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Correlation and Path Analyses among Seed Yield and Oil Content in Ethiopian Linseed (*Linum usitatissimum* L.) Genotypes

Kidist Negash*[1], Tafese Altaye[1], Betelhiem Belete[1] and Assefa Yeshewalul[1]

[1] Department of Plant Scicence, Debre Berhan Uiverstiy, Debre Berhan, Ethiopia

* Corresponding Author, Emai Adress: kidnegash2008@gmail.com

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ABSTRACT

The improvement of a trait of interest can be achieved through both direct and indirect selection of characters that are highly heritable and easy to select. This study aimed to determine the type and degree of correlations between seed yield, yield-related traits, and oil content in linseed. A 7×7 basic lattice design was used to evaluate 49 linseed landraces at Holetta, including four released varieties. Analysis of variance revealed significant differences among genotypes for most of the traits at (P ≤ 0.01 and P ≤0.05) probability level, indicating genetic variability and the potential for selecting desirable genotypes. At both the genotypic and phenotypic levels, seed yield was positively and significantly correlated with days to 50% flowering,days to maturity, number of capsules per plant, harvest index, oil content, number of primary branches ,plant height, number of secondary branches and number of seed per capsule at (P ≤ 0.01 and P ≤0.05) probability level. The path analysis revealed that at the phenotypic level, harvest index had the highest positive direct effect, followed by the week influence of the the plant height,capsule per plant, number of seed per capsule,days to flowering,and days maturity on seed yield.Where as at the genotypic level days to maturity followed by number of seed per capsule,harvest index, plant height and days to flowering, number secondary branches per plant had considerable direct effect on seed yield.Overall, this study demonstrated significant variation among genotypes for the assessed traits, highlighting the potential for selection and hybridization of the genotypes once the findings are verified over time and across different regions.

Keywords: Genotypic, Phenotypic, Association, Yield determinants, and Selection criteria

1. INTRODUCTION

Linseed (*Linum usitatissimum* L.) is an ancient cultivated plant species that is grown for the extraction of strong stem fiber and seed oil, which are used in paints, varnishes, inks, putty, linoleum, and other industrial products (Juita *et al*., 2012). Almost all linseed species are annual plants or shrubs, and they are the only genus in the Linaceae family with non-dehiscent capsules suitable for modern cultivation (Getinet and Nigussie, 1997). Cultivated linseed refers to a species with two types: one for oil (linseed) and another for fiber. There are two varieties of grown linseed: fiber and oil linseed (Bremer *et al*. 2011). Linseed crop is well-suited to cooler, longer growing seasons and high rainfall locations at elevations ranging from 1600 to 2800mm. It is an annual crop that is largely grown in temperate climates (Mansby *et al*., 2000) and cool tropics including the highlands of Ethiopia. Linseed requires cool temperatures during its growing period to produce good yields.The mean temperature can range from 10 to 30 °C although the crop grows best within 21 and 22 °C. The linseed crop is suitable for low rainfall area and is generally raised where the average annual rainfall ranges from 45 to 75 cm.

The major linseed growing countries of the world are Canada, China, USA, Ethiopia and India Tadeusz Zaj *et al*. (2005). Europe produces 12.1% of the world's linseed, while Canada produces the most (43.8%), followed by China (15.0%), the United States (8.89%), India (7.95%), and Ethiopia (7.10%) (Mulusew *et al*., 2013). In terms of overall production and area, linseed comes in second. Thirty percent of Ethiopia's entire oil seed production comes from it. The Central Statistical Authority (2018) reports that the land area covered was 79044.51 hectares, with a productivity of 1.11 tons per hectare and a production of 882096.51 tons, which is rather low when compared to the global average yield of 2.75 tons / ha. (CSA, 2018). In terms of production, China leads globally with an annual output of about 258,000 metric tons. Following China, Belgium produces approximately 128,790 metric tons, and the United States contributes around 73,450 metric tons annually. Ethiopia is a significant producer of linseed oil, ranking as the sixth-largest producer globally. In 2019, the country produced approximately 34,011 metric tons of linseed oil.

The low productivity of linseed in Ethiopia is attributed to multiple challenges, including a narrow genetic base, a lack of high-yielding cultivars, and its cultivation in marginal areas with poor soil fertility. Additionally, the crop faces severe biotic and abiotic constraints such as fungal diseases, pest infestations, weed competition, and low fertilizer supply (Worku *et al*., 2012; Belayneh *et al*., 1990; Seegeler, 1983). Oil content, another critical trait, is often compromised due to genetic limitations and suboptimal agronomic practices. Although linseed possesses desirable traits such as earliness, high oil content, and adaptability to various environments, yield improvement remains complex due to its polygenic inheritance and susceptibility to environmental fluctuations.

With regard to this complexity, direct selection for yield is less successful, requiring alternative breeding strategies that concentrate on comprehending the connections between traits that contribute

to production (Legesse, 2010). For yield improvement, research has indicated that indirect selection using yield components works better than direct selection (Thakur and Saini, 1995; Ford, 1964). More effective breeding techniques can be facilitated by selection based on the linkages between agronomic features, their association with yield, and their direct contribution to yield (Dewey and Lu, 1959). Association and path coefficient studies have been identified as useful methods for finding important agronomic factors that influence yield and oil content in order to address these issues.

Although it cannot demonstrate causation, correlation analysis aids in establishing links between various features. However, path coefficient analysis is a better tool for trait selection in breeding programs because it gives a more accurate picture of the direct and indirect effects of different qualities on yield (Mirhadi *et al*., 2006). Breeding plans are most successful when the primary yield components have a positive correlation since enhancing one feature frequently improves others. Trade-offs between features, such as grain size versus number, and environmental interactions that could change correlations make selection difficult (Devender *et al*., 2016). Path analysis has been frequently used in breeding programs to assess the contribution of various traits to yield because of these complexities (Naik *et al*., 2016). In linseed breeding, where yield enhancement is limited by a number of reasons, this approach is especially useful.

Given the significant constraints in linseed production and the widening yield gap between Ethiopia and global averages, there is an urgent need to conduct a comprehensive study to identify key traits influencing seed yield and oil content. This research is essential for providing breeders with data-driven selection criteria to accelerate genetic improvement programs. Moreover, enhancing linseed productivity would contribute to economic growth, improve farmer livelihoods, and strengthen Ethiopia's position in the global oilseed market. So, correlation analysis combined with path analysis is a more effective approach for studying yield-contributing features (Naik *et al.*, 2016).In this regard, the study intends to identify the most efficient selection criteria for breeding high-yielding and high-oil-content linseed varieties in Ethiopia; determine the direct and indirect effects of important agronomic traits on linseed productivity; and evaluate the association among grain yield and yield-related traits using correlation and path coefficient analyses.

2. Materials and Methods

2.1. Descripition of experimental site

The experiment was carried out during the main cropping season of 2018–2019 at the Holetta Agricultural Research Center (HARC). Holetta (West Shewa Zone of Oromia Region) is located 30 kilometers west of Addis Ababa at 905′0″ N and 44o29′ 0″ E. It is 2400 meters above sea level. It is among the most representative oilseed-growing locations in the central highlands of Ethiopia. While the annual total rainfall varied between 900 and 1000 mm, the highest temperature ranged between 2 and 22 °C during the growing seasons (June–November) and the lowest temperature was 6 °C at night (Dinsa *et al*., 2020). According to Dinsa *et al*. (2020), the

experimental area's soil type was sandy soil, with a pH range of 6.0 to 7.5.

2.2. Experimental materials and procedures

The genotypes utilized in this study were obtained from the HARC's High and Medium Land Oil Crops Improvement Program. A total of 49 genotypes, including four nationally released varieties (Kulumsa, Bekoji-14, Belye 96, and Berene) (Table 1), were used for the study using a simple lattice design with two replications. A plot of four rows, each of 3 m x 0.8 m along with 20 cm space between rows, was used with a path between blocks of 0.5 m. Each genotype seed would be sown at a seed rate of 25 kg/ha using hand drilling in rows. A fertilizer rate of 23/23 kg/ha N/P_2O_5 was applied during planting by incorporating them with the soil prior to sowing to avoid direct contact of fertilizer with the seeds. Hand weeding was carried out uniformly to all plots to keep the plots weed-free.

2.3. Agronomic traits and oil content assessment

Data on oil content, growth, yield-ralated data, and crop phenology were evaluated throughout the trial. Five plants in the center rows in each plot were chosen at random, and phenological data such as days to 50% flowering (50% DF) and days to 90% physiological maturity (90% DM) were noted. DF was calculated during the study by counting the number of days after seeding at which 50% of the linseed plants in each plot had flowered. 90% DM, on the other hand, was determined by calculating the number of days required for 90% of the linseed plants in each plot to reach physiological maturity. Plant height (PH) was taken into account for growth characteristics. Five randomly chosen plants per plot had their plant height (cm) measured from ground level to the tip of the main stem at 90% of the crop's physiological maturity; the mean values will be used to analyze the data.

On the other hand, Number of primary branches per plant (NPB), Number of secondary branches(NSB), Number of seeds per capsule (SPC), Seeds yield per plant (SY/P), Seed yield per plot **(**SY**),** and Thousand seed weight (TSW), Biological yield per plot (BY) was assessed as yield-related attributes. The NPB and NSB was assessed by counting the number of branches per plant, arising from the main plant at maturity and the number of branches, extending from the primary branches from five randomly taken plants and expressed as an average five plants per plot respectively. The SPC was recoreded by counting the average number of seeds per capsule obtained from five randomly selected plants. SY/P and Seed yield per plot SY also taken by measuring the weight of seeds of five randomly taken plants and seed yield per plot in grams after moisture of the grain is adjusted to 7%. The seed yield per plot was converted to seed yield per hectare. TSW was determined from randomly sampled grains incurred from the total harvested storable grains of each plot. A seed counter and sensitive balance will be used to determine the number of seeds and their weight (thousand seed weight). BY was recorded by weighing the above ground whole biomass of all the plants harvested from the two central rows before threshing and converted to biomass yield per hectare, and Harvest index (HI) was computed as ratio of dry seed yield to the above ground biological yield by using (Debouck and Hidalgo, 1986) formula as Harvest index =

$\frac{\text{Seed yield kg/ha}}{\text{Biological yield kg/ha}}$, and oil content (OC) was measured as the proportion of oil in the seed to total oven dried seed weight by nuclear magnetic resonance spectrometer (Robertson and Morrison, 1979).

Table 1. Description of linseed genotypes used in the study

No	Genotypes	Geographical Origin	Altitude (masl)	No	Genotypes	Geographical Origin	Altitude (masl)
1	Acc 10101	Oromiya	1980	26	Acc 243797	Amhara	2290
2	Acc 235166	Tigray	1990	27	Acc 10053	Amhara	1980
3	Acc 207786	Oromiya	2740	28	Acc 10054	Amhara	1930
4	Acc 230029	Oromiya	2560	29	Acc 10055	Amhara	1970
5	Acc 233992	Tigray	1930	30	Acc 241822	Amhara	2750
6	Acc 233993	Tigray	1900	31	Acc 10105	Oromiya	1800
7	Acc 233996	Tigray	1860	32	Acc 10056	Amhara	2500
8	Acc 234002	Tigray	1850	33	Acc 10059	Amhara	1730
9	Acc 234011	Tigray	2100	34	Acc 10067	Amhara	1880
10	Acc 10091	Amhara	1560	35	Acc 10068	Amhara	1960
11	Acc 234012	Tigray	2080	36	Acc 10086	Oromiya	1740
12	Acc 234005	Tigray	1850	37	Acc 10097	Oromiya	1900
13	Acc 238282	Amhara	2440	38	Acc 10117	Oromiya	1950
14	Acc 235019	Amhara	2040	39	Acc 10121	Oromiya	2600
15	Acc 235165	Tigray	1850	40	Acc 13712	Oromiya	3040
16	Acc 237501	Tigray	1820	41	Acc 10131	Amhara	2530
17	Acc 241820	Amhara	2280	42	Acc 10132	Amhara	2530
18	Acc 10114	SNNP	1800	43	Acc 10133	Amhara	2700
19	Acc 241825	Amhara	3190	44	Acc 10145	Oromiya	2050
20	Acc 242596	Tigray	1550	45	Acc 13679	Oromiya	1970
21	Acc 241829	Amhara	2945	46	Kulumsa	Released in 2016	2200- 2800
22	Acc 242588	Tigray	2220	47	Bekoji-14	Released in 2014	2200- 2800
23	Acc 235161	Tigray	2210	48	Belaye 96	Released in 1996	1800- 2800
24	Acc 242590	Tigray	1710	49	Berene	Released in 2001	1800- 2800
25	Acc 242592	Tigray	1810				

2.4. Data Analysis

2.4.1. Analysis of Variance (ANOVA)

The data were subjected to analysis of variance (ANOVA) using R software version R 4.4.2 as per the model for simple lattice design.The comparison of mean performance of genotypes was done following the significance of mean squares using Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Table 2.Analysis of variance (ANOVA) in simple lattice design and expected mean square

Source of variation	Df	SS	Mean square	F value	Expected mean squares
Replication (r)	r-1	SSR	MSr	$\frac{MSr}{MSe}$	$\sigma^2 k + \sigma r2$
Treatment (unadj.)	k^2-1	SST (unadj.)	MST (unadj.)	$\frac{MST(unadj)}{MSE}$	$\sigma \frac{k}{k+1} \sigma t^2$
Blocks with in replication	r (k-1)	SSB(adj.)	MSb	$\frac{MSB}{MSe}$	$\sigma^2 + \sigma t^2 + k\, \sigma t^2$
Intra block error	(k-1) (rk-k-1)	SSE	MSE		σ^2
RBCD error	(t-1)(r-1)	SSe	Mse		$\sigma^2 e$
Total	rk^2-1	SST			

r = Number of replications. k^2 = Number of treatments, k= Number of plots in a block, SS = Sum square, MS = Mean square, σ^2= Variance, t = Number of genotypes, MSE = Mean squares for error and $\sigma^2 e$= Error variance. RCBD= Randomized complete block design

Relative efficiency $= \frac{\text{Mean square errer in RBCD design}}{\text{Mean square error in simple lattice}}$ x 100 according to (Gomez and Gomez (1984)

2.4.2. Estimation of Correlation Coefficients

Phenotypic and genotypic correlation coefficients were estimated using the standard procedure suggested by Miller *et al*. (1958), from corresponding variance and covariance components as:

Phenotypic correlation coefficient

$(rp_{xy}) = \frac{\sigma_{p\,xy}}{\left(\sqrt{\sigma^2 p_x * \sigma^2 p_y}\right)}$

Genotypic correlation coefficient $(rg_{xy}) = \frac{\sigma_{g\,xy}}{\left(\sqrt{\sigma^2 g_x * \sigma^2 g_y}\right)}$

Where r_{pxy} is phenotypic correlation coefficient and r_{gxy} is genotypic correlation coefficient between characters x and y; σ g_{xy} and σ p_{xy} are genotypic covariance and phenotypic covariance between characters x and y, respectively. σ^2_{px} and σ^2_{gx} are phenotypic and genotypic variances for character x and σ^2_{py} and σ^2_{gy} are phenotypic and genotypic variances for character y.

Phenotypic correlation coefficient was tested for its significance using the formula suggested by Sharma (1998).

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}$$

Genotypic correlation coefficient was tested with the following formula suggested by Robertson (1959).

$$t = \frac{rg_{xy}}{SErg_{xy}}$$

where, $SErg_{xy} = \sqrt{\frac{(1-r^2{}_{g_{xy}})^2}{2h^2{}_x * h^2{}_y}}$

$SErg_{xy}$ = Standard error of genotypic correlation coefficient between character X and Y

h^2x = heritability for character X

h^2y = heritability for character y

The calculated value was compared with the tabulated 't' value at the 5% and 1% levels of significance for both phenotypic and genotypic correlations.

2.4.3. Path Coefficient Analysis

Path coefficient analysis was conducted as suggested by Dewey and Lu (1959) using the phenotypic as well as genotypic correlation coefficients to determine the direct and indirect effects of yield components on seed yield based on the following relationship.

$r_{ij} = Pij + \sum r_{ik} P_{kj}$

Where r_{ij} is mutual association between the independent traits (i) and the dependent trait, yield (j) as measured by the correlation coefficient, p_{ij} is component of direct effect of the independent trait (i) on the dependent variable (j); and $r_{ik}p_{kj}$ is the components of indirect effect of a given independent trait (i) on the dependent traits (j) *via* all other independent traits (k). The contribution of the remaining unknown factor was measured as the residual factor (P_R), which is calculated using the formula of Dewey and LU (1959) as:

$$P_R = \sqrt{(1-\sum r_{ij} p_{ij})}.$$

The magnitude of P_R indicates how best the causal factors account for the variability of the dependent factor (Singh and Chaudhary, 1999). That is, if the P_R value is small (for instance, nearly zero), the dependent character considered (seed yield) is fully explained by the variability in the independent characters, whereas a higher P_R value indicates that some other factors which have not been considered, need to be included in the analysis to account fully the variation in the dependent character (seed yield).

3. Results and Discussion

3.1. Analysis of Variance

The analysis of variance revealed significant differences among the genotypes studied for most of the characters studied, namely days to 50% flowering, days to maturity, primary branches per plant, secondary branches per plant, plant height, capsules per plant, seeds per capsule, seed yield kg/ha,harvest indexand oil content) have shown significant variations at ($P \leq 0.01$ and $P \leq 0.05$) probability level (Table 3).This considerable differences for most of the traits under the study indicated sufficient scope for improvement in the desirable direction for Ethiopian linseed genotypes.However,the remaining three traits (biological yield kg/ha,seed yield per plant and 1000-seed weight) were not statistically different for the evaluated genotypes which indicated lowe genetic variability and selection for these traits might be difficult.The highest mean square was manifested by seed yield ha^{-1} (3318592) while the least mean square was depicted by oil content (4.22).

The analysis of variance (ANOVA) revealed a block mean square of 196,763 and an intra-block error mean square of 102,098.These values provide insights into the effectiveness of the simple lattice design in controlling environmental variation.The relatively high block mean squares suggests that there were significant differences between the replications, indicating the presence of environmental heterogeneity across the field.This justifies the need for blocking in the experimental design, as it helps to account for large-scale environmental variations that could otherwise confound genotype performance.The intra-block error mean square represents the residual variation within incomplete blocks after adjusting for genotype effects.The result suggests that some variation remains uncontrolled.This may be due to micro-environmental differences within each replication that were not fully accounted for by the lattice arrangement.

A high amount of genetic variability for most of these characters has also been reported by some other workers *viz*.,Bibi *et al.* (2013), Yadav *et al*. (2014), Sharma *et al.* (2016) and Ronika *et al*. (2020) observed highly significant differences for plant height, number of branches per plant,number of capsules per plant, and harvest index.

Table 3. Mean squares for the different sources of variations of 13 quantitative traits for 49 linseed genotypes evaluate at Holotta

BY=Biological yield (kg ha^{-1}), DF = Days to 50% flowering, df= Degree of freedom, DM = Days to maturity, CPP= number of capsules per plant, CV=Coefficient of variance,HI=Harvest index, ns = none significant, ** and *= Significant at 1% and 5% probability level

Trait	Rep (df=1)	Blocks/reps (adj.) (df=6)	Treatments (Unadj(df=48)	Intra-block Error (df=42)	RCBD error (df=48)	RE of SL over RCBD	CV (%)
DF	29.76	45.09	50.68*	36.23	37.34	103.06	7.40
DM	658.33	139.92	388.22*	68.69	77.6	112.97	5.56
PB	17.91	8.15	13.63*	8.03	8.04	100.12	5.39
SB	0.70	6.46	6.90**	2.93	3.37	115.02	4.25
PH	5.07	111.42	327.89**	29.71	39.93	134.40	14.88
CPP	231.89	132.57	383.95**	63.38	72.03	113.65	10.52
SPC	3.83	6.65	10.39**	5.84	5.94	101.71	5.74
SY/P	2.25	0.15	0.78^{ns}	0.55	0.35	63.64	12.86
BY	1197478.00	5231946.00	6288115.00^{ns}	3344288.00	3816202.00	114.11	17.55
SY	313275	69665	318592 **	98126	94568	96.37	8.87
HI	28.24	40.01	26.17**	16.42	19.37	117.97	9.54
TSW	0.05	1.11	0.78^{ns}	0.75	0.84	112.00	7.95
OC	0.70	4.17	4.22**	1.87	2.15	114.97	11.34

respectively,OC= oil content ,PH=Plant height (cm),RCBD=Randomized complete block design, Rep= Replication, RE of SL= relative efficiency of simple lattice,PB = Number of primary branches per plant, SB=Number of secondary branches SPC= Number of seed per capsule,SY =Seed yield (kg ha^{-1}), SYP=seed yield per plant (g), TSW = 1000 seed weight (g)

3.2.Correlation of seed yield with other characters

Considering the possibility of high yield through yield attributes, as primary interest in crop improvement.Conversely, yield components not only directly affect the yield, but also indirectly by affecting other yield components in negative or positive ways (Ravikumar and Roopa, 2008).Positive significant correlation due to the effect of genes can be the result of strong coupling linkage between their genes, or the characters may be the product of pleiotropic genes that control these characters in the same direction (Singh, 2001).Bhima *et al*. (2016**)** stated that a positive correlation between two desirable traits makes the job of the plant breeder easy for improving both traits simultaneously, while a negative correlation expressed between two desirable traits makes it impossible to achieve significant improvement in both traits.

The estimates of phenotypic and genotypic correlation coefficients between each pair of characters are presented in Table 4.The result showed that the genotypic and phenotypic correlation coefficients were similar in directions for most of the characters under studied in this research, while in magnitude, genotypic correlations were commonly higher than corresponding phenotypic correlations.Similarly, Kumar and Paul (2016), Patial *et al*. (2018), and Upadhyay *et al*. (2019) observed that genotypic correlation coefficients were higher than phenotypic correlation coefficients for nearly all of the characteristics studied in their research. Seed yield showed positive and significant correlations at ($P \leq 0.01$ and $P \leq 0.05$) probability level with days to 50% flowering,days to maturity,number of capsules per plant, harvest index, oil content, number of primary branches ,plant height, number of secondary branches and number of seed per capsule at both genotypic and phenotypic levels.The existence of a positive correlation between seed yields and yield-related traits helps identify traits that could be used for indirect selection for the improvement of seed yield in the tested genotypes.

Almost similar findings have been reported by most of the workers in linseed. For instance,Paul *et al*. (2016) reported for harvest index was positive and significantly correlated with seed yield;Fekadu (2020) for date maturity and oil content significant correlation with seed yield;Rahimi *et al.* (2011) observed positive associations between seed yield and most of the traits in linseed.Acomparable finding was also reported by Patial *et al*. (2018) Meena *et al*. (2018), and Shiva *et al*. (2021).

Moreover in the present study,genotypic and phenotypic correlations among yield related components indicated in (Table 4).Days to maturity showed a positive and significant correlation with days to 50% flowering ,plant height and oil content at both genotypic and phenotypic levels which indicated that early-maturing genotypes are generally genotypes with shorter plant height.Whereas days to maturity registered for the traits negative and significant correlations with number of capsules per plant,number of seed per capsule , number of primary branches

and secondary branches per plants.A significant positive correlation was observed among the genotypes for capsules per plant with number primary and secondary branches per plant at both genotypic and phenotypic levels,which indicates the merits of these characters to improve seed yield.Although capsules per plant showed a negative significant correlation with days to 50% flowering, days to maturity, and oil content, suggesting that early flowering, days to maturity, a higher and oil content may be inversely related to capsules per plant.

Oil content showed highly positive and significant correlation with days to maturity and plant height at both genotypic and phenotypic levels; although oil content showed significant and negative correlation with numbers of primary and secondary branches pre plant and harvest index.Similar results were reported among yield related components by Ashish *et al*, (2015) that number of secondary branches per plant had positive and significant genotypic correlation with number of capsules per plant;Ranjana *et al.(*2018) who found highly significant and positive correlation between days to 50 per cent flowering and days to maturity; Gauraha *et al.* (2011) and Kumar and Paul (2016) who report significant positive correlations of number of secondary branches per plant with number of capsules per plant.

Based on the present finding, it is logical to give more attention to those traits having the greatest positive influence on seed yield ha^{-1}**,** which were days to 50% flowering,days to maturity, number of capsules per plant, harvest index, oil content, number of primary branches ,plant height, number of secondary branches and number of seed per capsule at both genotypic and phenotypic levels in the tested linseed genotypes for improvement in the breeding program.

3.3. Path Coefficient Analysis

In the present study, path analysis was carried out for 9 traits that have significant correlation with seed yield (Table 5).At the phenotypic level, harvest index had the highest positive direct effect, followed by the week influence of the plant height,capsule per plant, number of seed per capsule,days to flowering,and days maturity on seed yield.The harvest index positive direct effect on seed yield increase through the positive indirect effects of number of seed per capsule,plant height, capsule per plant, number primary and secondary branches per plant.Hence, these traits may be directly attributed to the improvement of seed yield and are important in the selection of better genotypes in linseed genotypes.Yet, days to 50% flowering,days to maturity and oil content had negative indirect effects on seed yield via harvest index.

The genotypic direct and indirect effect of different characters on seed yield ha^{-1} is presented in (Table 6).The path coefficient analysis revealed that days to maturity followed by number of seed per capsule,harvest index, plant height and days to flowering**,** number secondary branches per plant had a positive genotypic correlation with seed yield, which had exerted a considerable direct effect on seed yield**.**Days to maturity**,** contributed to seed yield mainly via their week and positive indirect effect with

plant height**,** oil content and days to flowering**.**

This study is consistent with the findings of Tadesse *et al*. (2009) and Chaudhary *et al.* (2014) both found that harvest index had a favorable direct effect on seed yield per plot.The scientists also advised that these qualities should be considered while establishing a linseed selection strategy for high-yielding cultivars.This result is consistent also with the findings of Paul *et al.* (2015) and;Tariq *et al.* (2014) and Ranjana *et al.* (2018), who discovered that the number of capsules per plant had the greatest positive phenotypic direct effect on seed yield per plot, and that selection for number of capsules per plant would be the most effective means of indirectly selecting for higher linseed seed yield.Singh.and Tewari, and Chaudhary *et al*. (2014) similarly found that harvest index and number of capsules per plant had a favorable direct effect on seed yield per plot.These properties, according to the authors, should be taken into account while establishing a linseed selection strategy for high yield variants.

Table 4. Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficient of yield and yield related traits for 49 linseed genotypes evaluated at Holota

Traits	DF	DM	PB	SB	PH	CPP	SPC	HI	OC	SY
DF	**1**	0.2098**	0.1273**	-0.1128**	0.1353*	-0.1427**	0.0676*	-0.0022*	0.0895**	0.0621**
DM	0.7545 **	**1**	-0.17195**	-0.15485**	0.6435*	-0.04855*	-0.01365*	-0.12445**	0.31855**	0.1392**
PB	-0.2111*	-0.3282*	**1**	0.4319*	0.0562**	0.5192*	-0.0307 ns	0.0854**	-0.2206**	0.0863*
SB	-0.0989*	-0.2997*	0.616*	**1**	-0.0111*	0.5272**	-0.1187*	0.0509*	-0.2639*	0.0608**
PH	0.3696**	0.8518**	-0.0728*	-0.3812*	**1**	0.1041*	-0.0073ns	0.1043*	0.3195*	0.4061*
CPP	-0.4687*	-0.0957*	0.7895*	0.629**	-0.0751*	**1**	-0.1986 *	0.0157 ns	-0.1224*	0.1031**
SPC	0.2355*	-0.0209*	0.588**	0.4455**	0.3831*	-0.1336 ns	**1**	0.2047*	0.1482*	0.1680*
HI	-0.1197*	0.2827**	0.249*	0.6577*	0.4781**	0.3953*	1.0002**	**1**	-0.0667*	0.8502**
OC	-0.0664**	0.6053**	-0.5013ns	-0.1943ns	0.9755**	0.0592*	-0.3908*	-0.4838 ns	**1**	0.0177**
SY	0.2321**	0.4027*	0.2575*	0.3002*	0.5406**	0.1802*	0.6620**	1.0009**	0.0846*	**1**

DF = Days to 50% flowering, DM = Days to maturity, CPP = number of capsules per plant , (cm), HI = Harvest index, OC = oil content, PB = number of primary braches PH = Plant height, SB = Number of secondary branches, SPC = Number of seed per capsule, SY = Seed yield (kg ha^{-1}),*Significant at 5 per cent level; ** = Significant at 1 per cent level and ns = none significant

Table 5. Estimates of direct (bold diagonal) and indirect effect (off diagonal) at phenotypic level for different characters on seed yield in linseed genotypes evaluated at Holota

Traits	DF	DM	PB	SB	PH	CPP	SPC	HI	OC	pr
DF	**0.0350**	0.0132	-0.0066	0.0001	0.0382	-0.0136	0.0016	-0.0018	-0.0040	0.0621**
DM	0.0073	**0.0628**	0.0089	0.0002	0.1815	-0.0046	-0.0003	-0.1025	-0.0141	0.1392**
PB	0.0045	-0.0108	**-0.0517**	-0.0005	0.0159	0.0497	-0.0007	0.0704	0.0097	0.0863*
SB	-0.0040	-0.0097	-0.0223	**-0.0012**	-0.0031	0.0504	-0.0028	0.0419	0.0116	0.0608**
PH	0.0047	0.0404	-0.0029	0.0000	**0.2823**	0.0100	-0.0002	0.0859	-0.0141	0.4061*
CPP	-0.0050	-0.0030	-0.0268	-0.0007	0.0294	**0.0956**	-0.0047	0.0129	0.0054	0.1031**
SPC	0.0024	-0.0009	0.0016	0.0002	-0.0021	-0.0190	**0.0237**	0.1686	-0.0065	0.1680*
HI	-0.0001	-0.0078	-0.0044	-0.0001	0.0294	0.0015	0.0049	**0.8238**	0.0030	0.8502**
OC	0.0031	0.0200	0.0114	0.0003	0.0902	-0.0117	0.0035	-0.0550	**-0.0441**	0.0177**

DF = Days to 50% flowering, DM = Days to maturity, CPP= number of capsules per plant , (cm), HI = Harvest index, OC= oil content, PB = number of primary braches PH = Plant height, SB = Number of secondary branches, SPC = Number of seed per capsule, SY = Seed yield (kg ha^{-1}) SYP=seed yield per plant,*Significant at 5 per cent level; ** = Significant at 1 per cent level

Table 6.Estimates of direct (bold diagonal) and indirect effect (off diagonal) at genonotypic level for different characters on seed yield in linseed genotypes evaluated at Holota

Traits	DF	DM	PB	SB	PH	CPP	SPC	HI	OC	gr
DF	**-0.4835**	0.5994	0.0514	-0.0174	0.0282	-0.0436	0.1098	-0.0312	0.0191	0.2321**
DM	-0.3648	**0.7944**	0.0799	-0.0526	0.0650	-0.0089	-0.0097	0.0737	-0.1742	0.4027*
PB	0.1021	-0.2607	**-0.2433**	0.1082	-0.0056	0.0735	0.2742	0.0650	0.1442	0.2575*
SB	0.0478	-0.2380	-0.1499	**0.1757**	-0.0291	0.0585	0.2077	0.1715	0.0559	0.3002*
PH	-0.1787	0.6766	0.0177	-0.0670	**0.0763**	-0.0070	0.1786	0.1247	-0.2807	0.5406**
CPP	0.2267	-0.0760	-0.1921	0.1105	-0.0057	**0.0931**	-0.0623	0.1031	-0.0170	0.1802*
SPC	-0.1139	-0.0166	-0.1431	0.0783	0.0292	-0.0124	**0.4662**	0.2619	0.1124	0.6620**
HI	0.0579	0.2246	-0.0606	0.1155	0.0365	0.0368	0.4682	**0.2608**	0.1392	1.0009**
OC	0.0321	0.4809	0.1220	-0.0341	0.0744	0.0055	-0.1822	-0.1262	**-0.2877**	0.0846*

DF = Days to 50% flowering, DM = Days to maturity, CPP= number of capsules per plant , (cm), HI = Harvest index, OC= oil content, PB = number of primary braches PH = Plant height, SB = Number of secondary branches, SPC = Number of seed per capsule, SY = Seed yield (kg ha^{-1}),*Significant at 5 per cent level; ** = Significant at 1 per cent level

4.Conclusion

The study indicated the presence of wide genetic variation among the tested linseed genotypes to develop high-yielding varieties.Correlation analysis showed that seed yield ha^{-1} had a highly significant and positive association with days to 50% flowering,days to maturity, number of capsules per plant, harvest index, oil content, number of primary braches ,plant height, number of secondary branches and number of seed per capsule at both genotypic and phenotypic levels.The significant and positive association between seed yield $ha^{-1}$and its components at both levels showed that characters contributed positively towards yield and emphasis should be given to those traits when selecting for high seed yield.The path analysis showed that, at the phenotypic level, harvest index had the highest positive direct effect, followed by the week influence of the the plant height,capsule per plant, number of seed per capsule,days to flowering,and days maturity on seed yield.Where as at the genotypic level days to maturity followed by number of seed per capsule,harvest index, plant height and days to flowering**,** number secondary branches per plant had a positive genotypic correlation with seed yield, which had exerted a considerable direct effect on seed yield.Moreover,the seed yield and oil content were positively correlated, selecting for higher yield could simultaneously improve oil content. Further multi-location trials are recommended to validate the stability and adaptability of high-yielding genotypes across different agro-ecological zones.

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Conflict of Interest Statement

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this manuscript.

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