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Association analysis in bold seeded and early maturing genotypes of linseed (*Linum usitatissimum* L.)

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Abstract
The experiment entitled "Association analysis in bold seeded and early maturing genotypes of linseed (*Linum usitatissimum*)" was conducted at Research cum Instruction farm, Department of Genetics and Plant Breeding, IGKV, Raipur, CG during Rabi 2022-23. The experiment was carried out in RCBD involving 32 early and 26 bold seeded genotypes of Linseed, including 5 check varieties with three replications. For 12 quantitative characters, observations were made on five competing plants that were chosen at random from each plot and replication. In early maturing and bold-seeded flax varieties, an analysis of correlations revealed significant and positive associations between seed yield/plant and several factors including plant height, the no. of seeds/capsule, 1000 seed weight, capsule length, capsule width, days to 50% flowering, and days to maturity. This suggests that an increase in one variable would likely result in an increase in another. The outcomes of a path coefficient analysis, considering seed yield/plant as the dependent variable, demonstrated that the no. of primary branches/plant, plant height, days to maturity, 1000 seed weight, and capsule length exhibited the most substantial positive direct effects. Direct selection for these attributes could potentially enhance yield due to their genuine relationship with seed yield and other traits being highlighted.

Keywords: Linseed, association analysis, correlation analysis, path coefficient analysis, seed yield

Introduction
Linseed (*Linum usitatissimum* L.) stands as a significant Rabi oilseed crop, with its origins traced back to the Mediterranean and southwest Asian regions (Vavilov, 1935) [27]. This annual plant species, which self-pollinates, is frequently called "Alsi." The Latin term "*Usitatissimum*" in the species name signifies "most useful," while "*Linum*," derived from "lin," denotes "thread" (Linnaeus, 1857) [16]. Within the Genus Linum, there are 290 species, but only "*Linum usitatissimum* L." holds economic significance. Linseed, with a somatic chromosome count of 2n = 30, differs from other species within the genus, which range from "16 to 86" (Meena, 2020) [18].

Cultivation of linseed covers approximately 32.23 lakh hectares worldwide, resulting in a production of 30.68 lakh tons, equating to an average productivity of around 952 kg/ha. In India, linseed is cultivated across 2.01 lakh hectares, yielding 1.37 lakh tons with an average productivity of 659 kg/ha. Notably, Madhya Pradesh holds the top position in linseed production in India. Linseed is grown in Chhattisgarh using *utera* cultivation, a type of rice-based rainfed farming. In Chhattisgarh, the total area under cultivation, linseed production, and productivity are 11.5 thousand hectare, 3.89 thousand tonnes and productivity is 338 kg/ha respectively (Anonymous, 2023) [2].

When choosing the most suitable plant variety, correlation studies offer valuable insights into the type, extent, and direction of the selection process. This becomes particularly crucial when breeders aim to integrate high yield potential with preferred agronomic traits and grain quality features. If two variables exhibit a positive correlation, their high values are interconnected, influencing each other positively. Conversely, in cases of negative correlation, high values of one variable correspond to low values of another, indicating opposing movements.

According to Dewey and Lu (1959) [7], path analysis is a special type of multivariate statistical analysis, which has a linear correlation with each other and can separate direct and indirect effect towards crop yield.

Materials and Methods

The present study took place at the Research cum Instructional farm of IGKV, located in Raipur (C.G), during the Rabi season of 2022-23. The experimental materials consist of 32 early and 26 bold seeded linseed genotypes including 5 check variety (RLC133, RLC138, RLC143, RLC148, RLC153) taken from AICRP on Linseed, IGKV, Raipur, C.G. (Table 2 and 3). Three replications of a RCBD were used to conduct the investigation. All selected linseed genotypes were sown on November 26, 2022, in plots of 3 rows, each measuring 3 meters in length, with a distance of 10 cm between plants and a row spacing of 30 cm. At the center of each plot, 5 plants were chosen at random for observation. Observation details are mentioned in Table 1

Statistical analysis

Estimation of correlation coefficient: By using an analytical correlation coefficient, the Miller *et al*., (1958) [19] technique examines the reciprocal link between various genotypic (G) and phenotypic (P) traits.

$$Rxy = \frac{CO\ xy}{\sqrt{Varx.vary}}$$

Where,
r_{xy} = Coefficient of correlation between x and y traits.
cov_{xy} = Covariance between x and y traits
Var_x = Variance of x trait
Var_y = Variance of y trait

Correlation coefficient was used tested for significance using t statistics at (n-2) degrees of freedom as given below

$$T_c = \sqrt{n} - 2 / \sqrt{1} - r^2$$

Path coefficient analysis: Wright (1921) [28] introduced path analysis, which Dewey and Lu expanded (1959) [7]. The genotypic correlation coefficient is split into direct and indirect outcomes using path coefficient analysis. It assesses how independent variables affect the dependent variable directly and indirectly.

Results and Discussion

Analysis of correlation coefficient

The correlation coefficients between genotype and phenotype for seed yield and its constituent traits are presented in (Table 2). Plant height (rg = 0.328, rp = 0.283), no. of seeds/capsule (rg = 0.284, rp = 0.192), 1000 seed weight (rg = 0.249, rp = 0.243), capsule length (rg = 0.055, rp = 0.014), capsule width (rg = 0.358, rp = 0.263), days to 50% flowering (rg = 0.353, rp = 0.325), and days to maturity (rg = 0.403, rp = 0.389) demonstrated a positive correlation coefficient, both genotypically and phenotypically, with seed yield/plant. Conversely, stem thickness (rg = -0.108, rp = -0.066), no. of primary branches/plant (rg = -0.009, rp = -0.003), no. of secondary branches/plant (rg = -0.178, rp = -0.091), and no. of capsules/plant (rg = -0.161, rp = -0.136) exhibited a negative correlation coefficient, both genotypically and phenotypically, with seed yield/plant.

Similar findings have also been documented by Dhirhi & Mehta (2019) [8], Dabalo *et al*. (2020) [6], Nedi & Nepir (2020) [21], and Sahu (2022) [24], indicating a positive and significant correlation between plant height and seed yield. Similarly, Gauraha *et al*. (2011) [9], Savita *et al*. (2006) [25], Chandrawati *et al*. (2016) [5], Kasana *et al*. (2018) [13], Sharma *et al*. (2016) [26], and Patel (2020) [22] have reported analogous results regarding the positive and significant correlation of 1000 seed weight with seed yield. Furthermore, Savita *et al*. (2006) [25], Rajanna *et al*. (2014) [23], Chaudhary *et al*. (2016), Chandrawati *et al*. (2016) [5], Kasana *et al*. (2016) [13], Sharma *et al*. (2016) [26], Kumar *et al*. (2017) [14], Ankit *et al*. (2018) [1], Patel (2020) [22], and Markande (2021) [17] observed that seed yield/plant exhibited a positive and significant correlation with days to 50% flowering, days to maturity, and 1000 seed weight.

Path coefficient analysis

Simply dividing the correlation coefficient into direct and indirect effects, the standardized component regression coefficient is used to analyse a path coefficient. In other words, it assesses the direct and indirect effects of several independent characteristics on a dependent character. Using the method proposed by Dewey and Lu (1959) [7], the amount and direction of the direct and indirect effects of various characteristics contributing to yield were estimated.

Direct effect

In the path coefficient analysis, positive direct effects were observed using the genotypic correlation coefficient. Capsule width (mm) (0.375) exhibited the highest positive direct effect, followed by plant height (cm) (0.282), days to 50% flowering (0.234), no. of seeds/capsule (0.155), no. of primary branches/plant (0.149), days to maturity (0.146), and no. of secondary branches/plant (0.108).

Conversely, negative direct effects were observed in the path coefficient analysis using the genotypic correlation coefficient. Stem thickness (-0.182) showed the highest negative direct effect, followed by the no. of capsules/plant (-0.129), capsule length (-0.080), and 1000 seed weight (-0.080).

Similar findings were reported by Nagaraj *et al*. (2009), Leelavathi & Mogali (2018) [15], Meena *et al*. (2020) [18], and Sahu (2021) regarding the no. of primary branches/plant, by Thakur *et al*. (2020) and Sahu (2022) [24] regarding plant height, and by Nedi & Nepir (2020) [21] and Sahu (2022) [24] regarding days to maturity and plant height.

Indirect effect

Plant height: Plant height exhibited a beneficial indirect impact on seed yield through factors such as stem thickness, the no. of primary branches/plant, the no. of seeds/capsule, 1000 seed weight, the no. of capsules/plant, capsule length, capsule width, days to 50% flowering, and days to maturity. Conversely, plant height demonstrated an adverse indirect effect on seed yield through the no. of secondary branches/plant.

Stem thickness: Stem thickness exhibited a beneficial indirect impact on seed yield through factors such as the no. of seeds/capsule, 1000 seed weight, days to 50% flowering, and days to maturity. Similarly, stem thickness displayed a favorable indirect effect on seed yield through plant height, no. of primary branches/plant, no. of secondary branches/plant, no. of capsules/plant, capsule length, and capsule width.

No. of primary branches/ plant: The no. of primary branches/plant exhibited a beneficial indirect influence on seed yield through factors such as stem thickness, no. of primary branches/plant, no. of secondary branches/plant, no. of capsules/plant, and days to 50% flowering. Conversely, it demonstrated an adverse indirect effect on seed yield through the no. of seeds/capsule, 1000 seed weight, capsule length, capsule width, and days to maturity.

No. of secondary branches/ plant: The no. of secondary branches/plant exhibited a beneficial indirect impact on seed yield through factors such as stem thickness, no. of primary branches/plant, no. of seeds/capsule, 1000 seed weight, no. of capsules/plant, and days to 50% flowering. Conversely, it displayed an adverse indirect effect on seed yield through plant height, capsule length, capsule width, days to 50% flowering, and days to maturity.

No. of seeds/ capsule: The no. of seeds/capsule demonstrated a beneficial indirect influence on seed yield through plant height, no. of secondary branches/plant, 1000 seed weight, no. of capsules/plant, days to 50% flowering, and days to maturity. Conversely, it exhibited an adverse indirect effect on seed yield through stem thickness, no. of primary branches/ plant, capsule length, and capsule width.

1000 seed weight: The 1000 seed weight displayed a favorable indirect impact on seed yield through factors such as stem thickness, no. of primary branches/plant, and no. of capsules/plant. Conversely, it exhibited an adverse indirect effect on seed yield through plant height, no. of secondary branches/plant, no. of seeds/capsule, capsule length, capsule width, days to 50% flowering, and days to maturity.

No. of capsules/ plant: The number of capsules per plant exhibited a beneficial indirect influence on seed yield through factors like 1000 seed weight, capsule width, and days to maturity. Conversely, it displayed an adverse indirect impact on seed yield through plant height, stem thickness, no. of primary branches/plant, no. of secondary branches/plant, no. of seeds/capsule, capsule length, and days to 50% flowering.

Capsule length: Capsule length exhibited a favorable indirect impact on seed yield through the no. of primary branches/plant, no. of secondary branches/plant, no. of seeds/capsule, capsule width, and days to maturity. Conversely, capsule length demonstrated an adverse indirect effect on seed yield through plant height, stem thickness, 1000 seed weight, no. of capsules/plant, and capsule width.

Capsule width: Capsule width demonstrated a favorable indirect impact on seed yield through factors such as plant height, stem thickness, 1000 seed weight, capsule length, days to 50% flowering, and days to maturity. Additionally, capsule width exhibited a positive indirect influence on seed yield through the no. of primary branches/plant, no. of secondary branches/plant, no. of seeds/capsule, and no. of capsules/plant.

Days to 50% flowering: It demonstrated a favorable indirect impact on seed yield through factors such as plant height, no. of primary branches/plant, no. of seeds/capsule, 1000 seed weight, no. of capsules/plant, capsule width, and days to maturity. Conversely, it exhibited an unfavorable indirect effect on seed yield through stem thickness, number of secondary branches/plant, and capsule length.

Days to maturity: It exhibited a positive indirect impact on seed yield through factors such as plant height, no. of seeds/capsule, 1000 seed weight, capsule width, and days to 50% flowering. Similarly, it demonstrated a positive indirect influence on seed yield through stem thickness, no. of primary branches/plant, no. of secondary branches/plant, no. of capsules/plant, and capsule length.

Path analysis compared with correlation coefficient

Direct effect & genotypic correlation coefficient, (Table 3&4 and Fig.1&2) both were positively observed for capsule width (0.375, 0.358), plant height (0.282, 0.328), days to 50% flowering (0.234, 0.353), no. of seeds/capsule (0.155, 0.284) and days to maturity (0.146, 0.403). Direct effect positive but correlation coefficient negative observed for no. of primary branches (0.032, -0.009) and no. of secondary branches (0.027, -0.178). Direct effect negative but correlation coefficient positive observed for 1000 seed weight (-0.079, 0.249) and capsule length (-0.081, 0.055). Direct effect & correlation coefficient both negative observed for no of capsules/plant (-0.129, -0.161) and stem thickness (-0.182, -0.108).

Summary

Association studies indicated that capsule width (mm) (rg = 0.358) displayed the most substantial positive and significant genotypic correlation coefficient, while days to maturity (rp = 0.389) exhibited the highest positive and significant phenotypic correlation coefficient. Consequently, enhancing these attributes could potentially boost the seed yield/plant (g). Conversely, the no. of secondary branches/plant (rg = -0.178) and the no. of capsules/plant (rp = -0.135) showed the highest negative and significant genotypic and phenotypic correlation coefficients, respectively.

The path coefficient analysis, with seed yield/plant as the dependent variable, revealed that capsule width (0.375) exhibited the most substantial positive direct effect, followed by plant height (cm) (0.282), days to 50% flowering (0.234), no. of seeds/capsule (0.155), no. of primary branches/plant (0.148), days to maturity (0.146), and no. of secondary branches/plant (0.108). Conversely, other important traits showed negative direct effects on the dependent variable; for instance, stem thickness (-0.182) demonstrated the highest negative direct effect, followed by the number of capsules/plant (-0.129), capsule length (-0.081), and 1000 seed weight (-0.080).

Table 1: A list of quantative characters

S. No	Traits
1	Days to 50% flowering
2	Days to maturity
3	Plant height (cm)
4	Number of primary branches per plant
5	Number of secondary branches per plant
6	Stem thickness(mm)
7	1000 seed weight/gm
8	Number of capsules per plant
9	Capsule length(mm)
10	Capsule width(mm)
11	Number of seeds per capsule
12	Seed yield per plant(gm)

Experimental material of present study

Table 2: Early Maturing Genotypes

S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes
1	GP 11	11	GP 556	21	Ex-28-6	31	GP 1109
2	GP 32	12	GP 568	22	GP 913	32	RLC 143 ©
3	GP 131	13	GP574	23	GP 958		
4	GS-105	14	GP 611	24	GP 1001		
5	GS-100	15	GP 633	25	GP 1002		
6	GP 278	16	GP 682	26	GP 1003		
7	GS-87	17	GP 691	27	CI-1697		
8	GP 351	18	GP 722	28	GP 1019		
9	Ex-53-9B	19	GP 829	29	GP 1021		
10	GP 532	20	GP 895	30	A 809		

Table 3: Bold Seeded Genotypes

S. No.	Genotypes	S.No.	Genotypes	S.No.	Genotypes
1	GP 10	11	GP 880	21	EC-99022
2	GP 47	12	GP 1566	22	GP 2831
3	GP 52	13	GP 1973	23	GP 2834
4	GP 68	14	GP 1981	24	GS-229
5	RLC 133©	15	GP 2006	25	GP 2861
6	RLC 148©	16	GP 2087	26	RLC 138©
7	RLC 153©	17	GP 2191		
8	CI-1968	18	GP 2336		
9	GP 429	19	GP 2405		
10	GP 711	20	GP 2434		

Sources of germplasm and checks: I.G.K.V. Raipur. © = Checks

Table 4: Correlation coefficient for seed yield and its contributing traits in linseed genotypes during Rabi 2022-23

S. No.	Characters		Stem thickness (mm)	No. of primary branches/ plant	No. of secondary branches/ plant	No. of seeds/ capsule	1000 seed weight (g)	No. of capsules/plant	Capsule length (mm)	Capsule width (mm)	Days to 50% flowering	Days to Maturity	Seed yield/ plant (g)
1.	Plant height (cm)	G	0.336**	0.018	-0.052	0.067	0.149	0.188*	0.368**	0.350**	0.083	0.104	0.328**
		P	0.205*	0.045	-0.015	0.042	0.124	0.170*	0.201*	0.216*	0.066	0.104	0.283**
2.	Stem thickness (mm)	G		0.200*	0.394**	-0.018	-0.065	0.445**	0.379**	0.135	-0.034*	-0.338*	-0.108
		P	-	0.111	0.221*	-0.105	-0.057	0.348**	0.182*	0.133	-0.020	-0.263**	-0.066
3.	No. of primary branches/ plant	G			0.010	-0.044	-0.053	0.237*	-0.062	-0.243*	0.075	-0.175*	-0.009
		P		-	0.055	-0.083	-0.039	0.129	0.016	-0.008	0.032	-0.131	-0.003
4.	No. of secondary branches/plant	G				0.010	0.082	0.158*	-0.105	-0.218*	-0.303**	-0.213*	-0.178*
		P			-	0.009	0.044	0.116	-0.054	-0.096	-0.207*	-0.143	-0.091
5.	No. of seeds/ capsule	G					0.066	0.119	-0.385**	-0.070	0.430**	0.193*	0.284**
		P				-	0.049	0.069	-0.158*	-0.001	0.312**	0.122	0.192*
6.	1000 seed weight (g)	G						-0.400**	0.115	0.317**	0.027	0.659**	0.249**
		P					-	-0.364**	0.084	0.235*	0.026	0.651**	0.243*
7.	No. of capsule/ plant	G							0.080	-0.168*	0.148	-0.486**	-0.161*
		P						-	0.049	-0.082	0.139	-0.445**	-0.136
8.	Capsule length (mm)	G								0.711**	-0.169*	-0.186*	0.055
		P							-	0.361**	-0.119	-0.149*	0.014
9.	Capsule width (mm)	G									0.022	0.241*	0.358**
		P								-	0.023	0.164*	0.263**
10.	Days to 50% flowering	G										0.299**	0.353**
		P									-	0.290**	0.325**
11.	Days to Maturity	G											0.403**
		P										-	0.389**

G- Genotypic correlation coefficient, P- Phenotypic correlation coefficient, *: Significance at 5%, **: Significance at 1%, ***: Significance at 0.1%

Table 5: Path analysis using phenotypic correlation coefficient for seed yield and its contributing trait in linseed genotypes during Rabi 2022-23

S. No.	Characters	Plant height (cm)	Stem thickness (mm)	No. of primary branches/ plant	No. of secondary branches/ plant	No. of seeds/ capsule	1000 Seed weight (g)	No. of capsules/ plant	Capsule length (cm)	Capsule width (cm)	Days to 50% flowering	Days to Maturity	PCC of seed yield/ plant
1.	Plant height (cm)	0.229	0.047	0.010	-0.003	0.009	0.028	0.039	0.046	0.049	0.015	0.024	0.283**
2.	Stem thickness (mm)	-0.008	-0.038	-0.004	-0.008	0.004	0.002	-0.013	-0.007	-0.005	0.001	0.010	-0.066
3.	No. of primary branches/ plant	0.002	0.004	0.033	0.002	-0.003	-0.001	0.004	0.001	-0.000	0.001	-0.004	-0.003
4.	No. of secondary branches/ plant	-0.000	0.006	0.002	0.027	0.000	0.001	0.003	-0.002	-0.003	-0.006	-0.004	-0.091
5.	No. of seeds/capsule	0.004	-0.009	-0.007	0.001	0.088	0.004	0.006	-0.014	-0.000	0.027	0.011	0.192*
6.	1000 seed weight (g)	-0.003	0.002	0.001	-0.001	-0.001	-0.022	0.008	-0.002	-0.005	-0.001	-0.015	0.243*
7.	No. of capsules/ plant	-0.017	-0.035	-0.013	-0.012	-0.007	0.036	-0.099	-0.005	0.008	-0.014	0.044	-0.136
8.	Capsule length (cm)	-0.001	-0.001	-0.000	0.000	0.001	-0.001	-0.000	-0.007	-0.003	0.001	0.001	0.014
9.	Capsule width (cm)	0.039	0.024	-0.002	-0.017	-0.000	0.042	-0.015	0.065	0.179	0.004	0.029	0.263**
10	Days to 50% flowering	0.015	-0.005	0.007	-0.048	0.072	0.006	0.032	-0.028	0.005	0.230	0.067	0.325**
11.	Days to Maturity	0.024	-0.059	-0.030	-0.032	0.028	0.148	-0.101	-0.034	0.037	0.066	0.227	0.389**
Residual Effect = 0.337													

Table 6: Path analysis using genotypic correlation coefficient for seed yield and and its contributing trait in linseed genotypes during Rabi 2022-23

S. No.	Characters	Plant height (cm)	Stem thickness (mm)	No. of primary branches/ plant	No. of secondary branches/ plant	No. of seeds/ capsule	1000 seed weight (g)	No. of capsules/ plant	Capsule length (cm)	Capsule width (cm)	Days to 50% flowering	Days to Maturity	GCC of seed yield/ plant
1.	Plant height (cm)	0.281	0.095	0.005	-0.015	0.019	0.042	0.053	0.104	0.099	0.023	0.029	0.328**
2.	Stem thickness (mm)	-0.061	-0.182	-0.037	-0.072	0.003	0.012	-0.081	-0.069	-0.025	0.006	0.062	-0.108
3.	No. of primary Branches/plant	0.003	0.030	0.148	0.002	-0.007	-0.008	0.035	-0.009	-0.036	0.011	-0.026	-0.009
4.	No. of secondary Branches/plant	-0.006	0.042	0.001	0.108	0.001	0.009	0.017	-0.011	-0.024	-0.033	-0.023	-0.178*
5.	No. of seeds/Capsule	0.010	-0.003	-0.007	0.002	0.155	0.010	0.018	-0.060	-0.011	0.067	0.023	0.284**
6.	1000 seed weight (g)	-0.012	0.005	0.004	-0.007	-0.005	-0.080	0.032	-0.009	-0.025	-0.002	-0.053	0.249**
7.	No. of capsules/ plant	-0.024	-0.058	-0.031	-0.020	-0.015	0.052	-0.129	-0.010	0.022	-0.019	0.063	-0.161*
8.	Capsule length (cm)	-0.030	-0.031	0.005	0.008	0.031	-0.009	-0.007	-0.081	-0.057	0.014	0.015	0.055
9.	Capsule width (cm)	0.131	0.051	-0.091	-0.082	-0.027	0.119	-0.063	0.267	0.375	0.008	0.091	0.358**
10	Days to 50% flowering	0.019	-0.008	0.018	-0.071	0.101	0.006	0.034	-0.040	0.005	0.234	0.070	0.353**
11.	Days to Maturity	0.015	-0.049	-0.026	-0.031	0.028	0.096	-0.071	-0.027	0.035	0.044	0.146	0.403**
Residual Effect = 0.277													

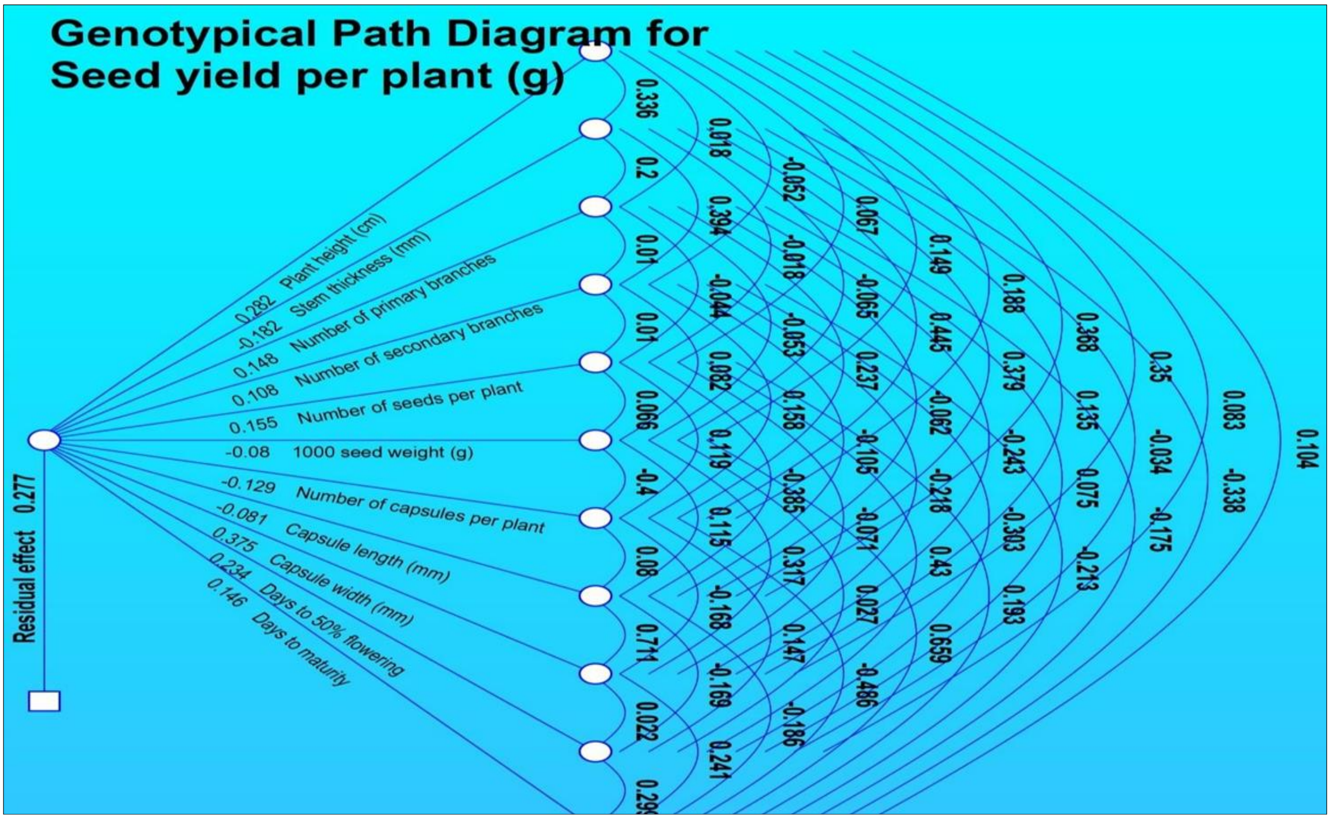

Fig 1: Genotypic path diagram for seed yield per plant (g)

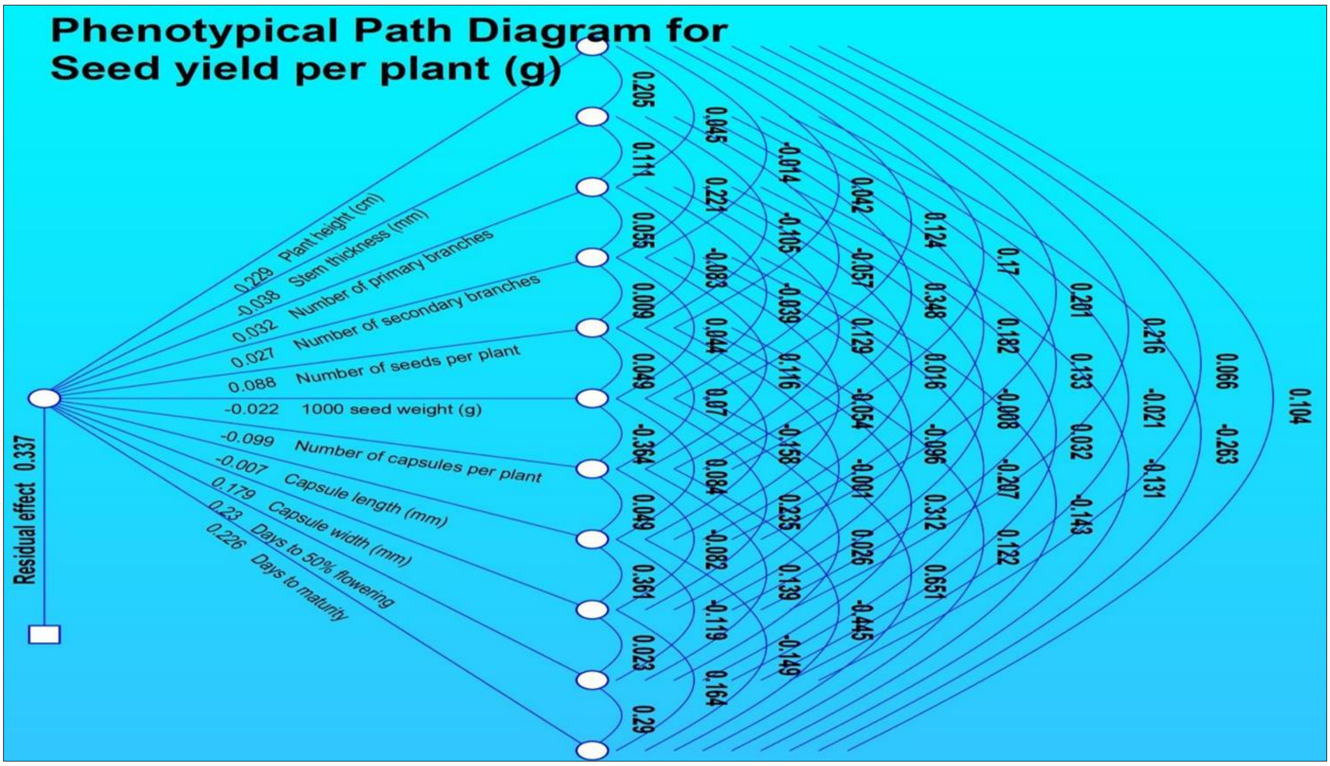

Fig 2: Phenotypic path diagram for seed yield per plant (g)

Conclusion

The outcomes of a path coefficient analysis utilizing seed yield/plant as the dependent variable revealed that the number of primary branches/plant, days to maturity, 1000 seed weight (g), plant height (cm), and capsule length (cm) exhibited the most significant positive direct impact. By elucidating the genuine relationship between seed yield and other attributes, focusing directly on these traits could potentially enhance yield improvements.

The findings from an association analysis conducted on early maturing and bold-seeded linseed indicated significant and positive correlations between seed yield/plant (g) and several traits, including the number of seeds/capsule, plant height, 1000 seed weight, capsule length, capsule width, days to 50% flowering, and days to maturity. This implies that enhancing one variable would likely lead to an increase in another. These characteristics hold promise for improving seed yield and for selecting superior genotypes from linseed cultivars.

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