Plant Archives Vol. 26, No. 2, 2026 pp. 1917-1922 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.263

ASSESSMENT OF FOLIAR APPLICATION OF ZINC AND IRON ON GROWTH AND QUALITY ATTRIBUTES OF INDIAN SPINACH (*Beta vulgaris* var. *bengalensis*)

Parikshit Durgam[1*], Eshu Sahu[1], Ganesh Prasad Nag[1], Bhagwat Kumar[2], Richa Sao[3] and Mukesh Kumar[1]

[1]Department of Vegetable Science, Mahatma Gandhi University of Horticulture and Forestry (MGUVV), Durg, Chhattisgarh, India, 491111.

[2]Department of Post-Harvest Technology, Mahatma Gandhi University of Horticulture and Forestry (MGUVV), Durg, Chhattisgarh, India, 491111.

[3]Department of Genetics and Plant Breeding, Mahatma Gandhi University of Horticulture and Forestry (MGUVV), Durg, Chhattisgarh, India, 491111.

*Corresponding author E-mail: ptdurgam@gmail.com

(Date of Receiving-01-07-2026; Date of Revision-13-09-2026; Date of Acceptance-22-09-2026)

ABSTRACT

Indian spinach (*Beta vulgaris* var. *bengalensis*) is an essential leafy vegetable highly valued for its nutritional profile and rapid growth. In the Bastar Plateau region, its physiological growth is frequently constrained by acidic Alfisols, which limit the availability of critical micronutrients. To address this, a field experiment was conducted during the *Rabi* season of 2025-26 at the Research cum Instructional Farm, Krantikari Debridhur College of Horticulture and Research Station, Jagdalpur, Bastar (C.G.). The study evaluated the efficacy of foliar micronutrient feeding on time-series growth and biochemical quality using a Randomized Block Design with eight treatments and three replications on the cultivar 'Naveen 31'. Treatments comprised varying concentrations of zinc sulphate (0.25% to 0.85%) combined with a uniform 0.50% ferrous sulphate, alongside a water-sprayed control. Foliar applications were administered at 20 and 40 days after sowing (DAS). Results revealed that treatment T6 (0.65% $ZnSO_4$ + 0.50% $FeSO_4$) significantly optimized structural growth, recording the highest plant height (36.20 cm) and maximum leaves per plant (19.20) at harvest. Treatment T5 (0.55% $ZnSO_4$ + 0.50% $FeSO_4$) maximized leaf area (152.00 cm^2) and total soluble solids (7.10 °Brix). Furthermore, T6 yielded the highest Vitamin C content (39.50 mg/100g), maximum relative water content (92.4%), and the lowest titratable acidity (0.11%). The precise foliar application of 0.65% $ZnSO_4$ with 0.50% $FeSO_4$ is concluded to be the most effective intervention for maximizing the vegetative progression and biochemical quality of Indian spinach in this agro-climatic zone.

***Key words*:** Indian spinach, *Beta vulgaris*, Foliar feeding, Zinc sulphate, Quality attributes

Introduction

Vegetables play a dominant role in fulfilling the nutritional security of an ever-increasing global population by providing indispensable components of a balanced diet (Singh, 2009). Among cultivated leafy vegetables, Indian spinach (*Beta vulgaris* var. *bengalensis)* is one of the most important due to its fast-growing habit, high yield potential, and demand during the *Rabi* season. Often revered worldwide as a "Nutritional Goldmine," it yields high amounts of Vitamin A, Vitamin C, iron, and calcium, which are biologically critical for preventing malnutrition and anemia, especially in tribal demographics like those residing in the Bastar region of Chhattisgarh.

However, realizing the ultimate growth potential of Indian spinach relies heavily on edaphic conditions. The Bastar Plateau is an Alfisol-dominated agro-ecological zone with high soil acidity (pH 6.88), where heavy leaching removes base cations and fixes essential micronutrients

such as Zinc and Iron in unavailable forms (Jatav and Sahu, 2016). The consequence is "Hidden Hunger," which severely restricts leaf area, internodal elongation, and ultimate crop yield.

Foliar feeding directly bypasses the complex chemistry of soil fixation to deliver soluble nutrients directly to the metabolically active leaves through stomatal openings (Boorboori *et al*., 2022). Zinc acts as a unique catalyst in tryptophan biosynthesis, a direct precursor for auxin (Indole-3-Acetic Acid), which drives rapid cell division and leaf expansion. Simultaneously, Iron is an absolute requirement for chlorophyll biosynthesis and acts as a structural co-factor for the cytochromes regulating photosynthetic electron transport (Bala *et al*., 2021). The present study was meticulously designed to track the physiological responses of Indian spinach to foliar zinc and iron applications across distinct temporal growth stages (20 DAS, 40 DAS, and at harvest) and evaluate their ultimate impact on biochemical quality.

Materials and Methods

Experimental Site and Soil Characteristics

The field experiment was conducted during the *Rabi* season of 2025 at the Research cum Instructional Farm, Krantikari Debridhur College of Horticulture and Research Station, Jagdalpur, Bastar (C.G.). The site is situated at 19°10' N latitude and 81°95' E longitude, at an elevation of 552 meters. Initial soil analysis indicated slightly acidic conditions (pH 6.88) with an electrical conductivity of 0.258 dS/m, medium organic carbon (0.59%), medium available nitrogen (301.06 kg/ha), low available phosphorus (8.71 kg/ha), and medium available potassium (264.64 kg/ha).

Experimental Design and Treatments

The trial was laid out in a Randomized Block Design (RBD) with eight treatments replicated three times. The total experimental area was 119.46 m², divided into 24 net plots measuring 2.0 m × 2.0 m. Seeds of the cultivar 'Naveen 31' were treated with Thiram (2 g/kg) and sown at a spacing of 20 cm × 6 cm.



Plate 1: Pictorial representation of treatments.



Plate 2: Pictorial representation of field layout.

The foliar treatments included:

T1: Control (Water Spray) T2: $ZnSO_4$ 0.25% + $FeSO_4$ 0.5%; T3: $ZnSO_4$ 0.35% + $FeSO_4$ 0.5%; T4: $ZnSO_4$ 0.45% + $FeSO_4$ 0.5%; T5 $ZnSO_4$ 0.55% + $FeSO_4$ 0.5%; T6: $ZnSO_4$ 0.65% + $FeSO_4$ 0.5%; T7: $ZnSO_4$ 0.75% + $FeSO_4$ 0.5%; T8: $ZnSO_4$ 0.85% + $FeSO_4$ 0.5%

A uniform basal dose of well-rotted FYM (10 t/ha) alongside standard NPK fertilizers was incorporated into all plots. The micronutrient solutions were applied utilizing a manual knapsack sprayer at 20 days and 40 days after sowing (DAS).

Data Collection and Mathematical Formulae

Five representative plants were randomly tagged in each plot to record time-series biometric observations (Plant height, number of leaves, leaf area) at 20 DAS, 40 DAS, and at final harvest. Biochemical quality traits were analyzed in the laboratory. Vitamin C was measured using the 2,6-dichlorophenol indophenol (DCPIP) titration method, Total Soluble Solids via a digital refractometer, and Titratable Acidity via the pale pink end point method.



Plate 3: Morphological comparison of leaf area expansion.

Moisture and Relative water content parameters were calculated using the following standard physiological formulae:

$$Moisture\ (\%) = \frac{Fresh\ weight - Dry\ weight}{Fresh\ weight} \times 100$$

$$\text{Relative water content (\%)} = \frac{Fresh\ weight - Dry\ weight}{Turgid\ weight - Dry\ weight} \times 100$$

Vitamin C / Ascorbic acid is calculated via:

$$\frac{Vitamin\ C}{(mg/100g)} = \frac{(Dry\ factor \times Titrate\ value \times Volume\ made\ up)}{Aliquot\ taken\ for\ estimation \times Weight\ of\ sample} \times 100$$

Statistical significance was evaluated using Analysis of Variance (ANOVA) for RBD as described by Panse and Sukhatme (1985), with the Critical Difference (CD) calculated at a 5% probability level alongside the Coefficient of Variation (C.V. %).

Results and Discussion

Growth parameters

Plant height (cm):

The effect of foliar micronutrients on plant height was recorded at 20 DAS, 40 DAS, and at harvest. The results revealed significant differences among the treatments. The maximum plant height (16.50 cm, 31.80 cm, and 36.20 cm at 20 DAS, 40 DAS, and harvest, respectively) was recorded under T6 ($ZnSO_4$ 0.65% + $FeSO_4$ 0.50%). In contrast, the minimum plant height (11.50 cm, 21.00 cm, and 22.28 cm at 20 DAS, 40 DAS, and harvest, respectively) was recorded in the control treatment (T1). The enhanced plant height under T6 may be attributed to zinc promoting the synthesis of tryptophan and auxin (IAA), which stimulates cell division and internodal elongation. Additionally, iron promotes cytochrome and chlorophyll production, supplying the necessary photosynthetic energy for this growth. Similar findings were reported by Khan *et al*., (2022) and Bala *et al*., (2021) in leafy vegetables.

Number of leaves per plant:

Significant differences among the treatments were observed for this parameter. The highest number of leaves per plant (8.10, 15.60, and 19.20 at 20 DAS, 40 DAS, and harvest, respectively) was recorded under T6 ($ZnSO_4$ 0.65% + $FeSO_4$ 0.50%). The minimum number

Table 1: Effect of foliar micronutrients on growth attributes of Indian spinach at 20 DAS, 40 DAS, and Harvest.

Treatment	Plant height (cm)			No. of Leaves			Leaf Area (cm^2)		
	20 DAS	40 DAS	At harvest	20 DAS	40 DAS	At harvest	20 DAS	40 DAS	At harvest
T1 Control	11.50	21.00	22.28	5.2	10.80	13.2	22.00	65	85
T2 $ZnSO_4$ 0.25% + $FeSO_4$ 0.5%	12.87	23.50	26.80	5.8	11.90	14.5	26.50	75	98
T3 $ZnSO_4$ 0.35% + $FeSO_4$ 0.5%	13.50	25.00	28.50	6	12.5	14.50	30.00	84	110
T4 $ZnSO_4$ 0.45% + $FeSO_4$ 0.5%	13.90	26.80	30	6.40	12.80	15.14	34.5	92	122
T5 $ZnSO_4$ 0.55% + $FeSO_4$ 0.5%	15.60	29.50	33.80	7.20	14.50	17.80	46.2	122	152
T6 $ZnSO_4$ 0.65% + $FeSO_4$ 0.5%	16.50	31.80	36.20	8.10	15.60	19.20	40.5	108	142
T7 $ZnSO_4$ 0.75% + $FeSO_4$ 0.5%	14.80	28.20	32.50	6.80	13.57	16.50	38.00	102	130
T8 $ZnSO_4$ 0.85% + $FeSO_4$ 0.5%	14.20	26.50	30.5	4.50	9.5	11.8	33.5	88	115
CD at 5%	**2.02**	**3.53**	**4.88**	**1.14**	**1.94**	**2.13**	**5.80**	**12.90**	**15.64**
S.E. m ±	**0.67**	**1.17**	**1.61**	**0.38**	**0.64**	**0.70**	**1.91**	**4.25**	**5.15**
C.V. (%)	**8.18**	**7.61**	**9.27**	**10.40**	**8.77**	**7.86**	**9.77**	**8.0**	**7.49**

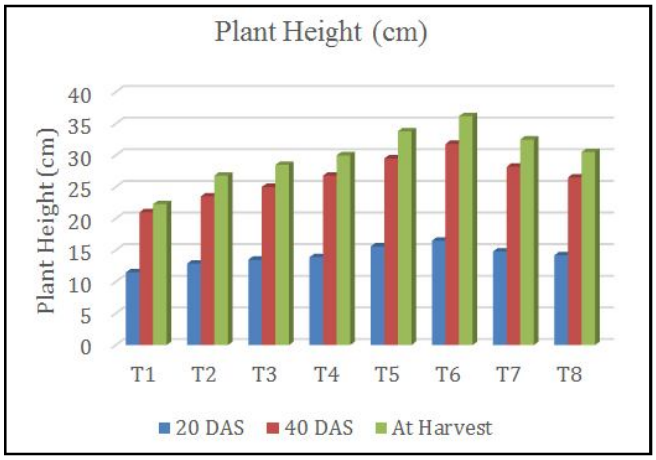


Fig. 1: Effect of micronutrients on plant height (cm).

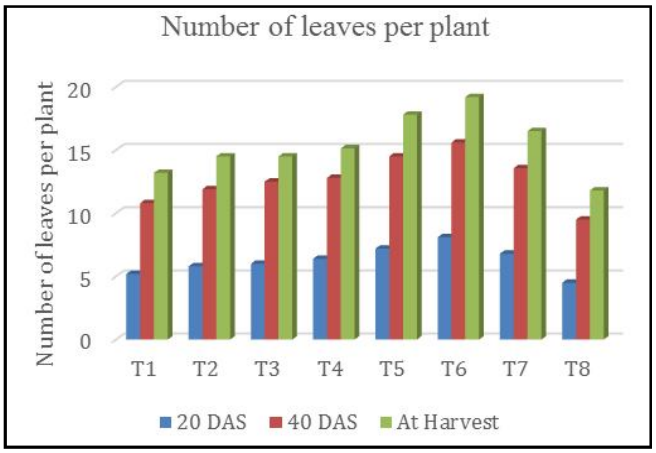


Fig. 2: Effect of micronutrients on number of leaves per plant.

Table 2: Effect of foliar micronutrients on biochemical quality of Indian spinach.

Treatment	Vitamin C (mg/100g)	TSS (°Brix)	Titratable acidity (%)	Moisture (%)	Relative water content (%)
T1 Control	27.00	4.5	0.19	88.8	87.5
T2 $ZnSO_4$ 0.25% + $FeSO_4$ 0.5%	29.50	5	0.17	89.5	88.8
T3 $ZnSO_4$ 0.35% + $FeSO_4$ 0.5%	31.00	5.2	0.16	89.8	89.5
T4 $ZnSO_4$ 0.45% + $FeSO_4$ 0.5%	32.17	5.5	0.15	92.4	89.8
T5 $ZnSO_4$ 0.55% + $FeSO_4$ 0.5%	36.80	7.10	0.13	91.5	91.5
T6 $ZnSO_4$ 0.65% + $FeSO_4$ 0.5%	39.50	5.80	0.11	90.5	92.4
T7 $ZnSO_4$ 0.75% + $FeSO_4$ 0.5%	34.50	6.4	0.14	90.2	90.5
T8 $ZnSO_4$ 0.85% + $FeSO_4$ 0.5%	33.5	4	0.15	87.5	90.2
CD at 5%	**4.20**	**0.77**	**0.02**	**2.54**	**2.14**
S.E. m ±	**1.39**	**0.25**	**0.01**	**0.84**	**0.71**
C.V. (%)	**7.28**	**8.12**	**9.47**	**1.62**	**1.36**

of leaves at harvest (11.80) was recorded under the highest toxicity dose in T8 ($ZnSO_4$ 0.85% + $FeSO_4$ 0.50%). The increased number of leaves under T6 is due to the combined action of zinc and iron, which increases the photosynthetic area and promotes the initiation of lateral leaf buds.Similar results were reported by Sahu *et al.*, (2022).

Leaf area (cm²):

The maximum leaf area (46.20 cm², 122.00 cm², and 152.00 cm² at 20 DAS, 40 DAS, and harvest, respectively) was recorded under T5 ($ZnSO_4$ 0.55% + $FeSO_4$ 0.50%), showcasing a prominent advantage over all other groups. The optimal zinc dosage of 0.55% successfully activates expansins, allowing leaves to expand fully. When the zinc dosage is increased to higher levels (T6 and T8), the plant's energy is redirected toward developing thicker leaves rather than maximizing surface area. Similar findings were reported by Zulfiqar *et al.*, (2020) and Gao *et al.*, (2022).

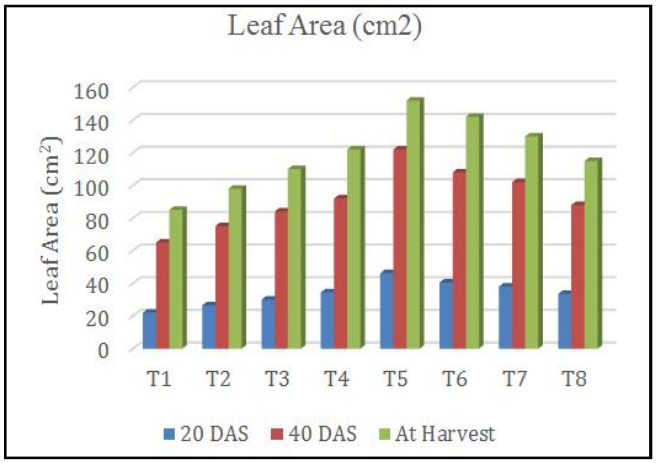


Fig. 3: Effect of micronutrients on leaf area (cm²).

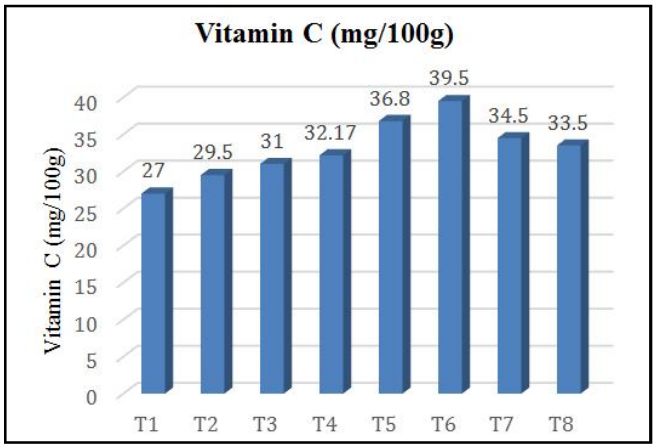


Fig. 4: Effect of micronutrients on vitamin C (mg/100g).

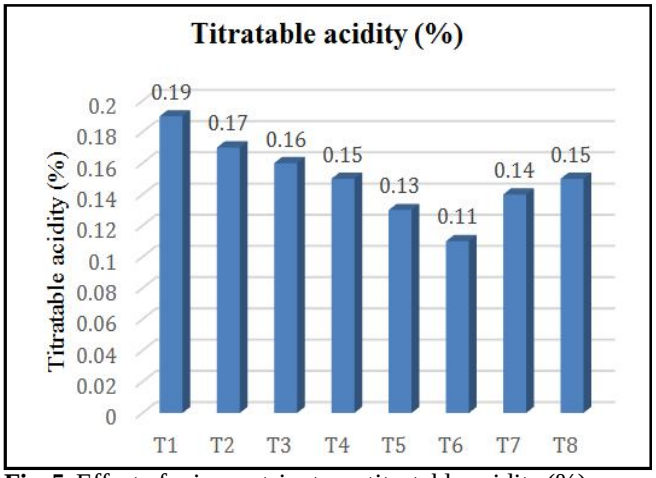


Fig. 5: Effect of micronutrients on titratable acidity (%).

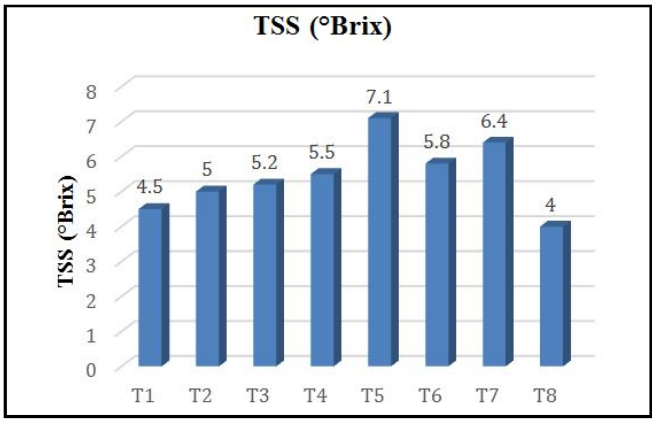


Fig. 6: Effect of micronutrients on TSS (°Brix).

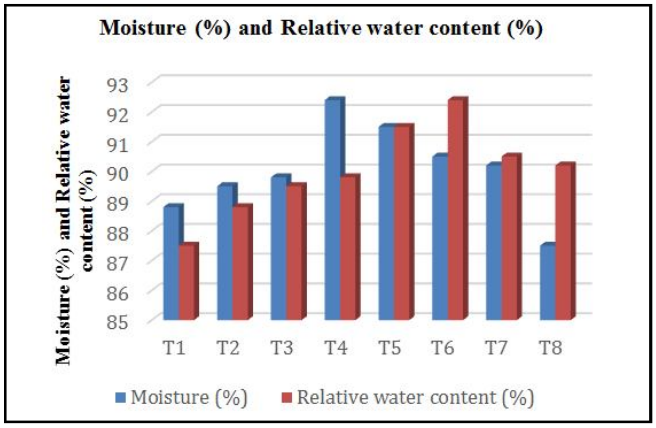


Fig. 7: Effect of micronutrients on Moisture (%) and Relative water content (%).

Biochemical Quality parameters

Vitamin C (mg/100g) and Titratable Acidity (%):

The maximum Vitamin C content (39.50 mg/100g) and the minimum (best) titratable acidity (0.11%) were recorded in T6 ($ZnSO_4$ 0.65% + $FeSO_4$ 0.50%). Zinc serves as a critical activator of the aldolase enzyme, while iron is an essential component in the electron transport chain. Together, they accelerate the Krebs cycle, driving the synthesis of ascorbic acid precursors while efficiently metabolizing sour organic acids into structural carbohydrates.Similar results were reported by Prakash *et al.*, (2022) and Sharma *et al.*, (2021).

Total Soluble Solids (°Brix):

The maximum Total Soluble Solids (7.10 °Brix) was achieved under T5 ($ZnSO_4$ 0.55% + $FeSO_4$ 0.50%). The optimal 0.55% zinc concentration provided the perfect enzymatic balance via carbonic anhydrase to convert organic acids into soluble sugars, enhancing the natural taste profile. Similar findings were reported by Kumar *et al.*, (2023).

Moisture (%) and Relative Water Content (%):

The maximum Relative Water Content (92.4%) was recorded in T6, ensuring maximum leaf succulence, while the minimum was recorded in T1. The foliar application of zinc maintained cellular membrane integrity and regulated stomatal conductance, preventing excessive transpiration losses. Similar findings were reported by Hassan *et al.*, (2020).

Conclusion

Based on the findings of the present investigation, it may be concluded that the targeted foliar application of T6 ($ZnSO_4$ 0.65% + $FeSO_4$ 0.50%) was the most effective treatment for improving the vegetative growth trajectory and biochemical quality of Indian spinach under Bastar Plateau conditions. This treatment recorded the maximum plant height and the highest number of leaves per plant across all growth stages. It also generated the highest Vitamin C content, optimal moisture retention, and the most desirable titratable acidity levels.

The superior performance of T6 may be attributed to the synergistic effect of zinc and iron, which directly bypassed soil-fixation barriers to rapidly enhance cellular division, chlorophyll biosynthesis, and overall photosynthetic capacity. Furthermore, treatment T5 ($ZnSO_4$ 0.55% + $FeSO_4$ 0.50%) proved highly effective for maximizing leaf area and total soluble solids.

Therefore, the foliar application of 0.65% $ZnSO_4$ in combination with 0.50% $FeSO_4$ is recommended as the most suitable nutrient management practice for optimizing the vegetative growth and nutritional profile of Indian spinach in this agro-climatic zone.

Acknowledgement

The authors are thankful to the Department of Vegetable Science, Krantikari Debridhur College of Horticulture and Research Station, Jagdalpur, Bastar (C.G.) for providing the necessary research facilities, field plots, and laboratory infrastructure to carry out this investigation.

References

Bala, R., Kalia A. and Singh M. (2021). Iron-mediated enhancement of chloroplast structural integrity and biomass yield in Indian spinach (*Beta vulgaris var. bengalensis*). *Indian Journal of Agricultural Biochemistry*, **34(1)**, 45-52.

Boorboori, M.R., Asghari B. and Tehrani M.M. (2022). Foliar application of micronutrients bypasses soil fixation constraints in calcareous soils: A review of mechanisms and yield improvements. *Journal of Plant Nutrition*, **45(14)**, 2145-2160.

Gao, X., Wang Y., Zhang J. and Li H. (2022). High endogenous auxin concentrations induced by zinc toxicity inhibit root elongation in leafy greens. *Journal of Plant Growth Regulation*, **41(3)**, 876-885.

Hassan, M.U., Chattha M.U., Khan I. and Chattha M.B. (2020). Zinc-induced membrane stability and relative water content improvements in crops under varying osmotic conditions. *Agricultural Water Management*, **240**, 106300.

Jatav, G.K. and Sahu S.S. (2016). Status of available sulphur and micronutrients in soils of Bastar plateau of Chhattisgarh. *The Ecoscan*, **9(1&2)**, 409-412.

Kamran, M., Afzal M. and Tahir M. (2018). Effect of foliar application of Zn on growth, yield and quality of spinach. *International Journal of Agriculture and Biology*, **20(2)**, 301-306.

Khan, A., Ali S., Rizwan M. and Tariq R. (2022). Zinc as a

precursor for tryptophan and indole-3-acetic acid synthesis: Impacts on internodal elongation and crop yield. *Journal of Soil Science and Plant Nutrition*, **22(1)**, 443-455.

Kumar, V., Sharma A. and Singh R.P. (2023). Enhancement of total soluble solids (TSS) and carbohydrate metabolism in vegetables via foliar zinc and iron fertilization. *Scientia Horticulturae*, **312**, 111865.

Panse, V.G. and Sukhatme P.V. (1985). *Statistical methods for agricultural workers* (4th ed.). Indian Council of Agricultural Research.

Prakash, J., Meena R.K. and Singh D. (2022). Iron as an essential co-factor in the electron transport chain: Implications for vegetable crop quality and yield. *Plant Physiology Reports*, **27(3)**, 334-341.

Sahu, K., Gayen R. and Sahu M.K. (2022). Effect of foliar micronutrients on yield and yield attributing characters in leafy greens under Alfisol conditions. *The Pharma Innovation Journal*, **11(9)**, 1970-1972.

Sharma, P.K., Kumar P. and Singh S. (2021). Metabolic conversion of organic acids and reduction of titratable acidity in spinach through zinc and iron catalysis. *Journal of Environmental Biology*, **42(3)**, 655-661.

Shojaei, H., Ghalavand A. and Zare M.J. (2023). Foliar feeding of micronutrients maximizes plot yield and biomass in calcareous and acidic soils. *Iranian Journal of Crop Sciences*, **25(1)**, 88-99.

Singh, M.V. (2009). Micronutrient deficiencies in Indian soils and their correction through foliar sprays. *Indian Journal of Fertilisers*, **5(4)**, 11-26.

Zulfiqar, U., Maqsood M. and Hussain S. (2020). Micronutrient-mediated modulation of leaf morphology and expansive growth in leafy vegetables. *Plant Growth Regulation Reports*, **39**, 145-152.