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Research Article

Variability and Performance Evaluation of Released Linseed Varieties for Yield and Related Traits in South Gondar Zone, Ethiopia

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Even though numerous improved linseed varieties have been released in Ethiopia, the mean seed yield per unit area of the crop remains low due to poor access to improved varieties. To improve the crop's production and productivity, testing the performance of improved linseed varieties in potential agroecologies where the varieties have never been grown before is an essential activity. Additionally, understanding the amount of genetic variation that is available within the linseed germplasm using genetic traits is also critical to the successful and sustainable improvement program of linseed. The main objective of this research was to evaluate the performance of improved linseed varieties and their genetic variability for seed yield and related traits in the Lay Gayint district, South Gondar zone, Ethiopia. The experiment was conducted following a randomized complete block design with three replications, and nine released varieties and one local linseed variety were assessed in the study. Seed yield and yield-related traits were collected and subjected to a combined analysis of variance. The result shows that there was a significant difference between the tested linseed varieties for all examined traits, indicating the existence of genotypic variation between the experimental linseed varieties. The varieties Berene, CI-1525, Yadeno, and Furtu produced relatively higher seed yields, with an average of 894.28, 879.36, 823.28, and 820.85 kg·ha^{-1}, respectively. Approximately 70% of the evaluated varieties produced higher seed yields than the local variety. The analysis of variance also resulted in a significant variety by year interaction effect for height of the plant, number of tillers, capsule number/plant, and seed yield, indicating the inconsistency of the varieties across the two growing seasons. Higher genotypic coefficient of variation (GCV) and phenotypic coefficients of variation (PCV) (>20%) coupled with high heritability estimated values (>80%) were observed for seed yield per hectare, the number of capsules per plant, and tiller number. Seed yield and the number of capsules per plant provided higher genetic advance estimations. To make the selection more successful, breeders should concentrate on traits with high genotypic variance and heritability estimates, and promising varieties should be introduced and dispersed within the research area.

1. Introduction

Ethiopia's oilseed crop, which is quickly expanding to fulfill both domestic and international demand, is critical to the country's foreign exchange revenues and income. Oilseed exports account for about 11.5% of Ethiopia's total export profits (https://www.trade.gov/country-commercial-guides/ethiopia-market-overview). Oilseeds supplied 5.90% (766167.66 ha) of grain crop area and 2.27% (7,774,444.17 quintals) of grain production to Ethiopia's national grain total [1]. Niger seed, sesame, and linseed accounted for 1.48% (19.766.00 ha), 2.85% (369,897.32 ha), and 0.61% (78,921.37 ha), respectively, of the grain crop area. These crops account for 0.63%, 0.76%, and 0.24% of grain crop production, respectively.

Linseed (*Linum usitatissimum* L.) is an annual field crop that belongs to the family Linaceae. The haploid chromosome number of L. *usitatissimum* is 15 ($n = 15$), and the diploid chromosome number is 30 ($2n = 30$). It is an important oil crop cultivated worldwide for oil and fiber. Five countries (Canada, China, Russia, India, and USA) provide 72.50% of global linseed production. The European top producer is the Russian Federation (13.86%) [2]. The crop is largely grown in temperate climates and cool tropics, including the highlands (>2500 m above sea level) of Ethiopia. It thrives best at altitudes of 2200–2800 m above sea level in Ethiopia, but it can also be grown at 1200 m and 3420 m above sea level [3]. Linseed grows in cold weather ranging from 10–30°C, but it produces the best harvests when temperatures are between 21–22°C during the growth period. In fact, linseed is the second biggest oil plant in terms of acreage cultivated and yield in the highland areas of Ethiopia, after Niger seed [4]. In Ethiopia, linseed supplies 10.3% (78,921.37 ha) of the oilseed crop area and 10.35% (80456.64 tons) of the production of the national oilseed total [1].

Despite its diverse uses for the local oil sector and foreign currency earnings, linseed productivity in Ethiopia is characterized by low yield, with an average yield of 1.02 t/ha [1], compared to more than 1.5 t/ha in developed countries [5]. One of the major production barriers affecting linseed productivity is a lack of access to improved varieties, which is why the majority (>90%) of Ethiopian farmers use unimproved seeds [6]. On the contrary, the Ethiopian Institute of Agricultural Research has released more than 19 improved linseed varieties [7] that, if properly assessed and produced by farmers, have the potential to increase crop output. To identify high-yielding improved linseed varieties and assess genetic variability using landraces and some improved varieties, studies have been conducted in southwestern Ethiopia [3], south Tigray, Ethiopia [8], Bale-Goro, Ethiopia [9], and the south-eastern highlands of Ethiopia [10]. The highland areas of the South Gondar zone are among the promising linseed producing areas, and this is the area's only major oil crop and is grown using local varieties. Despite its potential, there has been no analysis, or identification and production of improved linseed varieties in the Amhara region in general and in the South Gondar zone in particular. Testing the performance of improved linseed varieties in specific and potential agroecologies where improved varieties have not previously been grown is an indispensable activity.

Every crop improvement effort begins with a breeder looking into the existence of genetic variability for the desired traits [11]. Thus, the genetic variation in the materials at hand is critical to the success of any breeding program. This is due to the importance of genetic variation in influencing the amount of genetic progress that may be made through selection. According to Adugna [12], Ethiopia is believed to be the secondary place of variation, and it is the world's fifth largest linseed producer. Ethiopia's diverse agroclimatic conditions may have led to the country's linseed crop diversification. However, having variance in a population is not enough to improve desired qualities, and little or no research on the genetic variability of released linseed varieties has been conducted. As a result, breeders must evaluate the degree and distribution of genetic diversity in the genetic materials that are readily available. Therefore, this study was proposed to assess the performance of improved linseed varieties in the South Gondar zone, Lay Gayint district and to determine the degree of genotypic variation among improved linseed varieties.

2. Materials and Methods

2.1. Description of Study Area. The experiment was carried out at Lay Gayint district for two vegetation seasons in 2019 and 2020 (June-November). Lay Gayint, lit "Upper Gayint," is located in the Amhara Region of Ethiopia, 75 km from Debre Tabor and 180 km from Bahir Dar, the administrative center of the Amhara region. The district is located at 12° 00′ 0.00″ N latitude and 38° 19′ 60.00″ E longitude (https://latitude.to/articles-by-country/et/ethiopia/301492/lay-gayint). Lay Gayint's elevation ranges from 1494 to 3991 m above sea level and is divided into four climatic zones: lowland (12.5%), midland (39.42%), highland (45.39%), and alpine (2.71%) [13]. Lay Gayint soil types are classified as brown (55%), red (15%), black (15%), grey (10%), and other (5%) [14]. The type of soil for Lay Gayint is categorized as Lithic Leptosol (50%), Eutric Leptosol (30%), and Eutric Cambisol (20%) by the World Reference Base for Soil Resources, 2014 (update 2015), as mapped by FAO [15] and generated by ILRI, CIAT, and CCAFS [16] using the site's geographical values of coordination. The detailed seasonal rainfall and temperature values for the study area are presented in Figures 1 and 2.

2.2. Experimental Design and Field Work. A randomized complete block design (RCBD) with three replications was used in the study. The experimental plots were 1.6 m × 4 m (6.4 m^2) in size, with rows separated by 0.2 m. The distance between plots and blocks was 0.5 m and 1.5 m, respectively. Each plot had eight rows, with the middle six used for the collection of the data and the two outermost rows were used as border rows. Every year, all agronomic field operations at the experimental sites are carried out. The experimental sites were plowed three times with draught animals called oxen before planting, and 25 kg of seed per hectare was used for planting. After weighing the seeds with a sensitive balance, they were assigned to each row, and drilling was used for planting. Planting occurred during the first week of July 2019 and the last week of June 2020, following the onset of rain and when the locations received the moisture required for germination. Hand weeding was used three times during the experiment's growing seasons, and 30 kg·ha^{-1} of urea and 50 kg·ha^{-1} of NPS fertilizer were used according to crop recommendations. Harvesting begins in the last week of November of each cropping year, based on the maturity time of the varieties.

2.3. Experimental Materials. Nine improved linseed varieties from the Kulumsa and Holleta Agricultural Research Centers, as well as one local check from farmers, were collected and evaluated for performance and variability over seasons (Table 1). The varieties are released for the Bale, Arsi, and Central Highlands of Ethiopia, at an altitude of

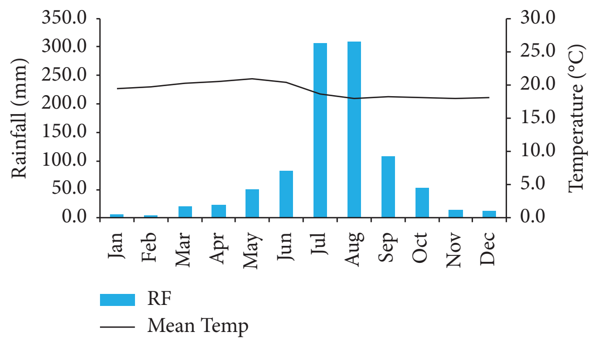

Figure 1: Monthly average rainfall and temperature distribution of Lay Gayint in the 2019 cropping season.

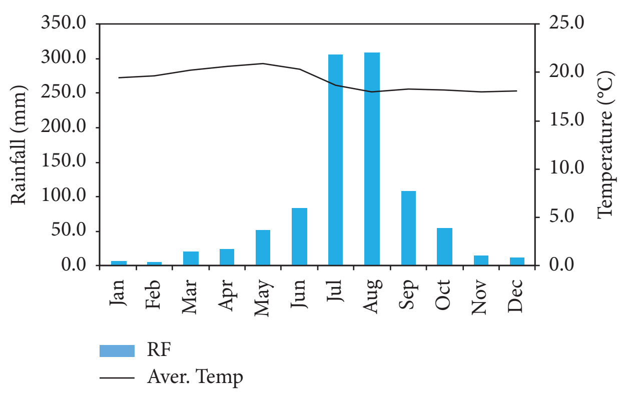

Figure 2: Monthly average rainfall and temperature distribution of Lay Gayint in the 2020 cropping season.

2000–2800 m above sea level. All the varieties under study are characterized by a brown seed color.

2.4. Data Collection. Data on flowering days, maturity days, tiller number/plant, capsule number/plant, plant height, and seed yield per hectare were collected from the six middle rows. Data for days to flowering, days to maturity, and seed yield were collected on a plot-by-plot basis. Plant height, tiller number per plant, and capsule number per plant were collected from ten randomly selected plants. Days to flowering were calculated from the date of planting when 75% of the crop stand produced the first flower. The number of days from planting to physiological maturity of the plants was used to compute the days to maturity. Plant height was taken as the average height of ten randomly selected plants, measured from the base to the tip of the plant. The number of tillers per plant was recorded as the average number of tillers from ten randomly sampled plants taken from the six middle rows of the plots that produced productive capsules. The number of capsules per plant was calculated as the mean number of capsules collected from ten randomly selected plants that were chosen for the measurement of the number of tillers per plant. Seed yield (kg ha^{-1}) was calculated as the entire seed yield produced from the plants harvested and threshed from the six middle rows of the plots and translated into seed yield per hectare.

2.5. Data Analysis. The analysis of variance (ANOVA) was computed separately for each year using SAS version 9.2, and the F test was used to test the homogeneity of error variance. Because the error variance between the two growing seasons was homogeneous, data from both seasons were subjected to a combined analysis of variance using SAS software, and means were compared using the least significance difference (LSD) at 5% probability.

The phenotypic and genotypic variances were estimated using the Burton and de Vane [17] method, which is described:

$$\text{Phenotypic variance}\left(\sigma^2 p\right) = \sigma^2 g + \sigma^2 e, \text{Genotypic variance}\left(\sigma^2 \text{g}\right) = \frac{Mg - Me}{r}, \quad (1)$$

where $\sigma^2 p$ = phenotypic variance; $\sigma^2 g$ = genotypic variance; $\sigma^2 e$ = environmental (error) variance; Mg = mean sum square of genotypes; Me = mean sum square of error; r = number of replications.

To evaluate genetic variability amongst populations, phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were estimated as described by Singh and Chaudhary [18] as follows:

$$\text{PCV} = \frac{\sqrt{\delta^2 P}}{x} x100, \text{GCV} = \frac{\sqrt{\delta^2 g}}{x} \text{X}100, \quad (2)$$

where x = Grand mean, $\sigma^2 g$ = Genotypic variance, and $\sigma^2 p$ = Phenotypic variance.

The genetic advance (GA) was calculated assuming that 5% of the genetic materials were chosen. Using the formula proposed by Robinson et al. [19], the amount of genetic progress that can be expected by selecting a specific proportion of superior progeny was calculated as follows:

$$GA = K * \sigma P * h^2, \quad (3)$$

where σP = phenotypic standard deviation, h^2 = broad sense heritability, K = selection differential (K = 2.06 at 5% selection intensity)

The genetic advance as a percent of mean (GAM) was calculated as follows:

$$\text{GAM} = \frac{GA}{\overline{X}} X100, \quad (4)$$

Table 1: List of experimental linseed varieties used at Lay Gayint in the 2019 and 2020 copping seasons.

Sn	Variety	Year of release	Breeder/maintainer
1	Kulumsa-1	2006	Kulumsa agricultural research center
2	Furtu	2013	Kulumsa agricultural research center
3	Kuma	2016	Kulumsa agricultural research center
4	Bekelcha	2010	Kulumsa agricultural research center
5	Yadeno	2015	Kulumsa agricultural research center
6	Bekoji -14	2014	Holeta agricultural research center
7	Berene	2001	Holeta agricultural research center
8	Jeldu	2010	Holeta agricultural research center
9	CI-1525	1984	Holeta agricultural research center
10	Local variety	—	—

where $\overline{X}$ = population mean.

3. Result and Discussion

3.1. Agronomic Performance of Tested Linseed Varieties. The results of the combined analysis of variance are depicted in Table 2. The combined analysis of variance over the two seasons revealed a significant ($P < 0.05$) difference in flowering days, maturity days, height of the plant, number of tillers/plant, capsule number/plant, and amount of seed per hectare between the studied varieties. This finding suggests that genotypic variability exists among the linseed varieties studied and the traits under consideration. This variability also provides opportunities for the best genotypes to be used in the crop's future improvement through breeding. Akbar et al. [20], Dash et al. [21], and Terfa and Gurmu [22] all found significant differences in flowering days, maturity days, height of the plant, capsule number/plant, and seed yield per hectare between linseed genotypes. Significant differences in days to maturity, plant height, number of capsules per plant, and seed yield per hectare have been reported by Sahito et al. [23] and Lea and Belay [24]. Days to flowering, days to maturity, and seed yield per hectare also showed significant differences between linseed varieties [25, 26].

The combined analysis of variance revealed a significant ($P < 0.05$) difference in seed yield per hectare among the studied varieties (Table 2). The mean seed yield of the varieties ranged from 563.24 to 894.28 $kg{\cdot}ha^{-1}$ with an average of 712.96 $kg{\cdot}ha^{-1}$ (Table 2, Figure 3). This indicated that there was significant genetic variability in seed yield (331.04 kg). High-yielding varieties cannot be generated from homogeneous populations. The availability of genetic variability between individuals within or among populations is one of the most critical challenges in plant breeding that might result in effective advancement in crop productivity. As a result, the existence of a significant variation in seed yield across the tested varieties enables plant breeders to continue the improvement of the crop through selection. As shown in Table 2, the variety "Berene" had the highest seed yield per hectare, followed by "CI-1525," "Yadeno," and "Furtu," with no significant differences. The varieties "Berene," "CI-1525," "Yadeno," and "Furtu," which represented approximately 40% of the varieties studied, produced higher seed yields than the average value of 712.96 $kg{\cdot}ha^{-1}$. The varieties "Bekoji-14," "Kuma," and local checks, on the other hand, yielded the least amount of seed per hectare. Furthermore, "Kulumsa-1," "Bekelcha," and "Jeldu" produce less seed yield than the average value of 712.96 $kg{\cdot}ha^{-1}$. Contrary to the findings of this study, "Kulumsa-1" and "Jeldu" have been described as high-yielding varieties [3]. "Berene," "CI-1525," "Yadeno," and "Furtu" seed yields outperformed the local check by 324.44 kg (36.28%), 309.52 kg (35.20%), 253.44 kg (30.78%), and 251.01 kg (30.58%), respectively. Amsalu [26], Dash et al. [21], and Ceh et al. [27] found significant variation in seed yield between linseed varieties using a combined analysis of variance. Moreover, a significant seed yield difference among linseed varieties is explained by Akbar et al. [20], Amsalu [25], Lea and Belay [24], Sahito et al. [23], and Terfa and Gurmu [22].

The capsule number/plant varied significantly ($P < 0.05$) among the linseed varieties studied (Table 2). There were 37.98 capsules per plant on average, ranging from 23.18 to 76.62. This reveals that the examined varieties contain a lot of diversity in their characteristics, implying that yield could be improved through indirect selection based on capsule count. The variety with the most capsules per plant was revealed to be "Bekelcha." It is commonly assumed that the greater the number of capsules in a plant, the better the yield per plant. Thus, whenever the number of capsules per plant is considered, the "Bekelcha" could be the potential variety for upcoming breeding activities on the crop. The variety "Berene," on the other hand, was the variety that produced the fewest capsules per plant. Sileshi et al. [3] and Singh et al. [28] found comparable results from their combined ANOVAs across locations, with values ranging from 26.9 to 79 and 43.0 to 186.0 capsules, respectively. A study by Dash et al. [21] found a substantial difference in the capsule number per plant across seasons among linseed varieties, with a mean value of 16.64 capsules. Akbar et al. [20], Lea and Belay [24], Sahito et al. [23], and Terfa and Gurmu [22] reported that capsule number/plant varies significantly among linseed varieties. Sileshi et al. [3] also reported higher numbers of capsules per plant from "Berene," "Kulumsa-1," and "Bekoji-14" than in this study, which might be due to better environmental conditions.

Significant ($P < 0.05$) differences in plant height were discovered among the varieties (Table 2). Based on the combined data from the two seasons, the tallest plant height was obtained from the variety "Bekelcha," followed by "CI-1525," "Jeldu," and "Kuma," and the shortest variety was "Yadeno." When plant height is taken into account as

Table 2: Mean performance of seed yield and related traits of linseed varieties combined over the two cropping seasons (2019 & 2020).

Varieties	DF	DM	PH (cm)	TN	NCP	SY (kg ha^{-1})
Kulumsa-1	89.17bcd	152.17de	67.8bcd	1.05de	29.53ef	679.83b
Furtu	88.67cd	155ab	69bc	1.42bc	45.03b	820.85a
Kuma	89.5bc	156.67a	69.63abc	1.38bc	36.85cd	569.53c
Bekelcha	87.67d	154.33bcd	73.1a	0.95de	76.62a	632.42bc
Yadeno	85.33e	154.83abc	66.77cd	1.58b	40.67bc	823.28a
Bekoji-14	90.67b	155.33ab	67bcd	0.83ef	34.43de	563.24c
Berene	90.17bc	152.67cde	68.3bc	0.63f	23.18g	894.28a
Jeldu	89.83bc	156.33ab	70.23abc	1.42bc	30.22ef	696.93b
CI-1525	89.83bc	152.67cde	70.77ab	1.17cd	36.97cd	879.36a
Local	96a	151.5e	63.87d	1.88a	26.27fg	569.84c
Minimum	85.33	151.5	63.87	0.63	26.27	563.24
Maximum	96	156.67	73.1	1.88	76.62	894.28
Mean	89.68	154.15	68.65	1.23	37.98	712.96
LSD (5%)	1.78	2.30	3.97	0.26	5.96	94.82
CV (%)	1.69	1.28	4.93	18.07	13.39	11.36

DF = flowering days; DM = maturity days; PH = height of the plant; TN = number of tiller; NCP = Number of capsule/plant; SY = Seed yield.

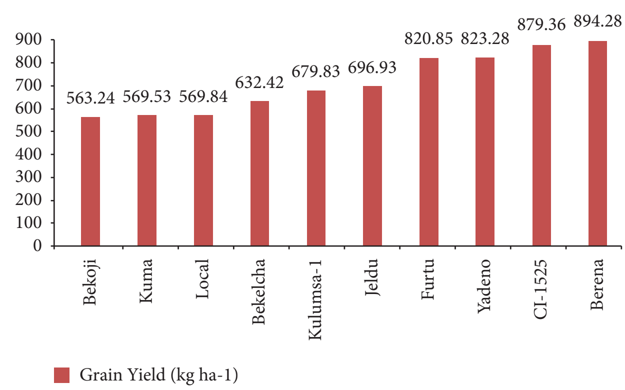

Figure 3: Comparative mean performance of seed yield combined over the two seasons (2019 and 2020).

a selection criterion, the results clearly show that "Bekelcha," "CI-1525," "Jeldu," and "Kuma" are the most viable varieties among all the tested varieties. With mean values of 72.11 cm, 53 cm, 67.8 cm, 87.82 cm, 88.78 cm, 91.05 cm, and 76.41 cm, respectively, Akbar et al. [20], Dash et al. [21], Gidey et al. [8], Lea and Belay [24], Sileshi et al. [3], Singh et al. [28], and Terfa and Gurmu [22] found statistically significant variation in plant height among the varieties. Lea and Belay [24] found larger plant heights from "CI-1525," "Furtu," and "Kuma," with mean values of 92.36 cm, 91.83 cm, and 93.56 cm, respectively. Sileshi et al. [3] also reported that "CI-1525," "Jeldu," and "Berene" resulted in the largest plant heights. The results indicate that "CI-1525," "Jeldu," and "Kuma" are consistent varieties across locations and over seasons for the trait plant height. On the contrary, a non-significant variation in the plant height among the studied 25 linseed genotypes was obtained by Amsalu [25].

The days to flowering varied significantly between varieties, ranging from 85.33 to 96 days (Table 2). "Yadeno" had an earlier flowering time, while the local variety had the longest flowering period, followed by "Bekoji-14," "Berene," "Jeldu," and "CI-1525," all of which had a longer anthesis period than the average of 89.68 days. The days to maturity varied significantly between varieties, ranging from 151.5 to 156.67 days (Table 2). The local variety matured first, while "Kuma" matured last. "Kuma," "Furtu," "Yadeno," "Bekoji-14," and "Jeldu" all had maturation periods that were longer than the average of 154.15 days. The influence of days to flowering and days to maturity on crop productivity is determined by the growing area's environmental conditions. Early flowering and maturing varieties are preferred for locations with limited rainfall, whereas varieties with long flowering and maturing durations are advised for potential areas with high rainfall, such as the Lay Gayint district. This enables the varieties, regardless of the genetic potential, to make better use of the available soil moisture. Days to flowering and days to maturity were found to be significantly and positively associated with seed yield at the genotypic and phenotypic levels in research investigations [21]. As a result, while selecting for improved seed yield, positively correlated yield parameters such as flowering and maturity time should be considered. Days to flowering and days to maturity reported by Akbar et al. [20], Amsalu [25], Amsalu [26], Dash et al. [21], Sahito et al. [23], and Terfa and Gurmu [22] all showed significant variation, which is consistent with the current study. In addition, Gidey et al. [8] and Singh et al.

[28] discovered comparable findings in maturity days and flowering days, respectively. The tiller number/plant resulted in a significant ($P < 0.05$) difference (Table 2). The local variety had the most tillers per plant, followed by "Kuma" and "Jeldu." On the other hand, the "Berene" and "Bekoji-14" varieties had the lowest average total number of tillers per plant.

The mean square values from the combined analysis of variance over the two years resulted in significant seasonal effects for flowering days, maturity days, height of the plant, and capsule number/plant, but not for tiller number and seed yield (Table 3). The significant year effect of the varieties across the two years revealed that the varieties respond differently across the two years, resulting in dissimilar varietal performance. This demonstrates the importance of testing the variety in different seasons in order to identify consistent genetic material throughout the years. The pooled analysis of variance also showed significant mean square values attributed to variety for the parameters investigated. Dash et al. [21] found significant effects due to year and genotype for flowering days, maturity days, height of the plant, capsule number/plant, and seed yield, which is consistent with the findings of this study. Ceh et al. [27] and Sileshi et al. [3] both report significant effects on seed yield due to location, year, and variety. According to Sileshi et al. [3], the year had a significant effect on the number of capsules per plant; location on the capsule number/plant, maturity days, and height of the plant; and variety on the capsule number/plant and height of the plant.

Plant height, tiller number per plant, number of capsules per plant, and seed yield per hectare were all significantly different in the interaction of variety × year (Table 3), implying that linseed varieties performed inconsistently in these plant parameters across the two growing seasons. This showed that seasonal environmental variables differed and had an impact on the performance of the varieties, necessitating the need to verify the stability of new genotypes over seasons. In contrast, for days to flowering and days to maturity, the interaction effect of variety × year was not significant, indicating that seasonal variation had no effect on the performance of the varieties' attributes in this regard, resulting in similar performance between seasons. Ceh et al. [27] discovered significant interactions between variety × location and year × location on seed yield. Days to flowering, days to maturity, plant height, capsule number per plant, and seed yield per hectare were all found to have a significant genotype × year interaction effect [21]. On the other hand, Singh et al. [28] found no significant interaction effect between genotype × year for the aforementioned plant parameters. Sileshi et al. [3] also found no significant year × variety, location × variety, or year × location × variety interaction effects for plant height, the number of capsules per plant, or seed yield per hectare, but did find a significant year × location interaction effect for plant height, the number of capsules per plant, and seed yield per hectare.

The combined analysis of variance across the two seasons revealed significant differences between the growing years in terms of days to flowering, days to maturity, plant height, and the number of capsules per plant (Table 4). The significant difference between years points out that the performance of such traits fluctuated over the two growing seasons, which could be attributed to climatic differences such as rainfall variability, temperature and humidity variation, variation in physical and chemical properties of the soil (because experimental plots were not fixed), and other abiotic factors. When comparing the two years, 2019 has higher values for days to flowering, days to maturity, and plant height than 2021.

On the other hand, the nonsignificant difference between years for tiller number/plant and seed yield (Table 4) reveals that the performance of these traits is constant over the two seasons and is unaffected by variation in the environment. Similar findings were discovered by Ceh et al. [27].

3.2. Estimates of Variance Components and Coefficient of Variation. An analysis of genotypic variance ($\sigma^2 g$), phenotypic variance ($\sigma^2 p$), environmental variance ($\sigma^2 e$), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), environmental coefficient of variation (ECV), broad sense heritability (h^2), genetic advance (GA), and genetic advance as percent of the mean (GA %) for the traits of the linseed varieties is shown in Table 5. The combined analysis yielded higher genotypic and phenotypic variances for capsule number/plant and seed yield/hectare (Table 5). The variance components revealed that, with the exception of plant height, all of the measured plant traits had greater genotypic variance than their corresponding environmental variance (Table 5). This implies that the differences in the phenotypic appearance of the traits of the studied linseed varieties are primarily due to genetic variation, with environmental factors having a minor impact. The fact that genotypic variance was greater than environmental variance indicated that the phenotypic expression of the traits was primarily controlled by the genetic effect, which can be utilized through breeding.

On the contrary, the environmental variance was greater than the genotypic variance for plant height, suggesting that the expression of the trait's phenotypic value is heavily influenced by the environment, and this implies that the probability of improving this trait through selection is becoming more difficult. Terfa and Gurmu [22] discovered greater genotypic variance than their corresponding environmental variance for flowering days, maturity days, height of the plant, capsule number per plant, and seed yield, which is consistent with the findings of this study except for plant height. For the capsule number per plant, height of the plant, and seed yield, Akbar et al. [20] discovered higher genotypic variance than the corresponding environmental variance, and the difference between phenotypic and genotypic variance is small. The current study confirms the results for capsule number/plant and seed yield. Singh et al. [28] found that capsule number/plant, days to flowering, and plant height had greater genotypic variance than the corresponding environmental variance. They also discovered that the difference between the phenotypic and genotypic variance of the traits was very small, indicating that the environment played a minor role in the phenotype. Unlike the

Table 3: Mean square value of combined analysis variance of yield and related traits to study linseed varieties grown in both cropping seasons (2019 and 2020).

Source of variation	Degree of freedom	DF	DM	PH (cm)	TN	NCP	SY (kg ha^{-1})
Year	1	132.02 **	546.02 **	640.27 **	0.09 ns	134.4 *	1291.4 ns
Variety (var)	9	43.65 **	19.39 **	38.58 **	0.85 **	1368.27 **	103792.02 **
Rep (year)	4	0.92	17.48	20.9	0.09	5.0	5744.00
Var × year	9	1.28 ns	7.09 ns	107.46 **	0.15 **	97.16 **	29315.58 **
Pooled error	36	2.31	3.87	11.47	0.05	25.88	6557.84
CV (%)		1.69	1.28	4.93	18.07	13.39	11.36

DF = flowering days; DM = maturity days; PH = height of the plant; TN = number of tiller; NCP = Number of capsule/plant; SY = seed yield.

Table 4: Combined mean performance of yield and yield-related traits of the linseed varieties over the two cropping seasons (2019 & 2020).

Year	DF	DM	PH (cm)	TN	NCP	SY (kg ha^{-1})
2019	91.17a	157.17a	71.91a	1.19a	36.48b	708.32a
2020	88.2b	151.13b	65.38b	1.27a	39.47a	717.59a
Mean	89.68	154.15	68.65	1.23	37.98	712.96
LSD (5%)	0.80	1.03	1.77	0.12	2.66	42.41
CV (%)	1.69	1.28	4.93	18.07	13.39	11.36

DF = flowering days; DM = maturity days; PH = height of the plant; TN = number of tiller; NCP = Number of capsule/plant; SY = Seed yield.

Table 5: Estimates of variance, coefficient of variation, broad sense heritability (h^2), genetic advance (GA), and genetic advance as percent of the mean (GA%) of yield and related traits of linseed varieties grown over the two seasons (2019 and 2020).

Traits	$\sigma^2 p$	$\sigma^2 g$	$\sigma^2 e$	PCV (%)	GCV (%)	ECV (%)	h^2 (%)	GA	GAM (%)
DF	16.09	13.78	2.31	4.47	4.14	1.70	85.64	7.08	7.89
DM	9.04	5.17	3.87	1.95	1.48	1.28	57.19	3.54	2.29
PH	20.51	9.04	11.47	6.60	4.38	4.93	44.08	4.11	5.99
TN	0.32	0.27	0.05	45.99	42.25	18.18	84.38	0.98	79.94
NCP	473.34	447.46	25.88	57.28	55.70	13.40	94.53	42.37	111.55
SY	38969.23	32411.39	6557.84	27.69	25.25	11.36	83.17	338.22	47.44

DF = flowering days; DM = maturity days; PH = plant height (cm); TN = number of tiller; NCP = Number of capsule per plant; SY = seed yield (kg ha^{-1}); $\sigma^2 p$ = phenotypic variance; $\sigma^2 g$ = genotypic variance; $\sigma^2 e$ = environmental variance; PCV (%) = Phenotypic coefficient of variation; GCV (%) = Genotypic coefficient of variation; ECV (%) = Environmental coefficient of variation; h^2 = Broad sense heritability; GA = Genetic advance; GAM (%) = Genetic advance as percentage of the mean.

current study and the majority of research findings, Amsalu [26] discovered smaller genotypic variance for seed yield, flowering days, maturity days, and height of the plant than their corresponding environmental variance, implying that phenotypic variation between varieties for these traits is primarily due to environmental variation, with genetic factors having a minor impact.

Estimates of the phenotypic coefficient of variation and the genotypic coefficient of variation for the traits under investigation are shown in Table 5, Figures 4 and 5. PCV values ranged from 1.9% to 57.28% and those of GCV from 1.48% to 55.7%. The lowest PCV and GCV values were recorded for days to maturity, and the maximum results were obtained for the number of capsules per plant. PCV and GCV values are classified as high when they are greater than 20%, medium when they are between 10% and 20%, and low when they are less than 10% [29, 30]. Based on these benchmarks, the number of capsules per plant, followed by the number of tillers per plant and seed yield, produced the highest values of the phenotypic and genotypic coefficients of variation over the seasons, indicating the existence of a large amount of genotypic variance between the varieties. The high GCV and PCV values of the traits indicate that phenotypic and molecular selection could be used to improve the traits. This is because the bigger the genotypic variance, the higher the heritability, and, as a result, the better the chances of selection success. Furthermore, the difference between PCV and GCV for these traits was very small, indicating that the environment had little effect on the phenotypic expression of these traits. Flowering days, maturity days, and height of the plant all had low PCV and GCV, indicating that there is little genetic variation among varieties in these traits. Terfa and Gurmu [22] explain the high GCV and PCV values for the number of capsules per plant and seed yield, as well as the medium PCV values for flowering days, height of the plant, and maturity days. Some of their findings are supported by the current study. Amsalu [25] and Dash et al. [21] reported high PCV values for seed yield, which is consistent with this study's results. Both Dash et al. [21] and Akbar et al. [20] found higher PCV values for

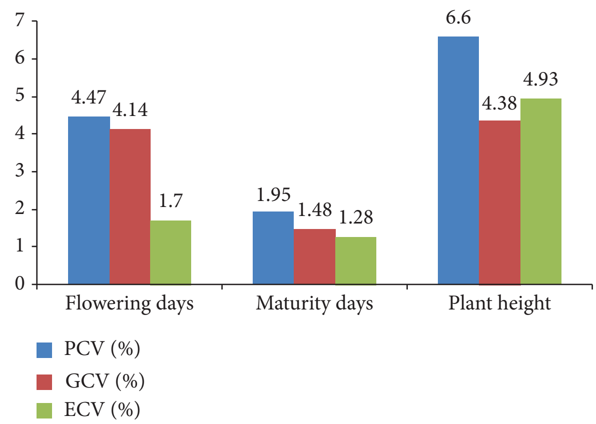

Figure 4: Comparative values of phenotypic, genotypic, and environmental coefficients of variation for days to flowering, days to maturity, and plant height combined over the two seasons.

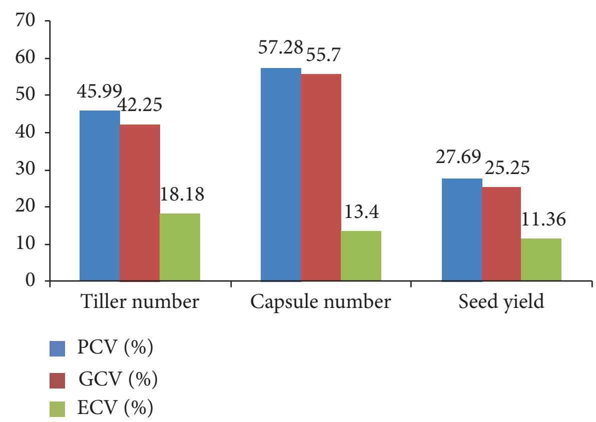

Figure 5: Comparative values of phenotypic, genotypic, and environmental coefficients of variation for tiller number, number of capsules per plant, and seed yield combined over the two seasons.

the number of capsules per plant. Similarly, Singh et al. [28] discovered high PCV and GCV values for the same trait, and all of these findings agree with the findings of this study. Furthermore, linseed varieties produced high GCV and PCV values for days to flowering and plant height [28], medium for plant height and seed yield [20], and low for days to flowering, days to maturity, and plant height [21].

3.3. Estimation of Broad Sense Heritability and Genetic Advance. The heritability and expected genetic advance estimates of the studied plant parameters of the linseed varieties are explained in Table 5. One of the fundamentals for an effective breeding program in selecting genotypes with desirable characteristics is knowledge of the nature and amount of variation and heritability in a plant population [31]. A high heritability indicates that genetics accounts for a large portion of a trait's variability, whereas a low heritability indicates that genetics does not account for the majority of the variation. Singh [32] divides heritability into three categories: low (less than 40%), medium (40–80%), and high (more than 80%). As a result, the estimated broad-sense heritability of this study ranges from 44.08% to 94.53%. The highest broad sense of heritability was found in the number of capsules per plant, followed by days to blooming, tiller number per plant, and seed output (Table 5). As a result, substantial progress can be made if some of these traits are used as selection criteria for genetic improvement.

The number of capsules per plant, tillers per plant, and seed yield all demonstrated high heritability values, which were associated with high GCV (Table 5) across seasons. Because of the close relationship between the variety and the phenotype as a result of high heritability coupled with a high GCV and the relatively small contribution of the environment to the phenotype, phenotypic selection for these traits may respond efficiently. To put it another way, if genotypic variability is high in comparison to environmental variation, selection will be efficient because the chosen trait will be passed down to descendants. On the other hand, maturity days and plant height, which have a low genotypic coefficient of variation (Table 5), have moderate heritability (Table 5), which could provide a low level of resemblance between parent and offspring for these traits. Akbar et al. [20] reported high heritability values for plant height, number of capsules per plant, and seed yield. Similar results are produced by Singh et al. [28] for days to flowering, plant height, and capsule number per plant. These findings are consistent with the current study's results in aspects of flowering days, the number of capsules, and seed yield. Medium values were also discovered for flowering days [22, 25, 26], the number of capsules per plant, days to maturity, and seed yield [22].

The estimated value of expected genetic advancement expressed as a percentage of the mean ranges from 2.29% to 111.55%. Robinson et al. [19] and Johnson et al. [33] classified genetic progress as low (0–10%), moderate (10–20%), or high (20%). Based on this point of reference, capsule number had the highest genetic progress as a percentage of the mean, followed by tiller number and seed yield, indicating that additive gene action occurs predominantly for the traits and selection has made it simple to improve these characters. These traits with greater genetic advance have a high heritability combined with a high genotypic coefficient of variation. Because, when combined with a heritability estimate, the genotypic coefficient of variation provides the most accurate picture of expected selection improvement [17], high heritability with a high value of the genotypic coefficient of variation for the number of capsules per plant, tiller number, and seed yield in this study provides the required projected genetic progress during selection.

On the other hand, flowering days with a high heritability value resulted in low genetic advance, which could be attributed to their low genotypic coefficient of variation. A study by Johnson et al. [33] showed that a higher heritability value does not always correlate with greater genetic advance. This is confirmed by this study's results, particularly by the days to flowering, which resulted in higher heritability but low genetic advance, which could be attributed to the trait's low GCV. As a result, because selection results from genetic variability and improvement from heritability and genetic progress, improving this trait is extremely difficult. To improve expected genetic gain, genetic advancement should be considered in conjunction with high heritability and GCV. Some plant parameters in this study, which have high heritability and GCV, resulted in large values of genetic advance. Akbar et al. [20] and Terfa and Gurmu [22] both reported high genetic improvement as a percentage of the mean for capsule number and seed yield, which is consistent with the current study's findings. In contrast, Singh et al. [28] revealed that for days to flowering and plant height, there is strong genetic advancement as a percentage of the mean, which yielded low values in this study.

4. Conclusion

Improved linseed varieties behave inconsistently across seasons due to agroecological variation and changing growing seasons, necessitating season-long testing to evaluate and select appropriate varieties for the area of interest. Genetic resources that perform consistently over time are considered consistent and appropriate for introduction and production in the examined areas. The combined analysis of variance during the two growing seasons revealed a statistically significant difference in seed yield and all relevant variables between the tested linseed varieties, demonstrating the presence of genetic variation among the released linseed varieties. For seed yield, combined ANOVAs demonstrated a significant variety × year interaction effect, resulting in varied varietal performance across seasons. This necessitates a season-by-season evaluation of the released varieties in order to find the most consistent and suitable varieties to be grown in the various agroecologies. The combined analysis of variance over the two growing seasons showed that Berene, CI-1525, Yadeno, and Furtu were found to be the high-yielding varieties that could be recommended for introduction, promotion, multiplication, and distribution in the study area and related agroecologies. The combined analysis of variance also revealed that seed yield, the number of capsules per plant, and the tiller number per plant resulted in higher estimated values of the genotypic coefficient of variation and phenotypic coefficient of variation, as well as higher broad sense heritability, indicating the ability of the traits to be improved easily through phenotypic and biotechnological selection methods. In general, Berene, CI-1525, Yadeno, and Furtu, which produce higher seed yield, should be introduced and distributed to the farmers of the study area, and traits with high GCV and PCV coupled with high heritability should be given due attention during linseed improvement programs through selection.

Data Availability

Data will be made available on request.

Conflicts of Interest

The authors declare no conflicts of interest.

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