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Effect of plant growth regulators on phenological study and growth analysis 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 phenological and growth parameters of mung bean (*Vigna radiata* L.) under the central plain zone of Uttar Pradesh. Conducted during the Kharif seasons of 2023 and 2024 at Chandra Shekhar Azad University of Agriculture and Technology, the experiment utilized a randomized block design comprising 33 plots across three replications. Treatments included control and PGR applications of Indole-3-acetic acid (IAA), Gibberellic acid (GA_3), Maleic hydrazide (MH), 2, 3, 5-Triiodobenzoic acid (TIBA), and Kinetin. Key phenological observations included days to flowering initiation, days to 50% flowering, and days to maturity. Growth analyses measured crop growth rate (CGR), relative growth rate (RGR), and relative water content (RWC). Results indicated significant variations in phenological traits across treatments. In 2023, days to flowering initiation ranged from 28.07 (GA_3@40 ppm) to 32.40 (Kinetin@15 ppm), while in 2024, it was from 26.47 (GA_3@60 ppm) to 30.80 (Kinetin@15 ppm). Days to 50% flowering similarly ranged from 30.13 to 34.27 days in 2023 and from 28.60 to 32.80 days in 2024. Maturity periods ranged from 52.00 to 56.00 days in 2023 and from 50.73 to 54.93 days in 2024. Growth analysis revealed that CGR ranged from 11.12 to 15.38 g/m²/day (2023) and 10.37 to 16.14 g/m²/day (2024). The maximum RGR recorded was 0.27 mg/g/day for Kinetin treatments in both years. RWC was highest at 70.54% (Kinetin@10 ppm) in 2023 and 70.64% (Kinetin@15 ppm) in 2024. Overall, Gibberellic acid (GA_3) and Kinetin demonstrated the most promising effects on phenological and growth parameters respectively, suggesting its potential to enhance mung bean productivity and support sustainable agricultural practices.

Keywords: Gibberellic acid, kinetin, mung bean, maleic hydrazide, and phenological study

1. Introduction

Green gram (*Vigna radiata* L.) also known as mung bean is one of the short span pulse crops in India and secure third place after chickpea and pigeon pea cultivation. Mung bean is widely grown in arid and semi-arid areas of the country. It is an extremely good source of high standard protein and holds 25-28% protein in addition to 1.0 - 1.4 percent oil, 3.3 percent fibre, 4.8-5.6 percent ash, 64 - 66 percent carbohydrate on the basis of dry weight (Shen, 2021) [24].

In India about 49 lakh ha area was covered under green gram and the production was about 26 lakh ton in 2022-23. The states of Rajasthan 23.25 lakh ha, Karnataka 4.14 lakh ha, Madhya Pradesh 5.08 lakh ha, Maharashtra 4.21 lakh ha and Bihar 1.69 lakh ha are the major producers of green gram in India. According to Government 3rd advance estimates, green gram production in 2022-23 is at 3.74 million tonnes.

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 (Rady *et al.*, 2021) [20], carbon-rich organic amendments (Kamran *et al.*, 2020; Kamran *et al.*, 2021), and synthetic mineral nutrients (Chen and Shi, 2016) [3]. 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) [10]. Plant growth regulators (PGRs) enhancing photosynthesis, other growth factors such as root development, flowering, and fruit setting, contributing to a more productive crop. Their ability to optimize these physiological functions makes them invaluable in modern agriculture, where maximizing yield and improving crop quality are essential goals. Indole-3-acetic acid (IAA) is known to play a critical role in various aspects of plant development. It influences root growth, promotes cell division, and facilitates cell elongation. Additionally, IAA is essential for the formation of adventitious roots, tissue swelling, and the induction of embryogenesis. It also contributes to callus initiation and the loosening of cell walls, even at low concentrations of this hormone (Pérez-Alonso *et al.*, 2021) [18]. 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) [9]. GA_3 achieves these effects by activating various metabolic processes, including the activities of crucial enzymes such as carbonic anhydrase (CA) and nitrate reductase (NR), which are essential for efficient nitrogen utilization (Wang *et al.*, 2019) [28]. Gibberellic acid (GA_3) also promotes plant growth and development by improving water uptake in plant tissues. It enhances the synthesis of photosynthetic pigments and boosts the process of photosynthesis. Additionally, GA_3 plays a crucial role in facilitating flower formation and fruit set in legumes. Naphthalene acetic acid (NAA) is known to enhance cell division and expansion, as well as promote fruit blossoming. It also helps to reduce fruit drop, thereby contributing to increased overall yield (Usha *et al.*, 2023) [26]. Kinetin, a synthetic cytokinin, is utilized to bolster plant resistance to stress and to delay the aging process (Mughal *et al.*, 2024) [15]. Recent research has demonstrated that applying various concentrations of kinetin to the leaves of mung beans at the onset of flowering can significantly improve photosynthetic efficiency, enhance protective enzyme activity, and boost overall yield (Wang *et al.*, 2015) [27].

Growth retardants such as maleic hydrazide can elevate endogenous ethylene levels, which in turn activates various metabolic processes and influences the carbon-to-nitrogen (C:N) ratio in plants. This hormonal adjustment helps stimulate flowering, improve fruit set, and balance the sex ratio of the flowers, ultimately leading to increased crop yield (Sharma *et al.*, 2022) [22]. 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. Additionally, TIBA's application is believed to improve the availability of assimilates by directing the translocation of photosynthetic products through hormonal regulation. It has been well-documented that plant growth hormones enhance the absorption of nutrients from the soil and boost metabolic activity within plant cells. By promoting more efficient nutrient uptake, these hormones facilitate better growth and development. Additionally, they stimulate various metabolic processes within the plant, contributing to improved overall physiological function and productivity (Engels *et al.*, 2012) [4]. TIBA (2, 3, 5-triiodobenzoic acid), a synthetic growth retardant, is employed to alter plant canopies and enhance growth and yield characteristics in various pulse crops. By modifying the canopy structure, TIBA helps optimize light interception and resource allocation, leading to better crop performance.

This study is designed to systematically assess the impact of selected bioregulators on mung bean growth and development. By evaluating different bioregulators, we aim to identify the most effective treatments for improving mung bean phenological study and growth analysis. Ultimately, these advancements will support food security and improve farmers' livelihoods by boosting productivity and profitability in mung bean farming.

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 levelled and prepared with irrigation to achieve optimum tilth before ploughing and layout as per the experimental design. A recommended basal dose of nitrogen, phosphorus, potassium, and sulfur was applied in a ratio of 20:40:20 using urea, single superphosphate, and muriate of potash. Mung bean variety IPM 205-07 (Virat) was sown at a spacing of 45 x 10 cm. The sowing operations were completed under optimum moisture condition by dibbling method, putting two seed at each dibbled. To manage weeds, two hand weedings and one hoeing were performed for each sowing treatment. For pest control, monocrotophos was sprayed according to recommendations. Additionally, the plots received treatments of IAA, MH, GA_3, TIBA, and Kinetin, applied with a hand sprayer at the flowering initiation stage. Spraying was conducted during the morning hours, between 8:00 and 10:00 A.M.

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 Observation recorded

2.4.1 Phenological observations

(a) Days to flowering initiation

The number of days from the date of sowing to flowering initiation was recorded and average was taken.

(b) Days to 50% Flowering

The number of days from the date of sowing to 50% flowering was recorded and average was taken.

(c) Days to maturity

The number of days taken from the time of sowing of seed to the time of physiological maturity was recorded and average was taken.

2.4.2 Growth analysis

(a) Crop growth rate (g/m²/day)

The method was suggested by Watson (1956). Crop growth rate (CGR) of five randomly selected plant form each plot was calculated by using the formula:

$$\textbf{Crop Growth Rate (CGR)} = \frac{(W2 - W1)}{P\,(T2 - T1)}$$

Where, W_1 and W_2 are whole plant dry weight at t_1 and t_2 respectively t_1 and t_2 are time interval in days, P is ground area.

(b) Relative growth rate (mg/g/day)

Relative growth rate of five randomly selected plant form each plot was calculated by using the following formula given by Fisher (1921) [5]:

$$\textbf{Relative Growth Rate (RGR)} = \frac{\text{Loge } W2 - \text{Loge } W1}{t2 - t1}$$

Where,

log e = Natural logarithm to the base (e = 2.3026)

W_1 = Dry weight of plants (g) at time t_1

W_2 = Dry weight of plants (g) at time t_2.

(c) Relative water content (%)

Relative water content of five randomly selected plant form each plot was calculated according to the method given by Weatherly and Slatyer, (1957) [30] as follows.

$$\textbf{Relative Water Content(RWC)} = \frac{(\text{Fresh Weight} - \text{Dry Weight})}{(\text{Turgid Weight} - \text{Dry Weight})} x100$$

2.5 Statistical analysis

The growth analysis and phenological parameters were recorded and analyzed as per Gomez and Gomez (1984) [7] the tested at 5% level of significance to interpret the significant differences.

3. Results and discussion

3.1 Phenological study

The number of days to flowering initiation varied significantly among the treatments for both the years and it ranged from 28.07 to 32.40 days in the year 2023 and 26.47 to 30.80 days in the year 2024 (Table 2). It depicted a clear reduction in days to flowering initiation in subsequent year. In 2023, the least number of days to flowering initiation was recorded in T_6 (GA_3@40 ppm) which took 28.07 days was on par with T_7 (GA_3@60 ppm) (28.40 days). The treatments T_6 and T_7 depicted 8.76% and 7.50% reduction in days to flowering initiation as compared to control (unsprayed). These treatments were immediately followed by T_2 (IAA@40 ppm) which took 30.13 days, while the maximum number of days to flowering initiation (32.40 days) was recorded in treatment T_{11} (Kinetin@15 ppm) which was on par with T_{10} (Kintin@10ppm) which took 32.20 days. In 2024, the least number of days to flowering initiation was recorded in T_7 (GA_3@60 ppm) which took 26.47 days was on par with T_6 (GA_3@40 ppm) (26.53 days). The treatments T_6 and T_7 depicted 9.57% and 9.82% reduction in days to flowering initiation as compared to control (unsprayed). These treatments were immediately followed by T_2 (IAA@40 ppm) which took 28.67 days, while the maximum number of days to flowering initiation (30.80 days) was recorded in treatment T_{11} (Kinetin@15 ppm) which was on par with T_{10} (Kintin@10ppm) which took 30.73 days. The consequences of the current investigation are additionally in concurrence with the investigation of Gelmesa *et al.* (2012) [6] and Harsh *et al.* (2024) [8].

The data pertaining to days to 50% flowering is presented in Table-2 and varied significantly for both the years among the treatments studied. In the year 2023, days to 50% flowering ranged from 30.13 to 34.27 days, while in the case of 2024, it ranged from 28.60 to 32.80 days. It depicted a clear reduction in days to 50% flowering in subsequent year. Furthermore, the pooled data of days to 50% flowering ranged from 29.39 to 33.53 days. In both the years (2023 and 2024), the least number of days taken to 50% flowering was recorded in treatment T_6 (GA_3@40 ppm), with 30.13 and 28.60 days, respectively, which was on par with T_7 (GA_3@60 ppm), which took 30.60 and 28.67 days, respectively. These treatments were immediately followed by T_5 (MH@375 ppm) with 32.33 days in the year 2023 and T_2 (IAA@40 ppm) with 31.47 days in the year 2024. The maximum number of days to 50% flowering was however, recorded in treatment T_{11} (Kinetin@15 ppm) in both the years, with 34.27 days in 2023 and 32.80 days in 2024. These results are in conformity with finding of Patel *et al.* (2011) [17] and Sharma *et al.* (2024) [21].

It is inferred from Table-2 that significant difference among the treatments for number of days to maturity during both of the years. In the first year (2023) of the experiment, number of days taken to maturity ranged from 52.00 to 56.00 days, while in the case of second year (2024), it ranged from 50.73 to 54.93 days. The pooled data, however, ranged from 51.37 to 55.40 days. During the first year (2023), the minimum days to maturity was recorded in treatment T_6 (GA_3@40 ppm) with 52.00 days which was on par with T_7 (GA_3@60 ppm) recorded 52.07 days. These treatments were immediately followed by T_3 (IAA@60 ppm) with 54.87 days. While, the maximum days to maturity was recorded in treatment T_{10} (Kinetin@10 ppm) with 56.00 days. In case of second year (2024) of the experiment, the minimum days to maturity was recorded in treatment T_6 (GA_3@40 ppm) with 50.73 days which was on par with T_7 (GA_3@60 ppm) recorded 51.00 days. These treatments were followed by T_2 (IAA@40 ppm) and T_3 (IAA@60 ppm), which recorded 53.53 days. Furthermore, the maximum days to maturity was recorded in T_{11} (Kinetin@15 ppm) with 54.93 days. These results are in line with finding of Thomson *et al.* (2015) [25] and Rai *et al.* (2019) [20].

3.2 Growth analysis

The crop growth rate recorded during 2023 and 2024 ranged from 11.12 to 15.38 g/m^2/day and 10.37 to 16.14 g/m^2/day, respectively. Furthermore, the pooled data carried out from the results of both the years ranged from 10.74 to 15.76 g/m^2/day (Table-3). The data pertaining to the crop growth rate recorded during 2023 and 2024, was recorded maximum in the same treatment T_{11} (Kinetin@15ppm) with values 15.38 and 16.14 g/m^2/day, respectively, which were on par with treatment T_{10} (Kinetin@10 ppm) recorded a value of 14.41 and 16.05 g/m^2/day, respectively. While, the minimum crop growth rate of 11.12 and 10.37 g/m^2/day were recorded in treatment T_4 (MH@250 ppm). Similar findings were reported by Nabi *et al.* (2014) [16] and Bobade *et al.* (2016) [2] and Adam *et al.* (2014) [1].

The result pertaining to relative growth rate recorded during

2023 ranged from 0.19 to 0.27 mg/g/day, while during 2024, it ranged from 0.18 to 0.28 mg/g/day. The pooled data ranged from 0.19 to 0.27 mg/g/day (Table-3). In the year 2023, the maximum relative growth rate of 0.27 mg/g/day was recorded in treatment T_{11} (Kinetin@15ppm) followed by treatment T_{10} (Kinetin@10 ppm) which recorded a relative growth rate of 0.25 mg/g/day. However, the minimum relative growth rate of 0.19 mg/g/day was recorded in treatment T_4 (MH@250ppm). In case of the experiment carried out in the year 2024, the maximum relative growth rate of 0.28 mg/g/day was recorded in two treatments namely T_{10} (Kinetin@10 ppm) and T_{11} (Kinetin@15ppm) followed by treatments T_6 (GA_3@40 ppm) and T_7 (GA_3@60ppm), which recorded relative growth rate of 0.25 mg/g/day. While the minimum relative growth rate of 0.18 mg/g/day was recorded in treatments T_4 (MH@250 ppm) and T_5 (MH@375 ppm). These results are in accordance with the findings of Suryawanshi *et al.* (2017) [24] and Iqbal *et al.* (2017) [10].

The results pertaining to the relative water content across all the eleven treatments are furnished in Table-3. The data recorded during 2023 ranged from 63.36 to 70.54%, while during 2024, it ranged from 63.70 to 70.64%. The pooled data, however ranged from 64.17 to 70.48%. The data recorded during 2023 revealed that, the maximum relative water content of 70.54% was obtained in treatment T_{10} (Kinetin@10ppm) which was on par with T_6 (69.16%) and T_{11} (70.16%). While, the minimum relative water content of 63.36% was recorded in treatment T_5 (MH@375 ppm). During 2024, the maximum relative water content of 70.64 was recorded in treatment T_{11} (Kinetin@15ppm) which was on par with T_{10} (Kinetin@10 ppm) (70.43%). While, the minimum relative water content of 63.70% was recorded in treatment T_4 (MH@250 ppm). The consequences of the current investigation are additionally in concurrence with the investigation of Islam *et al.* (2019) [11] and Miri *et al.* (2021) [14].

Table 2: Effect of plant growth regulators on phenological studies of mung bean

Treatment Symbol	Treatment	Days to flowering initiation			Days to 50% Flowering			Days to maturity		
		Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled
T_1	Control (Unsprayed)	30.53	29.07	29.80	33.00	31.73	32.37	54.87	53.73	54.30
T_2	IAA@40 ppm	30.13	28.67	29.40	32.80	31.47	32.13	54.93	53.53	54.23
T_3	IAA@60 ppm	31.00	29.20	30.10	33.00	31.73	32.37	54.87	53.53	54.20
T_4	MH@250 ppm	31.47	29.67	30.57	34.00	32.47	33.23	55.40	54.07	54.73
T_5	MH@375 ppm	31.33	29.73	30.53	32.33	32.60	32.47	55.47	54.00	54.73
T_6	GA_3@40 ppm	28.07	26.53	27.30	30.13	28.60	29.37	52.00	50.73	51.37
T_7	GA_3@60 ppm	28.40	26.47	27.43	30.60	28.67	29.63	52.07	51.00	51.53
T_8	TIBA@40 ppm	30.80	29.67	30.23	33.20	32.33	32.77	55.27	54.00	54.63
T_9	TIBA@60 ppm	31.67	30.07	30.87	33.60	32.13	32.87	55.00	53.67	54.33
T_{10}	Kinetin@10 ppm	32.20	30.73	31.47	33.60	32.53	33.07	56.00	54.67	55.33
T_{11}	Kinetin@15 ppm	32.40	30.80	31.60	34.27	32.80	33.53	55.87	54.93	55.40
S.E. (m) (±)		0.27	0.15	0.21	0.57	0.10	0.33	0.15	0.16	0.16
C.D. at 5%		0.80	0.44	0.62	1.67	0.30	0.98	0.45	0.47	0.46

Table 3: Effect of plant growth regulators on growth analysis of mung bean

Treatment Symbol	Treatment	Crop growth rate (g/m^2/day)			Relative growth rate (mg/g/day)			Relative water content (%)		
		Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled	Kharif-2023	Kharif-2024	Pooled
T_1	Control (Unsprayed)	13.57	13.14	13.36	0.24	0.23	0.23	66.17	65.09	65.63
T_2	IAA@40ppm	13.31	13.34	13.33	0.23	0.23	0.23	65.85	66.38	66.12
T_3	IAA@60ppm	13.17	13.20	13.19	0.23	0.23	0.23	66.01	66.43	66.22
T_4	MH@250ppm	11.12	10.37	10.74	0.19	0.18	0.19	64.63	63.70	64.17
T_5	MH@375ppm	11.38	10.39	10.89	0.20	0.18	0.19	63.36	63.90	63.63
T_6	GA_3@40ppm	12.94	14.35	13.65	0.23	0.25	0.24	69.16	68.73	68.95
T_7	GA_3@60ppm	13.80	14.30	14.05	0.24	0.25	0.24	68.48	68.78	68.63
T_8	TIBA@40ppm	13.52	13.28	13.40	0.24	0.23	0.23	67.16	65.97	66.57
T_9	TIBA@60ppm	13.60	13.80	13.70	0.24	0.24	0.24	66.05	66.29	66.17
T_{10}	Kinetin@10ppm	14.41	16.05	15.23	0.25	0.28	0.26	70.54	70.43	70.48
T_{11}	Kinetin@15ppm	15.38	16.14	15.76	0.27	0.28	0.27	70.16	70.64	70.40
S.E. (m) (±)		0.45	0.18	0.32	0.01	0.00	0.01	0.68	0.15	0.41
C.D. at 5%		1.33	0.53	0.93	0.02	0.01	0.02	2.00	0.43	1.22

4. Conclusion

The study on the effects of plant growth regulators (PGRs) on mung bean (*Vigna radiata* L.) demonstrated significant impacts on both phenological and growth parameters under the central plain zone of Uttar Pradesh. Among the treatments, application of Gibberellic acid (GA_3) @ 40 and 60 ppm consistently resulted in the earliest flowering initiation and maturity, whereas applications of Kinetin @ 10 and 15 ppm consistently resulted the highest crop growth rate, relative growth rate, and relative water content. Specifically, applications of Kinetin @ 10 and 15 ppm and application of Gibberellic acid (GA_3) @ 40 and 60 ppm significantly enhanced growth metrics compared to control and other PGR treatments, indicating its vital role in improving mung bean productivity.

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