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Effect of bioregulators on growth characteristics and yield of mung bean (*Vigna radiata* L.) under central plain zone of Uttar Pradesh

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Abstract
This study investigates the effects of various plant growth regulators (PGRs) on the growth, yield attributes, and yield of mung bean (*Vigna radiata* L.) under the central plain zone of Uttar Pradesh during Kharif-2023 and Kharif-2024. The experiment included treatments with indole-3-acetic acid (IAA), maleic hydrazide (MH), gibberellic acid (GA_3), 2,3,5-triiodobenzoic acid (TIBA), and kinetin. The experiment was laid out in Randomized Block Design with eleven treatments each replicated thrice. Mung bean variety *IPM 205-07 (Virat)* was grown with the recommended agronomic practices. Significant improvements in plant height, number of primary branches, leaf area, number of flowers, pods per plant, test weight, seed yield, and harvest index were observed. In Kharif-2023, maximum plant height (49.09 cm), primary branches (5.53), and leaf area (246.71 cm^2) were recorded in the GA_3 @ 60 ppm treatment. Seed yield peaked at 1231.85 kg/ha with kinetin @ 15 ppm, representing a 15.34% increase over control. In Kharif-2024, similar trends were noted, with the highest seed yield (1200.36 kg/ha) also in kinetin @ 15 ppm. The pooled analysis showed maximum values of plant height (48.54 cm), primary branches (5.40), leaf area (242.58 cm^2), seed yield (1216.11 kg/ha), and harvest index (35.41%) in kinetin @ 15 ppm. The study underscores the potential of PGRs, particularly kinetin, in enhancing mung bean productivity in this region.

Keywords: Gibberellic acid, kinetin, mung bean, maleic hydrazide, and yield

1. Introduction
Mung bean (*Vigna radiata* L.), commonly referred to as green gram or moong, is a significant leguminous crop. Pulses, including mung bean, are renowned for their high protein content, offering more than three times the quality of protein found in cereal grains. This makes them a valuable dietary component, especially in regions where protein sources are limited. (Hilger *et al.* 2015) [11]. Mung bean plays a crucial role in providing an affordable protein source in many developing countries across Asia. In these regions, it significantly helps in mitigating protein deficiencies and is often referred to as the “poor man’s meat” due to its accessibility and cost-effectiveness. Beyond its protein content, mung bean is also a rich source of essential minerals. Additionally, its proteins and carbohydrates are highly digestible, making it an excellent dietary choice for enhancing nutrition in economically challenged communities. (Mishra *et al.*, 2021) [16]. The crop integrates effectively into multi-cropping systems due to its quick growth and early maturation. In India, mung bean production reaches 3.676 million tonnes, cultivated across 5.547 million hectares. This adaptability and productivity make mung beans an important component of diverse agricultural practices. (Directorate of Pulses Development, GOI, 2022–23).

A variety of soil amendments, both artificial and natural, have been identified for their roles in enhancing soil fertility and improving plant production. These include phytohormones, carbon-rich organic amendments (Kamran *et al.*, 2021) [14], and synthetic mineral nutrients (Chen *et al.*, 2019) [6]. These amendments support soil health and promote effective agricultural practices throughout the entire growth cycle of crop plants, from germination to harvest. (Iqbal *et al.*, 2017) [13].

Plant growth regulators (PGRs) are increasingly recognized as vital components in overcoming obstacles to improving biological productivity in pulse crops. These sophisticated chemical substances are formulated to enhance seed yield and overall crop performance through various mechanisms. PGRs work by modulating key physiological processes within plants.

The primary natural auxin found in plants is indole-3-acetic acid (IAA). This plant hormone is predominantly located in the young leaves and the stem apex, where it plays a crucial role in regulating growth and development. IAA is one of the most important auxins, acting as a key regulator of various physiological processes such as cell elongation, root development, and fruit formation. Notably, IAA is considered non-toxic to plants even at relatively high concentrations, making it a vital and safe component for enhancing plant growth and optimizing agricultural practices. Gibberellic acid (GA_3) is a significant natural plant growth regulator (PGR) that promotes the growth, development, and yield of various crops. GA_3 is a type of phytohormone belonging to the terpenoid class of compounds, characterized by a structure containing 19–20 carbon atoms. It is naturally produced in newly developed leaves and in the embryos of germinating seeds. Over 136 different species of gibberellic acid have been identified, highlighting its widespread presence and importance in plant physiology (Hedden, 2020) [10]. A minimal quantity of gibberellic acid (GA_3) can significantly promote stem elongation by stimulating both cell division and cell expansion (Keykha *et al.*, 2014; Tan *et al.*, 2019) [15, 23]. This enhancement in stem growth leads to overall improvements in plant growth and development (Camara *et al.*, 2018) [5]. Kinetin, a synthetic cytokinin, is utilized to bolster plant resistance to stress and to delay the aging process.

Likewise, TIBA (2,3,5-Triiodobenzoic acid), a synthetic growth regulator, is employed to manage excessive vegetative growth and reduce the tendency of plants to overproduce foliage. It helps minimize the premature shedding of flowers and immature pods, while also modifying the crop canopy to enhance overall productivity. Research has demonstrated its effectiveness in improving the growth, yield, and yield attributes of several pulse species. By modifying the canopy structure, TIBA helps optimize light interception and resource allocation, leading to better crop performance (Adam and Jahan, 2014) [2].

This manuscript is crucial for the scientific community as it explores the effects of plant growth regulators on the growth, yield attributes and yield of mung bean (*Vigna radiata* L.) under rainfed conditions. Understanding how these treatments influence crop performance can provide insights into optimizing nutrient management and enhancing sustainable agriculture practices.

2. Materials and Methods

2.1 Experimental site

The experiment was conducted on Student's Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.) during Kharif-2023 and Kharif-2024. Kanpur is situated at a latitude of 260 29' 35" North and an east longitude of 800 18' 35" and is situated at a height of 125.9 meters above Mean Sea Level. The average annual rainfall is approximately 816 millimeters.

2.2 Crop husbandry

The experimental field was properly leveled followed by preparatory irrigation afterward at optimum tilth, then the field was ploughed and layout was done as per programme. The recommended dose of Nitrogen, phosphorus, potassium and sulphur were applied in the ratio of 20:40:20 as basal dose through urea, single superphosphate, and muriate of potash. Mung bean variety IPM 205-07 (Virat) was sown in field at distance of 45 × 10 cm. With the help of an object to keep crop free from weeds two hand weeding and one hoeing were undertaken for each sowing treatment. For protection of crop against insect-pests, spraying of monocrotophos as per recommendation was done. The plots were sprayed with IAA, MH, GA_3, TIBA and Kinetin as per treatments by using hand sprayer. The spraying was carried out at flowering initiation stage. The sprays were completed in morning hours at 8.00-10.00 A.M. The crop was harvested at maturity and was allowed to dry in sun. Separate bundles were made for each plot and weighted. The after drying harvest was threshed manually.

2.3 Treatment details

The experiment consists of thirty three plots in three replication and each replication had eleven plots.

Table 1: Details of the treatments

Symbol	Treatment Combinations
T_1	Control (Unsprayed)
T_2	IAA@40ppm
T_3	IAA@60ppm
T_4	MH@250ppm
T_5	MH@375ppm
T_6	GA_3@40ppm
T_7	GA_3@60ppm
T_8	TIBA@40ppm
T_9	TIBA@60ppm
T_{10}	Kinetin@10ppm
T_{11}	Kinetin@15ppm

2.4 Statistical analysis

Experimental data were analyzed statistically adopting the technique of analysis of variance (ANOVA) for Randomized Block Design (RBD). The level of significance was observed at 5 percent probability (Gomez, 1984) [9].

3. Results and Discussion

3.1 Growth parameters

The evaluated treatments displayed a plant height ranged from 46.01 to 49.09 cm in the first year (2023), while it ranged from 44.19 to 47.99 cm in the second year (2024). The pooled plant height ranged from 45.15 to 48.54 cm (Table-2). During the first and second year (2023 and 2024), the maximum plant height of 49.09 and 47.99 cm, respectively was recorded in treatment T_7 (GA_3@60 ppm) which was on par with T_6 (GA_3@40 ppm) which recorded a plant height of 48.53 and 47.95 cm, respectively followed by T_{11} (Kinetin@15 ppm) which recorded a plant height of 47.64 and 46.25 cm, respectively. While, the minimum plant height of 46.01 cm was recorded in treatment T_9 (TIBA@60 ppm) for the first year (2023) and minimum plant height of 44.19 cm recorded in T_8 (TIBA@40 ppm) for the second year (2024). These results are in line with finding of Aldesuquy *et al.* (2007) [4] and Adam *et al.* (2024) [3].

The number of primary branches ranged from 4.53 to 5.53 in the first year (2023) and from 3.53 to 5.27 in the second year (2024), while, the pooled data ranged from 4.03 to 5.40. In the year 2023, the number of primary branches plant^{-1} of 5.53 was recorded maximum in two treatments i.e., T_7 (GA_3@60 ppm) and T_{11} (Kinetin@15 ppm) which was on par with T_6 (GA_3@40 ppm) which recorded 5.47 primary branches plant^{-1}.

The minimum number of primary branches plant^{-1} of 4.53 was however, recorded in T_1 (control). While in the year 2024, the maximum number of primary branches plant^{-1} of 5.27 was recorded in treatment T_{11} (Kinetin@15 ppm) which was on par with T_{10} (Kinetin@10 ppm) with 5.07 primary branches plant^{-1}. However, the minimum number of primary branches plant^{-1} of 3.53 was recorded in the same treatment as in 2023, i.e., treatment T_1 (control). These results are in conformity with finding of Abdel *et al.* (2011) [1] and Prasad *et al.* (2023) [21].

The leaf area plant^{-1} across all the treatments ranged from 202.55 to 237.11 cm^2 in the year 2023, while, the values recorded in the year 2024, ranged from 193.39 to 238.55 cm^2. The pooled data of both the years ranged from 203.48 to 242.58 cm^2. In the first year (2023) of the experiment, the maximum leaf area plant^{-1} of 246.71 cm^2 was recorded in treatment T_6 (GA_3@40 ppm), which was on par with treatment T_7 (GA_3@60 ppm) (237.11 cm^2). This was followed by the treatment T_{11} (Kinetin@15 ppm) which recorded leaf area plant^{-1} of 226.44 cm^2. Across all the treatments studied, the minimum leaf area plant^{-1} of 202.55 cm^2 was recorded in treatment T_2 (IAA@40 ppm). The data pertaining to the second year of the experiment (2024) revealed maximum leaf area plant^{-1} of 238.55 cm in treatment T_6 (GA_3@40 ppm) which was on par with treatment T_7 (GA_3@60 ppm) (238.45 cm^2). This was immediately followed by treatment T_1 (control) which recorded leaf area plant^{-1} of 214.41 cm^2. However, the minimum leaf area plant^{-1} of 193.39 cm^2 was recorded in treatment T_5 (MH@375 ppm). These results are in line with finding of Verma *et al.* (2018) [25] and Parveen *et al.* (2023) [20].

3.2 Yield attributes

The results on number of flowers plant^{-1} varied significantly under different treatments with reference to control (Table-3). The number of flowers plant^{-1} recorded during the year 2023 varied from 36.87 to 59.60, whereas, during 2024, it ranged from 37.53 to 59.00. Furthermore, the result on pooled analysed data varied from 37.20 to 59.30. During both the years of experiment (2023 and 2024), the maximum number of flowers plant^{-1} of 59.60 and 59.00, respectively were recorded in treatment T_{11} (Kinetin@15ppm) which was on par with treatment T_{10} (Kinetin@10 ppm) recorded 59.33 and 58.60 flowers plant^{-1}, respectively, followed by treatment T_7 (GA_3@60 ppm) which recorded 55.33 and 55.33 flowers plant^{-1}, respectively. Furthermore, the minimum number of flowers plant^{-1} of 36.87 and 37.53, respectively was recorded in control (T_1). Similar findings were reported by Navya *et al.* (2021) [19] and Prasad *et al.* (2023) [21].

The range of variation recorded during both the years (2023 and 2024) for number of pods plant^{-1} were 23.47 to 44.13 and 22.20 to 43.20, respectively. Different treatments depicted a significant variation when compared to the control. Furthermore, the range of variation recorded for the pooled data for number of pods plant^{-1} was from 22.83 to 43.60. During 2023, the maximum number of pods plant^{-1} of 44.13 was recorded in treatment T_{10} (Kinetin@10 ppm), which was on par with T_{11} (Kinetin@15ppm) (43.87) and T_7 (GA_3@60 ppm) (43.07). While, the minimum number of pods plant^{-1} (23.47) was recorded in control (T_1). In case of 2024, it was recorded maximum in treatment T_6 (GA_3@40 ppm) with value 43.20, which was on par with treatments T_7 (GA_3@60 ppm) (42.47), T_{10} (Kinetin@10 ppm) (43.07) and T_{11} (Kinetin@15 ppm) (43.13). While the minimum number of pods plant^{-1} (22.20) was recorded in control (T_1). These results are in accordance with the findings of Iqbal *et al.* (2023) [12] and Adam *et al.* (2024) [3].

The data regarding test weight presented in Table-3 demonstrated significant difference among the treatments for both the years. In the first year (2023) of the experiment, 1000 seed weight/test weight ranged from 35.74 to 39.32 g, while in the case of second year (2024), it ranged from 34.63 to 38.93 g. The pooled analysed data ranged from 35.18 to 39.13 g. During the first year (2023), the maximum 1000 seed weight/test weight was recorded in treatment T_{10} (Kinetin@10 ppm) and T_{11} (Kinetin@15 ppm) with 39.32 g followed by T_7 (GA_3@60 ppm) with 38.20 g. While, the minimum 1000 seed weight/test weight was recorded in control (T_1) with 35.74 g. In case of second year (2024) of the experiment, the maximum 1000 seed weight/test weight was recorded in treatment T_{11} (Kinetin@15 ppm) with 38.93 g which was on par with T_{10} (Kinetin@10 ppm) (38.70 g) followed by T_6 (GA_3@40 ppm) (37.23 g). Furthermore, the minimum 1000 seed weight/test weight of 34.63 g was recorded in control (T_1). These results are in line with finding of Nandan *et al.* (2021) [18] and Nahid *et al.* (2024) [17].

3.3 Yield

Seed yield ha^{-1} varied significantly among the treatments for both the years and it ranged from 1068.00 to 1231.85 kg/ha in the year 2023 and 992.91 to 1200.36 kg/ha in the year 2024 (Table 4). It depicted a clear reduction in seed yield ha^{-1} in subsequent year. In 2023, the maximum seed yield ha^{-1} was recorded in T_{11} (Kinetin@15 ppm) with 1231.85 kg/ha, which was on par with T_{10} (Kinetin@10 ppm) (1225.15 kg/ha). The treatments T_{11} and T_{10} depicted increase of 15.34% and 14.71%, respectively over control (unsprayed). While the minimum seed yield ha^{-1} (1068.00 kg/ha) was recorded in control (T_1). In 2024, the maximum seed yield ha^{-1} was recorded in T_{11} (Kinetin@15 ppm) 1200.36 kg/ha was on par with T_{10} (Kinetin@10 ppm) (1197.90 kg/ha). The treatments T_{11} and T_{10} depicted increase of 20.89% and 20.64%, respectively over control (unsprayed). On the other hand, the minimum seed yield ha^{-1} (992.91 kg/ha) was recorded in control (T_1). The pooled data followed similar trend and recorded the maximum seed yield ha^{-1} in treatment T_{11} (Kinetin@15 ppm) with 1216.11 kg/ha, which was on par with T_{10} (Kinetin@10 ppm) (1211.52 kg/ha) and the minimum seed yield ha^{-1} (1030.46 kg/ha) was recorded control (T_1). These results are in confirmation with finding of Bobade *et al.*, (2016) and Dalai *et al.*, (2024) [7].

The data presented in Table-4 demonstrated significant difference among the treatments for both the years. In the first year (2023) of the experiment, harvest index ranged from 31.46 to 35.92%, while in the case of second year (2024), it ranged from 30.46 to 34.90%. The pooled analysed data ranged from 30.96 to 35.41%. During the first (2023) and second (2024) year of the experiment, the maximum harvest index was recorded in treatment T_{11} (Kinetin@15 ppm) with 35.92% and 34.90%, respectively which was on par with T_{10} (Kinetin@10 ppm) with 35.87% and 34.89%, respectively. It was followed by T_9 (TIBA@60 ppm) with 35.06% and 34.15%, respectively. On the other hand, the minimum harvest index of 31.46% and 30.46%, respectively was recorded in control (T_1). The pooled data of harvest index was recorded maximum in treatment T_{11} (Kinetin@15 ppm) with 35.41%, which was on par with treatment T_{10} (Kinetin@10 ppm) (35.38%). This was followed by treatment T_9 (TIBA@60 ppm) with 34.61%. While, the minimum harvest index of 30.96% was recorded in control (T_1). Similar findings were reported by Tasnim *et al.* (2019) [24] and Parveen *et al.* (2023) [20].

Table 2: Effect of plant growth regulators on growth parameters of mung bean

Treatment Symbol	Treatment	Plant height (cm)			Number of primary branches plant^{-1}			Leaf area plant^{-1} (cm^2)		
		Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled
T_1	Control (Unsprayed)	46.59	45.27	45.93	4.53	3.53	4.03	234.28	214.41	224.35
T_2	IAA@40ppm	47.02	45.59	46.30	5.07	4.07	4.57	202.55	204.41	203.48
T_3	IAA@60ppm	46.69	45.45	46.07	5.07	4.13	4.60	223.76	203.48	213.62
T_4	MH@250ppm	46.39	44.87	45.63	4.80	3.73	4.27	211.04	197.46	204.25
T_5	MH@375ppm	45.97	44.65	45.31	4.80	3.73	4.27	206.66	193.39	200.02
T_6	GA_3@40ppm	48.53	47.95	48.24	5.47	4.53	5.00	246.71	238.45	242.58
T_7	GA_3@60ppm	49.09	47.99	48.54	5.53	4.60	5.07	237.11	238.55	237.83
T_8	TIBA@40ppm	46.51	44.19	45.35	4.73	3.87	4.30	220.08	203.95	212.02
T_9	TIBA@60ppm	46.01	44.29	45.15	4.87	3.93	4.40	217.53	203.64	210.59
T_{10}	Kinetin@10ppm	47.25	46.20	46.72	5.27	5.07	5.17	220.82	211.17	215.99
T_{11}	Kinetin@15ppm	47.64	46.25	46.94	5.53	5.27	5.40	226.44	210.50	218.47
S.E. (m) (±)		0.31	0.13	0.22	0.16	0.11	0.13	4.67	0.97	2.82
C.D. at 5%		0.92	0.38	0.65	0.47	0.33	0.40	13.77	2.85	8.31

Table 3: Effect of plant growth regulators on yield attributes of mung bean

Treatment Symbol	Treatment	Number of flowers plant^{-1}			Number of pods plant^{-1}			Test weight (g)		
		Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled
T_1	Control (Unsprayed)	36.87	37.53	37.20	23.47	22.20	22.83	35.74	34.63	35.18
T_2	IAA@40ppm	40.53	41.00	40.77	26.27	26.27	26.27	36.23	35.16	35.70
T_3	IAA@60ppm	40.87	40.73	40.80	26.00	25.20	25.60	36.20	35.07	35.63
T_4	MH@250ppm	43.73	44.27	44.00	30.67	29.93	30.30	37.64	35.76	36.70
T_5	MH@375ppm	44.07	45.27	44.67	31.60	31.27	31.43	36.62	35.57	36.09
T_6	GA_3@40ppm	55.07	55.27	55.17	42.93	43.20	43.07	38.01	37.23	37.62
T_7	GA_3@60ppm	55.33	55.33	55.33	43.07	42.47	42.77	38.20	37.19	37.70
T_8	TIBA@40ppm	46.67	46.40	46.53	29.40	28.00	28.70	37.09	36.32	36.70
T_9	TIBA@60ppm	47.20	46.93	47.07	30.27	28.60	29.43	37.04	36.08	36.56
T_{10}	Kinetin@10ppm	59.33	58.60	58.97	44.13	43.07	43.60	39.32	38.70	39.01
T_{11}	Kinetin@15ppm	59.60	59.00	59.30	43.87	43.13	43.50	39.32	38.93	39.13
S.E. (m) (±)		0.36	0.37	0.37	0.39	0.40	0.39	0.35	0.08	0.22
C.D. at 5%		1.07	1.09	1.08	1.15	1.18	1.16	1.04	0.24	0.64

Table 4: Effect of plant growth regulators on yield of mung bean

Treatment Symbol	Treatment	Seed yield (kg ha^{-1})			Harvest index (%)		
		Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled
T_1	Control (Unsprayed)	1068.00	992.91	1030.46	31.46	30.46	30.96
T_2	IAA@40ppm	1110.67	1009.73	1060.20	32.69	31.62	32.15
T_3	IAA@60ppm	1095.26	1009.86	1052.56	32.75	31.51	32.13
T_4	MH@250ppm	1091.11	1033.35	1062.23	32.90	31.96	32.43
T_5	MH@375ppm	1102.81	1039.57	1071.19	33.00	31.98	32.49
T_6	GA_3@40ppm	1185.48	1157.85	1171.66	34.87	33.92	34.40
T_7	GA_3@60ppm	1186.22	1162.20	1174.21	35.06	34.06	34.56
T_8	TIBA@40ppm	1160.57	1097.02	1128.80	34.56	33.54	34.05
T_9	TIBA@60ppm	1166.03	1102.93	1134.48	35.06	34.15	34.61
T_{10}	Kinetin@10ppm	1225.15	1197.90	1211.52	35.87	34.89	35.38
T_{11}	Kinetin@15ppm	1231.85	1200.36	1216.11	35.92	34.90	35.41
S.E. (m) (±)		4.92	1.07	2.99	0.10	0.09	0.09
C.D. at 5%		14.52	3.14	8.83	0.29	0.26	0.28

4. Conclusion

The application of plant growth regulators, particularly Kinetin and GA_3, significantly enhanced the growth parameters, yield attributes, and overall seed yield of mung bean in the Central Plain Zone of Uttar Pradesh. These findings suggest that incorporating PGRs can be a beneficial strategy for improving mung bean productivity in this region.

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