



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 1169-1173
Received: 02-04-2026
Accepted: 18-05-2026

C Vajram
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture and Technology,
Modipuram, Meerut, Uttar Pradesh,
India

PK Singh
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

Mukesh Kumar
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

Adesh Singh
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

UP Shahi
Department of Soil Science, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

Neelesh Kapoor
Plant Biotechnology, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

Ragam Sandhya
Department of Agricultural
Statistics, Anand Agricultural
University, Anand, Gujarat, India

Ranganna Gari Thippeswami
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture & Technology, Meerut,
Uttar Pradesh, India

Corresponding Author:
C Vajram
Department of Agronomy, Sardar
Vallabhbhai Patel University of
Agriculture and Technology,
Modipuram, Meerut, Uttar Pradesh,
India

Influence of zinc and iron application strategies on growth, root development and nodulation of *Kharif* Mung Bean (*Vigna radiata* L.)

C Vajram, PK Singh, Mukesh Kumar, Adesh Singh, UP Shahi, Neelesh Kapoor, Ragam Sandhya and Ranganna Gari Thippeswami

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6o.5845>

Abstract

The present investigation entitled “Influence of Zinc and Iron Application Strategies on Growth, Root Development and Nodulation of *Kharif* Mung Bean (*Vigna radiata* L.)” was conducted during the kharif season of 2025 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh. The experiment was laid out in a Randomized Block Design with three replications comprising nine zinc and iron treatments. The experimental soil was sandy loam in texture, slightly alkaline in reaction, low in organic carbon and available nitrogen, medium in available phosphorus, potassium, iron and low to medium in available zinc. Mung bean variety ‘Samrat’ (PDM-139) was sown at a spacing of 30 cm × 10 cm. Among the treatments, foliar application of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% at pre-flowering and pod initiation stages (T₇) proved significantly superior and recorded the highest values for plant height (47.8 cm), number of branches plant⁻¹ (6.9), trifoliate leaves plant⁻¹ (15.6), leaf area index (4.48), crop growth rate (13.63 g m⁻² day⁻¹), root length (13.8 cm) and nodules plant⁻¹ (34.3). The treatment comprising soil application of ZnSO₄ @ 25 kg ha⁻¹ along with foliar application of FeSO₄ @ 0.5% at pre-flowering and pod initiation stages (T₈) ranked second for most growth attributes. The lowest values for all growth parameters were recorded under the control treatment. The results indicate that combined foliar application of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% at pre-flowering and pod initiation stages is an effective strategy for enhancing growth, root development and nodulation of kharif mung bean.

Keywords: Mung bean, zinc, iron, growth parameters, nodulation, foliar application

Introduction

The word ‘pulses’ is derived from a Latin word *puls*, meaning “thick soup” or “pottage.” pulses are one of the important food crops globally due to their higher protein content. Pulses are the major sources of protein in the diet of all categories of people, form an integral part of the Indian diet; pulses contain 20 to 25% protein by weight which is double the protein content of wheat and three times that of rice. Mung bean (*Vigna radiata* L.), often called as green gram, is a vital leguminous crop cultivated in arid and semiarid region of India. It is a crop with a less growing season. Mung bean is predominantly a self-pollinated crop. It is cultivated in North India throughout the kharif and summer seasons. The perfect conditions for its growth include a warm and humid climate, with temperatures ranging from 25-35 °C and consistent rainfall of 400-550 mm during the growing season. Owing to its short duration, mung bean fits well into multiple cropping and intercropping systems. Well-drained loamy to sandy loam soils are suitable for mung bean cultivation (Nair *et al.*, 2018) [17]. It serves as a superb green manure and a cover crop that prevents wind and water erosion. As a legume, it improves soil health and fixes approximately 30–40 kg N ha⁻¹ through symbiotic nitrogen fixation.

Among pulses, green gram ranks third, following chickpea and pigeon pea and occupies nearly 16% of the total pulse area (Kaur and Aulakh *et al.*, 2021) [12]. In India, mung bean occupies 5.8 million ha with a production of 4.2 million tonnes and a productivity of 719 kg ha⁻¹ (Department of Agriculture and Farmer Welfare, 2024) [5]. In Uttar Pradesh, mung bean occupies 0.094 million ha with a production of 0.058 million tonnes and a productivity of 618 kg ha⁻¹ (Directorate of Pulse Development, 2024) [6]. On a dry-weight basis, mung bean contains protein levels between

24 to 25%, fat content of 1.0 to 1.5%, fiber ranging from 3.5 to 4.5% and carbohydrates at 60 to 65%. Fe and Zn are found in green gram in amounts between 4.0-7.6 mg/100 g dry weight and 2.4-3.0 mg/100 g dry weight, respectively (Dahiya *et al.*, 2015) [4]. Singh and Behera (2011) [21] analyzed three lakh soil samples from India and found that approximately 49% and 12% of soils were deficient in zinc and iron respectively. Zinc (Zn) is recognized as the 8th essential micronutrient required for plant growth, development and reproduction. It acts as a structural, catalytic and regulatory component of numerous enzymes and Zn-finger proteins involved in signal transduction and the transcriptional regulation of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Zinc deficiency disrupts the biosynthesis of key phytohormones, including auxins, gibberellins and cytokinins, thereby restricting plant growth and crop development (Hassan *et al.*, 2020) [10]. Furthermore, Zn plays an important role in root nodulation and enhances biological nitrogen fixation in pulse crops through the formation of effective root nodules. According to Arnon and Stout (1939), iron (Fe) is an essential micronutrient required for plants and its absence prevents the completion of the plant life cycle. Iron (Fe) plays an essential role in plant growth and development, participating in the synthesis of chlorophyll, thylakoids and the formation of chloroplasts. It plays an active role in the *plants* metabolic processes (such as oxidative photophosphorylation). Dehydrogenase, proteases and peptidase enzymes that either directly or indirectly participate in the synthesis of carbohydrates and proteins are stimulated by iron. Nitrogenase is an essential iron element of the enzymes as it assists nitrifying bacteria in converting atmospheric nitrogen. Therefore, the present investigation was undertaken to evaluate the effect of different methods of zinc and iron application on growth, root development and nodulation of kharif mung bean (*Vigna radiata* L.).

Materials and Methods

The field experiment was conducted during the kharif season of 2025 at Crop Research Centre (CRC), Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.), India. The experimental site is situated at 29°10' N latitude and 77°70' E longitude with an altitude of 226 m above mean sea level. The region falls under the semi-arid to sub-tropical climate of the Upper Gangetic Plains. The experimental field soil was sandy loam in texture, comprising 57.4% sand, 24.0% silt and 18.6% clay. The soil was slightly alkaline in reaction (pH 7.8) with an electrical conductivity of 0.29 dS m⁻¹. It contained 0.47% organic carbon and low in available nitrogen (203.2 kg ha⁻¹), medium in available phosphorus (16.5 kg ha⁻¹) and potassium (194.2 kg ha⁻¹). The DTPA-extractable zinc and iron contents were 0.52 and 9.3 mg kg⁻¹, respectively. The mung bean variety Samrat (PDM-139) was sown on 21st August 2025 with recommended practices. The experimental field was laid out in a Randomized Block Design (RBD) design with nine treatments and three replications. The treatments comprised (T₁) Control, (T₂) Soil application of ZnSO₄ @ 25kg ha⁻¹, (T₃) Soil application of FeSO₄ @ 25kg ha⁻¹, (T₄) Soil application of ZnSO₄ @ 25kg ha⁻¹ + FeSO₄ @ 25kg ha⁻¹, (T₅) Foliar application of ZnSO₄ @ 0.5% at pre flowering and pod initiation stage, (T₆) Foliar application of FeSO₄ @ 0.5% at pre flowering and pod initiation stage, (T₇) Foliar application of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% at pre flowering and pod initiation stage, (T₈) Soil application of ZnSO₄ @ 25kg ha⁻¹ + Foliar application of FeSO₄ @ 0.5% at pre flowering and pod initiation stage and (T₉) Soil application of FeSO₄ @ 25kg ha⁻¹ + Foliar application of ZnSO₄ @ 0.5% at pre flowering and pod initiation stage.

Results and Discussion

Effect of Zinc and Iron application on Growth and Nodulation Parameters

Growth and nodulation parameters of mung bean, namely plant height (cm), number of branches plant⁻¹, number of trifoliate leaves plant⁻¹, leaf area index, crop growth g m⁻² day⁻¹, Root length (cm) and number of nodules plant⁻¹ were significantly influenced by zinc and iron treatments.

Plant height(cm)

The data on plant height at 25 DAS, 50 DAS and at harvest was significantly influenced, at 25 DAS, the maximum plant height (24.6 cm) was recorded in T₄, as soil applied micronutrients were already available in the root zone during early vegetative growth, facilitating better nutrient absorption and cell division. However, at 50 DAS and harvest stage, the combined foliar application treatment T₇ recorded the maximum plant height of 47.8 cm and 59.3 cm. The superiority of foliar application at later stages mainly by the direct absorption of zinc and iron through the leaf surface, which rapidly accelerates plant metabolism. Zinc plays a key role in the biosynthesis of plant growth regulators, particularly auxins, which actively participate in cell elongation and meristematic activity, ultimately boosting plant height. Enhanced iron availability through foliar spray promotes enzymatic and metabolic processes, including chlorophyll synthesis and photosynthetic efficiency, which further drives vegetative development. These results are in conformity with Boradkar *et al.* (2023) [2], Hafsa Farooq *et al.* (2025) [7] Haider *et al.* (2018) [9] and Rehaman *et al.* (2024) [19].

Number of branches plant⁻¹

Treatment T₇ recorded the significantly highest number of branches at 50 DAS (6.9 plant⁻¹) and at harvest (8.2 plant⁻¹). The lowest in control (T₁) (4.2 and 5.4 plant⁻¹). The enhancement in branching under combined foliar application of zinc and iron can be attributed to the role of iron in protein, chlorophyll and chloroplast development, as well as in the production of photosynthates that support axillary bud development and branching. The synergistic effect of zinc and iron applied together stimulates greater physiological activity compared to either element applied alone. These findings are in agreement with Praveena *et al.* (2018) [18], Habib *et al.* (2018) [8], Suman *et al.* (2022) [22] and Zeidan *et al.* (2010) [24].

Number of trifoliate leaves plant⁻¹

At 25 DAS, the maximum trifoliate leaves (4.1 plant⁻¹) were recorded with T₄ due to the early availability of soil applied zinc and iron in the root zone. At 50 DAS and at harvest stage, treatment T₇ recorded the significantly highest values of 15.6 plant⁻¹ and 13.8 plant⁻¹, respectively. The increase in leaf count under zinc and iron application can be attributed to improved cell division in apical and axillary meristems, enhanced nitrogen metabolism and greater photosynthetic capacity, which collectively support the production of more leaf bearing nodes. The findings are supported by Borah *et al.* (2021) [3], Karmakar *et al.* (2021) [11] and Kavya *et al.* (2021) [13].

Leaf area index

At 25 DAS, the highest LAI (2.31) was recorded with T₄, while at 50 DAS and at harvest stage, T₇ recorded the significantly highest LAI of 4.48 and 3.34, respectively. Higher LAI under combined foliar application of zinc and iron is attributed to the role of these micronutrients in promoting leaf area expansion through cell division and elongation, enhanced chlorophyll content and

improved photosynthetic pigment synthesis. These findings are supported by Blessena *et al.* (2019) ^[11], Saakshi *et al.* (2020) ^[20] and Marschner (2012) ^[16].

Crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$)

The crop growth rate of mung bean was significantly affected by the treatments during both the growth intervals, viz., 25-50 DAS and 50 DAS to harvest stage. Treatment T₇ recorded the highest CGR during both intervals with 13.63 and 8.52 $\text{g m}^{-2} \text{day}^{-1}$, respectively, control (T₁) recorded the lowest CGR at both intervals (8.44 and 4.35 $\text{g m}^{-2} \text{day}^{-1}$). The higher CGR under combined foliar application of zinc and iron is a direct consequence of enhanced photosynthetic efficiency, greater leaf area and improved dry matter production rate per unit ground area per unit time. These findings are consistent with Karmakar *et al.* (2021) ^[11] and Mahilane *et al.* (2018) ^[15].

Root length (cm)

At 25 DAS, the maximum root length (9.1 cm) was recorded with T₄. At 50 DAS and harvest, treatment T₇ recorded the highest root length (13.8 and 15.4 cm, respectively), followed by T₈ (13.1 and 14.7 cm). The superiority of soil application treatments during early growth stages for root elongation is because soil applied zinc and iron are directly available in the rhizosphere, promoting root cell division and elongation through activation of auxin biosynthesis. At later stages, foliar applied zinc and iron translocated to root tissue via phloem, further enhancing root development. These results are in agreement with Praveena *et al.* (2018) ^[18] and Usman *et al.* (2014) ^[23].

Number of nodules plant⁻¹

The highest number of nodules (34.3 plant⁻¹) was recorded under T₇. The lowest number of root nodules (24.4 plant⁻¹) was in the control (T₁). Zinc promotes nodulation by enhancing root hair development, which is the primary site of *Rhizobium* infection and by stimulating the production of flavonoids that act as signal molecules between the host legume and *Rhizobium* bacteria. Iron is an essential constituent of nitrogenase and leghemoglobin, both of which play a crucial role in biological nitrogen fixation within root nodules. These results are supported by Kuniya *et al.* (2018) ^[14] and Suman *et al.* (2022) ^[22].

Table 1: Effect of zinc and iron application on plant height (cm) of mung bean during various phenological stages

Treatments	Plant height (cm)		
	25 DAS	50 DAS	At harvest
T ₁ Control	19.6	40.7	49.4
T ₂ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	23.2	42.5	54.6
T ₃ Soil application of FeSO ₄ @ 25 kg ha ⁻¹	22.7	41.8	53.9
T ₄ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	24.6	44.5	56.4
T ₅ Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	19.9	43.6	55.7
T ₆ Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	19.6	43.1	55.2
T ₇ Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	20.1	47.8	59.3
T ₈ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	23.3	46.5	58.1
T ₉ Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	22.8	45.7	57.5

SEm (±)	0.5	0.6	0.8
C.D. (P=0.05)	1.4	1.8	2.3

Table 2: Effect of zinc and iron application on number of branches plant⁻¹ of mung bean at different stages of crop growth

Treatments	Branches plant ⁻¹	
	50 DAS	At harvest
T ₁ Control	4.2	5.4
T ₂ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	4.8	6.1
T ₃ Soil application of FeSO ₄ @ 25 kg ha ⁻¹	4.5	5.9
T ₄ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	5.6	6.8
T ₅ Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	5.4	6.5
T ₆ Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	5.2	6.3
T ₇ Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	6.9	8.2
T ₈ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	6.1	7.3
T ₉ Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	5.9	7.1
SEm (±)	0.2	0.2
C.D. (P=0.05)	0.6	0.7

Table 3: Effect of zinc and iron application on number of trifoliolate leaves plant⁻¹ of mung bean at different stages of crop development

Treatments	Trifoliolate leaves plant ⁻¹		
	25 DAS	50 DAS	At harvest
T ₁ Control	2.7	11.3	9.6
T ₂ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	3.6	12.7	10.9
T ₃ Soil application of FeSO ₄ @ 25 kg ha ⁻¹	3.2	12.5	10.6
T ₄ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	4.1	14.1	12.3
T ₅ Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	2.9	13.6	11.8
T ₆ Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	2.8	13.4	11.5
T ₇ Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	2.9	15.6	13.8
T ₈ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	3.8	14.5	12.9
T ₉ Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	3.4	14.4	12.6
SEm (±)	0.1	0.3	0.3
C.D. (P=0.05)	0.4	0.9	0.8

Table 4: Effect of zinc and iron application on leaf area index (LAI) of mung bean at various growth stages

Treatments	Leaf Area Index		
	25 DAS	50 DAS	At harvest
T ₁ Control	1.45	2.68	1.82
T ₂ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	2.19	3.24	2.47
T ₃ Soil application of FeSO ₄ @ 25 kg ha ⁻¹	1.94	2.86	2.14
T ₄ Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	2.31	3.64	2.92
T ₅ Foliar application of ZnSO ₄ @ 0.5% at pre-	1.52	3.47	2.65

	flowering and pod initiation stage			
T ₆	Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	1.48	3.32	2.57
T ₇	Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	1.63	4.48	3.34
T ₈	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	2.25	3.94	3.19
T ₉	Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	2.14	3.75	3.12
	SEm (±)	0.1	0.2	0.1
	C.D. (P=0.05)	0.2	0.4	0.3

Table 5: Effect of zinc and iron application on crop growth rate (g m⁻² day⁻¹) of mung bean during growth stages

	Treatments	CGR (g m ⁻² day ⁻¹)	
		25-50 DAS	50 DAS – at Harvest
T ₁	Control	8.44	4.35
T ₂	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	9.27	5.81
T ₃	Soil application of FeSO ₄ @ 25 kg ha ⁻¹	9.13	5.67
T ₄	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	10.24	7.15
T ₅	Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	10.07	6.73
T ₆	Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	9.92	6.13
T ₇	Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	13.63	8.52
T ₈	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	11.36	7.79
T ₉	Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	10.97	7.67
	SEm (±)	0.5	0.2
	C.D. (P=0.05)	1.4	0.6

Table 6: Effect of zinc and iron application on root length (cm) and nodules plant⁻¹ of mung bean

	Treatments	Root length (cm)			Root nodules plant ⁻¹
		25 DAS	50 DAS	At harvest	
T ₁	Control	7.4	10.6	11.8	24.4
T ₂	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	8.7	11.5	12.7	26.1
T ₃	Soil application of FeSO ₄ @ 25 kg ha ⁻¹	8.3	11.3	12.6	25.8
T ₄	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + FeSO ₄ @ 25 kg ha ⁻¹	9.1	12.6	13.5	28.6
T ₅	Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod initiation stage	7.4	12.2	13.3	27.8
T ₆	Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	7.3	11.9	13.1	27.2
T ₇	Foliar application of ZnSO ₄ @ 0.5% + FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	7.5	13.8	15.4	34.3
T ₈	Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of FeSO ₄ @ 0.5% at pre-flowering and pod initiation stage	8.9	13.1	14.7	32.8
T ₉	Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + Foliar application of ZnSO ₄ @ 0.5% at pre-flowering and pod	8.6	12.8	14.2	31.6

	initiation stage				
	SEm (±)	0.2	0.3	0.3	0.6
	C.D. (P=0.05)	0.7	0.8	0.9	1.9

Conclusion

Zinc and iron application through both soil and foliar modes significantly influenced the growth attributes, root development and nodulation of kharif mung bean (*Vigna radiata* L.), confirming the critical role of these micronutrients in crop growth under slightly alkaline, sandy loam soils of western Uttar Pradesh. Combined foliar application of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% at pre-flowering and pod initiation stages (T₇) proved significantly superior over all other treatments and recorded the highest plant height, number of branches plant⁻¹, trifoliate leaves plant⁻¹, leaf area index, crop growth rate, root length and number of nodules plant⁻¹, attributed to the synergistic interaction of zinc and iron enabling rapid foliar absorption and enhanced metabolic activity at critical growth stages.

Soil application of ZnSO₄ @ 25 kg ha⁻¹ combined with foliar application of FeSO₄ @ 0.5% at pre-flowering and pod initiation stages (T₈) consistently ranked second for most growth and nodulation parameters, highlighting the potential of integrated soil and foliar micronutrient management in mung bean production.

Based on the findings, foliar application of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% at pre-flowering and pod initiation stages is recommended as the most effective and practical zinc and iron application strategy for maximizing vegetative growth and nodulation in kharif mung bean under similar agro-climatic conditions.

Acknowledgement

The authors express sincere gratitude to the Hon'ble Vice Chancellor and Director of Research, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, for providing necessary facilities to carry out this study. The authors are also thankful to the Head, Department of Agronomy and the advisory committee for their guidance, support and valuable suggestions throughout the research work. Sincere thanks are extended to the faculty members and technical staff of the Crop Research Centre for their assistance during field experimentation.

References

- Blessena A, Deotale RD, Raut DA, Pise SE, Yellore SA, Hivare VS. Response of foliar application of tocopherol and micronutrients on morphophysiological parameter and yield of chickpea. *Journal of Soils and Crops*. 2019;29(2):336–342.
- Boradkar SG, Adsul PB, Shelke MS, Khule YR. Effect of iron and zinc application on soil properties, nutrient uptake and yield of green gram (*Vigna radiata* L.) in Inceptisol. *The Pharma Innovation Journal*. 2023;12(3):1663–1669.
- Borah L, Jumi S. Effect of foliar application of zinc on growth and yield of garden pea (*Pisum sativum* L.) in Assam condition. *International Journal of Chemical Studies*. 2021;9(2):869–872.
- Dahiya PK, Linnemann AR, Van Boekel MAJS, Khetarpaul N, Grewal RB, Nout MJR. Mung bean: technological and nutritional potential. *Critical Reviews in Food Science and Nutrition*. 2015;55(5):670–688.
- Department of Agriculture and Farmers Welfare. All India crop-wise area, production and yield (APY). New Delhi: Government of India; 2024.
- Directorate of Pulses Development. Annual report 2023–24.

- New Delhi: Ministry of Agriculture and Farmers Welfare, Government of India; 2024.
7. Farooq H, Ishtiaq R, Babar H, Faryad MH, Ameen M, Abbas MT, *et al.* Enhancing zinc and iron biofortification in mung bean (*Vigna radiata* L.) through various application methods. *Scientific Reports*. 2025;15(1):10974.
 8. Habib ASMA, Roy TS, Amin MR, Haque MZ, Rokonzaman M, Sarker P. Response of zinc on growth, yield and quality of black gram (*Vigna mungo* L.). *International Journal of Agronomy and Agricultural Research*. 2018;13(4):73–79.
 9. Haider MU, Farooq M, Nawaz A, Hussain M. Foliage applied zinc ensures better growth, yield and grain biofortification of mung bean. *International Journal of Agriculture and Biology*. 2018;20:2817–2822.
 10. Hassan MU, Aamer M, Chattha MU, Haiying T, Shahzad B, Barbanti L, *et al.* The critical role of zinc in plants facing drought stress. *Agriculture*. 2020;10(9):396.
 11. Karmakar M, Sarkar NC, Shivay YS. Agronomic biofortification of zinc in lentil. *International Journal of Bio-resource and Stress Management*. 2021;12(2):95–107.
 12. Kaur J, Aulakh GS. Impact analysis of frontline demonstrations on summer mung bean production in Ferozepur district of Punjab, India. *Indian Journal of Extension Education*. 2021;57(2):253–257.
 13. Kavaya P, Singh S, Hinduja N, Tiwari D, Sruthi S. Effect of foliar application of micronutrients on growth and yield of green gram (*Vigna radiata* L.). *Legume Research*. 2021;44(12):1460–1464.
 14. Kuniya N, Chaudhary N, Patel S. Effect of sulphur and zinc application on growth, yield attributes, yield and quality of summer cluster bean (*Cyamopsis tetragonoloba* L.) in light textured soil. *International Journal of Chemical Studies*. 2018;6(1):1529–1532.
 15. Mahilane C, Singh V. Effect of zinc and molybdenum on growth, yield attributes, yield and protein in grain of summer black gram (*Vigna mungo* L.). *International Journal of Current Microbiology and Applied Sciences*. 2018;7(1):1156–1162.
 16. Marschner P. Marschner's mineral nutrition of higher plants. 3rd ed. London: Academic Press; 2012.
 17. Nair RM, Boddepalli VN, Ramasamy S, Ali M, Ali A, Douglas C. Mung bean seed production training manual. Shanhu, Taiwan: AVRDC – The World Vegetable Center; 2018.
 18. Praveena R, Ghosh G, Singh V. Effect of foliar spray of boron and different zinc levels on growth and yield of kharif green gram (*Vigna radiata*). *International Journal of Current Microbiology and Applied Sciences*. 2018;7(8):1422–1428.
 19. Rehaman A, Panda RK, Prusty AK, Jena D. Effect of foliar application of zinc and iron on growth, yield and quality of mung bean (*Vigna radiata* L.). *Journal of Crop and Weed*. 2024;20(1):112–118.
 20. Saakshi AR, Rathod PS, Rachappa V, Dodamani BM, Ananda N. Growth, yield and economics of pigeon pea as influenced by biofortification of zinc and iron. *International Journal of Current Microbiology and Applied Sciences*. 2020;9(2):3088–3097.
 21. Singh MV, Behera SK. AIRCP on micro and secondary nutrients and pollutant elements in soil and plants: a profile. *Research Bulletin*. 2011;10:1–57.
 22. Suman S, Singh R, Singh E, Dwivedi K. Response of sulphur and iron fertilization on growth and yield of green gram (*Vigna radiata* L.). *The Pharma Innovation Journal*. 2022;11(3):259–263.
 23. Usman M, Tahir M, Majeed MA. Effect of zinc sulphate as soil application and seed treatment on green gram (*Vigna radiata* L.). *Pakistan Journal of Life and Social Sciences*. 2014;12(2):87–91.
 24. Zeidan MS, Mohamed MF, Hamouda HA. Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soil fertility. *World Journal of Agricultural Sciences*. 2010;6(6):696–699.