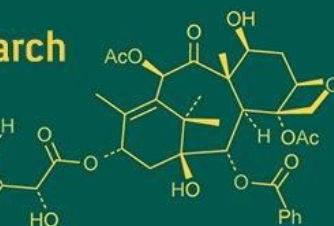
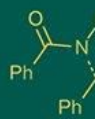
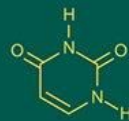
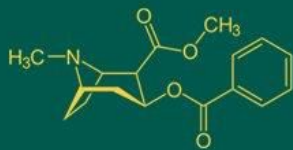


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Path analysis for evaluating trait interrelationships and seed yield in green gram [*Vigna radiata* (L.) Wilczek]

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Abstract

Green gram (*Vigna radiata* L. Wilczek) is a protein-rich pulse crop adaptable to diverse environments. Thirty-two genotypes were evaluated in *Kharif* 2024 using a randomized block design (two replications) for 14 morphological and nutritional traits. Analysis of variance revealed significant genetic variability for all traits. Path coefficient analysis showed number of pods per plant (0.958), 100 seed weight (0.946) and clusters per plant (0.251) exerted the strongest direct effects on seed yield. The residual effect (0.216) indicated that 78.4% of yield variation was explained by the studied traits. Results suggest that selection targeting these key traits can effectively enhance yield and quality in green gram breeding.

Keywords: Green gram, genetic variability, path coefficient, seed yield, nutritional traits

1. Introduction

Green gram (*Vigna radiata* L. Wilczek) or mung bean is a nutritionally rich pulse crop ranking third in India after chickpea and pigeon pea (Makwana *et al.*, 2020) [7]. Widely grown across Asia, Africa and Latin America, it contributes about 8% of India's pulse area, with major production in Rajasthan, Maharashtra, Madhya Pradesh, Karnataka and Gujarat (Gavhane *et al.*, 2024) [4]. It is a self-pollinating diploid ($2n = 2x = 22$) legume, well adapted to arid and semi-arid regions due to its early maturity, minimal water requirements and ability to grow in a variety of soils (Priyanka *et al.*, 2023) [12]. Optimal growth occurs in subtropical climates with 22-35 °C temperatures and 60-100 cm rainfall (Sharma *et al.*, 2024) [16]. Nutritionally, it contains 22-24% protein, 60 g carbohydrates and 7.3 mg iron per 100 g seeds, along with essential amino acids, vitamins (B, E, C in sprouts), calcium and phosphorus (Yadav *et al.*, 2024) [19].

Despite its nutritional and agronomic value, productivity remains suboptimal due to factors such as poor soil fertility, imbalanced nutrient use, limited adoption of improved cultivars and cultivation on marginal lands (Srivastava *et al.*, 2024; Aravinth *et al.*, 2023) [18, 2]. Enhancing yield, the primary goal in most breeding programs (Ramakrishnan *et al.*, 2018) [13], requires genotypes that combine high productivity with resistance to biotic and abiotic stresses (Makwana *et al.*, 2020) [7].

Seed yield is a multifaceted trait governed by several interrelated components, classifying it as both polygenic and dependent. Due to the limited effectiveness of direct selection, breeders often prioritize indirect selection through traits that have a strong positive impact on yield. Although correlation analysis helps reveal associations between traits, it does not clarify whether these relationships are direct or mediated by other traits. To overcome this limitation, path coefficient analysis breaks down the total correlation into its direct and indirect components, offering a more precise understanding of trait influence. This makes path analysis a valuable approach for identifying important traits that can be targeted through indirect selection to enhance yield (Reshmi *et al.*, 2022) [14].

Considering these aspects, the present study evaluated 32 green gram genotypes to determine the direct and indirect effects of yield-contributing traits.

The findings aim to guide efficient selection strategies for identifying high-performing genotypes and improving both seed yield and nutritional quality in green gram breeding programs.

2. Materials and Methods

The field experiment was conducted during *Kharif* 2024 at the research farm of Dr. Sharadchandra Pawar College of Agriculture, Baramati, situated in a semi-arid region with clay loam soil at 538 m altitude. Thirty two green gram genotypes and two checks were evaluated in a Randomized Block Design (RBD) with two replications. Each genotype was sown in two rows of 3 meter length with 45 cm × 15 cm spacing, following standard agronomic practices. Data were recorded on 10 agronomic and 4 nutritional traits from five randomly selected plants per plot. The traits included days to 50% flowering, days to maturity, plant height (cm), number of primary and secondary branches per plant, clusters per plant, pods per plant, seeds per pod, 100-seed weight (g), seed yield per plant (g), crude protein content (%), carbohydrate content (%), iron content (mg/kg) and zinc content (mg/kg). Data were subjected to analysis of variance (ANOVA) following Panse and Sukhatme (1985) [11]. Path coefficient analysis was performed according to Dewey and Lu (1959) [3] to partition correlations into direct and indirect effects. Statistical analyses were conducted using Microsoft Excel and Agri Analyze software.

3. Results and Discussion

3.1 Analysis of Variance

The ANOVA results from Table 1 showed significant differences among the 32 green gram genotypes for all fourteen traits, confirming the presence of considerable genetic variability. The highest variation was recorded for iron content, followed by days to maturity, plant height, carbohydrate content and number of pods per plant. Moderate variability was observed for days to 50% flowering, seed yield per plant, protein content, number of secondary branches per plant, clusters per plant, seeds per pod and zinc content. Similar observations were reported by Salman *et al.* (2023) [15] and Nayak *et al.* (2022) [10], who found significant genetic variability in green gram for related morphological and yield traits, indicating considerable potential for successful selection and genetic improvement.

3.2 Path analysis

The genotypic path coefficient analysis (Table 2, Figure 1) revealed that traits such as number of pods per plant, 100 seed weight and clusters per plant exerted the most pronounced and favorable direct effects on seed yield per plant, establishing them as key contributors to yield determination. These observations are in agreement with the findings reported by Ahmad and Belwal (2020) [1]. Secondary branches per plant also contributed positively through a moderate direct effect. In contrast, traits like primary branches per plant, plant height and days to 50% flowering displayed negative direct effects, yet they enhanced seed yield indirectly through their strong associations with major yield-influencing traits such as pods

and clusters per plant. Although seeds per pod showed a negative direct effect, it still had a beneficial impact via indirect pathways. This interpretation aligns with earlier findings of Ramakrishnan *et al.* (2018) [13], Mohan *et al.* (2021) [8], Mahla *et al.* (2022) [6] and Nalajala *et al.* (2022) [9], who highlighted similar key traits influencing yield. The residual effect at the genotypic level was estimated to be 0.216, indicating that 78.4% of the total variation in seed yield per plant was explained by the traits studied. These findings demonstrate the effectiveness of using path coefficient analysis alongside correlation analysis to identify not only the contributing traits but also the nature of their influence on yield, thereby offering a precise approach for selecting promising genotypes in green gram breeding.

Similarly, phenotypic path coefficient analysis (Table 3, Figure 2) confirmed that the number of pods per plant, 100 seed weight and clusters per plant had the most substantial direct influence on seed yield, making them effective criteria for selection in yield improvement. Secondary branches also showed a positive direct effect, whereas primary branches, although negative in their direct influence, contributed positively through indirect effects via other key traits. On the other hand, traits like days to 50% flowering, days to maturity and protein content exhibited negative direct effects. Traits such as seeds per pod and carbohydrate content, despite limited direct effects, positively influenced seed yield through their indirect association with traits like pods per plant and seed weight. The residual effect at the phenotypic level was recorded at 0.266, implying that 73.4% of the variation in seed yield was accounted for by the traits analyzed. These results align with those reported by Jadhav *et al.* (2019) [5], Sineka *et al.* (2021) [17], Mahla *et al.* (2022) [6] and Nalajala *et al.* (2022) [9], reinforcing the significance of pods per plant, seed weight and branching traits in green gram yield enhancement.

Tables and figures

Table 1: Analysis of Variance for 14 characters in 32 green gram genotypes.

Sr. No.	Characters	Mean sum of squares		
		Replications (2)	Treatment (32)	Error (64)
1.	Days to 50% flowering	1.27	9.32**	3.52
2.	Days to maturity	9.77	33.29**	8.54
3.	Plant height (cm)	15.87	29.95**	10.70
4.	Primary branches per plant	0.28	1.15**	0.12
5.	Secondary branches per plant	0.74	3.90**	0.31
6.	Clusters per plant	0.26	3.24**	0.36
7.	Pods per plant	6.68	27.31**	2.79
8.	Seeds per pod	1.47	2.47**	0.40
9.	100 seed weight (g)	0.24	0.97**	0.08
10.	Crude protein content (%)	3.55	7.30**	0.97
11.	Carbohydrate content (%)	14.33	26.24**	4.69
12.	Iron content (mg/kg)	6.94	277.24**	6.08
13.	Zinc content (mg/kg)	0.94	19.71**	0.63
14.	Seed yield per plant (g)	1.05	9.74**	0.51

*, ** denotes significant at 5% and 1% level of significance, respectively.

Table 2: Estimates of genotypic direct (diagonal) and indirect (above and below diagonal) effects of different characters on yield in Green gram.

Sr. No.	Character	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches per plant (no.)	Secondary branches per plant (no.)	Clusters per plant (no.)	Pods per plant (no.)	Seeds per pod (no.)	100 Seed weight (g)	Protein content (%)	Carbohydrate content (%)	Iron content (mg/kg)	Zinc content (mg/kg)	Genotypic correlation with seed yield per plant (g)
1.	Days to 50% flowering	-0.534	0.532	0.046	0.179	-0.055	-0.068	-0.366	0.036	0.104	0.001	0.012	-0.002	0.018	-0.098
2.	Days to maturity	-0.395	0.719	0.028	0.045	0.000	-0.036	-0.265	-0.204	-0.094	-0.001	-0.003	0.001	0.052	-0.154
3.	Plant height (cm)	0.142	-0.116	-0.172	-0.120	0.036	0.132	0.451	-0.020	0.051	-0.002	-0.032	0.004	0.001	0.357 *
4.	Primary branches per plant (no.)	0.184	-0.062	-0.040	-0.518	0.145	0.211	0.783	0.044	-0.088	-0.002	0.001	0.007	-0.081	0.584 **
5.	Secondary branches per plant (no.)	0.185	0.002	-0.039	-0.477	0.157	0.174	0.778	-0.011	-0.143	-0.002	0.008	0.008	-0.048	0.592 **
6.	Clusters per plant (no.)	0.144	-0.104	-0.090	-0.435	0.109	0.251	0.888	-0.087	0.077	-0.001	-0.007	0.002	-0.077	0.670 **
7.	Pods per plant (no.)	0.204	-0.199	-0.081	-0.423	0.128	0.232	0.958	-0.015	0.010	-0.003	0.004	0.008	-0.126	0.698 **
8.	Seeds per pod (no.)	0.031	0.234	-0.005	0.037	0.003	0.035	0.022	-0.626	0.512	-0.002	0.022	0.000	0.105	0.368 *
9.	100 Seed weight (g)	-0.059	-0.072	-0.009	0.048	-0.024	0.020	0.010	-0.338	0.946	0.001	0.033	-0.002	0.005	0.559 **
10.	Protein content (%)	-0.029	-0.079	0.024	0.069	-0.018	-0.011	-0.194	0.082	0.080	0.014	-0.017	-0.001	-0.032	-0.112
11.	Carbohydrate content (%)	-0.063	-0.018	0.056	-0.005	0.013	-0.017	0.038	-0.139	0.317	-0.002	0.098	0.003	0.002	0.281
12.	Iron content (mg/kg)	0.037	0.023	-0.024	-0.120	0.041	0.016	0.254	-0.008	-0.079	0.000	0.009	0.029	-0.035	0.143
13.	Zinc content (mg/kg)	0.032	-0.127	0.000	-0.142	0.026	0.066	0.409	0.223	-0.015	0.001	-0.001	0.003	-0.294	0.182

Residual effect (R): 0.216 *, ** denotes significance at 5 percent and 1 percent levels respectively. (Bold figures indicate direct effect)

Table 3: Estimates of phenotypic direct (diagonal) and indirect (above and below diagonal) effects of different characters on yield in Green gram.

Sr. No.	Character	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches per plant (no.)	Secondary branches per plant (no.)	Clusters per plant (no.)	Pods per plant (no.)	Seeds per pod (no.)	100 Seed weight (g)	Protein content (%)	Carbohydrate content (%)	Iron content (mg/kg)	Zinc content (mg/kg)	Genotypic correlation with seed yield per plant (g)
1.	Days to 50% flowering	-0.001	-0.011	0.001	0.001	-0.062	-0.033	-0.073	0.001	0.049	-0.002	0.009	0.000	0.000	-0.120
2.	Days to maturity	0.000	-0.032	-0.009	0.000	-0.015	-0.013	-0.020	0.009	-0.078	0.000	-0.003	0.001	0.001	-0.159
3.	Plant height (cm)	0.000	0.003	0.101	-0.001	0.056	0.032	0.110	0.007	-0.040	0.002	-0.006	0.001	0.000	0.266 *
4.	Primary branches per plant (no.)	0.000	0.000	0.018	-0.005	0.240	0.072	0.215	-0.002	-0.043	0.001	-0.001	0.002	-0.002	0.497 **
5.	Secondary branches per plant (no.)	0.000	0.001	0.018	-0.004	0.319	0.069	0.198	0.003	-0.073	0.001	0.004	0.002	-0.001	0.538 **
6.	Clusters per plant (no.)	0.000	0.004	0.027	-0.003	0.187	0.117	0.206	0.004	0.060	0.001	-0.009	0.000	-0.002	0.592 **
7.	Pods per plant (no.)	0.000	0.002	0.038	-0.004	0.214	0.082	0.295	0.003	-0.021	0.003	0.005	0.003	-0.003	0.617 **
8.	Seeds per pod (no.)	0.000	-0.005	0.013	0.000	0.016	0.009	0.017	0.057	0.188	0.002	0.018	0.000	0.003	0.317 *
9.	100 Seed weight (g)	0.000	0.005	-0.008	0.000	-0.047	0.014	-0.013	0.021	0.496	-0.001	0.021	-0.001	0.000	0.488 **
10.	Protein content (%)	0.000	0.000	-0.013	0.000	-0.020	-0.005	-0.055	-0.006	0.043	-0.016	-0.013	0.000	-0.001	-0.087
11.	Carbohydrate content (%)	0.000	0.001	-0.007	0.000	0.017	-0.013	0.016	0.012	0.120	0.002	0.086	0.001	0.000	0.237
12.	Iron content (mg/kg)	0.000	-0.002	0.013	-0.001	0.071	0.005	0.079	0.000	-0.039	0.000	0.007	0.011	-0.001	0.143
13.	Zinc content (mg/kg)	0.000	0.004	-0.001	-0.001	0.051	0.026	0.107	-0.016	-0.011	-0.001	0.002	0.001	-0.009	0.151

Residual effect (R): 0.266 *, ** denotes significance at 5 percent and 1 percent levels respectively. (Bold figures indicate direct effect)

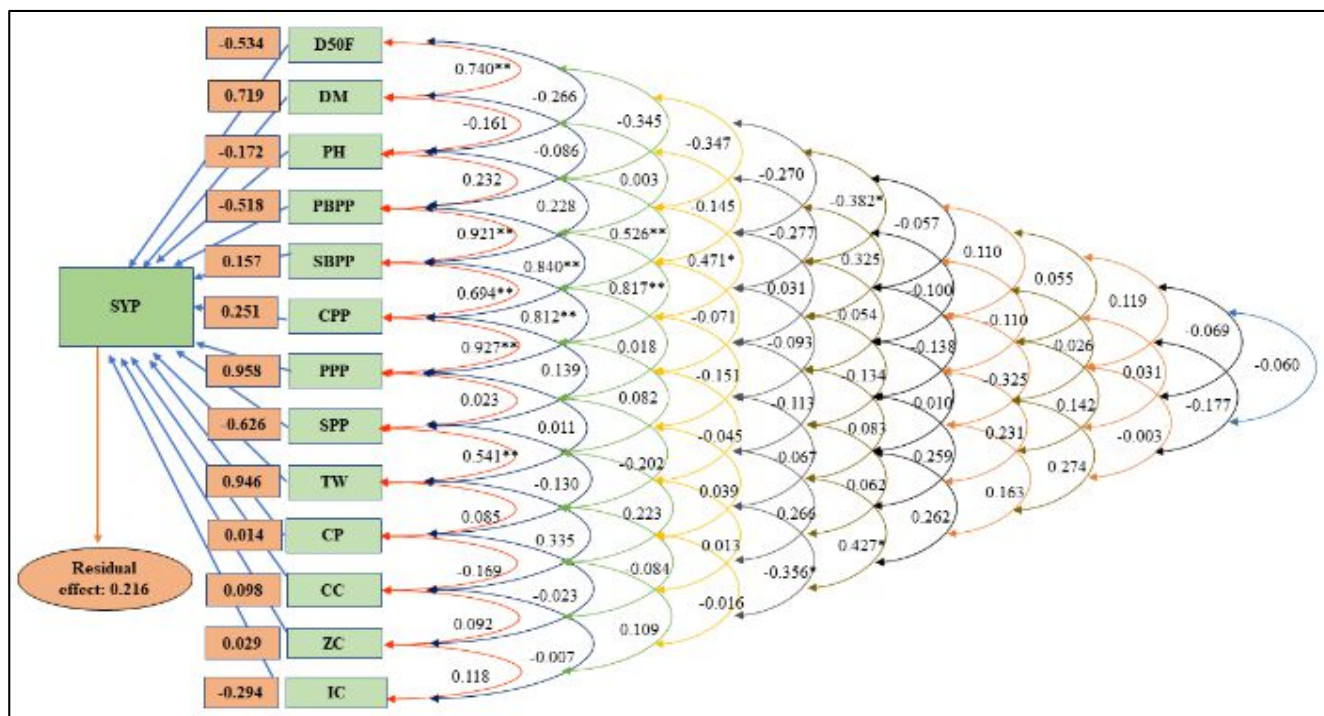


Fig 1: Genotypic path diagram

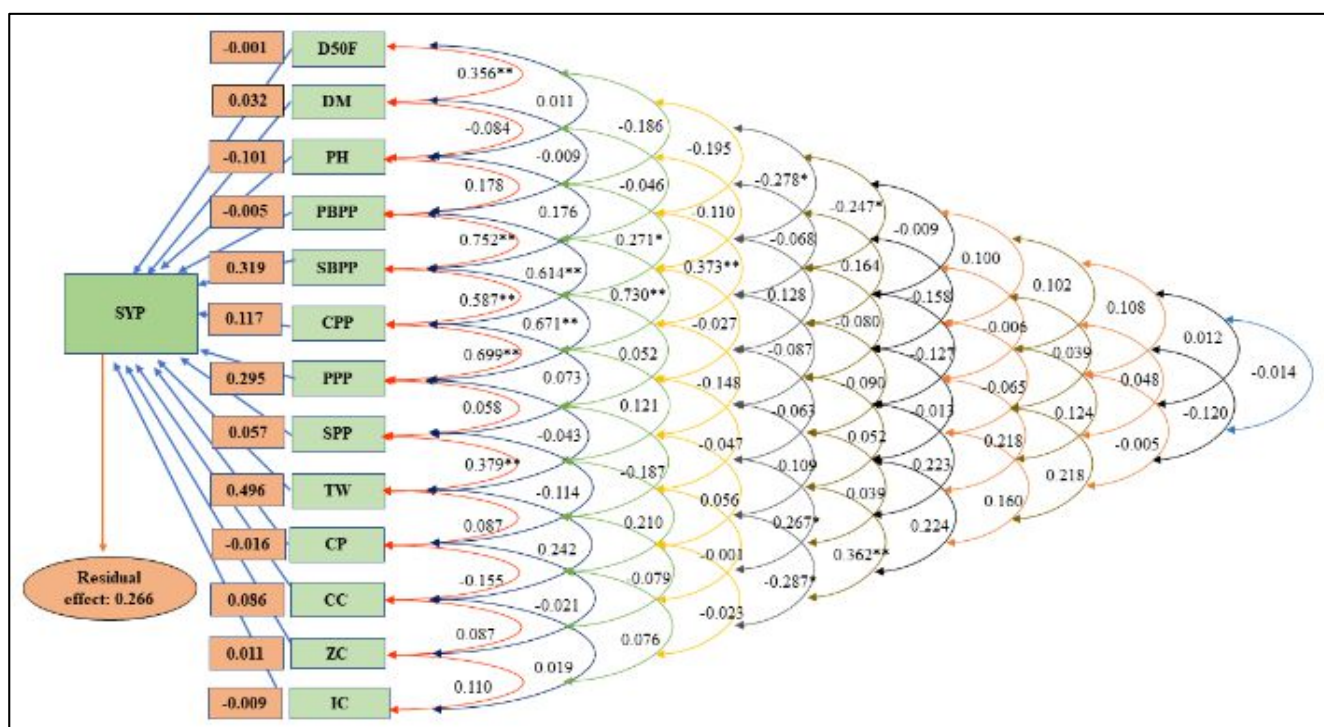


Fig 2: Phenotypic path diagram

4. Conclusion

Seed yield per plant in green gram was primarily governed by the number of pods per plant, 100-seed weight and clusters per plant, all of which exerted strong and favourable direct effects at both genotypic and phenotypic levels. Secondary branches per plant also contributed positively, while traits such as plant height, primary branches and days to 50% flowering, despite their negative direct effects, influenced yield indirectly via major yield components. The relatively low residual effects (0.216 genotypic; 0.266 phenotypic) indicate that most yield variation was explained by the studied traits. These results emphasize the utility of path coefficient analysis for precise trait dissection and

highlight pods per plant, seed weight and branching traits as effective selection criteria in green gram improvement programs.

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6. Conflict of Interest

The authors confirm that there are no competing interests associated with the publication of this research work.

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