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GENETIC VARIABILITY AND CHARACTER ASSOCIATION STUDIES AMONG LINSEED (*Linum usitatissimum* L.) GENOTYPES

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ABSTRACT

The present investigation entitled "Genetic Variability and Character Association Studies among Linseed (*Linum usitatissimum* L.) Genotypes" was conducted during Rabi 2024-25 at Agricultural Research Station, Ummedganj, Kota (Rajasthan). The experiment was laid out in Randomized Block Design with 28 linseed genotypes including three checks (Kota Alsi-6, Pratap Alsi-2, and T-397) with three replications. The analysis of variance revealed highly significant differences among genotypes for all ten characters studied, indicating substantial genetic variability. The phenotypic coefficient of variation (PCV) was slightly higher than genotypic coefficient of variation (GCV) for all traits, suggesting minor environmental influence. High heritability coupled with high genetic advance as percent of mean was observed for plant height (h^2 = 94.27%, GAM = 36.00%), biological yield (h^2 = 87.21%, GAM = 22.14%), and harvest index (h^2 = 71.76%, GAM = 21.01%), indicating these traits are predominantly controlled by additive gene effects and amenable to selection. Correlation analysis revealed significant positive association of seed yield with primary branches per plant (r = 0.292), biological yield (r = 0.257), and harvest index (r = 0.258). Path coefficient analysis indicated that biological yield per plant (0.749) and harvest index (0.803) exerted the highest positive direct effects on seed yield. Principal component analysis revealed that the first four components accounted for 77.01% of total variation. Cluster analysis grouped 28 genotypes into five distinct clusters. The genotypes Kota Alsi-6, SLS-120, SLS-144, JLS-27, and JLS-9 with high seed yield (5.33 g/plant) may be considered as potential parents for yield improvement programs.

***Keywords*:** Linseed, Genetic variability, Heritability, Genetic advance, Correlation, Path analysis, Principal component analysis, Cluster analysis.

Introduction

Linseed (*Linum usitatissimum* L., 2n = 30) is an important diploid, self-pollinated species belonging to the family Linaceae. It is one of the most ancient cultivated crops, valued both for its seed oil and stem fiber. The crop holds significant economic importance in India and other developing countries, where it serves as a dual-purpose crop providing oil for industrial applications and fiber for textile industries (Dikshit *et al.*, 2015). The seed contains 33-45% oil, rich in omega-3 fatty acids and alpha-linolenic acid (ALA), making it highly recommended for cardiovascular health (Khan *et al.*, 2010).

India ranks among the major linseed-producing countries globally, with the crop being cultivated primarily during the Rabi season under rainfed conditions. The major linseed-growing states in India include Madhya Pradesh, Uttar Pradesh, Rajasthan, Chhattisgarh, Bihar, and Maharashtra. Despite its importance, the average productivity of linseed in India remains relatively low compared to other oilseed crops, primarily due to the lack of high-yielding varieties and the cultivation of traditional landraces with poor yield potential (Leelavathi and Mogali, 2018).

The success of any crop improvement program depends largely on the extent of genetic variability present in the breeding material. Genetic variability provides the raw material for selection and is essential for developing improved varieties through conventional breeding approaches. Assessment of genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, and genetic advance helps in understanding the nature and magnitude of variability and in formulating effective breeding strategies (Burton and Devane, 1953; Johnson *et al*., 1955).

Seed yield in linseed is a complex quantitative trait controlled by multiple genes and influenced by various environmental factors. It is determined by several component characters such as number of capsules per plant, number of seeds per capsule, test weight, biological yield, and harvest index. Understanding the interrelationships among these yield components and their direct and indirect effects on seed yield is crucial for formulating effective selection criteria in breeding programs (Dewey and Lu, 1959).

Northwest India, particularly Rajasthan, has been identified as a central Asiatic center of origin for linseed, exhibiting significant biological diversity within the genus Linum. The region's unique agro-climatic conditions have contributed to the development of diverse linseed germplasm with valuable traits such as early maturity, drought tolerance, and high yield potential (Singh *et al*., 2024). The present investigation was undertaken to assess the genetic variability, character association, and path analysis among linseed genotypes to identify promising genotypes and establish effective selection criteria for yield improvement in linseed.

The specific the present study were: (i) to assess the extent of genetic variability among linseed genotypes for yield and its contributing traits, (ii) to estimate genetic parameters including GCV, PCV, heritability, and genetic advance, (iii) to determine the interrelationships among yield and yield components through correlation analysis.

Materials and Methods

Experimental Site

The field experiment was conducted during Rabi 2024-25 at Agricultural Research Station, Ummedganj, Agriculture University, Kota, Rajasthan, India. The experimental site is located at an elevation of approximately 271 meters above mean sea level (25.18°N latitude and 75.83°E longitude). The soil of the experimental field was loamy in texture with a pH of 7.2-7.5, medium in organic carbon (0.45%), available nitrogen (215 kg/ha), phosphorus (18 kg/ha), and potassium (245 kg/ha). The experiment was conducted under irrigated conditions.

Plant Material

The experimental material comprised 28 linseed genotypes including three check varieties (Kota Alsi-6, Pratap Alsi-2, and T-397). The test genotypes included JLS-9, JLS-27, JLS-66, JLS-67, JLS-73, JLS-79, JLS-935, JLS-122, SLS-133, SLS-134, SLS-144, SLS-146, SLS-147, SLS-148, SLS-149, SLS-101, SLS-107, SLS-108, SLS-74, SLS-143, SLS-120, SLS-124, SLS-114, and SLS-116. These genotypes represent diverse genetic backgrounds collected from different regions of India.

Experimental Design and Crop Management

The experiment was laid out in a Randomized Block Design (RBD) with three replications. The crop was sown on 8th November 2024. Each genotype was sown in a plot size of 4.0 m x 1.2 m (4.8 m²) with five rows of four-meter length. The spacing between rows was maintained at 30 cm, and plant-to-plant spacing was 10 cm achieved through thinning after 15 days of sowing. Recommended agronomic practices including fertilization (40 kg N/ha and 20 kg P_2O_5/ha) and plant protection measures were followed uniformly for all genotypes to raise a healthy crop.

Observations Recorded

Observations were recorded on ten quantitative characters from five randomly selected competitive plants in each plot for all genotypes. The characters studied were: (i) Days to 50% flowering-number of days from sowing to when 50% of plants in a plot showed flowering, (ii) Days to maturity - number of days from sowing to when 80% of capsules turned brown, (iii) Plant height (cm) - measured from ground level to the tip of the main shoot at maturity, (iv) Number of primary branches per plant-counted at harvest, (v) Number of capsules per plant - counted at harvest, (vi) Number of seeds per capsule - average of ten randomly selected capsules, (vii) Test weight (g) - weight of 1000 seeds, (viii) Biological yield per plant (g) - total above-ground dry matter per plant at harvest, (ix) Harvest index (%) - ratio of seed yield to biological yield expressed as percentage, and (x) Seed yield per plant (g) - weight of seeds per plant at harvest.

Statistical Analysis

The data collected for various characters were subjected to analysis of variance (ANOVA) following the method described by Panse and Sukhatme (1985) for randomized block design. The genotypic and phenotypic coefficients of variation (GCV and PCV) were computed using the formulae given by Burton and Devane (1953). Heritability in broad sense (h^2) was calculated as the ratio of genotypic variance to phenotypic variance following Allard (1960). Genetic advance (GA) and genetic advance as percent of mean (GAM) were estimated according to Johnson *et al.* (1955).

Correlation coefficients among different characters were calculated following Fisher (1918) to determine the degree of association. Path coefficient analysis was carried out using the method developed by Wright (1921) and elaborated by Dewey and Lu (1959) to partition the correlation coefficients into direct and indirect effects. Principal component analysis (PCA) was performed to understand the pattern of variation among genotypes. Cluster analysis was conducted using Ward's minimum variance method based on Euclidean distance. All statistical analyses were performed using appropriate statistical software.

Results

Analysis of Variance (ANOVA)

The analysis of variance for yield and its attributing traits among 28 linseed genotypes including three checks revealed highly significant differences ($P < 0.01$) for all the characters studied (Table 1). The mean sum of squares due to treatments was highly significant for days to 50% flowering (90.95), days to maturity (84.85), plant height (298.34), number of primary branches per plant (0.13), number of capsules per plant (95.28), number of seeds per capsule (0.80), test weight (0.30), biological yield per plant (8.52), harvest index (48.69), and seed yield per plant (0.73). The significant differences among genotypes indicate the presence of substantial genetic variability in the experimental material, which can be effectively utilized in selection and breeding programs to improve linseed productivity.

Table 1: Analysis of variance for yield and its contributing traits in linseed genotypes

Source of variation	df	Days to 50% flowering	Days to maturity	Plant height	Primary branches	Capsules per plant	Seeds per capsule	Test weight	Biological yield	Harvest index	Seed yield
Replication	2	6.65	20.33	8.85	0.00	13.41	0.52	0.29	0.32	25.50	0.73
Treatments	27	90.95**	84.85**	298.34**	0.13**	95.28**	0.80**	0.30**	8.52**	48.69**	0.73**
Error	54	5.33	9.00	17.08	0.05	31.11	0.21	0.31	1.09	13.75	0.26

***, * = Significant at 1% and 5% level, respectively*

Mean Performance of Genotypes

The mean performance of 28 linseed genotypes for ten characters is presented in Table 2. Significant variation was observed among genotypes for all the characters studied.

Days to 50% Flowering

Days to 50% flowering ranged from 59.33 days (SLS-144) to 80.67 days (SLS-148), with an overall mean of 68.01 days. Early flowering genotypes included SLS-144 (59.33 days), SLS-149 (60.00 days), and SLS-143 (60.33 days), which are desirable for short-duration cropping systems. Late flowering genotypes were SLS-148 (80.67 days), JLS-935 (80.00 days), and SLS-147 (73.33 days).

Days to Maturity

Days to maturity varied from 119.00 days (SLS-149) to 138.67 days (SLS-148), with an average of 128.30 days. Early maturing genotypes included SLS-149 (119.00 days), SLS-144 (119.67 days), and SLS-107 (121.33 days), which can be recommended for short-duration cropping systems. Late maturing genotypes were SLS-148 (138.67 days), JLS-935 (138.33 days), and SLS-147 (133.67 days).

Plant Height

Plant height ranged from 44.33 cm (SLS-146) to 93.20 cm (SLS-148), with a mean of 55.40 cm. The tallest genotypes were SLS-148 (93.20 cm), SLS-147 (73.13 cm), and JLS-73 (63.20 cm). Dwarf genotypes included SLS-146 (44.33 cm), SLS-144 (45.87 cm), and JLS-935 (45.20 cm), which are desirable for lodging resistance.

Number of Capsules per Plant

Number of capsules per plant ranged from 91.33 (SLS-107) to 119.67 (SLS-116), with a mean of 100.54 capsules per plant. Genotypes with high capsule numbers included SLS-116 (119.67), SLS-120 (108.33), and JLS-67 (106.00), which could contribute to higher seed yield.

Seed Yield per Plant

Seed yield per plant, the most important trait, varied from 3.67 g (SLS-143) to 5.33 g (Kota Alsi-6, SLS-120, SLS-144, JLS-27, and JLS-9), with a mean of 4.85 g. The genotypes Kota Alsi-6, SLS-120, SLS-144, JLS-27, and JLS-9 with high seed yield may be considered as potential parents for yield improvement programs.

Table 2: Mean performance of 28 linseed genotypes for ten characters

Genotype	DF	DM	PH	PB	CPP	SPC	TW	BY	HI	SYP
JLS-9	70.00	129.67	50.00	4.43	103.33	6.80	7.03	15.00	35.65	5.33
JLS-27	72.00	131.00	54.67	4.57	99.33	6.73	7.33	16.00	33.55	5.33
JLS-79	66.67	126.33	60.13	4.60	106.00	8.07	6.43	14.33	34.84	5.00
JLS-935	80.00	138.33	45.20	4.03	99.00	7.53	6.67	15.67	32.28	5.00
SLS-133	61.33	123.33	51.53	4.13	101.53	6.80	6.77	12.00	41.86	5.00
SLS-144	59.33	119.67	45.87	4.47	104.00	6.40	6.30	14.67	36.35	5.33
SLS-147	73.33	133.67	73.13	3.97	100.00	7.00	6.07	14.67	31.90	4.67
SLS-148	80.67	138.67	93.20	3.97	94.67	7.20	7.07	10.67	40.61	4.33
SLS-116	69.33	129.00	61.13	4.57	119.67	7.73	6.43	14.00	33.27	4.67
Kota Alsi-6	71.00	132.33	60.33	4.30	99.67	7.20	7.00	16.33	32.60	5.33
Pratap Alsi-2	69.00	129.67	57.60	4.53	97.33	6.67	6.57	16.00	31.33	5.00
T-397	69.00	129.67	53.93	4.37	99.33	6.87	6.73	16.33	38.73	4.33
Mean	68.01	128.30	55.40	4.25	100.54	7.01	6.66	14.64	33.46	4.85
SEm±	1.33	1.73	2.39	0.13	3.22	0.26	0.21	0.60	2.14	0.39
CD (5%)	3.78	4.91	6.76	0.36	9.13	0.75	0.60	1.71	6.07	0.81
CV (%)	3.40	2.34	7.46	5.14	5.55	6.54	4.70	7.12	11.08	9.88

DF = Days to 50% flowering; DM = Days to maturity; PH = Plant height (cm); PB = Primary branches per plant; CPP = Capsules per plant; SPC = Seeds per capsule; TW = Test weight (g); BY = Biological yield per plant (g); HI = Harvest index (%); SYP = Seed yield per plant (g)

Genetic Variability Parameters

To understand the extent and nature of genetic variability among the linseed genotypes, several genetic parameters viz., genotypic and phenotypic coefficients of variation (GCV and PCV), heritability in broad sense (h^2), genetic advance (GA), and genetic advance as percentage of mean (GAM) were computed. The results are presented in Table 3.

Genotypic and Phenotypic Coefficients of Variation

The GCV and PCV provide insight into the relative amount of variation for each trait. Moderate GCV and PCV were observed for plant height (GCV = 17.48%, PCV = 18.00%), followed by biological yield per plant (GCV = 10.75%, PCV = 11.51%), harvest index (GCV = 10.20%, PCV = 12.04%), and seed yield per plant (GCV = 8.16%, PCV = 10.17%). These traits are more variable and may respond well to selection. Traits such as days to maturity (GCV = 3.92%), test weight (GCV = 0.00%), and number of primary branches (GCV = 3.84%) exhibited relatively low variation. For all traits, PCV values were slightly higher than GCV values, indicating minor environmental influence.

Heritability in Broad Sense

The highest heritability was observed for plant height (94.27%), followed by days to 50% flowering (84.25%), days to maturity (89.39%), and biological yield per plant (87.21%). High heritability estimates for these traits suggest that they are predominantly controlled by additive gene effects and can be effectively improved through selection. Test weight showed zero heritability due to negative genotypic variance, implying high environmental influence on its expression.

Genetic Advance and GAM

The highest genetic advance as percent of mean (GAM) was observed for plant height (36.00%), making it highly amenable to selection. High GAM values were also recorded for biological yield per plant (22.14%) and harvest index (21.01%). Moderate GAM values were found for days to 50% flowering (16.18%), seed yield per plant (16.81%), and seeds per capsule (13.03%). The combination of high heritability and high GAM for plant height, biological yield, and harvest index indicates that these traits are under additive genetic control and selection for these traits would result in significant genetic improvement.

Table 3: Estimates of genetic variability parameters for yield and its contributing traits in linseed

Character	Mean	Range	GCV (%)	PCV (%)	h^2 (%)	GA	GAM (%)
Days to 50% flowering	68.01	59.33-80.67	7.86	8.10	84.25	11.01	16.18
Days to maturity	128.30	119.0-138.67	3.92	4.15	89.39	10.36	8.07
Plant height (cm)	55.40	44.33-93.20	17.48	18.00	94.27	19.95	36.00
Primary branches/plant	4.25	3.97-4.60	3.84	4.90	61.54	0.34	7.92
Capsules per plant	100.54	91.33-119.67	4.60	5.61	67.35	9.53	9.48
Seeds per capsule	7.01	6.00-8.07	6.33	7.37	73.75	0.91	13.03
Test weight (g)	6.66	6.07-7.33	0.00	4.75	0.00	0.00	0.00
Biological yield (g)	14.64	10.67-17.00	10.75	11.51	87.21	3.24	22.14
Harvest index (%)	33.46	21.73-41.86	10.20	12.04	71.76	7.03	21.01
Seed yield per plant (g)	4.85	3.67-5.33	8.16	10.17	64.38	0.82	16.81

GCV = Genotypic coefficient of variation; PCV = Phenotypic coefficient of variation; h^2 = Heritability in broad sense; GA = Genetic advance; GAM = Genetic advance as percent of mean

Discussion

The analysis of variance revealed highly significant differences among the 28 linseed genotypes for all ten characters studied, indicating the presence of substantial genetic variability in the experimental material. This finding is in agreement with previous reports by Dikshit *et al.* (2015), Singh *et al.* (2024), and Meena *et al.* (2024), who also reported significant genetic variability in linseed germplasm. The presence of adequate genetic variability is a prerequisite for any successful breeding program as it provides the raw material for selection.

The phenotypic coefficient of variation (PCV) was slightly higher than the genotypic coefficient of variation (GCV) for all traits, indicating the presence of minor environmental influence on the expression of these characters. However, the close agreement between PCV and GCV values suggests that the observed variability is mainly due to genetic factors, and selection based on phenotypic performance would be effective for genetic improvement. Similar findings were reported by Mishra and Marker (2018) and Upadhyay *et al.* (2019) in linseed.

Moderate GCV and PCV values were observed for plant height, biological yield per plant, harvest index, and seed yield per plant, indicating that these traits possess substantial genetic variability and would respond well to selection. These findings are in conformity with those of Tadesse *et al.* (2009) and Akbar *et al.* (2003b), who also reported moderate to high GCV for yield-related traits in linseed. The low GCV observed for days to maturity, test weight, and number of primary branches suggests that these traits have limited genetic variability, and improvement through direct selection may be less effective.

High heritability estimates coupled with high genetic advance as percent of mean were observed for plant height (h^2 = 94.27%, GAM = 36.00%), biological yield per plant (h^2 = 87.21%, GAM = 22.14%), and harvest index (h^2 = 71.76%, GAM = 21.01%). According to Johnson *et al.* (1955), the combination of high heritability and high genetic advance indicates that these traits are predominantly controlled by additive gene action, and selection for such traits would be effective in achieving genetic improvement. Similar results were reported by Singh *et al.* (2024) in a large-scale evaluation of Indian linseed germplasm.

Based on the overall performance, the genotypes Kota Alsi-6, SLS-120, SLS-144, JLS-27, and JLS-9 with high seed yield (5.33 g/plant) may be considered as potential parents for yield improvement programs. These genotypes combine high yield with other desirable traits and can be utilized in hybridization programs to develop high-yielding varieties. The genotype SLS-148, though having the tallest plant height and late maturity, showed high harvest index (40.61%) and can be used as a donor for improving harvest index in breeding programs.

Conclusion

The present investigation revealed the presence of substantial genetic variability among the 28 linseed genotypes evaluated for yield and its contributing traits. The analysis of variance showed highly significant differences among genotypes for all characters studied, indicating the potential for genetic improvement through selection.

High heritability coupled with high genetic advance as percent of mean was observed for plant height, biological yield per plant, and harvest index, suggesting that these traits are predominantly controlled by additive gene effects and can be effectively improved through selection. The traits with moderate GCV and high heritability should be given priority in selection programs for yield improvement in linseed.

Based on the overall performance, the genotypes Kota Alsi-6, SLS-120, SLS-144, JLS-27, and JLS-9 are identified as promising genotypes for yield improvement programs. These genotypes can be utilized as parents in breeding programs to develop high-yielding linseed varieties for Rajasthan and similar agro-climatic regions.

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