thus, estimates of genetic covariance component between two traits (σ $g_{xy)}$ and the phenotypic covariance component ((σ $p_{xy)}$) were derived in the same fashion as for the corresponding variance components.

$$r_{gxy} = \frac{\sigma g_{xy}}{\left[\sqrt{\sigma g_x \mathrm{X} \sigma^2 g_y}\right]}$$

$$r_{pxy} = \frac{\sigma p_{xy}}{\left[\sqrt{\sigma^2 p_x \mathrm{X} \sigma^2 p_y}\right]}$$

Where, σg_{xy} = genotypic covariance of two variables x and y

σp_{xy} = phenotypic covariance of two variable x and y

Path coefficient analysis

Path coefficient analysis was carried out using the phenotypic correlation coefficients as well as genotypic correlation coefficients to determine the direct and indirect effects of the yield components and other morphological characters on seed yield. Path coefficient analysis was also conducted to determine the direct and indirect effect of various traits on oil content using the general formula of Dewey and Lu (1959).

Path coefficient: $r_{ij} = p_{ij} + \sum r_{ik} p_{kj}$

Where,

r_{ij} = mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficients.

p_{ij} = components of direct effects of the independent character (i) on the dependent variable (j) as measured by the path coefficients and

$\sum r_{ik}p_{kj}$ = summation of components of indirect effects of a given independent character (i) on a given dependent character (j) *via* all other independent characters (k).

The residual effects were estimated using the formula:

$\sqrt{1}$ -R^2 where R^2= $\sum pijrij$

RESULT AND DISCUSSION

4.1. Correlation Studies

Considering the possibility of high yield through yield attributes, as primary interest in crop improvement, therefore, requires understanding the amount of the magnitude of correlations among various yield traits.

Estimates of correlation coefficient at phenotypic and genotypic level for individual locations are given in Table 2 and 3.

Correlation Coefficients of seed yield per plot with other traits at Sinana

At Sinana (Table 2), seed yield per plot showed positive and highly significant association with plant height (0.401), thousand seed weight (0.326), seed yield per plant (0.380), harvest index (0.480), biomass (0.490) and oil content (0.407) at phenotypic level. Similar results were reported by Mirza *et al.* (1996) where positive and significant association of harvest index and capsules per plant with seed yield was observed. Mishra and Yadva (1999) found positive and significant association of number of seeds per capsules with seed yield. Though non-significant, the association of number of secondary branches, number of capsules per plant and number of seeds per capsules with seed yield per plot was positive. This indicates theses characters could be useful for improvement of yield through selection. Badwal *et al*. (1970), Patil *et al*. (1980), and Khan and Gupta (1995) reported positive but non-significant association of number of seeds per capsules with seed yield per plot. Seed yield per plot also showed negative and non-significant association with days to flowering, days to maturity, tillers per plant and number of primary branches. The trend was same for the associations of seed yield per plot with other traits through the values of genotypic correlation coefficients were higher than corresponding phenotypic correlation.

Table 2. Estimates of Correlation coefficients at phenotypic (above diagonal) and Genotypic (below diagonal) levels of 14 characters in linseed Germplasm accessions at Sinana

Variable	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	SY/plot	BM	POC
DF		0.565**	0.143	0.165	0.039	-0.325**	0.012	0.158	-0.292**	-0.117	-0.227*	-0.148	0.032	-0.057
DM	0.910		0.124	0.105	0.240*	-0.075	0.160	0.169	-0.227*	-0.096	-0.151	-0.111	0.043	0.065
PH	0.136	0.229		-0.128	0.034	-0.124	0.187	-0.044	0.219*	0.298**	0.084	0.401**	0.321**	0.262*
TPP	0.305	0.273	0.034		0.482**	-0.021	0.399**	0.431**	-0.325**	0.140	-0.027	-0.125	-0.137	0.070
NPB	0.158	0.416	0.143	0.433		0.048	0.662**	0.148	-0.155	0.060	-0.124	-0.149	-0.089	-0.095
NSB	-0.402	-0.128	-0.248	0.050	0.061		0.096	-0.029	0.045	0.071	0.129	0.018	-0.040	0.005
NCPP	0.088	0.239	0.405	0.451	0.737	0.067		0.081	0.068	0.377**	-0.027	0.036	0.022	0.117
NSPC	0.224	0.234	-0.196	0.323	0.209	-0.060	0.197		-0.153	0.107	0.033	0.123	0.056	0.001
TSW	-0.547	-0.402	0.421	-0.128	-0.184	0.011	0.081	-0.301		0.248*	0.319**	0.326**	0.035	0.410**
SY/pl	-0.155	-0.132	0.512	0.152	0.033	0.086	0.439	0.096	0.435		0.162	0.380**	0.194	0.203
HI	-0.201	-0.393	0.522	0.024	-0.221	0.158	-0.129	0.039	0.579	0.177		0.482**	-0.117	0.379**
SY/plot	-0.052	-0.244	0.874	-0.039	-0.285	0.034	-0.058	0.105	0.545	0.422	0.529		0.490**	0.407**
BM	0.123	-0.0002	0.618	-0.025	-0.308	-0.107	-0.138	-0.038	0.171	0.344	0.037	0.610		0.269*
POC	-0.137	0.307	0.851	-0.087	-0.207	-0.060	0.10	0.028	0.967	0.293	0.653	0.731	0.663	

Where: DF= Days to flowering; DM= Days to maturing; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; TSW= Thousand seed weight (g); SY/pl= Seeds yield per plant; HI = Harvest index per plot (%); SY/plot= Seed yield per plot (g/plot); BM = Biomass per plot; POC= Percent oil content.

**, ** Indicates significant at 5 % and 1 % probability levels respectively.*

At Robe, the other location (Table 3), seed yield per plot showed positive and highly significant association with harvest index (0.727) and biomass (0.463) at phenotypic level. Positive and significant association of seed yield per plot with thousand seed weight and seed yield per plant was also observed. The correlation coefficients of these traits with seed yield per plot at genotypic level also high. Mahto and Mahto (1997) reported harvest index and number of capsules per plant showed positive and significant association with seed yield, which was in partial agreement with the present study. On the other hand, tillers per plant showed negative and highly significant association with seed yield per plot. Significant and negative phenotypic correlations of seed yield per plot with days to flowering and days to maturity were also observed. This correlation suggested that the relatively early flowering and early maturing germplasm could give higher yields as compared to late flowering and late maturing. Similarly, Badwal *et al*. (1970), Patil *et al.* (1980), and Khan and Gupta (1995) reported that the associations of seed yield per plot with days to flowering and maturity was negative and significant. In the same manner, Vijaya-kumar and Rao (1975), Gupta and Godwat (1981), Rai (1984), Chaudhary *et al*. (1984) also reported negative correlation of seed yield with days to flowering and tillers per plant which was in partial agreement with the present study.

Though non-significant, the associations of number of secondary branches per plant, number of capsules per plant, number of seed per capsules and percent oil content with seed yield per plot was positive. This indicated that these characters could also be used for indirect selection in a breeding program. Negative and non-significant associations of plant height and number of primary branches with seed yield per plot were also observed.

Table3. Estimates of Correlation coefficients at Phenotypic (above diagonal) and Genotypic (below diagonal) levels of 14 characters in linseed Germplasm accessions at Robe

Variable	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	SY/plot	BM	POC
DF		0.616**	0.207	0.433**	0.410**	-0.210	0.002	-0.108	-0.444*	-0.203	-0.433**	-0.260*	0.174	0.160
DM	0.772		0.291**	0.305**	0.255*	-0.048	-0.037	-0.181	-0.222	-0.259*	-0.518**	-0.303**	0.109	-0.189
PH	0.283	0.553		-0.043	0.036	-0.063	-0.040	0.007	0.100	0.007	-0.259*	-0.022	0.307**	-0.035
TPP	0.579	0.418	-0.058		0.640**	0.149	0.447**	-0.103	-0.482**	0.230*	-0.433**	-0.335*	0.103	0.039
NPB	0.557	0.292	0.048	0.564		0.114	0.578	-0.051	-0.254	0.257*	-0.179	-0.033	0.254*	-0.016
NSB	-0.256	-0.080	-0.133	0.112	0.097		0.235	-0.004	0.136	0.307**	0.196	0.164	-0.005	0.059
NCPP	0.012	-0.120	-0.072	0.495	0.585	0.316		-0.102	-0.018	0.586**	0.073	0.143	0.137	0.145
NSPC	-0.136	-0.303	0.037	-0.060	-0.015	-0.010	-0.098		0.038	0.181	0.081	0.021	-0.058	-0.064
TSW	-0.615	-0.343	0.180	-0.282	-0.386	0.200	0.043	0.128		0.217	0.235*	0.260*	0.088	0.400**
SY/pl	-0.253	-0.331	0.014	0.211	0.255	0.326	0.719	0.201	0.307		0.223*	0.278*	0.173	0.263*
HI	-0.550	-0.713	-0.153	-0.296	-0.228	0.188	0.182	0.218	0.293	0.263		0.727**	-0.199	0.122
SY/plot	-0.365	-0.502	-0.160	-0.192	-0.064	0.193	0.184	0.050	0.317	0.298	0.950		0.463**	0.153
BM	0.299	0.207	0.443	0.089	0.478	0.074	0.235	-0.337	0.132	0.328	0.132	0.403		0.105
POC	-0.384	-0.460	0.090	0.173	-0.035	0.194	0.620	-0.165	0.830	0.553	0.042	0.212	0.426	

Where: DF= Days to flowering; DM= Days to maturity; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; TSW= Thousand seed weight (g); SY/pl= Seeds yield per plant; HI = Harvest index per plot (%); SY/plot= Seed yield per plot (g/plot); BM = Biomass per plot; POC= Percent oil content

**, ** indicates significant at 5 % and 1 % probability level respectively*

Association of percent oil content with other traits at Sinana

Estimates of phenotypic correlation coefficients at Sinana (Table 2), showed positive and highly significant association of percent oil content with thousand seed weight (0.410), harvest index (0.379) and seed yield per plot. In addition, the association of percent oil content with plant height (0.262) and biomass (0.269) was positive and significant.

Though non-significant, the association of percent oil content with number of capsules per plant, and seed yield per plant was positive. Early studies indicated a positive association of oil content with seed weight (Chu and Culbertson, 1952; Geddes and Lehberg, 1936; Johnson, 1932; McGregor, 1937). Comstock (1960) obtained positive correlation between the seed weight and percent oil content of the individual F_2 and F_3 plants from two crosses. This suggests that one can select simultaneously for seed yield as well as high oil content by selecting for seed weight.

In contrary to this, the association of percent oil content with days to flowering and number of primary branches was negative. At genotypic level, the association of oil content with days to maturity, plant height, thousand seeds weight, seed yield per plant, harvest index, seed yield per plot and biomass was positive and of considerable magnitude. Percent oil content also showed low but negative association with days to flowering and number of primary branches.

As observed at Sinana, also the correlation of percent oil content with thousand seed weight at Robe was positive and highly significant at phenotypic level (Table 3). This implies that germplasm lines with heavy seed weight are associated with high amount of oil content. Therefore, this trait can be used as selection criteria for the improvement of percent oil content in linseed. Meanwhile, the correlation of percent oil content with seed yield per plant was positive and significant. This suggests possibility of simultaneously improvement of seed yield as well as oil content. This is further indicated by the fact that though low but positive association of number of capsules per plant, harvest index, seed yield per plot and biomass with percent oil content was observed. Also, percent oil content showed low but negative correlation with days to maturity.

Path analysis

The phenotypic and genotypic correlations were further analyzed by path coefficient analysis, which involves partitioning of the correlation coefficients into direct and indirect effects through alternate characters or pathways. Such analysis leads to identification of important component traits useful in indirect selection complex traits like yield and oil content.

Estimates of direct and indirect effects of various characters on seed yield per plot at Sinana

The path analysis revealed that (Table 4) at phenotypic level, maximum positive direct effect was exerted on seed yield per plot by biomass (0.446) and harvest index (0.446), followed by plant height (0.171), number of seeds per capsules (0.117) and seed yield per plant (0.142). Among these, biomass, harvest index, plant height and seed yield per plant had highly significant phenotypic correlation with seed yield per plot as well. However, the phenotypic association of number of seeds per capsules with seed yield per plot was non-significant though positive. Thousand seed weight and oil content had significant positive correlation with yield per plot but their direct positive effect was low (less than 0.100). However, seed weight exerted some positive indirect effect *via* harvest index while oil content exerted some positive indirect effect *via* harvest index and biomass. The analysis suggested that harvest index and biomass are the major contributors to seed yield per plot. The other traits which may have same importance are plant height and seed yield per plant as they have significant association with seed yield/plot and positive though low direct effect on the latter. Moreover, plant height has some positive indirect effect *via* biomass. Harvest index and seed yield per plant were found to be useful for indirect selection for yield per unit area by Rai (1984). However, Mirza *et al* (1996) and Mahto and Mahto (1997), in addition to harvest index, found days to flowering, branches per plant and capsules per plant as other important traits to determine yield. Since the three traits, other than harvest index have not been found having significant effect on yield, their studies in partial agreement with the present study. Since seed weight had significant positive correlation with yield per plot and it had some positive indirect effect *via* harvest index as well as it did not have any considerable negative effect *via* any other trait, it suggest that this trait may also useful for indirect selection. Moderate positive effect of seed weight on yield was also reported by Badwal *et al*. (1970). However, Rai (1984) reported its high positive effect on yield. Significant positive association of oil content with yield as well as its positive indirect effect *via* harvest index and biomass showed that improvement in oil content may also improve yield.

Table 4. Estimates of direct (bold- diagonal values) and indirect effects (off-diagonal values) at phenotypic levels of 13 traits on seed yield per plot in linseed at Sinana

Variable	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	BM	POC	r_p
DF	**-0.045**	-0.020	0.024	-0.005	-0.001	0.008	-0.0002	0.0186	-0.0233	-0.0167	-0.1012	0.0141	-0.0007	-0.148
DM	-0.025	**-0.035**	0.021	-0.003	-0.009	0.002	-0.0027	0.0199	-0.0181	-0.0137	-0.0674	0.0193	0.0008	-0.111
PH	-0.006	-0.004	**0.171**	0.004	-0.001	0.003	-0.0032	-0.0052	0.0174	0.0423	0.0377	0.1432	0.0032	0.401**
TPP	-0.007	-0.004	-0.022	**-0.033**	-0.015	-0.001	-0.0077	0.0379	-0.0102	0.0216	0.0109	-0.0113	0.0009	-0.039
NPB	-0.002	-0.008	0.006	-0.013	**-0.036**	-0.001	-0.0114	0.0174	-0.0124	0.0085	-0.0555	-0.0397	-0.0012	-0.149
NSB	0.014	0.003	-0.021	-0.0016	-0.002	**-0.023**	-0.0017	-0.0034	0.0036	0.0100	0.0575	-0.0177	0.0001	0.018
NCPP	-0.001	-0.006	0.032	-0.014	-0.024	-0.002	**-0.017**	0.0095	0.0055	0.0535	-0.0119	0.0098	0.0014	0.036
NSPC	-0.007	-0.006	-0.008	-0.010	-0.005	0.001	-0.0014	**0.118**	-0.0122	0.0152	0.0147	0.0248	-0.0011	0.123
TSW	0.013	0.008	0.037	0.004	0.006	-0.001	-0.0012	-0.0180	**0.079**	0.0351	0.1423	0.0157	0.0051	0.326**
SY/pl	0.005	0.003	0.051	-0.004	-0.002	-0.002	-0.0065	0.0126	0.0197	**0.143**	0.0725	0.0866	0.0025	0.380**
HI	0.010	0.005	0.014	-0.0008	0.004	-0.003	0.0005	0.0039	0.0254	0.0231	**0.446**	-0.0523	0.0047	0.482**
BM	-0.001	-0.002	0.055	0.0008	0.003	0.001	-0.0004	0.0066	0.0028	0.0276	-0.0524	**0.446**	0.0033	0.490**
POC	0.003	-0.002	0.045	-0.0022	0.003	-0.0001	-0.0020	0.0001	0.0327	0.0288	0.1691	0.1199	**0.012**	0.407**

Where: DF= Days to flowering; DM= Days to maturity; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; TSW= Thousand seed weight (g); SY/pl= Seeds yield per plant; HI = Harvest index per plot (%); BM = Biomass per plot; POC= Percent oil content.

*, ** indicated the significance of phenotypic correlation coefficient at 5% and 1% probability level respectively Residual=0.102

Estimates of direct and indirect effects of various characters on seed yield per plot at Robe

At Robe (Table 5), the path coefficient analysis at phenotypic level revealed that harvest index (0.975) had the maximum positive direct effect followed by biomass (0.699) and tillers per plant (0.600). The positive correlation of harvest index and biomass with seed yield was also highly significant However, tillers per plants, inspite of having high positive direct effect (0.600) on seed yield per plot, had negligible association with yield because of its negative indirect effect *via* harvest index and biomass. In similar way, days to maturity showed positive direct effect on seed yield but its association with yield was negative. This was mainly due to the counter balancing by the negative indirect effect *via* days to flowering and harvest index. Days to flowering had negative direct effect as well as negative indirect effect *via* harvest index and thus its association with yield was significantly negative. However, days to flowering had positive indirect effect *via* tillers per plant. Secondary branches though had low negative direct effect on yield per plot, it had positive indirect effect *via* harvest index and its association with yield was positive but non-significant. Similarly, number of capsules per plant had low negative direct effect on yield and its correlation with yield was non-significant. Seed yield per plant had negligible negative direct effect on yield per plot but due its positive indirect effect *via* tillers per plant, harvest index and biomass it had significant positive association with yield per plot. The analysis showed that harvest index and biomass are the important determinants of yield per plot and selection for earliness would bring about improvement in yield. As stated earlier, earlier studies by Rai (1984), Mirza *et al*. (1996) and Mahto and Mahto (1997) have indicated the importance of harvest index in determining yield Rai (1984) had also suggested selection for earliness to obtain high yield. The residual effect of 0.368 suggested that about 63 % of variation in seed yield per plot was accounted for by the characters included in the present study.

Table 1. Estimates of direct (bold- diagonal values) and indirect effects (off-diagonal values) at phenotypic levels of 13 traits on seed yield per plot in linseed at Robe

Variables	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	BM	POC	r_p
DF	**-0.228**	0.068	0.012	0.266	-0.074	0.014	-0.0003	0.002	-0.018	0.008	-0.441	0.121	0.010	-0.260*
DM	-0.140	**0.110**	0.017	0.183	-0.046	0.003	0.0061	0.003	-0.009	0.010	-0.528	0.076	0.012	-0.303**
PH	-0.047	0.032	**0.059**	-0.026	-0.006	0.004	0.0067	-0.0009	0.004	-0.0008	-0.264	0.215	0.002	-0.022
TPP	-0.101	0.033	-0.003	**0.600**	-0.102	-0.008	-0.0824	0.001	-0.011	-0.008	-0.302	-0.207	-0.002	-0.192
NPB	-0.093	0.028	0.002	0.338	**-0.180**	-0.008	-0.0961	0.001	-0.010	-0.010	-0.182	0.177	0.001	-0.033
NSB	0.048	-0.005	-0.004	0.067	-0.021	**-0.068**	-0.0391	0.0011	0.005	-0.012	0.200	-0.004	-0.004	0.164
NCPP	-0.0322	-0.004	-0.002	0.297	-0.104	-0.016	**-0.166**	0.002	-0.001	-0.023	0.074	0.096	-0.009	0.143
NSPC	0.025	-0.020	-0.001	-0.036	0.009	0.001	0.0170	**-0.016**	0.002	-0.007	0.083	-0.040	0.004	0.021
TSW	0.101	-0.024	0.006	-0.169	0.046	-0.009	0.0029	-0.001	**0.040**	-0.008	0.239	0.062	-0.025	0.260*
SY/pl	0.046	-0.028	-0.0001	0.127	-0.046	-0.021	-0.0975	-0.003	0.009	**-0.039**	0.227	0.121	-0.017	0.278*
HI	0.099	-0.057	-0.015	-0.178	0.032	-0.013	-0.0121	-0.001	0.009	-0.009	**0.975**	-0.139	-0.008	0.727**
BM	-0.040	0.012	0.018	0.053	-0.046	0.002	-0.0227	0.001	0.004	-0.007	-0.203	**0.699**	-0.007	0.463**
POC	0.036	-0.021	-0.002	0.023	0.003	-0.004	-0.0241	0.001	0.016	-0.010	0.124	0.073	**-0.063**	0.153

Where: DF= Days to flowering; DM= Days to maturity; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; SY/pl= Seeds yield per plant; TSW= Thousand seed weight (g); HI = Harvest index per plot (%); BM = Biomass per plot; POC= Percent oil content *,** indicated the significant of phenotypic correlation coefficient at 5% and 1% probability level respectively, Residual= 0.25

Estimates of direct and indirect effects of various characters on percent oil content at Sinana

At phenotypic level (Table 6), maximum positive direct effect on percent oil content was exerted by thousand seeds weight (0.300) followed by seed yield per plot (0.262), days to maturity (0.210), tillers per plant (0.166) harvest index (0.118) and number of capsules per plant (0.117). Thousand seed weight, seed yield per plot and harvest index also had significant and positive correlation with percent oil content. Though days to maturity had positive direct effect on percent oil content, its phenotypic association with the latter was negligible. The direct effect of number of capsules per plant was exactly equal in magnitude to the phenotypic correlation between number of capsules per plant and percent oil content. Even though the magnitude was poor, negative direct effect was exerted on percent oil content by number of primary branches. This study suggested that seed weight, seed yield per plot, harvest index and number of capsules per plant are important in determining oil content. The analysis also indicated the probability of simultaneous improvement in seed yield and oil content.

Table 6. Estimates of direct (bold- diagonal values) and indirect effects (off-diagonal values) at phenotypic levels of 13 traits on percent oil content in linseed at Sinana

Variables	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	SY/plot	BM	r_p
DF	**-0.065**	0.118	0.006	0.027	-0.007	0.010	0.001	-0.008	-0.088	0.008	-0.027	-0.039	0.004	-0.057
DM	-0.037	**0.210**	0.005	0.017	-0.041	0.002	0.019	-0.009	-0.068	0.007	-0.018	-0.029	0.006	0.065
PH	-0.009	0.026	**0.043**	-0.021	-0.006	0.004	0.022	0.002	0.066	-0.021	0.010	0.105	0.042	0.262*
TPP	-0.011	0.022	-0.006	**0.166**	-0.073	-0.002	0.053	-0.016	-0.038	-0.014	0.003	-0.010	0.166	0.070
NPB	-0.003	0.050	0.001	0.072	**-0.169**	-0.002	0.078	-0.008	-0.047	-0.004	-0.015	-0.039	-0.012	-0.095
NSB	0.021	-0.016	-0.005	0.008	-0.008	**-0.031**	0.011	0.001	0.014	-0.005	0.015	0.005	-0.005	0.005
NCPP	-0.001	0.034	0.008	0.075	-0.112	-0.003	**0.117**	-0.004	0.021	-0.027	-0.003	0.009	0.003	0.117
NSPC	-0.010	0.035	-0.002	0.054	-0.025	0.001	0.009	**-0.051**	-0.046	-0.008	0.004	0.032	0.007	0.001
TSW	0.019	-0.048	0.009	-0.021	0.026	-0.001	0.008	0.008	**0.300**	-0.018	0.038	0.085	0.005	0.410**
SY/pl	0.012	-0.020	0.013	0.025	-0.010	-0.002	0.044	-0.005	0.074	**-0.071**	0.019	0.099	0.025	0.203
HI	0.015	-0.032	0.004	0.004	0.021	-0.004	-0.003	-0.002	0.096	-0.027	**0.118**	0.126	0.004	0.379**
SY/plot	0.010	-0.023	0.017	-0.006	0.025	-0.001	0.004	-0.006	0.098	-0.014	0.057	**0.262**	-0.006	0.407**
BM	-0.002	0.009	0.014	-0.004	0.015	0.001	0.003	-0.003	0.011	-0.011	-0.021	0.128	**-0.004**	0.269*

Where: DF= Days to flowering; DM= Days to maturity; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; TSW= Thousand seed weight (g); SY/pl= Seeds yield per plant; HI = Harvest index per plot (%); SY/plot= Seed yield per plot (g/plot); BM = Biomass per plot; º,ºº indicated the genotypic correlation coefficient is of the magnitude where corresponding phenotypic correlation coefficient value is significant at 5% and 1% level of probability, respectively Residual=0.459

Estimates of direct and indirect effects of various characters on percent oil content at Robe

As at Sinana, at Robe (Table 7) the path analysis at phenotypic level revealed that thousand seed weight exerted maximum positive direct effect on percent oil content (0.411). This indicated that this trait could be useful for the improvement of percent oil content at both locations. The other traits that had positive direct effect on percent oil content were seed yield per plant (0.163), tillers per plant (0.152) and biomass (0.121). Thousand seed weight and seed yield per plant also had positive and significant correlations with percent oil content. The direct effect of thousand seed weight is almost equal in magnitude with the correlation of this trait with percent oil content. As seed weight was found to be an important trait for improvement in oil content at Sinana as well, this study suggested that selection for high seed weight could be quite useful trait for indirect selection. Days to maturity and seed yield per plot had low negative direct effect on oil content. However, due to positive indirect effect *via* seed weight (magnitude equivalent to its negative direct effect), the seed yield per plot had positive, though low, association with oil content. This suggested that the simultaneous improvement in seed yield and oil content is possible in the material under study. Residual effect of 0.31 indicated at 69% of variation on oil content has been accounted for by the 13 traits included as independent variables in this study.

The study at the two locations indicated that seed weight could be used as indicator of high oil content and there is probability for simultaneous improvement in seed yield as well as oil content at both locations.

Table7.Estimates of direct (bold- diagonal values) and indirect effects (off-diagonal values) at phenotypic levels of 13 traits on percent oil content in linseed at Robe

Variables	DF	DM	PH	TPP	NPB	NSB	NCPP	NSPC	TSW	SY/pl	HI	SY/plot	BM	r_p
DF	**0.072**	-0.086	-0.013	0.067	-0.018	0.011	0.0001	0.013	-0.182	-0.033	-0.040	0.028	0.021	-0.160
DM	0.044	**-0.139**	-0.018	0.046	-0.011	0.003	0.0001	0.021	-0.091	-0.042	-0.047	0.032	0.013	-0.189
PH	0.015	-0.041	**-0.062**	-0.007	-0.002	0.003	-0.003	-0.001	0.041	0.001	-0.024	0.002	0.037	-0.035
TPP	0.032	-0.042	0.003	**0.152**	-0.025	-0.006	-0.005	0.007	-0.116	0.034	-0.027	0.020	0.011	0.039
NPB	0.029	-0.036	-0.002	0.086	**-0.044**	-0.006	-0.005	0.006	-0.104	0.042	-0.016	0.003	0.031	-0.016
NSB	-0.015	0.007	0.004	0.017	-0.005	**-0.053**	-0.002	0.001	0.056	0.050	0.018	-0.018	-0.001	0.059
NCPP	-0.002	0.005	0.003	0.075	-0.025	-0.012	**-0.009**	0.012	-0.007	0.096	0.007	-0.015	0.017	0.145
NSPC	-0.008	0.025	-0.005	-0.009	0.002	-0.006	0.001	**-0.119**	0.016	0.030	0.007	-0.002	-0.007	-0.064
TSW	-0.032	0.031	-0.006	-0.043	0.011	-0.007	0.0001	-0.005	**0.411**	0.035	0.021	-0.028	0.011	0.400**
SY/pl	-0.015	0.036	0.0001	0.032	-0.011	-0.016	-0.005	-0.021	0.089	**0.163**	0.020	-0.030	0.021	0.263*
HI	-0.031	0.072	0.016	-0.045	0.008	-0.010	-0.001	-0.010	0.096	0.036	**0.091**	-0.077	-0.024	0.122
SY/plot	-0.019	0.042	0.001	-0.029	0.001	-0.009	-0.001	-0.002	0.107	0.045	0.066	**-0.107**	0.056	0.153
BM	0.012	-0.015	-0.019	0.014	-0.011	0.0001	-0.001	0.007	0.036	0.028	-0.018	-0.049	**0.121**	0.105

*Where: DF= Days to flowering; DM= Days to maturity; PH= Plant height (cm); TPP= Tillers per plant; NPB= No. of primary branches; NSB= No. of secondary branches; NCPP= No. of capsules per plant; NSPC= No. of seeds per capsule; TSW= Thousand seed weight (g); SY/pl= Seeds yield per plant; HI = Harvest index per plot (%); SY/plot= Seed yield per plot (g/plot); BM = Biomass per plot; *,** indicated the significance of phenotypic correlation coefficient at 5% and 1% probability level, respectively Residual = 0.31*

CONCLUSIONS

Linseed is an important oil seed crop of Ethiopia. However, there is lack of information on extent of genetic diversity in the Ethiopian germplasm and there is need to study associations among seed yield, yield related traits and oil content to design effective breeding strategies. Keeping this in view the present investigation was undertaken on 81 geographically diverse Ethiopian strains of linseed. These accessions were evaluated at the Agricultural Research Center, Sinana and on farmers' field at Robe during 2001/2002 cropping seasons. Data on 14 traits, namely, days to flowering, days to maturity, plant height, tillers per plant, number of primary branches, number of secondary branches, number of capsules per plant, seeds per capsules, thousand seed weight, seed yield per plant, harvest index, seed yield per plot, biomass and percent oil content were recorded at both the locations. Seed yield per plot was found to be significantly associated with seed weight, seed yield per plant, harvest index and biomass at both locations. However, plant height had highly significant correlation with seed yield per plot at Sinana, and at this location the association of percent oil content with seed yield per plot was also positive and significant. At Robe, plant height was not associated with seed yield per plot though oil content had low, though non significant, association with seed yield per plot. In combined analysis over locations, seed yield per plot was positively and significantly associated with seed weight and harvest index, whereas it had negative association with days to flowering, days to maturity and tillers per plant. Oil content had significant association with seed weight at both locations. In addition to this, it had significant positive association with harvest index, seed yield per plot, plant height and biomass at Sinana and statistically significant correlation with seed yield per plant at Robe. Path analysis for yield per plot showed that harvest index, biomass, seed yield per plant and oil content were the important determinants of seed yield at Sinana. At Robe also, harvest index and biomass were found to be the important traits determining yield per plot. Analysis over locations further supported the importance of harvest index and biomass as predictor of yield per plot. Path analysis for percent oil content at Sinana suggested that seed weight and harvest index were the main predictors of oil content. Path analysis for oil content at Robe also supported the observation that seed weight was important indicator of oil content. In conclusion, the present investigation indicated that there is wide range of genetic variability and diversity in Ethiopian linseed germplasm though the present investigation was conducted on only a part of it. There is large scope of simultaneous improvement in seed yield as well as oil content through selection. Hybridization among accessions from different clusters identified in this study could lead to considerable genetic improvement by following appropriate selection strategies in the segregating generations. However, it would be worthwhile to study more available germplasm over years and locations to identify more diverse accessions as well as to confirm the importance of the traits identified as predictors of yield and/or oil content.

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ANNEXURE 1

Table 2.The List of linseed accessions and their origin used in the study

No.	Accession No.	Collection place/area	No.	Accession No.	Collection place/area
1.	PGRC/E 10002	Shewa/J.meacha	42.	PGRC/E 13736	Wello/Ambasel
2.	PGRC/E 10005	Sidamo	43.	PGRC/E 10155	Gonder
3.	PGRC/E 10007	Kefa/Jima	44.	PGRC/E 10013	Harerge
4.	PGRC/E 10008	Gonder/D.tabor	45.	PGRC/E 10015	Illubabor
5.	PGRC/E 10010	Kefa	46.	PGRC/E 10012	Gojjam
6.	PGRC/E 10022	Wollo	47.	PGRC/E 13673	Gojjam/Mota
7.	PGRC/E 10026	Gojjam/ Koladamot	48.	PGRC/E 13658	Bako
8.	PGRC/E 10037	Sidamo/Jemjem	49.	PGRC/E 10014	Shewa
9.	PGRC/E 10039	Eritria/Seraye	50.	PGRC/E 10082	Harerge/Alemaya
10.	PGRC/E 10041	Bale/Ginner	51.	PGRC/E 10173	Gojjam/Bichena
11.	PGRC/E 10046	Wellega/Nekamt	52.	PGRC/E 10122	Sidamo/Arero
12.	PGRC/E 10061	Gamogofa	53.	PGRC/E 10092	Shewa/Yefitana timug
13	PGRC/E 10068	Gojjam/ Bahrdar	54.	PGRC/E 10044	Tigray/Shire
14.	PGRC/E 10080	Harar	55.	PGRC/E 10158	Sidamo/awassa
15.	PGRC/E 10085	Harar	56.	PGRC/E 10047	Illubabor/Bunobedelle
16.	PGRC/E 10104	Shewa/J.M	57.	PGRC/E 10133	Tigray/Agame
17.	PGRC/E 10109	Shewa/J.Meacha	58.	PGRC/E 10048	Tigray/Shire
18.	PGRC/E 10111	Shewa/ Merabete	59.	PGRC/E 10081	Harerge/Habro
19.	PGRC/E 10118	Shewa/J.Mmeacha	60.	PGRC/E 10172	Gamugofa/Garadula
20.	PGRC/E 10120	Sidamo	61.	PGRC/E 10139	Welega/Horegudru
21.	PGRC/E 10125	Tigray/Inderta	62	PGRC/E 10132	Tigray/Agame
22.	PGRC/E 10138	Wellega/Horogudru	63.	PGRC/E 13673	Gojjam/Mota
23.	PGRC/E 10144	Wellega	64.	PGRC/E 10073	Gojjam/Debremarkos
24.	PGRC/E 10159	Gonder/Wegera	65	PGRC/E 10161	Gonder/Denbi
25.	PGRC/E 10162	Gonder	66.	PGRC/E 10180	Shewa/Menagesha
26.	PGRC/E 10169	Gonder	67.	PGRC/E 10182	Shewa
27.	PGRC/E 10176	Gojjam/Metekel	68.	PGRC/E 10178	Shewa/K.Hadiya
28.	PGRC/E 10179	Shewa	69.	PGRC/E 10043	Gojjam/Koladdamot
29.	PGRC/E 10204	Wollo/Awsa	70.	PGRC/E 10191	Shewa/Jibatenameach
30.	PGRC/E 10006	Illubabor	71.	PGRC/E 10171	Gamugofa/Gamu
31.	PGRC/E 10042	Tigray/Axum	72.	PGRC/E 10088	Shewa/Teguletnabulga
32.	PGRC/E 10047	Illubabor/Buno	73.	PGRC/E 10051	Bale/Genale
33.	PGRC/E 10062	Bale/Meliyu	74.	PGRC/E 10177	Gojam/Debremarkos
34.	PGRC/E 10235	Gonder	75.	PGRC/E 10071	Gojam/Dejen
35.	PGRC/E 10064	Gamogofa/Hamrbako	76.	PGRC/E 10174	Gojam/Koladegadamo
36.	PGRC/E 10072	Gojam/Debremarkos	77.	PGRC/E 10164	Gonder/Wegera
37.	PGRC/E 10073	Gojam/Debremarkos	78.	PGRC/E 10121	Sidamo/Jemjem
38.	PGRC/E 10060	Gonder	79.	PGRC/E 10147	Wello/Yeju
39.	PGRC/E 13737	Wello/Ambasel	80.	PGRC/E 10207	Wello/Kallu
40.	PGRC/E 13731	Wello/Ambasel	81.	PGRC/E 10200	Wello/Kalu
41	PGRC/E 13738	Wello/Ambasel			