OPEN ACCESS Freely available online

Journal of Agricultural Science and Food Research

Research Article

Association and Path Analyses among Morpho-Agronomic Traits, Fatty Acids Contents and Oil Yield in Linseed (*Linumussitatisimum* L.) Genotypes in Ethiopia

Tadesse Ghiday*, Wassu Mohamed, Yemane Tsehaye, Adugna Wakjira, Chemeda Daba, Tesfaye Dissasa

Department of Agriculture, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

ABSTRACT

The improvement for a trait of interest can be achieved by both direct and indirect selection of characters that are more heritable and easy to select. The aim of this study was to determine the degree and nature of associations among morphoagronomic taits, fatty acid contents and oil yield. One hundred twenty six (120 accessions and six improved varieties) linseed (*Linum usitatissimum* L.) genotypes were evaluated for their morphoagronomic taits, fatty acid contents and oil yield using a Alpha lattice Design with two replications at farm fields of Holeta Agricultural Research Center (HARC) and Kulumsa Agricultural Research Center (KARC) during 2019/2020 cropping season in Ethiopia. At genotypic and phenotypic levels seed yield per plant had highly significant positive correlations with plant height, number of primary braches per plant, number of secondary braches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant and oil yield per plant, indicating that selection based on these parameters would considerably enhance seed yield per plant. Oil yield per plant had positive and highly significant phenotypic and genotypic correlation coefficients with plant height, number of primary branches, number of secondary branches, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant, linolenic fatty acid and seed yield per plant, indicating that selection based on these parameters would considerably enhance oil yield per plant. Biological yield per plant and seed yield per plant revealed positive and the highest direct effect on seed yield per plant and oil yield per plant, respectively. Selection to improve seed yield and oil yield per plant will be effective through biological yield per plant and seed yield per plant, respectively.

Keywords: Genotypic correlation; Morphoagronomic traits; Fatty acid content; Oil yield; Phenotypic correlation; Selection

INTRODUCTION

Linseed, *Linum usitatissimum* L. (n=15), also called flax, is an important oilseed crop which belongs to the family linaceae. Linseed is the only widely grown and economically important species in Ethiopia. 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. The crop is predominantly self-pollinated, but out crossing (less than 2%) occasionally results from insect activity [1].

Linseed is one of the important oilseed crops of Ethiopia. Arsi, Bale, Chercher Mountains, Eastern Welega, Eastern Gojam, Tigray, southeast Welo, and Shewa are the major areas of production where frost is a problem for other oilseed crops such as noug (*Guizotia abyssinicca* cass) and Ethiopian mustard (*Brassica carinata* A. Braun) in Ethiopia. Linseed is a major oilseed and rotation crop for barley in higher elevations of Ethiopia.

Correspondence to: Tadesse Ghiday, Department of Agriculture, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; E-mail: tghiday2012@gmail.com

Received: 14-Aug-2023, Manuscript No. JBFBP-23-26092; **Editor assigned:** 16-Aug-2023, PreQC No. JBFBP-23-26092 (PQ); **Reviewed:** 31-Aug-2023, QC No. JBFBP-23-26092; **Revised:** 13-Jan-2025, Manuscript No. JBFBP-23-26092 (R); **Published:** 20-Jan-2025, DOI: 10.35248/2593-9173.25.16.195

Citation: Ghiday T, Mohamed W, Tsehaye Y, Wakjira A, Daba C, Dissasa T (2025) Association and Path Analyses among Morpho-Agronomic Traits, Fatty Acids Contents and Oil Yield in Linseed (*Linumussitatisimum* L.) Genotypes in Ethiopia. J Agri Sci Food Res. 16:195.

Whereas on overseas countries linseed is widely grown in cool temperate regions of Argentina, Northern Europe, China, Russia, USA and Canada. This crop is grown for fibre (fibre flax), seed oil (linseed) or both seed oil as well as fibre (example dual purpose flax linseed), but recently it has gained a new interest in the emerging market of functional food due to its high content of fatty acids, Alpha Linolenic Acid (ALA), an essential Omega-3 fatty acid and lignin oligomers which constitute about 57% of total fatty acids in linseed [2].

For any crop improvement programme, systematic study and evaluation of germplasm is of great importance for genetic improvement of the crop. Seed and oil yields are complex traits and highly influenced by many genetic and environmental factors. So, direct selection for seed or oil yield as such could be misleading. A successful selection depends upon the information on the association of morpho-agronomic traits and biochemical properties with seed yield or oil yield [3]. The inter-relationship between important seed and oil yield components is best estimated by correlation coupled with path coefficient analysis. These techniques used in the breeding programme to exploit the yield potential for enhancing the productivity of the linseed and to develop high seed and oil yielding improved varieties.

Correlation is the mutual relationship between the variables, it aids in determining the most effective procedures for selection of superior genotypes. When there is positive correlation between major yield components, breeding strategies would be very effective but on the reverse, selection becomes very difficult. Wakjira reported seed yield per plot was highly significant and positively associated with seed yield per plant, thousand seed weight and capsule per plant [4]. In addition, oil yield was significantly and positively associated with polyunsaturated (linoleic and linolenic) fatty acids, whereas it was negatively correlated with saturated (palmitic and stearic) fatty acids. Oil yield also had weak positive correlation with unsaturated oleic acid. Tadesse reported seed yield per plot was significantly associated with seed weight, seed yield per plant, harvest index and biomass at Robe and Sinana in Ethiopia [5]. Path analysis indicated that harvest index and biomass were main determinate of yield per plot at both locations. Days to maturity and seed yield per plot had low negative direct effect on oil content. Seed yield had high positive direct effect and high positive correlation. This suggested that the simultaneous improvement in seed yield and oil content is possible in the material under his study. Mulusew reported that oil content was positive and significantly associated only with linolenic acid but negatively and significantly associated with palmitic acid, oleic acid and linolenic acid was negatively associated with linoleic acid [6]. Crude protein and iodine value shows negative and non-significant correlation with other quality traits.

The estimates of correlation coefficients alone may be often misleading due to mutual cancellation of component characters. So, study of correlation coupled with a path analysis is more effective tool in the study of yield contributing characters.

Path coefficient analysis is an important technique for partitioning the correlation coefficient into direct and indirect effect of the causal components on the complex component. Naik reported biological yield per plant exerted high positive direct effects on seed yield [7]. Patial observed that harvest index exerts substantial negative direct effect on seed yield [8]. The adequate information on extent of variability may also be helpful to improve the yield by selecting the yield component traits. Identification and selection of major yield components is an essential prerequisite for linseed improvement. Keeping these considerations in mind, an attempt was made to assess the correlation among the yield components and their direct and indirect effect on seed yield.

MATERIALS AND METHODS

Experimental sites

The study was conducted during 2019/20 in central Oromia, Ethiopia in two selected locations, namely, Holeta (90°3′ 41" N, 38° 30′ 44″ E) and Kulumsa (08°01′ 10" N, 39°09′ 11″ E). Holeta and Kulumsa are agricultural research stations of Ethipian Institute of Agricultural Research (EIAR). These two sites represent agro-ecology of central Oromia and favorable for highland oil crops in Ethiopia. Holeta and Kulumsa are situated at an altitude of 2400 and 2200 m above sea level and receive a total rainfall of 976 and 820 mm, respectively. The mean minimum and maximum temperatures at Holeta site range from 6.1 to 22.4°C. Kulumsa has an average minimum and maximum temperature of 10.5 and 22.8°C. Holeta and Kulumsa has nitosol and luvisol soil types and soil PH 4.9 and 6, respectively.

Experimental material

The seeds of 120 accessions were obtained from Ethiopian Biodiversity Institute (EBI) and the seeds of six improved varieties were obtained from Holeta and Kulumsa Agricultural Research Centers were used for this experiment. Belay-96, Berene and Kulumsa-1 released in 1997, 2001 and 2006, respectively, while Jeldu, Kasa-2 and Bekoji released in 2010, 2012 and 2014, respectively. The 120 accessions were collected from different geographic regions and altitudes (1480 to 3440 m.a.s.l.) (Table 1).

Table 1: List of accessions, collection former administrative region, collection areas latitude, longitude and altitude ranges.

Administrative region (Former)	No acc.	List of accession code	Latitude range	Longitude range	Altitude range (m.a.s.l.)
Bale	7	10052, 239715, 212854, 212857,	06-59-00-N to 0716-24-N	29-12-00-E to 40-38-00-E	1800-2560

		230033, 23058, 230029			
Tigray	30	219969, 234008, 242592, 242589, 234011, 234005, 235170, 235161, 234011, 10126, 234004, 233996, 234012, 10133, 10134, 241828, 234009, 235163, 234012, 242588, 234010, 219964, 234003, 235171, 233989, 233992, 233993, 233994, 233995, 234002	12-42-00-N to 14-57-00-N	37-4-00-E to 39-48-00-E	1500-2550
Gonder	15	10054, 10059, 10055, 226028, 10162, 13675, 13682, 13676, 13677, 13679, 241823, 241818, 241825, 226025, 241820	11-03-00-N to 12-59-00-N	37-01-00-E to 38-25-00-E	1730-3190
Gojam	11	241816, 10066, 10068, 10070, 10067, 10149, 10150, 226032, 13568, 13578, 216012	10-07-00-N to 11-36-00-N	36-58-00-E to 38-13-00-E	1810-2635
Welo	14	233987, 10143, 10145, 243800, 241829, 241827, 13696, 13712, 13719, 239716, 13760, 212625, 243799, 215716	10-36-00-N to 12-48-00-N	39-01-00-E to 39-48-00-E	1964-3440
Shewa	25	241831, 10088, 10094, 10096, 10097, 10095, 10093, 10101, 10103, 10104, 10105, 10108, 10113, 13503, 13507, 13509, 236846, 212512, 212517, 207791, 208360, 208425, 13598, 13515, 13517	07-12-00-N to 39-39-00-N	37-22-00-E to 39-53-00-E	1480-3150
GamoGofa	1	10061	06-12-00-N	37-37-00-E	2400
Illubabor	3	13755, 13756, 10084	08-17-00-N to 08-32-00-N	35-40-00-E to 36-28-00-E	1750-2000
Kefa	1	10087	07-44-00-N	37-16-00-E	1740
Welega	1	13753	08-38-00-N	34-57-00-E	1680
Arsi	7	23700, 236998, 13511, 13548, 13620, 13654, 236997	07-08-00-N to 07-47-00-N	39-12-00-E to 40-00-00-E	2340-2900

Hararghe	5	10078, 230825, 10077, 230827, 10079	08-50-00-E to 09-15-00-N	40-36-00-E to 41-22-00-E	1900-2440
Released varieties	6	Bekoji, Belay-95, Berene, Jeldu, Kassa-2, Kulumsa-1			
Total	126				

Source: Ethiopian Biodiversity Institute (BID) and Holeta Agricultural Research Center (HARC)

Experimental design and procedures

The experiment was conducted under field conditions and laid out using alpha lattice design Patterson and Williams [9], with two replications, at each location. In each replication there are 21 blocks and 6 plots in each block at each location. Each entry was planted in two rows plots measuring three meters in length, with an inter-row and intra-row spacing of 0.2 m and 0.1 m, respectively. The trials were maintained following the standard agronomic practices of linseed production. Data were recorded from ten randomly selected competitive plants of each genotype characters namely DF=days to 50% flowering, DM: Days to Maturity; PH (cm): Plant Height; PB: Number of Primary Branches; SB: Number of Secondary Branches; NC: Number of Capsules per Plant; NSC: Number of Seeds per Capsule; TSW(g): Thousand Seed Weight; BYP (kg): Biological Yield per Plant; HI (%): Harvest Index and SYP (g): Seed Yield per Plant. The quality characters were taken after harvesting the plants. The oil content, fatty acid content and quality characters of the seed such as CRB (%): Carbohydrate and PRT (%)=crude protein while the fatty acids composition content OA (%): Oleic Acid; LN (%): Linoleic Acid; LNN (%): Linolenic Acid; OYP (%): Oil Yield per Plant was determined at quality laboratory of Ethiopian Institute of agricultural research, Ethiopia, Holeta Highland Oil Crops Laboratory in Ethiopia.

Data analysis

All the data were subjected to analysis using SAS software 9.2. The Analysis of Variance (ANOVA) of each location (Holeta or Kulumsa) was carried out according to the model:

$P_{ijks}=\mu+g_i+b_{k(j)(s)}+r_{j(s)}+l_s+(gl)_{is}+e_{ijks}$

Where: P_{ijks}=Phenotypic value of i^{th} genotype under j^{th} replication at s^{th} location and k^{th} incomplete block within replication j and location s; μ=Grand mean; g_i=The effect of i^{th} genotype; $b_{k(j)(s)}$=The effect of incomplete block k within replication j and location s; $rj_{(s)}$=The effect of replication j within location s; ls=The effect of location s; $(gl)_{is}$=The interaction effects between genotype and location; and e_{ijks}=The residual or effect.

Correlation coefficients: The correlation coefficients were calculated to determine the degree of association of characters with seed yield per plant, yield components, oil yield per plant and quality characters of the seed and among themselves. Phenotypic and genotypic correlations were computed by the formula suggested by Miller [10]:

$$r_p = \frac{p_{cov_{xy}}}{\sqrt{\left(\sigma^2_{p_x} \times \sigma^2_{p_y}\right)}}$$

Where,

r_p=Phenotypic correlation coefficient

p_{covxy}=Phenotypic covariance between character x and y

σ^2_{px}=Phenotypic variance of x character

σ^2_{py}=Phenotypic variance of y character

$$r_g = \frac{g_{cov_{xy}}}{\sqrt{\left(\sigma^2_{g_x} \times \sigma^2_{g_y}\right)}}$$

Where,

r_g=Genotypic correlation coefficient

g_{covxy}=Genotypic covariance between character x and y

σ^2_{gx}=Genotypic variance of x character

σ^2_{gy}=Genotypic variance of y character

The coefficients of correlation will be tested using "r" tabulated value at n-2 degree of freedom, at 5% and 1% probability level, where n is the number of accessions described by Robertson.

Path coefficient analysis: Path coefficient analysis was carried out using the genotypic and phenotypic correlation coefficients to determine the direct and indirect effects of the yield components and seed quality related characters. Path coefficient analysis was also conducted to determine the direct and indirect effect of various traits on seed yield per plant and oil yield per plant using the general formula of Dewey and Lu [11].

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

$\Sigma r_{ik}p_{kj}$=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:

$$1 - R^2 \text{ where } R^2 = \sum r_{ij}p_{ij}$$

Data processing was done by SAS software. The contribution of the remaining unknown characters was measured as the residual effect as demonstrated by Singh and Chaudhary [12].

RESULTS AND DISCUSSION

Correlation coefficients of seed and oil yield per plant with other traits at two locations

Correlation of seed and oil yield: Estimates of genotypic and phenotypic correlation coefficients at Holeta and Kulumsa environments are shown in Tables 2 and 3, respectively. The analysis of correlations in each location showed that genotypic correlation coefficients were generally higher than their corresponding phenotypic correlations indicating strong hereditary association among the traits due to genetic factors such as linkage and/or pleiotropic effect enabling consistent performance across wide range of environments as described by Waitt and Levin [13]. Seed and oil yield are very complex characters which are governed by polygenes and the result of numerous simple characters presumably showing considerable variations from one environment to another. The correlation between the traits may be due to linkage or pleiotropy or environment. Similarly, a narrow difference between phenotypic and genotypic correlation coefficient was obtained for almost all the pairs of characters studied showing that masking or modifying effects of the environment was little demonstrating that the presence of an inherent association among these characters. Similar results were reported in linseed studies of Wakjira, Tadesse, Mulusew and Worku [14].

Correlation among seed and oil yield and yield components: Genotypic and phenotypic correlations for all possible combinations of traits at phenotypic and genotypic correlation estimates between seed yield per plant and the various characters at Holeta and Kulumsa were presented in Tables 2 and 3, respectively. At genotypic and phenotypic levels seed yield per plant had highly significant positive correlations with plant height, number of primary braches per plant, number of secondary braches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant and oil yield per plant, indicating that selection based on these parameters would considerably enhance seed yield per plant. These results partially agree with the finding of Tadesse, Patil and Worku [15].

Table 2: Phenotypic correlation coefficient between 17 morphoagronomic and oil traits of 126 linseed genotypes above diagonal at Holeta and below diagonal at Kulumsa in 2019/20.

	DF	DM	PH	PB	SB	NC	NSC	TSW	BYp	HI	CRB	PRT	OA	LN	LNN	OYP	Syp
DF		0.87**	-0.79**	-0.52**	-0.14	-0.57**	-0.63**	-0.67**	-0.64**	0.33**	0.07	0.01	0.04	0.07	-0.07	-0.69**	-0.77**
DM	0.87**		-0.72**	-0.48**	-0.12	-0.61**	-0.62**	-0.76**	-0.60**	0.30**	0.03	0.09	0.1	0.04	-0.07	-0.70**	-0.78**
PH	-0.79**	-0.72**		0.60**	0.12	0.56**	0.70**	0.70**	0.64**	-0.31**	-0.03	0.01	-0.04	-0.06	0.02	0.70**	0.80**
PB	-0.52**	-0.48**	0.60**		0.23**	0.52**	0.67**	0.64**	0.65**	-0.33**	-0.06	-0.06	0.07	-0.14	0.01	0.68**	0.75**
SB	-0.16	-0.13	0.12	0.23**		0.27**	0.26**	0.23**	0.16	0.11	-0.05	0.05	0.01	-0.02	0.09	0.25**	0.25**
NC	-0.57**	-0.61**	0.56**	0.52**	0.27**		0.62**	0.68**	0.54**	-0.21*	-0.05	0.01	-0.01	-0.02	0.03	0.63**	0.71**
NSC	-0.63**	-0.62**	0.70**	0.67**	0.27**	0.62**		0.76**	0.82**	-0.47**	-0.1	-0.04	-0.02	-0.11	0.07	0.82**	0.89**
TSW	-0.65**	-0.72**	0.66**	0.62**	0.23**	0.62**	0.74**		0.68**	-0.31**	-0.06	-0.06	0.01	-0.07	0.11	0.79**	0.87**
BYP	-0.64**	-0.60**	0.64**	0.65**	0.17	0.54**	0.82**	0.66**		-0.80**	-0.06	-0.04	-0.02	-0.11	0.04	0.79**	0.86**
HI	0.33**	0.31**	-0.32**	-0.33**	0.1	-0.22*	-0.47**	-0.31**	-0.80**		0.01	0.02	0.01	0.07	0.01	0.42**	-0.46**
CRB	0.09	0.03	-0.02	-0.04	-0.09	-0.04	-0.09	-0.07	-0.06	0.02		-0.63**	-0.12	0.59**	-0.69**	-0.46**	-0.06
PRT	-0.01	0.06	-0.02	-0.03	0.04	0.02	-0.03	-0.01	-0.03	0.03	-0.68**		0.09	-0.24**	0.34**	0.13	-0.06

OA	0.07	0.12	-0.05	0.06	-0.01	-0.01	-0.03	0.01	-0.03	0.02	-0.11	0.1		-0.14	0.09	0.06	0.02
LN	0.1	0.05	-0.08	-0.14	-0.03	-0.04	-0.13	-0.07	-0.13	0.08	0.59**	-0.28**	-0.12		-0.28**	-0.36**	-0.11
LNN	-0.03	-0.01	-0.01	-0.01	0.11	-0.01	0.01	0.07	0.01	0.02	-0.66**	0.32**	0.09	-0.30**		0.35**	0.06
OYP	-0.70**	-0.70**	0.71**	0.67**	0.27**	0.63**	0.83**	0.77**	0.80**	-0.43**	-0.46**	0.18*	0.03	-0.37**	0.30**		0.90**
SYP	-0.77**	-0.78**	0.80**	0.75**	0.26**	0.71**	0.89**	0.84**	0.86**	-0.46**	-0.06	-0.03	0.01	-0.12	0.02	0.91**	

Tabular r=0.18 at 5%; r=0.23 at 1%

Note: * and **: Significant at p<0.05 and p<0.01 probability levels, respectively. DF=Days to 50% Flowering; DM=Days to Maturity; PH (cm)=Plant Height; PB=Number of Primary Branches; SB=Number of Secondary Branches; NC=Number of Capsules per plant; NSC=Number of Seeds per Capsule; TSW (g)=Thousand Seed Weight; BYP (kg)=Biological Yield per Plant; HI (%)=Harvest Index; CRB (%)=Carbohydrate; PRT (%)=Crude Protein; OA (%)=Oleic Acid; LN (%)=Linoleic acid; LNN (%)=Linolenic acid; OYP (%)=Oil Yield per Plant and SYP (g)=Seed Yield per Plant.

Table 3: Genotypic correlation coefficient between 17 morphoagronomic and oil traits of 126 linseed genotypes above diagonal at Holeta and below diagonal at Kulumsa in 2019/20.

	DF	DM	PH	PB	SB	NC	NSC	TSW	BYp	HI	CRB	PRT	OA	LN	LNN	OYP	Syp
DF		0.91**	-0.87**	-0.61**	-0.15	-0.66**	-0.68**	-0.74**	-0.71**	0.42**	0.07	0.01	0.05	0.08	-0.08	-0.73**	-0.81**
DM	0.90**		-0.81**	-0.54**	-0.13	-0.67**	-0.66**	-0.80**	-0.65**	0.39**	0.03	0.08	0.11	0.04	-0.09	-0.71**	-0.80**
PH	-0.86**	-0.81**		0.73**	0.15	0.70**	0.81**	0.83**	0.76**	-0.41**	-0.04	-0.01	-0.03	-0.07	0.03	0.79**	0.89**
PB	-0.60**	-0.54**	0.73**		0.26**	0.62**	0.78**	0.71**	0.74**	-0.44**	-0.06	-0.05	0.09	-0.15	-0.01	0.75**	0.82**
SB	-0.16*	-0.13	0.15	0.26**		0.30**	0.29**	0.24**	0.19*	0.11	-0.05	0.05	0.02	-0.02	0.1	0.27**	0.27**
NC	-0.65**	-0.67**	0.70**	0.62**	0.30**		0.67**	0.76**	0.61**	-0.29**	-0.04	0.02	0.02	-0.03	0.01	0.66**	0.75**
NSC	-0.68**	-0.66**	0.82**	0.77**	0.29**	0.67**		0.83**	0.89**	-0.57**	-0.09	-0.04	-0.02	-0.12	0.07	0.86**	0.93**
TSW	-0.73**	-0.77**	0.80**	0.69**	0.25**	0.71**	0.82**		0.78**	-0.46**	-0.07	-0.03	0.02	-0.06	0.13	0.83**	0.92**
BYP	-0.71**	-0.65**	0.76**	0.74**	0.20*	0.61**	0.89**	0.77**		-0.81**	-0.06	-0.04	-0.02	-0.12	0.06	0.83**	0.90**
HI	0.42**	0.39**	-0.41**	-0.44**	0.1	-0.29**	-0.57**	-0.44**	-0.82**		0.03	0.03	0.01	0.08	-0.02	-0.51**	-0.55**
CRB	0.09	0.02	-0.05	-0.02	-0.1	-0.04	-0.09	-0.07	-0.06	0.02		-0.65**	-0.13	0.62**	-0.78**	-0.46**	-0.06
PRT	0.01	0.08	0.01	-0.06	0.05	0.02	-0.04	-0.03	-0.04	0.1	-0.70**		0.1	-0.26**	0.42**	0.16	-0.05
OA	0.07	0.12	-0.05	0.06	0.01	-0.02	-0.04	0.01	-0.04	-0.55**	-0.11	0.1		-0.14	0.12	0.06	0.02
LN	0.1	0.04	-0.08	-0.15	-0.04	-0.04	-0.13	-0.08	-0.14	0.1	0.61**	-0.27**	-0.12		-0.34**	-0.38**	-0.11
LNN	-0.05	-0.02	0.01	-0.03	0.13	-0.04	0.03	0.09	0.02	0.01	-0.74**	0.38**	0.1	-0.34**		0.38**	0.06
OYP	-0.74**	-0.71**	0.80**	0.74**	0.29**	0.66**	0.86**	0.83**	0.83**	-0.51**	-0.45**	0.18*	0.03	-0.39**	0.33**		0.91**
SYP	-0.80**	-0.80**	0.90**	0.82**	0.27**	0.75**	0.93**	0.90**	0.90**	-0.55**	-0.05	-0.05	0.01	-0.12	0.02	0.91**	

Note: * and **: Significant at p<0.05 and p<0.01 probability levels, respectively. DF=Days to 50% Flowering; DM=Days to Maturity; PH (cm)=Plant Height; PB=Number of Primary Branches; SB=Number of Secondary Branches; NC=Number of Capsules per plant; NSC=Number of Seeds per Capsule; TSW (g)=Thousand Seed Weight; BYP (kg)=Biological Yield per Plant; HI (%)=Harvest Index; CRB (%)=Carbohydrate; PRT (%)=Crude Protein; OA (%)=Oleic Acid; LN (%)=Linoleic acid; LNN (%)=Linolenic acid; OYP (%)=Oil Yield per Plant and SYP (g)=Seed Yield per Plant.

At both locations besides seed yield per plant, the oil yield per plant showed a highly significant positive correlation at genotypic and phenotypic levels with plant height, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant and linolenic fatty acid, implying that selection based on these eight characters could enhance the oil yield per plant, which ultimately would lead to an increase in seed yield per plant. This result agrees with the finding of Wakjira, Tadesse, Gauraha and Rao and Mulusew, Reddy, Kumar, Kaur and Patial [16-19].

Seed yield per plant had highly significant negative correlations at phenotypic and genotypic levels at both locations with days to flowering, days to maturity, and harvest index, suggesting that early maturity would favorably enhance seed yield per plant. This result agrees with the finding of and Kumar, Kaur and Patial and partially agree with findings of Tadesse and Worku.

At both locations oil yield per plant had positive and highly significant phenotypic and genotypic correlation coefficients with plant height, number of primary branches, number of secondary branches, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant, linolenic fatty acid and seed yield per plant, indicating that selection based on these parameters would considerably enhance oil yield per plant. Crude protein content had positive significant phenotypic and genotypic correlation coefficient with oil yield per plant at Kulumsa, implying that selection based on crude protein content using phenotypic and genotypic correlation at Kulumsa could enhance the oil yield per plant. This result agrees with the finding of Wakjira, Gauraha and Rao, Reddy, Mulusew, Kumar, Kaur and Patial.

Besides oil yield per plant, seed yield per plant showed a highly significant positive correlation at genotypic and phenotypic levels with plant height, number of primary braches per plant, number of secondary braches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight and biological yield per plant, implying that selection based on these characters could enhance the seed yield per plant, which ultimately would lead to an increase in oil yield per plant. This result agrees with the finding of Gauraha and Rao, Reddy, Kumar, Kaur and Patial.

Days to 50% flowering, days to maturity, harvest index, carbohydrate and linoleic fatty acid content had negative and highly significant phenotypic and genotypic correlation coefficients with oil yield per plant at both locations, suggesting that reduced linoleic fatty acid would favorably enhance oil yield per plant. This result agrees with the finding of Wakjira and Mulusew.

At both locations, among all fatty acids, linoleic acid showed a highly significant negative association with linolenic acid at phenotypic and genotypic levels. This negative correlation of linolenic acid with linoleic acid can be best understood by the fatty acid biosynthesis pathway. You found that both linoleic and linolenic acids have a common biosynthesis pathway, so one can increase at the cost of the other. Similar findings were also reported by Bayrak and Pali and Mehta [20,21]. The results obtained in the present study indicate that high oil yield per plant will result in high linolenic acid and reduce linoleic acids. However, Pali and Mehta suggested that an increase in oil yield per plant will lead to an increase in linolenic acid. Pali, Bayrak and Bhatty also observed a negative association of linoleic acid with linolenic acid [20-22]. Considering the obtained results, the present study suggests that selection to increase oil yield per plant would not affect linseed oil quality, since selection does not affect total fatty acid compositions, despite the noticeable changes in different fatty acids.

The phenotypic path coefficient analysis of seed yield per plant at Holeta and Kulumsa

Seed yield per plant was the dependent variable while other evaluated morphoagronomic traits, oil yield and fatty acid contents which are significantly correlated at phenotypic level were considered as independent variables. Direct and indirect effects of these components were determined on seed yield per plant and their contributions in each of the two environments are shown in Table 4. The path coefficient analysis at phenotypic level revealed at Holeta and Kulumsa, respectively that biological yield per plant (0.629 and 0.627) had the highest positive direct effect on seed yield per plant. Similarly, biological yield per plant had highly significant and positive correlations ($rp=0.86^{**}$, $rp=0.86^{**}$) with seed yield per plant in each location (Holeta and Kulumsa), respectively at phenotypic level, indicating a direct selection through biological yield per plant will be effective in order to improve seed yield per plant of linseed. These results are in agreement with the findings of Tariq; Paul for biological yield per plant and partially agree with the findings of Tadesse for harvest index and biomass yield.

Table 4: Direct (bold and underlined) and indirect effects (off diagonal) of traits on seed yield per plant at phenotypic level at two location in 2019/20.

Location	Trait	DF	DM	PH	PB	SB	NC	NSC	TSW	BYP	HI	OYP	SYP rp
Holeta	DF	0.026	-0.119	-0.071	-0.034	0.003	-0.025	-0.061	-0.103	-0.4	0.095	-0.082	-0.77^{**}

Kulumsa		0.05	-0.145	-0.077	-0.037	0.003	-0.032	-0.062	-0.072	-0.399	0.096	-0.094	-0.77**
Holeta	DM	0.022	-0.136	-0.064	-0.031	0.002	-0.027	-0.061	-0.117	-0.375	0.087	-0.082	-0.78**
Kulumsa		0.043	-0.167	-0.07	-0.034	0.003	-0.034	-0.062	-0.08	-0.374	0.087	-0.093	-0.78**
Holeta	PH	-0.02	0.098	0.09	0.039	-0.002	0.025	0.068	0.107	0.404	-0.089	0.083	0.80**
Kulumsa		-0.039	0.12	0.097	0.043	-0.002	0.031	0.069	0.074	0.403	-0.09	0.095	0.80**
Holeta	PB	-0.013	0.066	0.054	0.064	-0.004	0.023	0.065	0.099	0.41	-0.095	0.08	0.75**
Kulumsa		-0.026	0.081	0.059	0.071	-0.004	0.029	0.066	0.069	0.407	-0.096	0.09	0.75**
Holeta	SB	-0.004	0.017	0.011	0.015	-0.018	0.012	0.026	0.035	0.101	0.031	0.029	0.25**
Kulumsa		-0.008	0.021	0.012	0.016	-0.02	0.015	0.026	0.026	0.104	0.028	0.036	0.26**
Holeta	NC	-0.015	0.084	0.051	0.034	-0.005	0.043	0.06	0.105	0.34	-0.061	0.074	0.71**
Kulumsa		-0.028	0.103	0.055	0.037	-0.005	0.056	0.061	0.07	0.339	-0.062	0.084	0.71**
Holeta	NSC	-0.016	0.085	0.063	0.043	-0.005	0.027	0.097	0.116	0.515	-0.134	0.097	0.89**
Kulumsa		-0.031	0.104	0.068	0.048	-0.005	0.035	0.099	0.082	0.514	-0.135	0.11	0.89**
Holeta	TSW	-0.017	0.104	0.063	0.041	-0.004	0.03	0.074	0.154	0.426	-0.089	0.093	0.87**
Kulumsa		-0.032	0.121	0.064	0.045	-0.005	0.035	0.073	0.111	0.414	-0.088	0.103	0.84**
Holeta	BYP	-0.016	0.081	0.058	0.042	-0.003	0.024	0.08	0.104	0.629	-0.228	0.093	0.86**
Kulumsa		-0.032	0.1	0.063	0.046	-0.003	0.03	0.081	0.073	0.627	-0.23	0.106	0.86**
Holeta	HI	0.009	-0.042	-0.028	0.021	-0.002	-0.009	-0.046	-0.048	-0.504	0.285	-0.049	-0.46**
Kulumsa		0.017	-0.051	-0.031	-0.024	-0.002	-0.012	-0.047	-0.034	-0.503	0.286	-0.057	-0.46**
Holeta	OYP	-0.018	0.095	0.063	0.044	-0.004	0.027	0.08	0.122	0.496	-0.119	0.118	0.90**
Kulumsa		-0.035	0.117	0.069	0.048	-0.005	0.035	0.082	0.086	0.499	-0.122	0.133	0.91**
Holeta Residual=0.027767; Kulumsa Residual=0.02908													

Note: **: Significant at p<0.01 probability levels. DF: Days to 50% Flowering; DM: Days to Maturity; PH (cm): Plant Height; PB: Number of Primary Branches; SB: Number of Secondary Branches; NC: Number of Capsules per plant; NSC: Number of Seeds per Capsule; TSW (g): Thousand Seed Weight; BYP (kg): Biological Yield per Plant; HI (%): Harvest Index; CRB (%): Carbohydrate; PRT (%): Crude Protein; OA (%): Oleic Acid; LN (%): Linoleic Acid; LNN (%): Linolenic Acid; OYP (%): Oil Yield per Plant and SYP (g): Seed Yield per Plant.

It was observed that thousand seed weight and oil yield per plant exhibited positive and relatively low direct effect on seed yield per plant at Holeta and Kulumsa (Table 4). Traits such as oil yield per plant and thousand seed weight exerted positive indirect effects on seed yield per plant *via* biological yield per plant in both environments. Harvest index showed relatively higher negative indirect effect to seed yield per plant through biological yield per plant. Similar results were reported by Patial where harvest index showed relatively higher negative indirect effect to seed yield per plant through biological yield per plant was observed.

Plant height, number of primary braches per plant, number of capsules per plant and number of seeds per capsule had negligible direct positive effect and positive, highly significant correlation at phenotypic level with seed yield per plant. Number of secondary branches per plant had negative direct effect but positive highly significant phenotypic correlation with seed yield per plant at both locations. These indicate that the indirect effects seem to be the reason of correlation. In such situations, the indirect causal factors must be considered simultaneously.

Days to 50% flowering and harvest index had positive direct effect but negative highly significant phenotypic correlation at both locations. Under these circumstances, a restricted selection model is to be followed, that is restrictions are to be imposed to nullify the undesirables indirect effects, in order to make use of the direct effects. Days to maturity had negative direct effect and negative highly significant correlation at phenotypic level at both locations, indicating selection of early maturity is effective for improving seed yield per plant.

The residual effects of the present study were 0.027767 and 0.02908 at Holeta and Kulumsa, respectively which means the characters in the path analysis expressed the variability in seed yield per plant by 97.2233% and 97.092%, respectively.

The genotypic path coefficient analysis of seed yield per plant at Holeta and Kulumsa

The path coefficient analysis at genotypic level at Holeta and Kulumsa (Table 5) showed that biological yield per plant (0.5836 and 0.5841) had the highest positive direct effect on seed yield per plant. Similarly, biological yield per plant had highly significant and positive correlations (r_p=0.90**, r_p=0.91**) with seed yield per plant in each location (Holeta and Kulumsa) at genotypic level. This indicates a direct selection through biological yield per plant will be effective in order to improve seed yield per plant of linseed. These results are in agreement with the findings of Tariq; Paul for biological yield per plant and partially agree with the finding of Tadesse for harvest index and biomass yield.

Table 5: Direct (bold and underlined) and indirect effects (off diagonal) of traits on seed yield per plant at genotypic level at two location in 2019/20.

Holeta	DF	0.054	-0.111	-0.109	-0.054	0.002	-0.012	-0.063	-0.146	-0.412	0.096	-0.053	-0.81**
Kulumsa		0.094	-0.143	-0.128	-0.057	0.002	-0.025	-0.056	-0.108	-0.412	0.094	-0.066	-0.80**
Holeta	DM	0.049	-0.123	-0.101	-0.048	0.002	-0.012	-0.061	-0.157	-0.382	0.089	-0.052	-0.80**
Kulumsa		0.085	-0.159	-0.119	-0.051	0.002	-0.026	-0.054	-0.115	-0.382	0.087	-0.063	-0.80**
Holeta	PH	-0.047	0.099	0.126	0.064	-0.002	0.012	0.075	0.162	0.441	-0.095	0.058	0.89**
Kulumsa		-0.081	0.128	0.148	0.068	-0.002	0.027	0.067	0.119	0.442	-0.092	0.071	0.90**
Holeta	PB	-0.033	0.066	0.092	0.088	-0.004	0.011	0.072	0.14	0.435	-0.102	0.055	0.82**
Kulumsa		-0.057	0.086	0.108	0.094	-0.004	0.024	0.063	0.103	0.433	-0.099	0.066	0.84**
Holeta	SB	-0.008	0.016	0.019	0.023	-0.015	0.005	0.027	0.047	0.112	0.025	0.02	0.27**
Kulumsa		-0.015	0.021	0.023	0.024	-0.014	0.011	0.024	0.037	0.114	0.023	0.026	0.28**
Holeta	NC	-0.036	0.083	0.089	0.055	-0.004	0.018	0.062	0.15	0.354	-0.067	0.048	0.75**
Kulumsa		-0.062	0.107	0.104	0.058	-0.004	0.038	0.055	0.106	0.355	-0.065	0.059	0.76**
Holeta	NSC	-0.037	0.081	0.102	0.068	-0.004	0.012	0.093	0.163	0.522	-0.132	0.063	0.93**
Kulumsa		-0.065	0.104	0.121	0.073	-0.004	0.026	0.082	0.123	0.522	-0.128	0.077	0.92**
Holeta	TSW	-0.04	0.098	0.104	0.063	-0.004	0.014	0.076	0.197	0.455	-0.105	0.061	0.92**
Kulumsa		-0.068	0.123	0.118	0.065	-0.004	0.027	0.067	0.149	0.449	-0.099	0.074	0.90**
Holeta	BYP	-0.038	0.08	0.095	0.066	-0.003	0.011	0.083	0.153	0.584	-0.188	0.061	0.90**
Kulumsa		-0.066	0.104	0.112	0.07	-0.003	0.023	0.073	0.114	0.584	-0.182	0.074	0.91**
Holeta	HI	0.023	-0.048	-0.052	-0.039	-0.002	-0.005	-0.053	-0.09	-0.475	0.23	-0.037	-0.55**
Kulumsa		0.04	-0.062	-0.061	-0.042	-0.002	-0.011	-0.047	-0.066	-0.476	0.224	-0.045	-0.58**

Holeta	OYP	-0.04	0.087	0.099	0.066	-0.004	0.012	0.08	0.164	0.484	-0.117	0.073	0.91**
Kulumsa		-0.07	0.113	0.119	0.069	-0.004	0.025	0.071	0.123	0.487	-0.113	0.089	0.92**
Holeta Residual=0.027767; Kulumsa Residual=0.02908													

Note: **: Significant at p<0.01 probability levels. DF: Days to 50% Flowering; DM: Days to Maturity; PH (cm): Plant Height; PB: Number of Primary Branches; SB: Number of Secondary Branches; NC: Number of Capsules per plant; NSC: Number of Seeds per Capsule; TSW (g): Thousand Seed Weight; BYP (kg): Biological Yield per Plant; HI (%): Harvest Index; CRB (%): Carbohydrate; PRT (%): Crude protein; OA (%): Oleic Acid; LN (%): Linoleic Acid; LNN (%): Linolenic Acid; OYP (%): Oil Yield per Plant and SYP (g): Seed Yield per Plant.

Thousand seed weight and plant height exhibited positive direct effect on seed yield per plant at Holeta and Kulumsa (Table 5). Plant height and thousand seed weight exerted positive indirect effects on seed yield per plant *via* biological yield per plant in both environments (Table 4). Harvest index showed relatively higher negative indirect effect to seed yield per plant through biological yield per plant. Similar results were reported by Patial where harvest index showed relatively higher negative indirect effect to seed yield per plant through biological yield per plant was observed.

Plant height, number of primary braches per plant, number of capsules per plant and number of seeds per capsule had positive negligible direct effect and positive highly significant correlation at genotypic level with seed yield per plant. Number of secondary branches per plant had negligible negative direct effect but positive highly significant genotypic correlation with seed yield per plant at both locations. These indicate that the indirect effects seem to be the reason of correlation. In such situations, the indirect causal factors must be considered simultaneously.

Days to 50% flowering and harvest index had positive direct effect but negative highly significant genotypic correlation at both locations. This indicates to impose restrictions to nullify the undesirables' indirect effects, in order to make use of the direct effects.

Days to maturity had negative direct effect and negative highly significant correlation at genotypic level at both locations, indicating selection of early maturity is effective for improving seed yield per plant.

The residual effects of the present study were 0.018241 and 0.018739 at Holeta and Kulumsa, respectively which means the characters in the path analysis expressed the variability in seed yield per plant by 98.1759% and 98.1261%, respectively.

The phenotypic path coefficient analysis of oil yield per plant at Holeta and Kulumsa

Oil yield per plant was the dependent variable while other evaluated traits were considered as independent variables. Direct and indirect effects of these components were determined on oil yield per plant and their contributions in each of the two environments are shown in Table 6. The path coefficient analysis at phenotypic level revealed at Holeta and Kulumsa, respectively that seed yield per plant (0.897 and 0.889) had the highest positive direct effect on oil yield per plant. Similarly, oil yield per plant had highly significant and positive correlations (r_p= 0.90**, r_p= 0.91**) with seed yield per plant in each location (Holeta and Kulumsa), respectively at phenotypic level, indicating the need for direct selection for this trait in order to improve oil yield per plant of linseed. These results are in agreement with the findings of Wakjira; Tadesse; Mulusew; Tariq; Paul for biological yield per plant.

Table 6: Direct (bold and underlined) and indirect effects (off diagonal) of traits on oil yield per plant at phenotypic level at two location in 2019/20.

Location		DF	DM	PH	PB	SB	NC	NSC	TSW	BYp	HI	CRB	PRT	LN	LNN	SYP	OYP rp
Holeta	DF	0.035	-0.035	0.024	-0.004	-0.001	0.016	-0.009	0.004	0.001	-0.003	-0.024		-0.003	-0.003	-0.691	-0.69**
Kulumsa	DF	0.033	-0.009	-0.009	0.002	-0.003	0.011	0.004	-0.002	0.002	-0.008	-0.042	0.001	-0.002	0	-0.683	-0.70**
Holeta	DM	0.03	-0.04	0.022	-0.004	-0.001	0.017	-0.009	0.004	0.001	-0.003	-0.011		-0.002	-0.003	-0.702	-0.70**
Kulumsa	DM	0.029	-0.01	-0.008	0.002	-0.002	0.012	0.004	-0.002	0.002	-0.007	-0.012	-0.007	-0.001	0	-0.695	-0.70**

Holeta	PH	-0.027	0.029	-0.03	0.005	0.001	-0.016	0.01	-0.004	-0.001	0.003	0.012		0.003	0.001	0.718	0.70**
Kulumsa	PH	-0.026	0.007	0.012	-0.003	0.002	-0.011	-0.005	0.002	-0.002	0.007	0.012	0.002	0.002	0	0.712	0.71**
Holeta	PB	-0.018	0.019	-0.018	0.008	0.001	-0.015	0.01	-0.004	-0.001	0.003	0.02		0.007	0	0.671	0.68**
Kulumsa	PB	-0.017	0.005	0.007	-0.005	0.004	-0.01	-0.005	0.002	-0.002	0.008	0.016	0.003	0.003	0	0.664	0.67**
Holeta	SB	-0.005	0.005	-0.004	0.002	0.005	-0.007	0.004	-0.001	0	-0.001	0.017		0.001	0.003	0.228	0.25**
Kulumsa	SB	-0.005	0.001	0.001	-0.001	0.017	-0.005	-0.002	0.001	0	-0.002	0.043	-0.004	0.001	0	0.228	0.27**
Holeta	NC	-0.02	0.025	-0.017	0.004	0.001	-0.028	0.009	-0.004	-0.001	0.002	0.017		0.001	0.001	0.637	0.63**
Kulumsa	NC	-0.019	0.006	0.007	-0.002	0.005	-0.019	-0.004	0.002	-0.001	0.005	0.02	-0.002	0.001	0	0.631	0.63**
Holeta	NSC	-0.022	0.025	-0.021	0.005	0.001	-0.017	0.015	-0.004	-0.001	0.004	0.034		0.005	0.002	0.797	0.82**
Kulumsa	NSC	-0.021	0.006	0.008	-0.003	0.004	-0.012	-0.007	0.002	-0.002	0.011	0.044	0.003	0.003	0	0.79	0.83**
Holeta	TSW	-0.023	0.031	-0.021	0.005	0.001	-0.019	0.011	-0.006	-0.001	0.003	0.021		0.003	0.004	0.783	0.79**
Kulumsa	TSW	-0.021	0.007	0.008	-0.003	0.004	-0.012	-0.005	0.003	-0.002	0.007	0.033	0.001	0.002	0	0.748	0.77**
Holeta	BYp	-0.022	0.024	-0.02	0.005	0.001	-0.015	0.012	-0.004	-0.001	0.007	0.021		0.005	0.002	0.774	0.79**
Kulumsa	BYp	-0.021	0.006	0.008	-0.003	0.003	-0.01	-0.006	0.002	-0.003	0.018	0.029	0.004	0.003	0	0.766	0.80**
Holeta	HI	0.012	-0.012	0.01	-0.003	0.001	0.006	-0.007	0.002	0.001	-0.009	-0.005		-0.003	0	-0.409	-0.42**
Kulumsa	HI	0.011	-0.003	-0.004	0.002	0.002	0.004	0.003	-0.001	0.002	-0.023	-0.007	-0.003	-0.002	0	-0.407	-0.43**
Holeta	CRB	0.002	-0.001	0.001	0	0	0.001	-0.001	0	0	0	-0.357		-0.027	-0.026	-0.052	-0.46**
Kulumsa	CRB	0.003	0	0	0	-0.002	0.001	0.001	0	0	0	-0.466	0.077	-0.013	-0.003	-0.053	-0.46**
Holeta	PRT																0.13^{ns}
Kulumsa	PRT	0	-0.001	0	0	0.001	0	0	0	0	-0.001	0.317	-0.112	0.006	0.001	-0.029	0.18*

Holeta	LN	0.003	-0.002	0.002	-0.001	0	0.001	-0.002	0	0	-0.001	-0.211		-0.046	-0.01	-0.096	-0.36**
Kulumsa	LN	0.003	-0.001	-0.001	0.001	-0.001	0.001	0.001	0	0	-0.002	-0.274	0.031	-0.023	-0.001	-0.109	-0.37**
Holeta	LNN	-0.002	0.003	-0.001	0	0	-0.001	0.001	-0.001	0	0	0.248		0.013	0.038	0.052	0.35**
Kulumsa	LNN	-0.001	0	0	0	0.002	0	0	0	0	0	0.308	-0.036	0.007	0.004	0.013	0.30**
Holeta	Syp	-0.027	0.031	-0.024	0.006	0.001	-0.02	0.013	-0.005	-0.001	0.004	0.021		0.005	0.002	0.897	0.90**
Kulumsa	Syp	-0.025	0.008	0.009	-0.003	0.004	-0.014	-0.006	0.002	-0.002	0.01	0.028	0.004	0.003	0	0.889	0.91**

Holeta Residual=0.027767; Kulumsa Residual=0.02908

Note: ns and **; non-significant and significant at p< 0.01 probability levels, respectively. DF: Days to 50% flowering; DM: Days to Maturity; PH (cm): Plant Height; PB: Number of Primary Branches; SB: Number of Secondary Branches; NC: Number of Capsules per plant; NSC: Number of Seeds per Capsule; TSW (g): Thousand Seed Weight; BYP (kg): Biological Yield per Plant; HI (%): Harvest index; CRB(%): Carbohydrate; PRT(%): Protein; OA(%): Oleic acid; LN(%): Linoleic acid; LNN(%): Linolenic aid and SYP (g): Seed yield per plant.

It was observed that number of secondary branches per plant and linolenic fatty acid exhibited negligible positive direct effect on oil yield per plant and highly significant phenotypic correlation at both locations. Plant height, number of primary branches per plant, number of seeds per capsule and thousand seed weight had positive highly significant correlation at phenotypic level with oil yield per plant but the direct effect was negative and negligible, the indirect effects seem to be the cause of correlation.

Days to 50% flowering had negative highly significant correlation with oil yield per plant but positive negligible direct effect. This indicates to impose restrictions to nullify the undesirables' indirect effects, in order to make use of the direct effects.

Days to maturity, harvest index, number of capsules per plant, biological yield per plant, carbohydrate content and linoleic fatty acid had negative highly significant correlation with oil yield per plant and negative direct effect on oil yield per plant. This indicates selection of reduced linoleic fatty acid content is important to improve oil yield per plant.

At Kulumsa crude protein content had positive significant correlation at phenotypic level with oil yield per plant but the direct effect was negative and negligible, then the indirect effects seem to be the cause of correlation.

The residual effects of the present study were 0.011324 and 0.006013 at Holeta and Kulumsa, respectively which means the characters in the path analysis expressed the variability in oil yield per plant by 99.8676% and 99.3987%, respectively.

The genotypic path coefficient analysis of oil yield per plant at Holeta and Kulumsa

The path coefficient analysis at genotypic level at Holeta and Kulumsa (Table 7), revealed that seed yield per plant (0.975 and 0.884) had the highest positive direct effect on oil yield per plant. Similarly, seed yield per plant had highly significant and positive correlations (r_g=0.91**, r_g=0.92**) with oil yield per plant in each location (Holeta and Kulumsa), at genotypic level. The genotypic correlation between seed yield per plant and oil yield per plant is almost equal to its direct effect, this shows genotypic correlation explains the true relationship and direct selection through seed yield per plant will be effective to improve oil yield per plant of linseed. These results are in agreement with the findings of Wakjira; Tadesse; Mulusew; Tariq; Paul for seed yield per plant [23,24].

Table 7: Direct (bold and underlined) and indirect effects (off diagonal) of traits on oil yield per plant at genotypic level at two location in 2019/20.

Location		DF	DM	PH	PB	SB	NC	NSC	TSW	BYP	HI	CRB	PRT	LN	LNN	SYP	OYP rg
Holeta	DF	0.053	-0.026	-0.009	0.001	-0.004	0.01	0.017	0.04	0.038	-0.023	-0.033		-0.002	-0.002	-0.787	-0.73**
Kulumsa		0.046	-0.029	-0.002	-0.003	-0.003	0.018	0.005	-0.005	0.002	-0.011	-0.043	0	-0.003	0	-0.711	-0.74**

Holeta	DM	0.048	-0.029	-0.008	0.001	-0.004	0.01	0.016	0.043	0.035	-0.022	-0.014		-0.001	-0.002	-0.775	-0.71**
Kulumsa		0.042	-0.033	-0.002	-0.003	-0.003	0.019	0.004	-0.005	0.002	-0.01	-0.007	-0.009	-0.001	0	-0.703	-0.71**
Holeta	PH	-0.046	0.023	0.01	-0.001	0.004	-0.011	-0.02	-0.044	-0.04	0.023	0.017		0.002	0.001	0.872	0.79**
Kulumsa		-0.04	0.026	0.002	0.004	0.003	-0.02	-0.005	0.005	-0.002	0.011	0.022	0	0.002	0	0.791	0.80**
Holeta	PB	-0.033	0.016	0.007	-0.002	0.008	-0.01	-0.019	-0.038	-0.04	0.025	0.028		0.003	0	0.799	0.75**
Kulumsa		-0.028	0.018	0.002	0.005	0.005	-0.017	-0.005	0.005	-0.002	0.011	0.011	0.006	0.004	0	0.723	0.74**
Holeta	SB	-0.008	0.004	0.002	-0.001	0.029	-0.005	-0.007	-0.013	-0.01	-0.006	0.024		0.001	0.003	0.263	0.27**
Kulumsa		-0.007	0.004	0	0.001	0.02	-0.008	-0.002	0.002	0	-0.003	0.046	-0.005	0.001	0	0.242	0.29**
Holeta	NC	-0.035	0.019	0.007	-0.001	0.009	-0.015	-0.017	-0.041	-0.032	0.016	0.019		0.001	0	0.732	0.66**
Kulumsa		-0.03	0.022	0.002	0.003	0.006	-0.028	-0.004	0.005	-0.001	0.008	0.017	-0.002	0.001	0	0.664	0.66**
Holeta	NSC	-0.037	0.019	0.008	-0.002	0.008	-0.01	-0.025	-0.044	-0.048	0.032	0.042		0.003	0.002	0.906	0.86**
Kulumsa		-0.032	0.021	0.002	0.004	0.006	-0.019	-0.007	0.005	-0.002	0.015	0.041	0.004	0.003	0	0.822	0.86**
Holeta	TSW	-0.04	0.023	0.008	-0.001	0.007	-0.012	-0.021	-0.053	-0.041	0.026	0.03		0.001	0.003	0.896	0.83**
Kulumsa		-0.033	0.025	0.002	0.004	0.005	-0.02	-0.005	0.007	-0.002	0.011	0.032	0.004	0.002	0	0.796	0.83**
Holeta	BYp	-0.038	0.019	0.008	-0.001	0.005	-0.009	-0.022	-0.042	-0.053	0.045	0.029		0.003	0.001	0.881	0.83**
Kulumsa		-0.033	0.021	0.002	0.004	0.004	-0.017	-0.006	0.005	-0.002	0.021	0.028	0.004	0.003	0	0.798	0.83**
Holeta	HI	0.022	-0.011	-0.004	0.001	0.003	0.004	0.014	0.024	0.043	-0.056	-0.013		-0.002	0	-0.533	-0.51**
Kulumsa		0.019	-0.013	-0.001	-0.002	0.002	0.008	0.004	-0.003	0.002	-0.026	-0.008	-0.003	-0.002	0	-0.485	-0.51**
Holeta	CRB	0.004	-0.001	0	0	-0.002	0.001	0.002	0.004	0.003	-0.002	-0.448		-0.014	-0.02	-0.059	-0.46**
Kulumsa		0.004	-0.001	0	0	-0.002	0.001	0.001	0	0	0	-0.461	0.073	-0.015	-0.002	-0.048	-0.45**
Holeta	PRT																0.16ns
Kulumsa		0	-0.003	0	0	0.001	-0.001	0	0	0	-0.001	0.321	-0.105	0.007	0.001	-0.045	0.18*
Holeta	LN	0.004	-0.001	-0.001	0	-0.001	0.001	0.003	0.003	0.006	-0.004	-0.279		-0.023	-0.009	-0.104	-0.38**
Kulumsa		0.005	-0.001	0	-0.001	-0.001	0.001	0.001	-0.001	0	-0.003	-0.283	0.028	-0.024	-0.001	-0.107	-0.39**
Holeta	LNN	-0.004	0.003	0	0	0.003	0	-0.002	-0.007	-0.003	0.001	0.348		0.008	0.025	0.055	0.38**
Kulumsa		-0.002	0.001	0	0	0.003	0.001	0	0.001	0	0	0.341	-0.04	0.008	0.003	0.019	0.33**

Holeta	SYP	-0.043	0.023	0.009	-0.002	0.008	-0.012	-0.023	-0.049	-0.048	0.031	0.027		0.002	0.001	0.975	0.91**
Kulumsa		-0.037	0.026	0.002	0.004	0.005	-0.021	-0.006	0.006	-0.002	0.014	0.025	0.005	0.003	0	0.884	0.92**

Holeta Residual=0.027767; Kulumsa Residual=0.02908

Note: ns and **; non-significant and significant at p< 0.01 probability levels, respectively. DF: Days to 50% flowering; DM: Days to Maturity; PH (cm): Plant Height; PB: Number of Primary Branches; SB: Number of Secondary Branches; NC: Number of Capsules per plant; NSC: Number of Seeds per Capsule; TSW (g): Thousand Seed Weight; BYP (kg): Biological Yield per Plant; HI (%): Harvest index; CRB(%): Carbohydrate; PRT(%): Protein; OA(%): Oleic acid; LN(%): Linoleic acid; LNN(%): Linolenic aid and SYP (g): Seed yield per plant.

Plant height, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight and linolenic fatty acid had positive highly significant correlation at genotypic level with oil yield per plant but the direct effect was negative or negligible. At Kulumsa crude protein content had positive significant correlation at genotypic level with oil yield per plant but the direct effect was negative and negligible, this indicates that the indirect effects seem to be the reason of correlation.

Days to 50% flowering had negative highly significant correlation with oil yield per plant but positive negligible direct effect. This is mainly due to unfavorable indirect effect on oil yield per plant *via* days to 50% flowering.

Days to maturity, harvest index, carbohydrate content and linoleic fatty acid had negative highly significant correlation with oil yield per plant and negative direct effect on oil yield per plant. This indicates selections of reduced linoleic fatty acid containing genotypes are important to improve oil yield per plant.

The residual effects of the present study were 0.0042 and 0.005 at Holeta and Kulumsa, respectively which means the characters in the path analysis expressed the variability in oil yield per plant by 99.58% and 99.5%, respectively.

CONCLUSION

At genotypic and phenotypic levels seed yield per plant had highly significant positive correlations with plant height, number of primary braches per plant, number of secondary braches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant and oil yield per plant, indicating that selection based on these parameters would considerably enhance seed yield per plant. At both locations besides seed yield per plant, the oil yield per plant showed a highly significant positive correlation at genotypic and phenotypic levels with plant height, number of primary branches per plant, number of secondary branches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant and linolenic fatty acid, implying that selection based on these eight characters could enhance the oil yield per plant, which ultimately would lead to an increase in seed yield per plant.

At both locations oil yield per plant had positive and highly significant phenotypic and genotypic correlation coefficients with plant height, number of primary branches, number of secondary branches, number of capsules per plant, number of seeds per capsule, thousand seed weight, biological yield per plant, linolenic fatty acid and seed yield per plant, indicating that selection based on these parameters would considerably enhance oil yield per plant. Besides oil yield per plant, seed yield per plant showed a highly significant positive correlation at genotypic and phenotypic levels with plant height, number of primary braches per plant, number of secondary braches per plant, number of capsules per plant, number of seeds per capsule, thousand seed weight and biological yield per plant, implying that selection based on these characters could enhance the seed yield per plant, which ultimately would lead to an increase in oil yield per plant. At both locations, among all fatty acids, linoleic acid showed a highly significant negative association with linolenic acid at phenotypic and genotypic levels. The results obtained in the present study indicate that high oil yield per plant will result in high linolenic acid and reduce linoleic acids.

At both locations, the path coefficient analysis at phenotypic and genotypic level revealed that biological yield per plant had the highest positive direct effect on seed yield per plant, and a direct selection through biological yield per plant will be effective in order to improve seed yield per plant of linseed. At both locations, the path coefficient analysis at phenotypic and genotypic level revealed at that seed yield per plant had the highest positive direct effect on oil yield per plant, and a direct selection through seed yield per plant will be effective in order to improve oil yield per plant of linseed.

COMPETING INTERESTS

The authors declare that they have no competing interests.

REFERENCES

1. Dillman AC, Hopper TH. Effect of clirnate on the yield and oil content of flaxseed and on the iodine number of linseed oil. USDA Tech Bull. 1928;844:1-69.
2. Goyal A, Sharma V, Upadhyay N, Gill S, Sihag M. Flax and flaxseed oil: An ancient medicine and modern functional food. J Food Sci Technol. 2014;51(9):1633-1653.
3. Tyagi AK, Sharma MK, Mishra SK, Kumar R, Kumar P, Kerkhi SA. Evaluation of genetic divergence in linseed (*Linum usitatissimum* L.) germplasm. Progress Agric. 2015;15(1):128-133.

4. Wakjira A, Labuschagne MT, Hugo A. Variability in oil content and fatty acid composition of Ethiopian and introduced cultivars of linseed. J Sci Food Agric. 2004;84(6):601-607.

5. Tadesse T, Singh HA, Weyessa B. Correlation and path coefficient analysis among seed yield traits and oil content in Ethiopian linseed germplasm. Int J Sustain Crop Prod. 2009;4(4):8-16.

6. Mulusew Fikere MF, Firew Mekbib FM, Adugna Wakjira AW. Seed oil diversity of Ethiopian linseed (*Linum usitatissimum* L.) landraces accessions and some exotic cultivars. Afr J Biochem Res. 2013;7(6):76-85.

7. Naik BS, Dash J, Mohapatra UB. Path-coefficient analysis of seed yield and its components in linseed (*Linum usitatissimu*m L.): A review. Int J Advan Res. 2016;4(3):1571-1579.

8. Patial R, Paul S, Sood VK, Sharma D. A comparative analysis of genetic variability in linseed (*Linum usitatissimum* L.) under normal and late sown conditions. J Pharmacogn Phytochem. 2018;7(2):3956-3958.

9. Patterson HD, Williams E. A new class of resolvable incomplete block designs. Biometrika. 1976;63(1):83-92.

10. Miller PA, Williams JC Jr, Robinson HF, Comstock RE. Estimates of genotypic and environmental variances and covariances in upland cotton and their implications in selection. Agron J. 1958;50(3):126-131.

11. Dewey DR, Lu K. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron J. 1959;51(9):515-518.

12. Singh RK, Chaudhary BD. Biometrical methods in quantitative genetic analysis. Biometrical methods in quantitative genetic analysis. 1981.

13. Waitt DE, Levin DA. Genetic and phenotypic correlations in plants: A botanical test of Cheverud's conjecture. Heredity. 1998;80(3):310-319.

14. Worku N, Heslop-Harrison JS, Adugna W. Diversity in 198 Ethiopian linseed (*Linum usitatissimum*) accessions based on morphological characterization and seed oil characteristics. Genet Resour Crop Evol. 2015;62:1037-1053.

15. Patil VD, Makne VG, Chaudhari VP. Association analysis in linseed. Indian J Genet Pl Br. 1981;40(1):235-237.

16. Gauraha D, Rao SS. Association analysis for yield and its characters in linseed (*Linum usitatissimum* L.). Res J Agric Sci. 2011;2:258-260.

17. Reddy MP, Arsul BT, Shaik NR, Maheshwari JJ. Estimation of heterosis for some traits in linseed (*Linum usitatissimum* L.). J Agri Vet Sci. 2013;2(5):11-17.

18. Kumar N, Paul S. Selection criteria of linseed genotypes for seed yield traits through correlation, path coefficient and principal component analysis. J Anim Plant Sci. 2016;26(6):1688-1695.

19. Kaur V, Kumar S, Yadav R, Wankhede DP, Aravind J, Radhamani J, et al. Analysis of genetic diversity in Indian and exotic linseed germplasm and identification of trait specific superior accessions. J Environ Biol. 2018;39(5):702-709.

20. Bayrak A, Kiralan M, Ipek A, Arslan N, Cosge B, Khawar KM. Fatty acid compositions of linseed (*Linum usitatissimum* L.) genotypes of different origin cultivated in Turkey. Biotechnol Biotechnol Equip. 2010;24(2):1836-1842.

21. Pali V, Mehta N. Studies on genetic variability, correlation and path analysis for yield and its attributes in linseed (*Linum usitatissimum* L.). Plant Arch. 2013;13(1):223-227.

22. Bhatty RS. Nutrient composition of whole flaxseed and flaxseed meal. Flaxseed in Human Nutrition, AOCS press Publishers. 2019:22-42.

23. Tariq MA, Hussain T, Ahmad I, Saghir M, Batool M, Safdar M, et al. Association analysis in linseed (*Linum usitatissimum* L.). J Biol Agricult Healthcare. 2014;4(6):60-62.

24. Paul S, Satasiya P, Kumar A. Genetic variability, correlation and path coefficient analysis of introduced genotypes of linseed (*Linum usitatissimum* L.) in mid-hills of North-West Himalayas. J Pharmacogn Phytochem. 2020;9(1):1189-1192.