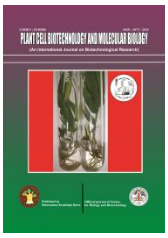

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Boosting Mungbean Growth and Root Nodulation with Phytohormonal Seed Priming for Sustainable Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The goal of the current study was to evaluate the impact of pre sowing phytohormonal seed priming on growth, yield, nodulation, heritability, genetic variability, genetic advance, genetic diversity analysis for Greengram (*Vigna radiata L.*) genotypes for 16 quantitative characters during Kharif 2023 in the field experiment centre, Department of Genetics and Plant Breeding, Naini Agriculture Institute, Sam Higginbottom University of Agriculture Technology and Sciences, Uttar Pradesh. To perform the study, 16 quantitative traits of 20 greengram genotypes were measured using randomized block design replicated thrice. Due to the efforts of promoting sustainable farming systems, new approaches to increasing crop yields without compromising the productivity of the land have been achieved. In order to recover soil fertility by encouraging active nodulation, this study investigates a sustainable method for improving mungbean production and growth. The best

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approach, therefore, is to apply organic amendments that promote promotion of soil microbial activity together with bio-inoculants whereby specific *rhizobial* strains that have exhibited be hallmark efficiency in nitrogen fixation will have to be adopted. The technology is aimed at increasing the efficiency of the interaction between mungbean roots and *rhizobial* bacteria through the optimization of the inoculation process and changes in the management practices of the root environment. This study assesses how this approach affects mungbean growth metrics, yield, and markers of soil fertility, like microbial diversity and nitrogen content. The aim of the study is to show a strong correlation between improved soil nutrient levels and microbial health and increased plant growth and output. The phytohormones are effective in decreasing the chemical nitrogen requirement and are useful for environment friendly farming. Out of tested 20 genotypes MGG – 347, TM 2000 – 2, PANTM - 4, PAU – 911 and DGGS - 4 have exhibited high seed yield per plant due to enhanced nodulation. Phytohormonal approach enhances better plant health and creates a healthier state of the soil in the long run. This acts as a positive strategy regarding soil reconditioning as well as a general improvement of the palette of the existing bio landscape regarding the prospect of expanding mungbean cultivation in a manner that is enduring.

Keywords: Mungbean; nitrogen fixation; soil fertility; symbiotic; rhizobial.

1. INTRODUCTION

Pulses or leguminous crops, including green gram, lentils, chickpeas, and many others, have special importance at the nutritional, environmental, economic, and social stages (Asif et al., 2013). An excellent source of protein, micronutrients, and dietary fiber, pulses are essential to address nutrition adequacy, especially in vegetarian/vegan diets and provide protections from chronic diseases (Hosseini et al., 2021). Greengram also known as mungbean (*Vigna radiata*) is a nutritious legume with many health benefits for the consumers. It is a valuable nutritional component because of its well-known high protein content, particularly in vegetarian and vegan diets (Sharma et al., 2024). Additionally, greengram is an excellent source of dietary fibre, vitamins, and minerals. The fibers enhance the well-being of the gut, and digestion, and regulating the blood sugar level (Sudhakaran et al*.,* 2021). In addition, it is crammed with Vitamin A, Vitamin C, Vitamin B_1 (Thiamin), Vitamin B_3 (Niacin), Vitamin B_2 (Riboflavin) Vitamin B_9 (Folate) vital for energy metabolism and proper health of the body (Kumar and Xu, 2018). Further, greengram is also a good source of the same minerals as zinc, iron magnesium and potassium are must for physiological processes such as oxygen transport and immune response respectively (Saini et al*.*, 2024). Indole acetic acid (IAA) and salicylic acid (SA) are phytohormones that are essential for controlling many elements of plant growth and development, including as seed germination. IAA, an endogenous auxin, regulates cell growth, root formation and differentiation of vascular tissues in plants consequently enhancing their growth. This involves controlled mobilization and seed germination by encouraging cell elongation in the embryonic part and increased synthesis of hydrolytic enzymes essential for seed coat penetrating and radicle emergence (El-Mergawi et al., 2020). On the other hand, SA acts as a signalling molecule in response defenses in plants against abiotic and biotic stresses, including pathogen attacks, drought, and high salinity. SA also participate in germination of seed by controlling the balance between ROS generation and detoxification, thus controlling seed dormancy and the capability of seed germination (Miura and Tada, 2014). Furthermore, interaction of IAA and SA, with phytohormones, like gibberellins and abscisic acid, finely orchestrate the germination process and ensure optimal seedling establishment (El-Mergawi et al*.,* 2020; Miura and Tada, 2014). Nodulation and priming are important processes in the Fabaceae family plants, which are responsible for a good quantity of their growth, output, and stand against challenges. Biological nitrogen fixation through nodulation mainly helps convert existing nitrogen in the atmosphere that is in a form unavailable to plants into a Usable form so that the need for Manufactured nitrogenous fertilizer is minimized, Organic nitrogen also increases the fertility of the soil that supports; other crops and plants and the process subsequently is an aspect of sustainable agriculture (Sulieman and Tran, 2015). Priming up-regulates plants preparation to strategies for abiotic and biotic stresses resulting increased germination percent, seedling strength, and crop yield because it optimizes the physiological and biochemical response mechanisms in plants to stress factors (Conrath, 2011). Together, these processes perform an important part in ensuring health as well as productivity for Fabaceae crops, with broad implications for agriculture and the environment. The aim of this experiment is to study the action of salicylic acid and indole acetic acid on the root nodulation of mungbean and hence increasing the soil fertility.

2. MATERIALS AND METHODS

The present investigation was carried out at central research farm of Genetics and Plant Breeding Department, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, during Kharif 2023. For the investigation, a total of 20 greengram genotypes were employed. The genotypes used in the experiment were- LGG-450, SHALIMAR-2, MGG-295, ADT-3, PUS-9531, PANTM-5, SML-668, MGG-347, IPM 302 – 2, DGG – 1, TM 2000 – 2, PANTM – 4, SUKETI – 1, IPM 99 – 125, DGGS – 4, PAU – 911, TAURM – 2, HUM – 16, COGG – 6 and MH 2 – 15. Three replications of the Randomized Block Design (RBD) were used to raise the genotypes. In 3 replications plant to plant spacing is 10 cm and row to row spacing is 30cm with plot size 1mx1m. In each replication there were 3 lines, T0 designated to control or the seeds without any presowing treatment, T1 were seeds were treated with Indole Acetic Acid (100ppm or 0.1g/L) and T2 seeds were treated with Salicylic Acid (50ppm or 0.05g/L). This was done to compare the changes in each genotype and note the result from phytohormonal treatment.

Five randomly chosen plants from each plot in each replication were used to record the data. Replication-wise, the readings for the five chosen plants were averaged, and the resulting mean data was subsequently utilized to do statistical analysis for the various features. The following pre-harvest observations, post-harvest observations, & nodule observations for the following characters were recorded in Table 2.

Table 1. Brief about the experiment conducted

Crop	Greengram
Season	*Kharif* – 2023
Design used in experiment	Randomized Block Design (RBD)
Replication Number	03
Genotypes Number	20
Treatment 1	IAA (Indole Acetic Acid)
Treatment 2	SA (Salicylic Acid)
Gross area	163.06 m^2
Net area	21.6 m^2
Spacing	30 cm × 10 cm
Sowing Date	25 August, 2023
Fertilizer dose	NPK @ 20:40:20 kg NPK/ha

Table 2. List of characteristics observed in this experiment

Observations	Characteristics
Pre – Harvest Observations	1. Days to 50% Flowering
	2. Days to 50% Pod Setting
	3. Plant Height
	4. Number of Primary Branches
	5. Number of Secondary Branches
	6. Days to Maturity
Post –Harvest Observations:	7. Number of Seeds per Plant
	8. Number of Seeds per Pod
	9. Biological Yield per Plant
	10. Seed Index
	11. Harvest Index
	12. Seed Yield per Plant
Nodule Observations:	13. Total Number of Nodules per Plant
	14. Number of Active Nodules per Plant
	15. Fresh Weight of Active Nodules
	16. Dry Weight of Active Nodules

3. RESULTS AND DISCUSSION

In this section we will study the in-depth examination of the obtained results, we aim to uncover the extent of genetic variation within the germplasm and explore the relationships between various quantitative traits, contributing to a better understanding of the diversity among greengram germplasm used in this study.

3.1 Analysis of Variance

The results of the analysis of variance showed that there were very significant differences for every attribute among the accessions, demonstrating the existence of extensive genetic diversity for many characters among the genotypes of greengram. The analysis of variance for 16 characters studied in the present investigationis given in Table 3.

Based on the analyzed results, days to maturity, plant height, number of primary branches, number of secondary branches, days to 50% flowering, and days to 50% pod setting, seed index, fresh weight of nodules, dry weight of nodules and seed yield per plant all showed notable variations among genotypes. The results highlight the genetic variability among the tested genotypes and suggest that careful selection of genotypes could result in enhanced performance for these characteristics in future breeding programs or agricultural practices.

3.2 Mean Performance of 20 Genotypes of Greengram

The average performance of 20 genotypes of greengram was evaluated for various agronomic traits. The mean performance of all genotypes provides useful information about the genetic variation and prospect of different Greengram varieties. This data would help in choosing better genotypes with desirably-quality traits for future crosses for increasing the yield and profitability of Greengram cultivation. Based on the observation Table 4 has been constructed according to which after the phytohormonal priming, the mean performance of days to 50% Flowering ranged from 51.12 days to 55.98 days with a grand mean of 53.40 days; days to 50% Pod Setting ranged from 61.38 days to 67.92 days with a grand mean of 64.56 days; days to 50% Pod Setting ranged from 61.38 days to 67.92 days with a grand mean of 64.56 days; plant height ranged from 42.96 cm to 89.27 cm with a grand mean of 65.06 cm; number of primary branches ranged from 3.14 to 5.12 with a grand mean of 4.14; number of secondary branches ranged from 6.88 to 9.17 with a grand mean of 8.02; days to maturity ranged from 72.59 days to 82.10 days with a grand mean of 76.70 days; number of pods per plant ranged from 32.77 to 40.09 with a grand mean of 36.71; number of seeds per pod ranged from 7.46 to 10.57 with a grand mean of 9.13; biological yield per plant ranged from 4.67 grams to 8.15 grams with a grand mean of 6.38 grams; seed index ranged from 2.94 to 5.74 with a grand mean of 4.53; harvest index ranged from 48.92 to 72.30 with a grand mean of 62.29.

After phytohormonal treatment the mean performance of fresh weight of nodules ranged from 15.33 to 20.33 with a grand mean of 17.72 grams and maximum fresh weight of nodules has been noted in IPM 99 - 125 (20.3333) followed by SHALIMAR-2 (19.6667), ADT-3 (18.6667), PUSA - 9531 (18.6667), SML - 668(18.6667), PANTM - 4 (18.6667) and PANTM - 5 (18.3333); Mean performance of dry weight of nodules ranged from 7.67 to 11.67 with a grand mean of 9.65 and maximum dry weight of nodules has been noted in PANTM - 4 (11.6667) followed by IM 2000 - 2 (11), LGG-450 (10.6667), SUKETI - 1 (10.6667), IPM 99 - 125 (10.6667), COGG- 6 (10.6667), PANTM - 5 (10), SML - 668 (10), DGG - 1 (10) and DGGS - 4 (10); Mean performance of fresh weight of nodules ranged from 0.57 grams to 3.19grams with a grand mean of 1.95 grams and maximum fresh weight of nodules has been shown SUKETI - 1 (3.1867) followed by MH 2 - 15 (2.8333), SHALIMAR-2 (2.72), PAU - 911 (2.6333), IPM 302 - 2 (2.4867), MGG-295 (2.0767), PUSA - 9531 (2.0733) and IM 2000 - 2 (2.0333); Mean performance of dry weight of nodules ranged from 0.37 grams to 1.19 grams with a grand mean of 0.82 grams and maximum dry weight of nodules has been shown by COGG - 6 (1.1907), DGGS - 4 (1.1769) followed by PAU - 911 (1.1258), IPM 99 - 125 (1.0946), PANTM - 4(1.0906), PANTM - 5 (1.0682), SHALIMAR-2 (1.0244), TAURM - 2 (0.908) and PUSA -9531 (0.8905); Mean performance of seed yield per plant ranged from 2.37 grams to 3.64 grams with a grand mean of 2.98 grams and maximum seed yield per plant have been shown by MGG - 347 (3.6382) followed by IM 2000 - 2 (3.515), PANTM - 4 (3.4782), PAU - 911 (3.4066), DGGS - 4(3.4035), HUM - 16 (3.3593), DGG - 1 (3.1388) and COGG - 6 (3.1287).

Table 3. Variance analysis for each of the 16 characters examined in Greengram

Sl. No.	Source of Variation	Mean Sum of Squares		
		Replication	**Treatment**	**Error**
	Degree of freedom	**2**	**19**	**38**
1	Days to 50% Flowering	31.673	5.90*	0.230
2	Days to 50% Pod Setting	49.314	8.34*	0.232
3	Plant Height	41.287	3.70**	0.283
4	Number of Primary Branches	10.804	0.90*	0.084
5	Number of Secondary Branches	5.773	1.45*	0.051
6	Days to Maturity	13.120	15.310	0.063
7	Number of Seeds per Plant	40.484	11.259	0.249
8	Number of Seeds per Pod	42.555	2.07**	0.254
9	Biological Yield per Plant	24.548	2.74*	0.072
10	Seed Index	17.536	1.59**	0.115
11	Harvest Index	4.310	0.000	0.281
12	Total Number of Nodules per Plant	6.717	4.36**	3.576
13	Number of Active Nodules per Plant	6.200	3.56**	3.253
14	Fresh Weight of Active Nodules	5.505	1.08*	0.056
15	Dry Weight of Active Nodules	5.198	0.20**	0.064
16	Seed Yield per Plant	12.153	0.51*	0.058

***Significant at 5% level of significance * Significant at 1% level of significance*

Table 4. Average performance of 16 quantitative characters among 20 Greengram genotypes assessed during *Kharif* -2023

Sl. No	Genotype	D 50%F	D50%PS	PH	NPB	NSB	DM	NSPl	NSPo	BYP	SI	HI	TNNPI	NANPI	FWN	DWN	SYP
1	LGG-450	54.17	62.97	70.61	3.76	7.89	75.65	34.18	9.85	4.67	5.54	60.69	17.33	10.67	1.56	0.83	3.10
2	SHALIMAR-2	52.73	64.85	43.23	4.87	8.02	78.23	35.43	9.40	6.94	3.66	57.63	19.67	7.67	2.72	1.02	2.40
3	MGG-295	53.57	64.04	63.47	4.12	7.42	75.64	36.83	8.92	6.80	4.02	61.58	15.33	9.33	2.08	0.64	2.37
4	ADT-3	55.02	66.67	60.12	4.40	8.69	74.90	36.92	8.48	6.75	2.94	67.99	18.67	8.67	1.56	0.56	2.39
5	PUSA - 9531	51.12	63.91	42.96	3.89	7.96	74.92	34.85	10.43	4.95	4.54	72.30	18.67	9.33	2.07	0.89	2.59
6	PANTM - 5	53.78	66.29	63.81	4.87	9.06	72.59	35.94	9.76	8.15	3.65	71.35	18.33	10.00	1.92	1.07	2.41
7	SML - 668	52.23	61.38	59.75	3.42	7.04	73.61	36.40	9.08	5.22	4.19	60.61	18.67	10.00	1.43	0.48	2.87
8	MGG - 347	52.34	64.04	60.29	3.25	7.38	76.87	38.52	9.03	7.35	4.62	51.58	17.33	8.67	1.36	0.58	3.64
9	IPM 302 - 2	52.61	63.82	65.19	4.15	9.17	77.71	39.45	8.62	7.91	4.35	68.00	16.67	8.67	2.49	0.87	2.62
10	DGG - 1	52.66	63.06	61.19	3.65	8.75	74.07	34.88	10.05	6.82	3.68	62.24	17.67	10.00	1.68	0.61	3.14
11	TM 2000 - 2	55.36	64.80	60.43	4.75	8.02	75.35	37.74	9.19	6.74	5.15	65.09	16.67	11.00	2.03	0.37	3.52
12	PANTM - 4	54.08	63.61	62.01	3.87	8.29	75.87	40.09	8.58	6.79	5.74	66.98	18.67	11.67	1.77	1.09	3.48
13	SUKETI - 1	54.64	64.28	62.49	4.06	6.89	82.10	38.18	7.60	5.74	4.81	67.66	17.67	10.67	3.19	0.80	3.00
14	IPM 99 - 125	52.25	66.27	83.63	4.72	7.66	78.06	32.77	8.94	4.98	4.87	51.30	20.33	10.67	1.67	1.09	2.99
15	DGGS - 4	54.78	63.34	58.83	4.13	8.03	76.13	38.03	10.57	5.92	4.98	55.50	17.67	10.00	1.53	1.18	3.40
16	PAU - 911	51.58	66.57	67.03	4.11	8.95	77.33	37.88	9.95	6.26	5.66	59.13	17.33	7.67	2.63	1.13	3.41
17	TAURM - 2	51.40	66.70	60.99	4.40	7.87	78.76	35.39	8.46	5.80	4.86	69.04	17.33	9.33	1.98	0.91	2.72
18	HUM - 16	52.98	62.82	70.39	3.14	8.60	78.47	36.91	8.75	7.11	4.87	48.92	17.33	8.67	0.57	0.59	3.36
19	COGG - 6	54.64	67.92	68.07	4.05	6.88	78.43	34.70	9.43	6.23	4.42	65.23	15.67	10.67	1.84	1.19	3.13
20	MH 2 - 15	55.98	63.88	89.27	5.12	7.81	79.33	39.13	7.46	6.41	4.13	62.90	17.33	9.67	2.83	0.53	3.02
Min		51.12	61.38	42.96	3.14	6.88	72.59	32.77	7.46	4.67	2.94	48.92	15.33	7.67	0.57	0.37	2.37
Max		55.98	67.92	89.27	5.12	9.17	82.10	40.09	10.57	8.15	5.74	72.30	20.33	11.67	3.19	1.19	3.64
Mean		53.40	64.56	65.06	4.14	8.02	76.70	36.71	9.13	6.38	4.53	62.29	17.72	9.65	1.95	0.82	2.98
C.V.		0.90	0.75	14.80	7.02	2.82	0.33	1.36	5.52	4.22	7.49	0.85	10.67	18.69	12.11	30.71	8.11
F ratio		25.64	35.96	18.53	10.67	28.40	243.56	45.27	8.16	37.96	13.83	483.13	1.22	1.09	19.62	3.18	8.88
F Prob.		0.56	0.11	1.12	0.26	0.33	0.15	0.08	0.16	0.22	0.26	0.19	0.29	0.39	0.32	0.18	0.22
S.E.		0.28	0.28	2.63	0.17	0.13	0.14	0.29	0.29	0.16	0.20	0.31	1.09	1.04	0.14	0.15	0.14
C.D. 5%		0.79	0.80	15.88	0.48	0.37	0.41	0.82	0.83	0.44	0.56	0.88	0.76	0.56	0.39	0.42	0.40

Analysis of the total number of nodules per plant (Fig. 1), the number of active nodules per plant (Fig. 2), and the seed yield (Fig. 3) shows how phytohormonal treatment and nodulation are related. Nodulation is an environmentally benign method of replacing nitrogen in fertilizer. IAA mediates root development to facilitate the formation of beneficial interactions with nitrogen-fixing microorganisms such as Rhizobium and maintenance of nodule functions through modulation of nodule senescence by SA. These phytohormones can significantly reduce the needs for chemical nitrogen fertilizers by increasing the efficiency of biological nitrogen fixing process, promoting the enlviable green / sustainable agricultural practices. This hormone-mediated method reduces environmental effect while increasing plant health and productivity, making it a viable substitute for chemical inputs in the growth of greengram. Table 5 discusses the impact of phytohormonal priming on 20 genotypes of greengram.

Table 5. Effect of treatment on 20 genotypes of greengram

Sl. No.	Characters under consideration	Effect
I.	Days to 50% Flowering	It is enhanced with T1 (52.467 days). The genotypes LGG-450 and SHALIMAR-2 have shown maximum.
II.	Days to 50% Pod Setting	It is enhanced with T1 (62.80 days). The genotypes MGG – 347 andCOGG – 6 have shown maximum.
III.	Plant Height	It is enhanced with T1 (89.27 cm). The genotypes SUKETI - 1 have shownmaximum.
IV.	Number of primary Branches	It is enhanced with T1 (3.40). The genotypes MH 2 – 15, COGG –6 and ADT-3 have shown maximum.
V.	Number of Secondary Branches	It is enhanced with T1 (7.60). The genotypes MGG – 347, COGG – 6, SUKETI – 1 and HUM – 16 have shown maximum.
VI.	Days to Maturity	It is enhanced with T1 (75.80). The genotypes SUKETI – 1, MH 2 – 15 andTAURM - 2 have shown maximum
VII.	Number of Seeds per Plant	It is enhanced with T1 (9.62). The genotypes LGG-450, SHALIMAR-2 and IM 2000 – 2 have shown maximum
VIII.	Number of Seeds per Pod	It is enhanced with T1 (10.62). The genotypes SUKETI – 1 andPANTM - 4 have shown maximum
IX.	Biological Yield per Plant	It is enhanced with T1 (7.20). The genotypes PANTM – 5, LGG-450and SHALIMAR-2 have shown maximum
X.	Seed Index	It is enhanced with T1 (6.12). The genotypes LGG-450, SHALIMAR-2 and IPM 302- 2have shown maximum
XI.	Harvest Index	It is enhanced with T1 (59.77). The genotypes SML – 668, PAU – 911 and ADT-3 have shown maximum
XII.	Total Number of Nodules per Plant	It is enhanced with T1 (17.85). The genotypes IPM 99 – 125, ADT-3 and SHALIMAR-2 have shown maximum
XIII.	Number of Active Nodules per Plant	It is enhanced with T1 (9.72). The genotypes PANTM – 4,IM 2000 – 2, COGG – 6 and LGG-450 have shown maximum
XIV.	Fresh Weight of Nodules	It is enhanced with both treatments used for the study T1 (1.76) & T1 (1.76). The genotypes PANTM – 4, IPM 99 – 125 and IPM 302 - 2 have shown maximum
XV.	Dry Weight of Nodules	It is enhanced with T1 (0.32). The genotypes SUKETI – 1, SML – 668, PANTM – 5 and TAURM – 2 have shown maximum
XVI.	Seed Yield per Plant	It is enhanced with T1 (2.41 grams). The genotypes MGG – 347**,** MGG-295, MGG – 347 and HUM – 16 have shown maximum

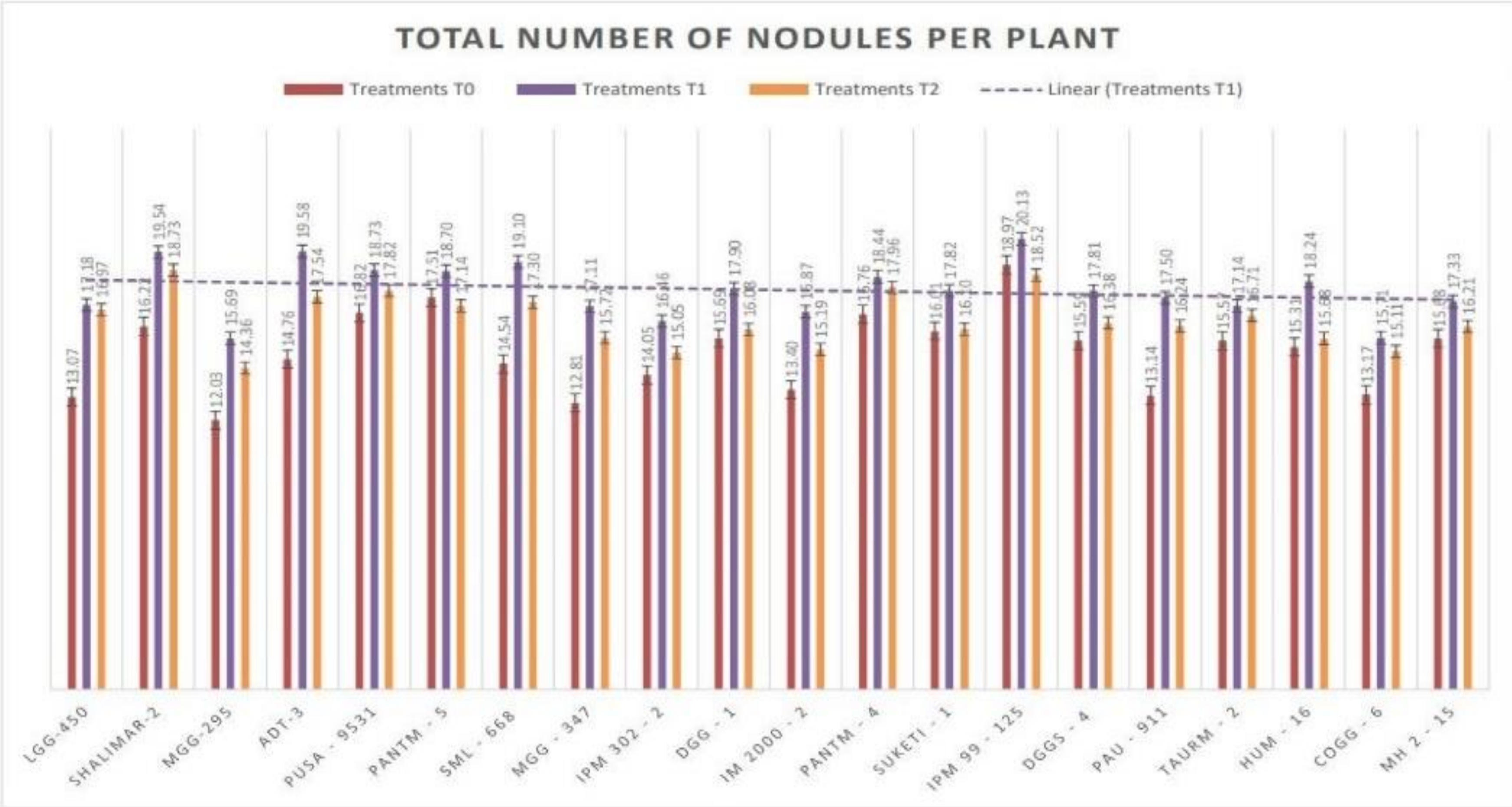

Fig. 1. Bar diagram depicting Effect of Indole Acetic Acid (T1), Salicylic Acid (T2) on Total Number of Nodules per Plant with Control (T0)

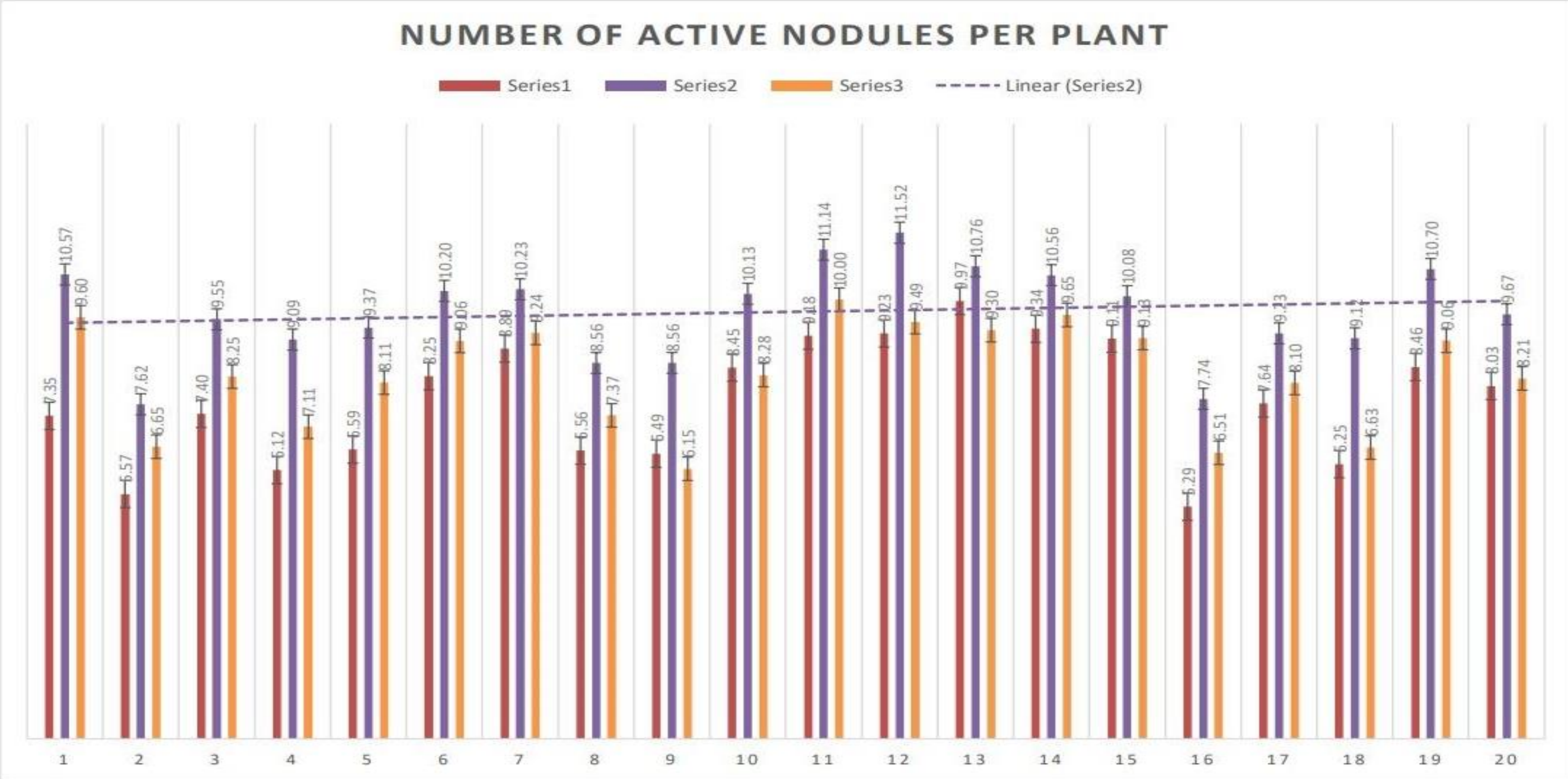

Fig. 2. Bar diagram depicting Effect of Indole Acetic Acid (T1), Salicylic Acid (T2) on Number of Active Nodules per Plant with Control (T0)

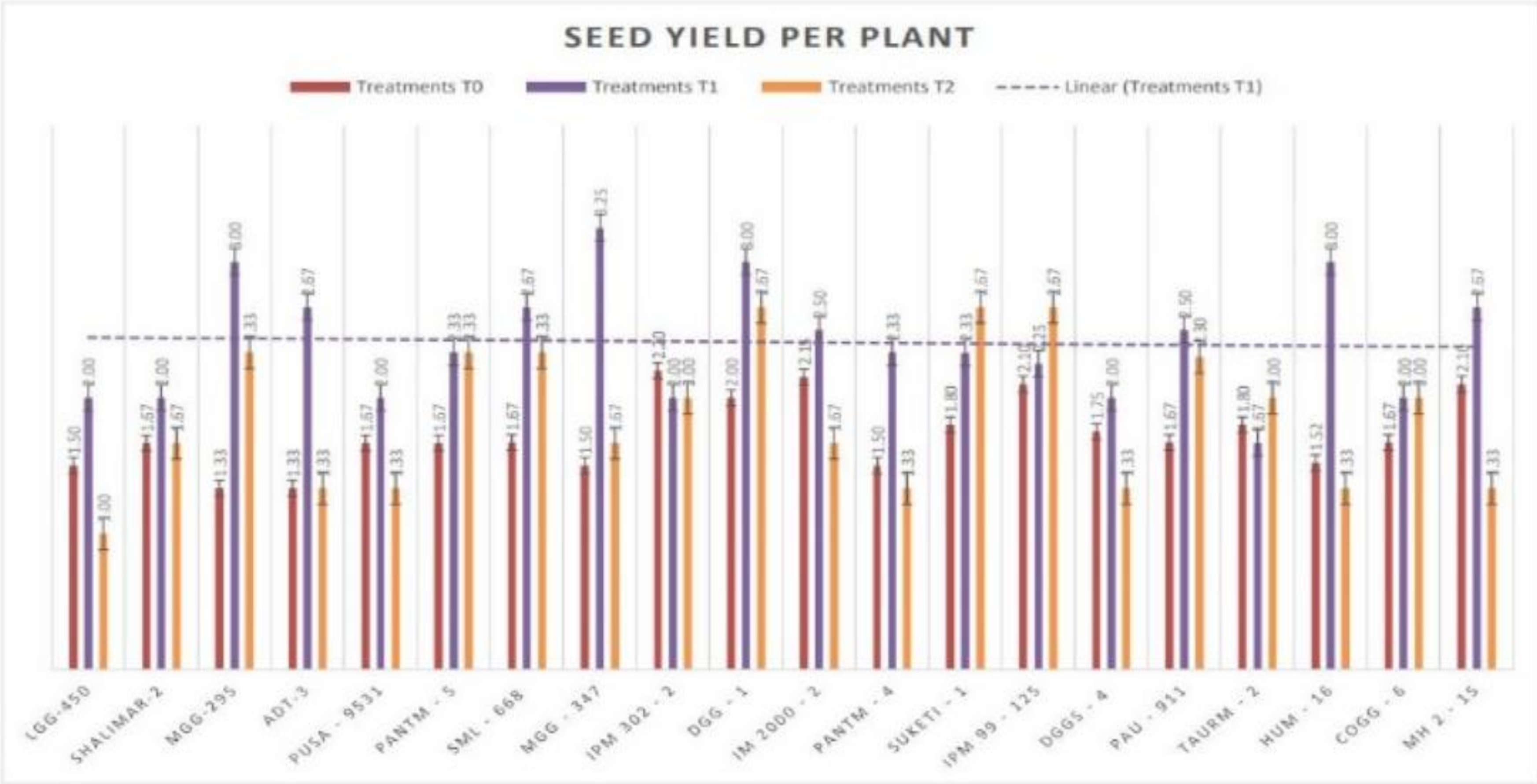

Fig. 3. Bar diagram depicting Effect of Indole Acetic Acid (T1), Salicylic Acid (T2) on Seed Yield per Plant with Control (T0)

3.3 Assesment of Component of Variablity

In any effort to enhance crops, understanding genetic variability is crucial. This involves analysing the range of genetic and observable differences within a population, measured through mean genotypic and phenotypic variation, as well as, heritability, coefficients of variation, genetic gain, and genetic advance (Table 6). Environmental pressures thus greatly determine how traits are expressed, making phenotypic and genotypic analysis challenging. Thus, assessing variability via biometric features like genotypic and phenotypic variation, genetic advance, heritability (broad sense), and genotypic coefficient of variation is essential for breeders crafting selection programs to improve crop genetics.

From the analysis in Table 6 we can conclude,

A wide range of phenotypic coefficient of variation (PCV) was observed for all the traits ranged from dry weight of active nodules (31.611) to days to 50% pod setting (2.583). Higher magnitude of PCV was recorded for dry weight of active nodules (31.611), fresh weight of active nodules (30.969). A wide range of genotypic coefficient of variation (GCV) was observed for all the traits ranged from fresh weight of active nodules (30.17) to days to 50% pod setting (2.546). Higher magnitude of GCV was recorded for fresh weight of active nodules (30.17), dry weight of active nodules (26.172). Heritability (%) in broad sense which range from number of active nodules per plant (8.6) to harvest index (99.8). High estimate of genetic advance as percent of mean was recorded for fresh weight of active nodules (60.545), dry weight of active nodules (44.638), seed index (30.747), biological yield per plant (30.072), seed yield per plant (25.501), number of primary branches (24.727), harvest index (22.185). These results revealed that there was a comparative higher degree of genotypic correlation coefficients than their phenotypic counterparts in most of the characters studied. This indicated that there was a higher degree of association between two characters of genotypic association, their phenotypic association was lessened due to the influence of environment.

3.4 Correlation Coefficient

Analysis of correlation coefficients is used as a statistical technique with a view to have a measure of strength and direction of association between several variables. As a complex characteristic that is determined by various climate properties, crop yield is improved by relating yield to the characteristics that underlie the yield (Table 7). This leads to a betterment of breeding of crops initiatives as it applies suitable selection criteria. Using correlation coefficient analysis, one can at the same time factor several traits that influence this yield.

Genotypic Correlation coefficient analysis revealed that Seed Yield per plant has shown positive and significant association with Total Number of Nodules per Plant (0.1215*), Number of Active Nodules per Plant (0.1365**), while negative and significant association with Fresh Weight of Active Nodules (-0.3118*), Dry Weight of Active Nodules (-0.0577*), Plant Height (-0.1314**), Number of Secondary Branches (-0.0286**). Positive and non- significant association with Days to 50% Flowering (0.0803), Days to Maturity (0.1463), Number of Seeds per Plant (0.259), Number of Seeds per Pod (0.0262), Seed Index (0.22), while negative and non-significant association with Days to 50% Pod Setting (-0.1489), Number of Primary Branches (-0.0902), Biological Yield per Plant (-0.0318), Harvest Index (- 1.3265).

Phenotypic correlation coefficient analysis revealed that Seed Yield per plant has shown positive and significant association with days to 50% flowering (0.139**), total number of nodules per plant (0.1688**), number of active nodules per plant (0.3042*), number of seeds per plant (0.3172*), while negative and significant correlation with plant height (-0.2611**), number of secondary branches (-0.1152*), biological yield per plant (-0.0857**), fresh weight of active nodules (-0.2865*), dry weight of active nodules (-0.0399**). Positive and non- significant association with days to maturity (0.1628), number of seeds per pod (0.0831), seed index (0.6978), while negative and non-significant association with days to 50% pod setting (-0.2079), number of primary branches (-0.4071), harvest index (-0.4744).

Significant positive association of these above attributes indicated that these attributes were mainly influencing the seed yield in greengram. Thus, selection practiced for the improvement in one character will automatically result in the improvement of the other character even if direct selection for improvement has not been made for the yield character.

Table 6. Assesment of component of variablity

Sl.No.	Characters	GCV	PCV	h^2 (BroadSense)	Genetic Advancement 5%	Gen.Adv as % of Mean 5%
1	Days to 50% Flowering	2.575	2.627	96.1	2.777	5.2
2	Days to 50% Pod Setting	2.546	2.583	97.2	3.339	5.172
3	Plant Height	7.021	7.306	92.4	2.114	13.9
4	Number of Primary Branches	12.609	13.245	90.6	1.023	24.727
5	Number of Secondary Branches	8.516	8.67	96.5	1.382	17.232
6	Days to Maturity	2.939	2.945	99.6	4.635	6.042
7	Number of Seeds per Plant	5.218	5.277	97.8	3.903	10.631
8	Number of Seeds per Pod	8.534	9.11	87.7	1.503	16.467
9	Biological Yield per Plant	14.794	14.993	97.4	1.917	30.072
10	Seed Index	15.497	16.089	92.8	1.394	30.747
11	Harvest Index	10.781	10.792	99.8	13.818	22.185
12	Total Number of Nodules per Plant	2.886	6.805	18	0.447	2.521
13	Number of Active Nodules per Plant	3.32	11.289	8.6	0.194	2.011
14	Fresh Weight of Active Nodules	30.17	30.969	94.9	1.178	60.545
15	Dry Weight of Active Nodules	26.172	31.611	68.5	0.367	44.638
16	Seed Yield per Plant	13.141	13.95	88.7	0.759	25.501

Table 7. Genotypic correlation coefficient between yield and its component traits

S No.	Traits	D 50%F	D50%PS	PH	NPB	NSB	DM	NSPl	NSPo	BYP	SI	HI	TNNPI	NANPI	FWN	DWN
1	D 50%F	1														
2	D50%PS	0.0681**	1													
3	PH	-0.0811	0.1793**	1												
4	NPB	0.2799	0.4734	0.0124**	1											
5	NSB	-0.1323	0.0819*	0.0562*	0.0503*	1										
6	DM	0.3254	0.7677	0.0546	0.1515	-0.5485	1									
7	NSPl	0.9343	-0.8494	-0.1997	-0.0586	0.2338	0.76	1								
8	NSPo	-0.3752	-0.0243	0.1657	-0.092	0.1304**	-1.108	-0.659	1							
9	BYP	0.1984	0.1872**	-0.0211*	0.052*	0.346	-0.2694	0.9134	-0.107	1						
10	SI	- 0.1062**	-0.1564	-0.2335	-0.0973	-0.0526	0.4371	0.2585*	0.0581*	-0.2546	1					
11	HI	1.1718	2.8765	1.3039	1.194	0.6274	-2.935	1.2746	-0.504	0.4348	-1.037	1				
12	TNNPI	-0.4207	-0.045*	0.2703	0.121	0.1337**	-0.358	-0.641	0.0278*	-0.2881	- 0.0826	- 1.0873	1			
13	NANPI	0.6425	-0.1776	-0.347	0.0031	-0.2649	-0.2154	-0.2193	-0.0784	-0.3167	0.2893	1.7185	-0.0921	1		
14	FWN	0.1173**	0.2363	0.0273	0.1906	-0.0324	0.607	0.2878	-0.1476	0.0034*	-0.0108	1.815	-0.0328	-0.0477	1	
15	DWN	-0.0691	0.1976	0.0875	0.0256	0.0187	0.1004*	-0.1003	0.071	-0.0266	0.0523	0.127	0.1072**	0.0236*	0.0275*	1
16	SYP	0.0803	-0.1489	- 0.1314**	-0.0902	- 0.0286**	0.1463	0.259	0.0262	-0.0318	0.22	-1.3265	0.1215*	0.1365**	- .3118*	- .0577*

** Significant at 5% Level of Significance ** significant at 1% Level of Significance*

(Days to 50% Flowering, or D50%F Days to 50% Pod setting, or D50%P Plant Height, or PH NPB, or the number of main branches Days to Maturity (DM), Number of Secondary Branches (NSB), NPP: Pod count per plant, BYP, or biological yield per plant, and NSPo, or number of seeds per pod Seed Index (SI), Harvest Index (HI), Total Nodule Number per Plant or TNNPl, NANPl or the quantity of active nodules in a plant The nodule's fresh weight (FWN), dry weight (DWN), Seed Yield per Plant, or SYP)

Table 8. Phenotypic correlation coefficient between yield and its component traits

S No	Traits	D 50%F	D50%PS	PH	NPB	NSB	DM	NSPl	NSPo	BYP	SI	HI	TNNPI	NANPI	FWN	DWN
1	D 50%F	1														
2	D50%PS	0.0235**	1													
3	PH	-0.0579*	0.0911**	1												
4	NPB	0.3549	0.5174	0.0194***	1											
5	NSB	-0.14*	0.0718*	0.0684*	0.1397	1										
6	DM	0.1034	0.2028	0.0203*	0.1196*	-0.3501	1									
7	NSPl	0.3385	-0.2641	-0.0879	-0.0607	0.1784*	0.1727	1								
8	NSPo	-0.3361	-0.0376**	0.1936**	-0.1984	0.2441	-0.5879	-0.4157	1							
9	BYP	0.1487	0.1192	-0.0285*	0.1101**	0.5275	-0.1261*	0.4951	-0.1501	1						
10	SI	- .1021**	-0.1219	-0.289	-0.2546	-0.11**	0.2655	0.1754	0.1009**	-0.376	1					
11	HI	0.1233	0.2572	0.1703*	0.3264	0.1374	-0.1926	0.0959	-0.0898	0.0688**	-0.213	1				
12	TNNPI	-0.2698*	-0.033	0.1926	0.1964	0.1275**	- .1211**	-0.2874	0.0681**	-0.2543	-0.1193	- .1262	1			
13	NANPI	0.4482	-0.1109*	-0.2927	0.0303*	-0.3677	-0.1008	-0.0775	-0.0829	-0.3199	0.3385	0.2297	-0.0216	1		
14	FWN	0.1265**	0.2393	0.043	0.5858	-0.0754*	0.4473	0.2464	-0.3069	0.018	- 0.0431*	0.4503	-0.0448	-0.1098	1	
15	DWN	-0.1931	0.4582	0.3533	0.2021	0.1052**	0.1564	-0.2017	0.3726	-0.1052	0.2917	0.0667	0.2091	0.0507*	0.1818**	1
16	SYP	0.139**	-0.2079	-0.2611**	-0.4071	-0.1152*	0.1628	0.3172*	0.0831	- 0.0857**	0.6978	-0.4744	0.1688**	0.3042*	-0.2865*	- 0.0399**

** Significant at 5% Level of Significance ** significant at 1% Level of Significance*

(Days to 50% Flowering, or D50%F Days to 50% Pod setting, or D50%P Plant Height, or PH NPB, or the number of main branches Days to Maturity (DM), Number of Secondary Branches (NSB), NPP: Pod count per plant, BYP, or biological yield per plant, and NSPo, or number of seeds per pod Seed Index (SI), Harvest Index (HI), Total Nodule Number per Plant or TNNPl, NANPI or the quantity of active nodules in a plant The nodule's fresh weight (FWN), dry weight (DWN), Seed Yield per Plant, or SYP

Table 9. Path analysis for significantly correlated quantitative traits at genotypic level

Traits	D 50%F	D50% PS	PH	NPB	NSB	DM	NSPl	NSPo	BYP	SI	HI	TNNPl	NANPl	FWN	DWN	SYP
D 50%F	-0.1926	-0.0045	0.0111	-0.0683	0.027	-0.0199	-0.0652	0.0647	-0.0286	0.0197	-0.0237	0.052	-0.0863	-0.0244	0.0372	0.139
D50%PS	0.0158	0.6714	0.0612	0.3474	0.0482	0.1361	-0.1773	-0.0253	0.0801	-0.0818	0.1727	-0.0221	-0.0745	0.1607	0.3077	-0.2079
PH	-0.0186	0.0292	0.3208	0.0062	0.0219	0.0065	-0.0282	0.0621	-0.0091	-0.0927	0.0546	0.0618	-0.0939	0.0138	0.1133	-0.2611
NPB	-0.1132	-0.1651	-0.0062	-0.319	-0.0446	-0.0382	0.0194	0.0633	-0.0351	0.0812	-0.1041	-0.0627	-0.0097	-0.1869	-0.0645	-0.4071
NSB	-0.033	0.0169	0.0161	0.0329	0.2355	-0.0825	0.042	0.0575	0.1242	-0.0259	0.0324	0.03	-0.0866	-0.0178	0.0248	-0.1152
DM	0.0321	0.0629	0.0063	0.0371	-0.1086	0.3103	0.0536	-0.1824	-0.0391	0.0824	-0.0597	-0.0376	-0.0313	0.1388	0.0485	0.1628
NSPl	0.2111	-0.1647	-0.0548	-0.0379	0.1113	0.1077	0.6237	-0.2593	0.3088	0.1094	0.0598	-0.1793	-0.0484	0.1537	-0.1258	0.3172
NSPo	-0.2194	-0.0246	0.1264	-0.1295	0.1593	-0.3837	-0.2713	0.6527	-0.098	0.0658	-0.0586	0.0444	-0.0541	-0.2003	0.2432	0.0831
BYP	0.0025	0.002	-0.0005	0.0018	0.0088	-0.0021	0.0082	-0.0025	0.0167	-0.0063	0.0011	-0.0042	-0.0053	0.0003	-0.0018	-0.0857
SI	-0.0327	-0.039	-0.0924	-0.0814	-0.0352	0.0849	0.0561	0.0323	-0.1203	0.3198	-0.0681	-0.0382	0.1083	-0.0138	0.0933	0.6978
HI	-0.0933	-0.1948	-0.1289	-0.2471	-0.104	0.1458	-0.0726	0.068	-0.0521	0.1612	-0.7571	0.0956	-0.1739	-0.3409	-0.0505	-0.4744
TNNPl	-0.0236	-0.0029	0.0169	0.0172	0.0112	-0.0106	-0.0252	0.006	-0.0223	-0.0105	-0.0111	0.0876	-0.0019	-0.0039	0.0183	-0.1688
NANPl	0.4177	-0.1033	-0.2728	0.0283	-0.3427	-0.0939	-0.0723	-0.0772	-0.2981	0.3155	0.2141	-0.0201	0.932	-0.1023	0.0473	0.3042
FWN	0.0352	0.0667	0.012	0.1632	-0.021	0.1246	0.0687	-0.0855	0.005	-0.012	0.1255	-0.0125	-0.0306	0.2786	0.0507	-0.2865
DWN	0.151	-0.3582	-0.2762	-0.158	-0.0822	-0.1223	0.1577	-0.2913	0.0823	-0.228	-0.0521	-0.1634	-0.0397	-0.1421	-0.7817	-0.0399
SYP	0.139	-0.2079	-0.2611	-0.4071	-0.1152	0.1628	0.3172	0.0831	-0.0857	0.6978	-0.4744	-0.1688	0.3042	-0.2865	-0.0399	-0.3425
Partial R^2	-0.0268	-0.1396	-0.0837	0.1299	-0.0271	0.0505	0.1979	0.0542	-0.0014	0.2232	0.3592	-0.0148	0.2835	-0.0798	0.0312	

(Days to 50% Flowering, or D50%F Days to 50% Pod setting, or D50%P Plant Height, or PH NPB, or the number of main branches Days to Maturity (DM), Number of Secondary Branches (NSB), NPP: Pod count per plant, BYP, or biological yield per plant, and NSPo, or number of seeds per pod Seed Index (SI), Harvest Index (HI), Total Nodule Number per Plant, or TNNPl NANPl, or the quantity of active nodules in a plant The nodule's fresh weight (FWN), dry weight (DWN), Seed Yield per Plant, or SYP).

Table 10. Path analysis for significantly correlated quantitative traits at phenotypic level

Traits	D50%F	D50%PS	PH	NPB	NSB	DM	NSPl	NSPo	BYP	SI	HI	TNNPl	NANPl	FWN	DWN	SYP
D 50%F	1.1694	0.0352	-0.0646	0.4565	-0.1648	0.1228	0.4148	-0.4097	0.1789	-0.1285	0.1484	-0.6998	1.7058	0.1699	-0.2734	0.1493
D50%PS	0.0502	1.6659	0.1701	0.9199	0.1215	0.3451	-0.4493	-0.0316	0.2011	-0.2255	0.4341	-0.0902	-0.5617	0.4078	0.931	-0.2314
PH	-0.0819	0.1514	1.4826	0.033	0.1142	0.0336	-0.1447	0.2953	-0.031	-0.4614	0.2696	0.7339	-1.5037	0.0646	0.5649	-0.3143
NPB	-1.0761	-1.5222	-0.0613	-2.7567	-0.3897	-0.3551	0.1617	0.6731	-0.2917	0.7318	-0.94	-1.2515	-0.0513	-1.7168	-0.6294	-0.4419
NSB	-0.0772	0.04	0.0422	0.0775	0.548	-0.1953	0.098	0.1344	0.2944	-0.0601	0.075	0.2098	-0.6636	-0.0443	0.07	-0.1071
DM	-0.3526	-0.6957	-0.0761	-0.4327	1.1967	-3.3586	-0.591	2.1113	0.4255	-0.9269	0.6511	1.0454	1.0019	-1.5405	-0.6956	0.1659
NSPl	-0.7243	0.5507	0.1992	0.1198	-0.365	-0.3593	-2.0419	0.8975	-1.0321	-0.3922	-0.2023	1.349	0.7295	-0.5226	0.4969	0.3456
NSPo	0.8662	0.0469	-0.4925	0.6038	-0.6063	1.5543	1.0868	-2.4725	0.3602	-0.2624	0.2371	-0.1724	0.7771	0.7983	-1.0475	0.086
BYP	0.1453	0.1147	-0.0198	0.1005	0.5101	-0.1203	0.48	-0.1384	0.9497	-0.3649	0.0652	-0.5673	-0.9953	0.0059	-0.1244	-0.0862
SI	-0.2956	-0.3641	-0.8369	-0.7139	-0.295	0.7421	0.5166	0.2854	-1.0334	2.6892	-0.5898	-0.6181	3.4572	-0.0703	0.9318	0.8003
HI	-0.2773	-0.5693	-0.3972	-0.745	-0.2989	0.4235	-0.2165	0.2095	-0.15	0.4792	-2.1848	0.6919	-1.7453	-1.0061	-0.1921	-0.5049
TNNPl	-0.0036	-0.0003	0.003	0.0028	0.0023	-0.0019	-0.004	0.0004	-0.0036	-0.0014	-0.0019	0.0061	-0.0034	-0.0007	0.0059	-0.6072
NANPl	0.1208	-0.0279	-0.084	0.0015	-0.1003	-0.0247	-0.0296	-0.026	-0.0868	0.1065	0.0662	-0.0466	0.0828	-0.021	0.0283	1.0886
FWN	0.4866	0.82	0.1459	2.0859	-0.271	1.5363	0.8572	-1.0814	0.0209	-0.0876	1.5424	-0.3661	-0.8496	3.3494	0.7285	-0.3118
DWN	0.1993	-0.4766	-0.3249	-0.1947	-0.1089	-0.1766	0.2075	-0.3613	0.1117	-0.2955	-0.075	-0.8313	-0.2916	-0.1855	-0.8527	-0.0577
SYP	0.1493	-0.2314	-0.3143	-0.4419	-0.1071	0.1659	0.3456	0.086	-0.0862	0.8003	-0.5049	-0.6072	1.0886	-0.3118	-0.0577	-0.0268
Partial R^2	0.1746	-0.3855	-0.466	1.2181	-0.0587	-0.5571	-0.7056	-0.2128	-0.0819	2.1522	1.1031	-0.0037	0.0902	-1.0444	0.0492	

(Days to 50% Flowering, or D50%F Days to 50% Pod setting, or D50%P Plant Height, or PH NPB, or the number of main branches Days to Maturity (DM), Number of Secondary Branches (NSB), NPP: Pod count per plant, BYP, or biological yield per plant, and NSPo, or number of seeds per pod Seed Index (SI), Harvest Index (HI), Total Nodule Number per Plant, or TNNPl NANPl, or the quantity of active nodules in a plant The nodule's fresh weight (FWN), dry weight (DWN), Seed Yield per Plant, or SYP)

3.5 Path Coefficient Analysis

An additional analysis of the correlated traits is required to determine the direct effects of particular yield components on yield as well as the indirect effects of other yield components on grain yield, as correlation does not show a cause-and-effect relationship, it is insufficient to explain true associations. The path coefficient analysis provided by indicates the relative significance of each component contributing to the end product, or yield, as well as the effective measure of direct and indirect reasons of connection. The path analysis used in this inquiry aims to determine the cause-and-effect relationship between seed yield and related features. By partitioning correlation, path coefficient analysis enables the separation of direct and indirect effects through other characteristics.

Genotypic Path coefficient analysis revealed that maximum positive direct effect on seed yield per plant was obtained by fresh weight of active nodules (3.3494), seed index (2.6892), days to 50% pod setting (1.6659), plant height (1.4826), days to 50% flowering (1.1694), biological yield per plant (0.9497), number of secondary branches (0.548), number of active nodules per plant (0.0828), total number of nodules per plant (0.0061). Negative direct effect on seed yield per plant was obtained by dry weight of active nodules (-0.8527), number of seeds per plant (- 2.0419), harvest index (-2.1848), number of seeds per pod (-2.4725), number of primary branches (-2.7567), days to maturity (-3.3586).

Phenotypic Path coefficient revealed that maximum positive direct effect on seed yield per plant was obtained by number of active nodules per plant (0.932), days to 50% pod setting (0.6714), number of seeds per pod (0.6527), number of seeds per plant (0.6237), plant height (0.3208), seed index (0.3198), days to maturity (0.3103), fresh weight of active nodules (0.2786), number of secondary branches (0.2355), total number of nodules per plant (0.0876), biological yield per plant (0.0167). Negative direct effect on seed yield per plant was obtained by days to 50% flowering (-0.1926), number of primary branches (-0.319), harvest index (- 0.7571), dry weight of active nodules (-0.7817).

The results of the path coefficient analysis demonstrate that the direct and indirect effects of the above- mentioned characters were mainly responsible for the seed yield, resulting in the conclusion that greengram productivity can be improved by simultaneously selecting for days to 50% flowering, seed index, number of pods per plant, plant height and dry weight of nodules. Selection for these traits will increase the breeding effectiveness of the program in terms of increasing yield. Therefore, these characteristics could be evaluated as the most crucial strategic characteristics for greengram seed yield per plant.

4. CONCLUSION

The study reveals that treatments have consistently enhances various growth and yield parameters in Greengram genotypes. As a result of presowing treatment with indole acetic acid (T1), it was observed that the earliest days to 50% flowering (52.467 days) and days to 50% pod setting (62.80 days) was enhanced especially in LGG-450, SHALIMAR-2, MGG-347, and COGG-6. T1 also supports maximum plant height (89.27 cm), primary branches (3.40), and secondary branches (7.60) especially in the progeny of SUKETI-1 and COGG-6. Days to maturity are extended to 75.80 days under T1, with SUKETI-1 and MH 2-15 exhibiting maximum durations. Seed-related parameters, including number of seeds per plant (9.62), seeds per pod (10.62), and biological yield per plant (7.20), are significantly improved with T1, as seen in genotypes such as LGG-450 and SHALIMAR- 2. Furthermore, T1 enhances the seed index (6.12), harvest index (59.77), and nodulation traits, with the highest fresh and dry weight of nodules (1.76 and 0.32, respectively). The total number of nodules per plant (17.85) and active nodules per plant (9.72) also peak under T1 which is 60% more than the plants in control(T0) where total number of nodules per plant (12.04) and active nodules per plant (6.02) and this shows that Indole Acetic Acid treatment enhanced the nodulation which further boost the soil fertility, because more the number of nodules more will be the nitrogen provided to the soil reclaiming the fertility. Finally, seed yield per plant reaches its maximum (2.41 grams) with T1 treatment, especially in genotypes MGG-347 and HUM-16. From the result, it is evident that T1 was effective in enhancing growth and yield performance of Greengram. Treatment with Salicylic Acid (T2) promote and enhance fresh weight of active nodules (in genotypes LGG-450, ADT-3, IPM 302-2, DGG-1, DGGS-4, TAURM-2, HUM-16 and COGG-6) and dry weight of active nodules (in

ADT-3, IPM 302-2, IM 2000-2 DGGS- 4 and PANTM-4). Furthermore, T2 increased the seed yield in SUKETI-1 and IPM 99-125 which was 40% more than the control plants. Hence the pre-sowing phytohormonal seed priming had a positive impact on nodulation, growth and yield of greengram (*Vigna radiata L.*) which offers a promising prospect in the field of agriculture. Out of tested 20 genotypes MGG - 347(3.6382), TM 2000 - 2(3.515), PANTM - 4(3.4782), PAU - 911(3.4066) and DGGS - 4 (3.4035) have exhibited high seed yield per plant. Other genotypes like PANTM – 5, SML - 668, DGG - 1, ADT-3 and PUSA - 9531 have shown early maturity among the tested 20 greengram genotypes. Thus, by generating variety through hybridization and selection, these genotypes may be employed in future breeding programs to create superior varieties with desirable economic qualities helpful to humanity. The successful outcome of this study opens a window into complex interactions between hormonal treatments and crop performance primarily in greengram involving examining of mechanisms to improve nodulation, biomass generation and finally yield. As the research progresses concerning seed priming, future work promises in explaining the precisely hormonal regulation and molecular control of crop response to seed priming that would foster more effective and efficient priming techniques. The practical application impacts are not limited to study work but have real value for the farmers desiring better crop yields and less vulnerability to environmental conditions. Application of seed priming in the farming practices will enable farmers to achieve optimal production of greengram using minimal resources and with least environmental influence. This highlights the need for adopting environmentally sustainable ways in offering food security in agriculture and underlines the need of the researchers to pursue innovative way in solving ecological problems in agriculture around the world. If more research is done and more innovations have evolved, greengram should be promising to return more yields with better utilization of resources so that the food security of the global communities is improved.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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