



Physiological and Morphological Responses to Foliar Application of Dormancy Modulating Chemicals in Mung Bean (*Vigna radiata* L.) Germplasm

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ABSTRACT

Background: Sprouting susceptibility in mung bean is influenced by both morphological and physiological factors. Dormancy, a natural mechanism that delays germination under adverse conditions, is crucial in mitigating pre-harvest sprouting. Varieties lacking dormancy traits are particularly vulnerable, as their seeds are more prone to absorbing moisture and initiating germination prematurely.

Methods: The objective was to evaluate the effects of these treatments on key agronomic traits such as pod production, seed size and seedling growth, with a focus on improving seed quality and dormancy resistance. Field trials were conducted using 10 varieties obtained from ICAR-IIPR, Kanpur using 7 treatments during the *Kharif* 2022-23 following field trials in augmented block design at the Crop Research Centre of Rabindranath Tagore University and laboratory experiments were conducted in the Botany Research Laboratory at Rabindranath Tagore University, Raisen in Factorial Completely Randomized Design (FCRD) for evaluation of material.

Result: The results demonstrated that GA₃ (T₁) had the most significant positive effect across all cultivars, with the highest pod counts (e.g., V₁T₁: 40.45 pods) and seed sizes (e.g., V₁T₁: 3.37 mm horizontal seed size). Other treatments, such as IAA (T₆) and KNO₃ (T₅), also showed substantial improvements in pod production and seed development. In contrast, MH (T₄) and ABA (T₂) significantly reduced pod formation (e.g., V₁T₄: 11.25 pods), seed size and overall seedling growth, indicating their potential to induce dormancy and inhibit growth. The study concludes that GA₃, IAA and KNO₃ can be effectively used to enhance mung bean productivity, while MH and ABA should be carefully managed due to their suppressive effects. These findings have practical implications for improving seed quality and dormancy resistance in mung bean cultivation.

Key words: ABA, Dormancy-modulating chemicals, Foliar application, IAA, IPM, Pre-harvest sprouting (PHS).

INTRODUCTION

The mung bean [*Vigna radiata* (L.) Wilczek] holds a critical position in global agriculture, especially within developing countries like India, where it serves as a vital food crop and a significant source of nutrition. As one of India's primary food legumes, mung bean offers a high-quality protein source, essential amino acids, vitamins and minerals, the crop plays an important role in addressing nutritional needs and enhancing food security. India remains the largest producer of mung bean, with approximately 1.593 mha cultivated during the 2023-24 season, compared to 1.557 mha in the 2022-23 season. The leading states contributing to mung bean production include Rajasthan, with 1.399 mha. According to the government's third advance estimates, mung bean production in 2022-23 reached 3.74 mt (Agricultural Market Intelligence Centre, PJTSAU, 2023). Despite increased average yields of 650 kg ha⁻¹, challenges such as pre-harvest sprouting persist, particularly in tropical and subtropical climates. Pre-harvest sprouting, often triggered during the crop's maturation phase, leads to pod splitting and early seed germination, negatively affecting both yield and seed quality. This lack of tolerance highlights the need for genetic and agronomic interventions to improve both productivity and seed quality in susceptible varieties (Singh *et al.*, 2021). Dormancy, a natural mechanism that delays germination under adverse conditions, is crucial in

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mitigating pre-harvest sprouting. The seed coat's structural integrity is key to preventing rapid water uptake, known as imbibition injury, which can lead to germination (Duke and

Takefuda, 1981). Hard-seeded varieties exhibit greater resistance to sprouting due to structural traits such as reduced pore size and increased wax content in the seed coat, which limit water permeability (Yaklich *et al.*, 1985). Seed yield of mung bean exhibited significant variation under different combinations of nutrients and declined significantly with successive decreasing sulphur application (Sachan *et al.*, 2020).

In addition to seed coat characteristics, pod morphology plays a critical role in managing pre-harvest sprouting. Traits such as pod wall thickness, cuticular wax presence and mechanical resistance to rupture significantly influence water absorption. Thicker pods with higher wax content are less likely to allow moisture penetration, reducing the chances of sprouting (Krul, 1978). Varieties with lower enzyme activity and higher levels of abscisic acid (ABA), a plant hormone that inhibits germination, are more resistant to premature sprouting (Hilhorst, 1995). Given the significant yield losses caused by pre-harvest sprouting, this study aims to evaluate the physiological and morphological responses of mung bean to identify effective strategies for enhancing resistance. By applying dormancy-modulating chemicals as a foliar treatment, the research seeks to mitigate yield losses and improve food security.

MATERIALS AND METHODS

The study focused on evaluating ten released mungbean varieties, selected based on their consistent agronomic traits and susceptibility to pre-harvest sprouting. These experiments aimed to screen the germplasm for resistance to precocious germination and induce dormancy through foliar chemical treatments. Field trials were conducted during the *Kharif* 2022-23 using 10 varieties obtained from ICAR-IIPR, Kanpur. The experiment involved 7 treatments and was laid out in an augmented block design at the Crop Research Centre (CRC) of Rabindranath Tagore University. The layout consisted of 3 blocks, each containing 20 entries and 10 checks that were repeated across all blocks. A total of 450 rows (5 Row of each treatment or 150 rows in each Block), each 100 cm in length, were sown with a spacing of 30 cm between rows and 10 cm between plants.

Observations were recorded on 5 plants per treatment. Subsequent laboratory experiments were conducted at the botany research laboratory, Rabindranath Tagore University, Raisen, using a factorial completely randomized design (FCRD). The material was evaluated for the following traits *viz.*, number of pods per plant, number of seeds per pod, pod angle (OC), pod thickness (mm), pod length (cm), 1000-seed weight (g), seed size (mm) and seedling length (cm).

The experimental material comprised ten mungbean genotypes obtained from ICAR-IIPR, Kanpur. These genotypes, selected for their potential tolerance to pre-harvest sprouting, were subjected to simulated rainfall conditions. The genotypes used were IPM 2-3 (V_1), IPM 2-

14 (V_2), Meha (V_3), Soorya (V_4), Virat (V_5), Varsha (V_6), Kanika (V_7), Vashudha (V_8), Heena (V_9) and Shikha (V_{10}). The field trials followed an augmented block design (Federer, 1956) at the Crop Research Centre (CRC) of Rabindranath Tagore University. Six different chemical treatments, along with a control, were tested for their effectiveness in inducing dormancy and preventing pre-harvest sprouting. The treatments were: control (T_0 - water spray), gibberellic acid (GA_3) @ 80 ppm (T_1), abscisic acid (ABA) @ 50 ppm (T_2), hydrogen peroxide (H_2O_2) @ 10 mm (T_3), maleic hydrazide (MH) @ 1000 ppm (T_4), potassium nitrate (KNO_3) @ 1 mm (T_5) and indole-3-acetic acid (IAA) @ 100 ppm (T_6).

The statistical analysis in this research was conducted using an augmented design in R studio to evaluate treatment effects efficiently. FCRD was employed to assess interactions among factors. Mean comparisons were performed using the LSD test through agri analyse online software, ensuring precise differentiation of treatment effects.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA)

The analysis of variance (ANOVA) results revealed that the foliar treatments significantly impacted the number of pods per plant, with a statistically significant effect at the 5% significance level. The number of seeds per pod indicated that the comparison between the Control (T_0), pod angle indicated that the foliar treatments had a significant effect. For pod thickness indicated that none of the sources of variation had a significant effect, demonstrating the overall effectiveness of the chemical treatments (Table 1).

The ANOVA revealed significant differences in the 1000-seed weight, horizontal and vertical seed sizes, vertical seed size, seedling length across all three factors: variety (V Factor), treatment (T Factor) and their interaction (V Factor $\times$ T Factor). The interaction between variety and treatment was significant at the 1% level, indicating that the impact of treatment on seed size varies depending on the variety. This suggests that different mungbean varieties respond differently to the treatments applied, making it necessary to explore specific variety-treatment interactions through multiple comparison tests (Table 2).

Pods per plant (No.)

The highest pod counts were recorded under treatment T_1 (GA_3 at 80 ppm). These results indicate that GA_3 was particularly effective in enhancing pod production when compared to their respective controls. Other treatments, such as T_6 (IAA at 100 ppm), T_5 (KNO_3 at 1 mm) and T_3 (H_2O_2 at 10 mm), also resulted in notable increases in the number of pods per plant for several cultivars, demonstrating their potential to enhance pod formation in certain genetic backgrounds. Treatment T_4 (MH at 1000 ppm) and T_2 (ABA at 50 ppm) consistently resulted in the lowest pod counts across V_8T_4 (4.59) suggest that MH has a suppressive effect on pod formation (Table 3).

The application of GA₃ (T₁) had the most profound positive effect on pod production across all cultivars. This finding aligns with studies by Yogananda *et al.* (2004). The significant increase in the number of pods per plant across treatments can be attributed to the role of GA₃ in promoting cell elongation and division, resulting in improved reproductive development. While, MH and ABA were found to suppress pod formation, consistent with findings by Gupta *et al.* (1985) and Vaithialingam and Rao, (1973b), reported similar dormancy-inducing and growth-suppressing effects of MH. The suppressive effects of ABA are well-documented in studies showing ABA's role in inhibiting growth and promoting dormancy (Birgitkucera *et al.*, 2005).

Seeds per pod (No.)

Highest number of seeds per pod was recorded in the T₁ (GA₃ at 80 ppm) treatments across V₅T₁ (12.46). These treatments showed a notable increase in seed count per pod compared to the control (T₀), indicating the effectiveness of GA₃ in promoting seed formation. Additionally, treatments such as T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T³ (H₂O₂ at 10 mm) also exhibited significant increases in seed count per pod in several cultivars when compared to their respective controls. Conversely, some treatments resulted in a decrease in the

number of seeds per pod compared to their control. For instance, treatments like T₄ (MH at 1000 ppm) consistently showed lower seed counts, including V₁T₄ (8.74). Furthermore, the T₂ (ABA at 50 ppm) treatment also resulted in a significant reduction in seeds per pod, indicating a negative impact of ABA on seed formation (Table 3).

The significant increase in seeds per pod observed with GA₃ treatments (T₁) is supported by earlier studies that showed GA₃ as an effective growth regulator for enhancing seed formation and improving reproductive growth (Finkelstein *et al.*, 2008). On the other hand, the negative effects of MH and ABA on seed production can be attributed to their roles in inducing dormancy and inhibiting germination-related processes (Vaithialingam and Rao, 1973a).

Pod angle (Degree)

The effect of the different foliar applications on pod angle varied widely, with angles ranging from 85.90 degrees in the V₁T₁ treatment to 65.94 degrees in the V₆T₄ treatment. This variation indicates that some treatments resulted in more upright pod positioning, while others led to a more acute angle, potentially affecting pod exposure to sunlight and air circulation, which could influence pod development and overall plant health. The maximum pod angles were observed in treatments: V₁T₁ (85.90 degrees), when

Table 1: Analysis of variance for the number of pods per plant, number of seeds per pod, pod angle (degrees) and pod thickness (mm) in mungbean genotypes.

Source of variation	d.f.	Mean sum of squares			
		Pod per plant (No.)	Seed per pod (No.)	Pod angle (Degree)	Pod thickness (mm)
Block (Ignoring Treatments)	2	8.69 ^{ns}	4.31 [*]	2.79 ^{ns}	0.00 ^{ns}
Treatment (Eliminating Blocks)	69	63.61 [*]	1.14 ^{ns}	15.19 [*]	0.01 ^{ns}
Treatment: Check	9	28.74 ^{ns}	3.27 ^{**}	11.37 ^{ns}	0.01 ^{ns}
Treatment: Test and test vs. Check	60	68.84 [*]	0.82 ^{ns}	15.76 [*]	0.00 ^{ns}
Treatment (ignoring Blocks)	69	62.12 [*]	1.25 ^{ns}	14.84 [*]	0.01 ^{ns}
Treatment: Check	9	28.74 ^{ns}	3.27 ^{**}	11.37 ^{ns}	0.01 ^{ns}
Treatment: Test	59	61.82 [*]	0.97 ^{ns}	14.73 [*]	0.00 ^{ns}
Treatment: Test vs. Check	1	380.19 ^{**}	0.09 ^{ns}	52.16 ^{**}	0.01 ^{ns}
Block (eliminating treatments)	2	59.99 ^{ns}	0.20 ^{ns}	14.98 ^{ns}	0.01 ^{ns}
Residuals (Error)	18	26.44	0.82	6.01	0.00

ns P > 0.05; * P <= 0.05; ** P <= 0.01.

Table 2: Analysis of variance for the pod length (cm), 1000 seed weight (g), seed size (mm) and seedling length (cm) in mungbean genotypes.

Source of variation	d.f.	Mean sum of squares				
		Pod length (cm)	1000 seed weight (g)	Seed size horizontal (mm)	Seed size vertical (mm)	Seedling length (cm)
V Factor	9	2.2829 ^{**}	108.812 ^{**}	0.224 ^{**}	0.825 ^{**}	50.259 ^{**}
T Factor	6	0.6078 [*]	393.622 ^{**}	0.382 ^{**}	0.526 ^{**}	87.709 ^{**}
V Factor × T Factor	54	0.5044 ^{**}	18.75 ^{**}	0.084 ^{**}	0.117 NS	18.864 ^{**}
Residual (Error)	210	0.2586	0.193	0.045	0.09	1.125
Total	279					

** Sig. at 1% level, * Sig. at 5% level.

Table 3: Impact of foliar application of dormancy-modulating chemicals treatments on the number of pods per plant, number of seeds per pod and pod angle (degrees) in mungbean genotypes.

Variety	Pod per plant (No.)							Seed per pod (No.)							Pod angle (Degree)						
	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
IPM 2-3 (V ₁)	27.05	40.45	24.65	29.45	11.25	34.67	35.45	10.14	11.74	9.74	10.27	8.74	10.34	10.74	80.67	85.90	80.50	80.90	79.70	81.90	83.40
IPM 2-14 (V ₂)	27.07	33.45	26.45	28.45	20.85	31.25	32.05	9.54	11.34	9.33	9.74	9.14	10.54	10.74	76.90	80.40	75.17	78.40	72.90	78.40	79.90
Meha (V ₃)	29.65	38.85	24.85	33.85	17.25	34.00	36.05	10.54	12.14	10.00	10.54	9.94	10.94	11.74	74.40	81.50	72.90	76.00	72.70	76.40	76.70
Soorya (V ₄)	25.35	37.25	19.15	33.13	16.15	35.05	36.75	10.14	12.33	9.94	10.26	8.86	11.26	12.26	74.44	78.40	74.20	76.04	71.94	76.60	77.94
Virat (V ₅)	26.75	31.35	22.55	27.15	11.15	28.15	28.67	11.06	12.46	11.06	11.20	11.06	11.86	12.46	74.44	79.27	74.44	74.94	66.94	75.94	78.94
Varsha (V ₆)	29.95	34.75	29.93	31.15	12.75	31.75	32.75	9.46	11.46	9.26	10.26	9.20	11.26	11.46	73.94	80.34	71.44	74.63	65.94	79.84	80.24
Kanika (V ₇)	24.95	32.99	23.75	27.33	8.15	31.35	31.79	10.80	12.06	10.46	10.86	10.46	11.40	11.60	72.94	78.15	72.44	73.75	71.44	76.70	77.54
Vashudha (V ₈)	21.19	29.59	13.99	21.59	4.59	25.59	26.20	11.00	11.80	10.60	11.20	8.80	11.40	11.53	72.65	80.15	72.15	74.65	68.65	78.65	79.10
Heena (V ₉)	20.19	29.07	19.99	20.59	7.99	21.79	26.19	11.40	12.20	11.40	11.60	11.20	11.80	11.80	73.45	82.25	72.15	77.65	71.15	77.90	81.65
Shikha (V ₁₀)	22.99	28.19	22.39	22.59	4.39	25.39	27.47	11.13	12.00	11.00	11.40	9.60	11.40	11.60	74.65	79.10	70.65	74.75	70.65	75.65	76.65
Mean				26.01							10.86							76.20			
SEm ±				6.23							1.09							2.97			
SED				8.06							0.96							3.92			
C.V				19.15							8.33							3.20			
CD 5%				13.08							2.30							6.24			

compared to their respective control treatments (Check). In addition, treatments such as T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm) also exhibited significant increases in pod angles across several cultivars. Conversely, the minimum pod angles were recorded in treatments V₆T₄ (65.94 degrees). These treatments, particularly under T₄ (MH at 1000 ppm) and T₂ (ABA at 50 ppm), showed a significant decrease in pod angle compared to their respective controls (Table 3).

The increase in pod angle observed in treatments such as GA₃ (T₁), IAA (T₆) and KNO₃ (T₅) suggests that these treatments promote more upright pod growth, which is beneficial for improving air circulation and reducing disease risk (Naidu *et al.*, 1994). Conversely, MH (T₄) and ABA (T₂) treatments resulted in more acute pod angles, potentially influencing pod exposure to environmental conditions and negatively affecting pod development. Foliar application of salicylic acid and potassium in mung bean also confirmed by Majeed *et al.* (2016). These findings are consistent with previous research highlighting the effects of growth regulators on plant architecture (Porwal *et al.*, 2002).

Pod thickness (mm)

Despite the lack of significant variation, minor differences in pod thickness were observed across the treatments. The thickest pods were recorded under treatment T₄ (MH at 1000 ppm) in most cultivars, including V₆T₄ (0.84 mm), when compared to their respective control (Check). Notably, the T₂ (ABA at 50 ppm) treatment across all tested varieties also produced relatively thicker pods, suggesting that some inherent genetic factors may contribute to pod thickness, independent of the treatments applied. On the other hand, the thinnest pods were observed in treatment T₁ (GA₃ at 80 ppm), followed by treatments T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm) compared to controls (Table 4).

These treatments did not show a substantial impact on pod thickness. The lack of significant variation in pod thickness across treatments aligns with previous studies indicating that pod thickness may be more genetically controlled than environmentally influenced (Williams *et al.*, 1984). However, minor variations in pod thickness observed with MH and ABA treatments could be linked to their effects on cell wall structure and integrity, as documented by Gupta *et al.* (1985).

Pod length (cm)

Highest pod lengths were recorded in V₈T₁ (8.60 cm) particularly those treated with T₁ (GA₃ at 80 ppm), were statistically at par with interactions T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm), demonstrating their effectiveness in enhancing pod length. Conversely, certain treatments resulted in reduced pod lengths compared to their controls. For instance, the following combinations exhibited shorter pod lengths: V₃T₄ (6.30 cm). These results suggest that treatment T₄ (MH at 1000 ppm) negatively affected pod length in most varieties. Additionally,

Table 4: Impact of foliar application of dormancy-modulating chemicals treatments on the pod thickness (mm), pod length (cm) and 1000-seed weight (g) in mungbean genotypes.

Variety	Pod thickness (mm)						Pod length (cm)						1000-Seed weight (g)								
	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
IPM 2-3 (V ₁)	0.77	0.67	0.77	0.76	0.82	0.73	0.72	7.18	7.85	7.10	7.40	6.70	7.43	7.48	36.54	38.5	34.88	36.72	26.97	37.71	38.11
IPM 2-14 (V ₂)	0.69	0.53	0.69	0.68	0.83	0.67	0.64	7.00	7.60	7.00	7.08	6.63	7.25	7.35	35.1	39.53	34.81	36.68	26.7	37.53	37.68
Meha (V ₃)	0.76	0.7	0.82	0.75	0.82	0.73	0.73	6.63	7.15	6.60	6.90	6.30	6.98	7.13	29.76	31.88	29.25	29.98	25.08	30.1	30.97
Soorva (V ₄)	0.76	0.65	0.76	0.7	0.81	0.69	0.67	7.08	7.78	7.08	7.20	6.90	7.25	7.28	32.88	37.51	32.05	33.07	25.6	34.19	34.88
Virat (V ₅)	0.7	0.65	0.72	0.68	0.77	0.67	0.66	7.53	8.23	7.45	7.65	7.38	7.65	7.73	34.53	35.69	32.92	34.79	25.21	34.94	35.36
Varsha (V ₆)	0.75	0.67	0.79	0.75	0.84	0.73	0.68	6.90	7.80	6.83	7.48	6.63	7.55	7.68	30.77	33.61	29.58	31.73	26.29	32.37	32.39
Kanika (V ₇)	0.74	0.69	0.74	0.73	0.78	0.72	0.7	7.28	7.85	7.15	7.48	6.88	7.50	7.78	32.97	35.58	31.67	33.83	27.04	34.34	35.2
Vashudha (V ₈)	0.66	0.52	0.69	0.64	0.78	0.63	0.58	7.53	8.60	7.38	7.75	7.33	7.98	8.50	35.35	41.7	24.07	37.31	25.03	38.06	38.1
Heena (V ₉)	0.73	0.61	0.74	0.71	0.75	0.66	0.64	7.18	7.78	7.15	7.18	7.05	7.33	7.63	31.24	32.44	30.91	31.24	26.9	31.43	32.44
Shikha (V ₁₀)	0.73	0.51	0.77	0.7	0.81	0.68	0.67	7.15	7.63	7.13	7.28	6.55	7.45	7.53	32.8	34.69	30.71	32.95	25.62	33.82	34.4
Mean				0.71							7.32							32.81			
Sem ±				0.07							0.25							0.22			
SED				0.07							0.36							0.31			
CD (LSD) 5%				0.15							0.71							0.61			
CD (LSD) 1%				N/A							0.94							0.81			
C.V. (%)				8.53							6.94							1.34			

treatments involving T₂ (ABA at 50 ppm) consistently showed significant reductions in pod length (Table 4).

Pod length showed significant variation across treatments, with GA₃ (T₁), IAA (T₆) and KNO₃ (T₅) treatments consistently producing longer pods. This aligns with research indicating that GA₃ promotes cell elongation, leading to enhanced pod growth (Yogananda *et al.*, 2004). In contrast, MH (T₄) and ABA (T₂) treatments resulted in shorter pod lengths, likely due to their growth-suppressing effects, as previously reported by Vaithalingam and Rao, (1973b).

1000-Seed weight (g)

Highest 1000-seed weights in V₈T₁ (41.70 g) which were significantly greater than their respective control treatments. T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm) also showed maximum 1000-seed weights compared to their controls while minimum in V₈T₄ (25.03 g). These combinations, particularly T₄ (MH at 1000 ppm), T₂ (ABA at 50 ppm) consistently produced lower seed weights. further indicating that ABA may negatively impact seed weight in mungbean (Table 4).

The results showed significant differences in 1000-seed weight across treatments, with GA₃, IAA and KNO₃ treatments producing heavier seeds. This supports earlier findings that GA₃ enhances seed weight by promoting nutrient allocation and seed development (Finkelstein *et al.*, 2008). The negative impact of MH and ABA on seed weight can be attributed to their role in inducing dormancy and inhibiting growth, as noted by Gupta *et al.* (1985) and Hu *et al.* (2010).

Seed size (mm)

Seed size horizontal (mm)

The highest horizontal seed sizes were observed in V₁T₁ (3.37 mm). Additionally, all tested variety interactions with treatments T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm) also produced statistically larger horizontal seed sizes when compared to control (T₀). On the other hand, the lowest horizontal seed sizes were found in V₂T₄ (2.77 mm). Furthermore, all varieties in combination with treatment T₂ (ABA at 50 ppm) showed a significant reduction in horizontal seed size, indicating the negative impact of this treatment on seed size (Table 5).

Seed size vertical (mm)

The highest vertical seed sizes were recorded in V₈T₁ (4.81 mm). Additionally, variety interactions with treatments T₆, T₅ and T₃ also resulted in increased vertical seed sizes compared to their control treatments (T₀). Conversely, the lowest vertical seed sizes were observed in V₇T₄ (3.72 mm). As with horizontal seed size, variety interactions with treatment T₂ resulted in a reduction in vertical seed sizes, which were lower than controls, indicating that this treatment may have a negative impact on vertical seed size (Table 5).

The interaction between variety and treatment significantly affected horizontal seed size, with GA₃, IAA and KNO₃ treatments producing the largest seeds. This result

Table 5: Impact of foliar application of dormancy-modulating chemicals treatments on the seed size horizontal (mm), seed size vertical (mm), seed size vertical (mm) and seedling length (cm) in mungbean genotypes.

Variety	Seed size horizontal (mm)						Seed size vertical (mm)						Seedling length (cm)								
	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
PM 2-3 (V ₁)	3.14	3.37	3.00	3.26	2.96	3.29	3.31	4.33	4.53	4.23	4.37	4.21	4.48	4.49	38.26	41.30	38.07	39.85	33.15	40.33	41.06
PM 2-14 (V ₂)	3.08	3.25	2.92	3.09	2.77	3.12	3.15	4.19	4.65	4.05	4.24	4.05	4.27	4.60	37.25	40.80	36.66	38.01	34.30	38.21	40.70
Meha (V ₃)	2.82	3.07	2.81	2.93	2.81	2.96	3.05	3.91	4.15	3.90	3.99	3.81	4.10	4.11	33.66	41.24	31.44	34.57	30.76	34.61	37.32
Soorya (V ₄)	3.13	3.24	3.07	3.14	2.92	3.16	3.22	4.10	4.26	4.03	4.12	3.77	4.23	4.25	36.78	39.91	35.42	37.41	34.20	38.86	39.70
Virat (V ₅)	3.13	3.28	3.06	3.14	3.01	3.16	3.17	4.08	4.18	4.07	4.09	4.02	4.10	4.11	35.83	41.43	34.82	36.07	33.30	37.65	39.76
Varsha (V ₆)	2.91	3.16	2.91	3.03	2.89	3.11	3.12	4.19	4.40	4.16	4.23	4.14	4.24	4.32	35.75	40.94	35.35	38.93	34.58	39.68	39.78
Kanika (V ₇)	3.12	3.36	3.09	3.23	2.96	3.29	3.34	4.09	4.60	4.05	4.26	3.72	4.28	4.57	37.80	40.69	37.80	38.65	37.13	38.80	40.05
Vashudha (V ₈)	3.13	3.36	3.12	3.21	2.96	3.24	3.29	4.38	4.81	4.24	4.52	4.19	4.57	4.78	38.98	41.72	37.79	39.42	35.84	40.04	40.14
Heena (V ₉)	2.98	3.15	2.98	3.06	2.97	3.08	3.12	4.02	4.28	3.92	4.02	3.81	4.08	4.18	34.52	41.01	33.57	35.48	33.45	35.91	39.39
Shikha (V ₁₀)	3.09	3.35	3.02	3.12	2.24	3.17	3.35	3.95	4.34	3.91	3.99	3.41	4.10	4.11	36.10	40.08	34.36	36.39	33.64	37.92	38.82
Mean				3.09							4.18							37.47			
Sem ±				0.11							0.15							0.53			
SED				0.15							0.21							0.75			
CD (LSD) 5%				0.30							0.42							1.48			
CD (LSD) 1%				0.39							0.55							1.95			
C.V. (%)				6.86							7.17							2.83			

is consistent with studies showing that GA₃ and IAA promote seed enlargement by enhancing cell division and expansion (Ravat and Nirav, 2015). The reduction in seed size observed with ABA and MH treatments aligns with previous research highlighting their inhibitory effects on seed development (Vaithalingam and Rao, 1973b).

Seedling length (cm)

The interaction between variety and treatment was particularly significant, highlighting the combined influence of these factors on seedling length. The combination of variety V₈ and treatment T₁ (GA₃ at 80 ppm) resulted in the highest seedling length (41.72 cm). Additionally, treatments T₆ (IAA at 100 ppm), T₅ (KNO₃ at 1 mm) and T₃ (H₂O₂ at 10 mm) also resulted in substantial increases in seedling length. Conversely, the lowest seedling lengths were observed in combinations involving treatment T₄ (MH at 1000 ppm), including V₃T₄ (30.76 cm). These combinations demonstrated significantly lower seedling lengths compared to their respective control. Additionally, interactions involving treatment T₂ (ABA at 50 ppm) showed reduction in seedling length across all varieties, suggesting that ABA negatively impacts seedling growth (Table 5).

GA₃ consistently promoted the longest seedling lengths, further reinforcing its role as a growth enhancer (Finkelstein *et al.*, 2008). Chemical inducers of seed dormancy can interfere with various physiological processes essential for seed germination, thereby delaying or inhibiting the emergence of the radicle and subsequent seedling growth (Gupta *et al.*, 2024). The reduced seedling lengths observed with MH (T₄) and ABA (T₂) treatments reflect their inhibitory effects on growth and are in line with findings from Hu *et al.* (2010). IAA treatment effect to significant extent for growth and to a level of non-significant for ionic concentration confirmed by (Saima *et al.*, 2022).

CONCLUSION

GA₃ was consistently the most impactful treatment, promoting the highest pod counts, seed numbers, pod lengths and seedling lengths, highlighting its role as a potent growth regulator in mungbean cultivation. GA₃'s ability to stimulate cell elongation, division and reproductive growth. Treatments involving MH and ABA exhibited suppressive effects on pod formation, seed count, pod angles and overall seedling growth, indicating their potential to induce dormancy and inhibit growth processes. The variation in response across different cultivars suggests that the interaction between genetic background and chemical treatment plays a crucial role in determining the efficacy of these dormancy-modulating chemicals. The application of GA₃, IAA and KNO₃ offers a promising approach for improving mungbean productivity, enhancing both seed yield and quality by promoting growth and overcoming dormancy issues. Future studies should investigate the long-term effects of these chemical treatments on seed storability, dormancy resistance and their performance under varying

environmental conditions to further optimize their use in mungbean cultivation strategies.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

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