Plant Archives Vol. 26, Supplement 1, 2026 pp. 2494-2503 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.supplement-1.334

ROLE OF MICRONUTRIENT FOLIAR SPRAY IN ENHANCING GROWTH, YIELD, AND QUALITY OF KASURIMETHI (*TRIGONELLA CORNICULATA* L.)

Siddappa R.[1*], K. J. Deepika[1], B. N. Maruthi Prasad[1], B. R. Premalatha[2], and R. Manjunath[3]
[1]Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Mysuru, Karnataka, India.
[2]Department of Agronomy, N.R.M., College of Horticulture, Bengaluru, Karnataka, India
[3]Department of Microbiology, NRM, College of Horticulture, Bengaluru, Karnataka, India
*Corresponding author E-mail: sidduhorti3@gmail.com
(Date of Receiving : 03-11-2025; Date of Acceptance : 12-01-2026)

ABSTRACT

Kasurimethi (*Trigonella corniculata* L.) is an important annual spice cum medicinal crop. Micronutrients spray plays a significant role in high yield production and helps in accepted as essential part of crop production, especially on Horticultural crops. The current study was conducted at the Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Bengaluru. Three micronutrients such as iron, copper and zinc were evaluated at 2 different concentration @ 0.25 and 0.5 % and spice special @ 0.5 % at 30 and 60 days after sowing. The study findings revealed that the highest plant height (46.91 cm), number of branches (22.20), plant spread (303.37cm^2), yield concerning number of pods per plant (676.03) and seed yield (4.82 q ha^{-1})was observed in plants sprayed with zinc @ 0.25 %. Whereas in plants sprayed with iron @ 0.25% had shown high dry leaf yield per hectare (0.75tonne) and high trigonelline content in seeds (0.16 %). From this study, it was proven that foliar spray of micronutrients such as zinc @ 0.25% has enhanced growth and yield of pods while iron @ 0.25% has increased the dry leaf yield.
***Keywords* :** Foliar spray, Kasurimethi, Micronutrients, Quality.

Introduction

Kasurimethi (*Trigonella corniculata* L.) is an important *rabi* season, herbaceous, bushy, annual spice cum medicinal crop (Tayade*et al.*, 2021), belongs to the family Fabaceae, with diploid chromosome number (2n=16). This intensely perfumed annual herb, is often referred to as "Marwari methi" and "Champamethi". It is mainly grown as a leafy vegetable and for seeds in the plains of North India and the crop is native to the Mediterranean region (Anon, 2004). It is a slow growing bushy annual herb growing to the height of 60 cm, sub-erect with pinnate leaves and oblong-wedge-shaped leaflets that are 1-4 cm long, 8-35 mm broad and have notched tips (Pasricha and Gupta, 2014). During most of its vegetative phase, Kasurimethi remains in a rosette stage, with short stems and densely arranged leaves close to the ground, radiating outward from a central point. Its 1.50-6.00 cm long peduncle has 8-20 hermaphrodite flower clusters when in bloom they are bright orange-yellow and are borne on long stalks having close raceme type of inflorescence and it is self-pollinated. The petals are almost equal and shorter whereas the flower stalks are 3 mm long. Pods are 1.20-2.00 cm long, sickle-shaped, 4 to 8 seeded which are smaller and scented. The economic part of Kasurimethi is dried leaves.

The primary regions of cultivation of Kasurimethi in India are the states of Maharashtra, Rajasthan, Gujarat, Uttar Pradesh, Madhya Pradesh, Haryana and Punjab (Anupama *et al.*, 2017). The smell of Kasurimethi is highly renowned throughout India and the name Kasurimethi is a geographical indication of Kasur, Pakistan (Yadav *et al.*, 2021).

Micronutrients play a crucial role in crop nutrition, influencing growth, yield and quality. Iron (Fe) functions as a cofactor in several redox processes, including the formation of chlorophyll, thylakoid synthesis, lipid metabolism and photosynthesis (Jeong and Connolly, 2009). Copper is an enzyme activator and is used in protein synthesis, nitrogen metabolism, respiration, photosynthesis, lignification, phenol metabolism and other processes (Pilon *et al*., 2006). An essential part of the metabolism of N compounds is also played by copper. Zinc aids in the regulation of biological membranes, antioxidant defense enzymes (Broadley *et al*., 2007).

Foliar application of micronutrients has been shown to improve plant growth and yield by facilitating quicker uptake and assimilation (Kalidasu *et al*., 2008). This method, commonly used to prevent soil fixation, ensures optimal growth and balanced nutrient levels, preventing growth suppression due to nutrient imbalances (Mengel *et al*., 2001). Furthermore, foliar feeding has become an essential part of crop management due to its efficiency in nutrient delivery (Patil and Chetan, 2018).

Furthermore, foliar feeding of nutrients has been demonstrated to be far more inexpensive and effective than soil treatment. When the roots are unable to supply the essential nutrients, foliar spraying of micronutrients can be highly beneficial (Kinaci and Gulmezoglu, 2007). Foliar feeding is a useful technique for providing nutrients to plants during their intense growth phase, as it can enhance their mineral status and boost crop output. Keeping the importance in view and the lack of constructed work under this region, the present investigation is prioritized and formulated on the optimization of the type and concentration of micronutrients through foliar spray on growth and yield in Kasurimethi as its main objective.

Material and Methods

Study location

A field experiment on foliar spray of micronutrients in Kasurimethi in the garden land conditions was conducted during kharif season at the College of Horticulture, Bengaluru.

Soil and climatic condition of the experimental site

The soil has a red sandy loam texture with homogeneous fertility. The soil samples were collected at a depth of 0 and 15 cm randomly in a zigzag pattern to reflect the entire experimental site before the start of experiment. Analysis was done on the composite soil samples for their nutrient fertility status. Concerning chemical properties, the soil was acidic in reaction (pH: 5.46), low in total soluble salts (EC: 0.35 dSm^{-1}), organic carbon is medium (OC: 0.69 %), low level of nitrogen (210.00 kg ha^{-1}), medium in potassium availability (185.65 kg K_2O ha^{-1}) and medium available phosphorus (25.38 kg P_2O_5 ha^{-1}).

Weather conditions prevailed during the period of study (June to September, 2024) revealed that the mean maximum and minimum temperature ranged from 29.9 to 29.4 ℃ and 19.5 to 19.6 ℃ respectively. Relative humidity's average maximum and minimum values varied from 84 to 87 per cent and 54 to 62 per cent respectively.

Experimental details

The field experiment was conducted using a Randomized Complete Block Design (RCBD) comprising ten treatments replicated three times. The crop selected for the study was Kasurimethi (*Trigonella corniculata* L.), using the Pusa Kasuri variety. The gross plot size was 2 m × 2 m (4 m²), while the net plot size was 1.7 m × 1.85 m (3.145 m²). The crop was sown during the kharif season with a spacing of 30 cm × 15 cm. The recommended fertilizer dose applied was 40:60:50 kg N: P_2O_5: K_2O ha^{-1}.

Treatment Details

The experiment comprised ten treatments involving foliar application of different micronutrient solutions at 30 and 60 days after sowing (DAS). The treatments were as follows: T_1 – Control with distilled water spray; T_2 – foliar spray of $ZnSO4_4$ at 0.25%; T_3 – $ZnSO_4$ at 0.50%; T_4 – $CuSO_4$ at 0.25%; T_5 – $CuSO_4$ at 0.50%; T_6 – $FeSO_4$ at 0.25%; T_7 – $FeSO_4$ at 0.50%; T_8 – combined foliar spray of $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ at 0.25%; T_9 – combined spray of $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ at 0.50%; and T_{10} – foliar spray of Spice Special @ 0.5%. All treatments were applied twice during the crop cycle, at 30 and 60 DAS.

Sowing; The seeds of the variety Pusa Kasuri were collected from the Directorate of Seed Spices Research Institute, Ajmer, Rajasthan and these seeds were sown directly in the field at the rate of 18-20 kg ha^{-1} at 30 cm spacing between the rows and 15 cm between plants by sowing 2-3 seeds per hill at a shallow depth of 1-1.5 cm in a well-prepared plot. Then, immediately after sowing, mild irrigation was given.

Observations were recorded for growth and yield characteristics on randomly selected 5 plants in each replication for the all the characters viz., plant height (cm), number of leaves per plant, and plant spread (cm^2) The yield characters viz., fresh herb yield per plant, dry herb yield per plant, number of pods per plant, pod length(cm), number of seeds per pod, seed yield per plant(g), seed yield /ha, protein content and Trigonelline content were recorded by using the standard methods.

Statistical analysis

Fisher's method of analysis of variance (ANOVA), as described by Sundararaj *et al.* (1972), was used to statistically analyze the experimental data collected on various growth, physiological, yield and quality parameters during the study. The data were subjected to analysis in WASP 2.0.

Results and Discussion

Growth Parameters

The foliar application of micronutrients significantly influenced plant height at later growth stages, though no significant differences were observed at 30 DAS (Table 1). At 60, 90, and 120 DAS, the maximum plant height (37.18, 44.16, and 46.91 cm, respectively) was recorded with $ZnSO_4$ @ 0.25% (T_2), indicating the importance of zinc during active vegetative growth. Zinc enhances IAA synthesis, promoting cell division and elongation (Nandal and Solanki, 2021). However, at 60 DAS, plant height under T_2 was statistically at par with the control (T_1), possibly due to favorable environmental conditions or efficient utilization of native soil nutrients in the absence of added micronutrients.

In contrast, the lowest plant height (24.32, 26.06, and 27.33 cm at 60, 90, and 120 DAS, respectively) was observed in T_9 ($ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50%), likely due to micronutrient toxicity. Excess Zn, Cu, and Fe can induce oxidative stress by generating reactive oxygen species (ROS), disrupt chloroplast and mitochondrial membranes, and interfere with nutrient uptake and enzyme activities (Yruela, 2009). High Zn levels may impair NAD^+ synthesis, reducing ATP production and metabolic efficiency, ultimately suppressing growth (Zhang *et al.*, 2017). Excess Cu inhibits root elongation and photosynthetic efficiency (Woolhouse and Walker, 1981), while Fe overload exacerbates oxidative damage. These findings suggest that while moderate foliar application of Zn enhances growth, higher concentrations or combinations of micronutrients may cause toxicity, reducing plant height (Harmanjit and Neera, 2021).

The results obtained indicated that, the number of branches did not differ substantially at 30 DAS (Table 2). A significant increase in the number of branches was observed at 60, 90, and 120 DAS with $ZnSO_4$ @ 0.25% foliar spray (T_2), recording 18.00, 21.13, and 22.20 branches per plant, respectively. This enhanced branching may be attributed to optimal zinc availability, which plays a critical role in auxin regulation and cell division. Zinc influences auxin transport via PIN-FORMED (PIN) proteins, which are key in establishing auxin gradients necessary for axillary bud activation and branch development (Reinhardt *et al.*, 2003). The moderate Zn level in T_2 likely ensured hormonal balance and sufficient metabolic activity, supporting robust branching alongside overall plant vigor.

Conversely, the lowest number of branches (13.80, 15.13, and 16.40 at 60, 90, and 120 DAS, respectively) was recorded under T_9 ($ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50%). This decline is likely due to micronutrient antagonism and toxicity at higher concentrations, where excess Zn, Cu, and Fe interfere with nutrient uptake and hormone biosynthesis (Xu*et al.*, 2024). Elevated Zn levels can inhibit iron availability and impair photosynthesis through stomatal closure and reduced chlorophyll synthesis, ultimately limiting energy supply and hormone production necessary for branch initiation (Kaur and Garg, 2021). Additionally, excess Cu disrupts chloroplast membranes, further suppressing photosynthetic efficiency and growth (Silva Lobato*et al.*, 2016). The resulting hormonal and energetic imbalances likely contributed to reduced lateral bud development and branching.

The findings showed that at 30 DAS, there was no discernible variation in the plant spread (Table 3). At 60, 90, and 120 DAS, significantly greater plant spread (469.91, 489.96, and 303.37 cm², respectively) was recorded in plants treated with $ZnSO_4$ @ 0.25% (T_2). The observed increase in plant height and branch number in the same treatment corroborates the broader canopy development, as balanced vertical and lateral growth contribute synergistically to overall plant spread.

Conversely, the lowest spread (171.33, 100.20, and 90.06 cm² at 60, 90, and 120 DAS, respectively) was observed in T_9 ($ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50%). This may be attributed to micronutrient toxicity and antagonistic interactions, particularly zinc-induced chlorophyll inhibition via disruption of enzymes such as porpho bilinogendeaminase and chlorophyll synthase (Balafrej *et al.*, 2020).

Yield parameters

Fresh herbage yield reflects the overall growth response of the crop to external treatments (Table 4).

At 60 DAS, the highest fresh leaf yield per plant (52.15 g), per plot (4.74 kg), and per hectare (11.85 t) was recorded in plants treated with $FeSO_4$ @ 0.25% at 30 and 60 DAS (T_6). Iron is vital for photosynthetic and respiratory processes, particularly due to its role in the electron transport chain and CO_2 fixation via redox reactions (Fe^{2+}/Fe^{3+}). Enhanced photosynthesis increases energy production, stimulating cell division and expansion in leaf tissues, thereby contributing to greater biomass accumulation (Krohling *et al.*, 2016). Iron application also promotes chlorophyll synthesis, resulting in improved light absorption and increased leaf area, further supporting higher leaf yield.

In contrast, the lowest fresh leaf yield (38.36 g/plant, 3.49 kg/plot, 8.72 t/ha) was observed under T_9 ($ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50%), likely due to nutrient toxicity and oxidative stress. Elevated micronutrient levels can impair photosynthetic efficiency by inducing chlorosis, necrosis, and cellular damage, ultimately reducing biomass production (Chrysargyris*et al.*, 2022).

At 90 DAS, fresh leaf yield declined across treatments, possibly due to natural senescence as Kasurimethi is typically harvested before flowering for optimal leaf quality. The reduced chlorophyll content and nutrient reallocation to reproductive structures result in diminished leaf biomass. Nevertheless, T_6 maintained the highest yield (26.30 g/plant, 2.39 kg/plot, 5.98 t/ha), while T_9 recorded the lowest (18.86 g/plant, 1.71 kg/plot, 4.28 t/ha).

At 60 DAS, the dry leaf yield per plant, per plot and hectare was highest (6.50 g, 591.50 g and 1.47 t respectively) in plants sprayed with $FeSO_4$ @ 0.25 per cent at 30 and 60 DAS (T_6).This can be explained by the fact that, fresh leaf yield is the primary source of biomass in plants, which consists of both moisture and dry matter. When plants have a high fresh leaf yield, they inherently have more total biomass available. After moisture removal, a larger proportion of this fresh biomass is converted into dry leaf yield. Because it supplies more material from which moisture can be extracted, the higher fresh biomass leads to a higher dry matter content after drying, increasing the dry leaf weight (Cho *et al.*, 2007). The lowest (4.90 g, 445.90 g and 1.11 t respectively) was found in plants sprayed with $ZnSO_4$+$CuSO_4$+$FeSO_4$ @ 0.50 per cent (T_9). This is due to the foliar spray of micronutrients in high concentration, which can result in nutrient imbalances within the plant, while plants need a variety of nutrients for growth and an over-supply of specific micronutrients can lead to toxicity, reducing the plant's ability to efficiently convert resources into dry matter. This stress can hinder normal metabolic functions such as photosynthesis, leading to lower dry leaf yield. At 90 DAS, the dry leaf yield per plant, per plot and hectare was highest (3.30 g, 300.30 g and 0.75 t respectively) in plants sprayed with $FeSO_4$ @ 0.25 per cent at 30 and 60 DAS (T_6). The lowest (2.10 g, 191.10 g and 0.47 t respectively) was found in plants sprayed with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50 per cent at 30 and 60 DAS (T_9). The dry leaf yield is less due to off-season cultivation, whereas in traditionally grown belts, specifically during the Rabi season, the recorded yield is 3 tons per hectare (Table 5).

Notably, the foliar spray of $ZnSO_4$ @ 0.25 per cent at 30 and 60 DAS (T_2) had a significant impact on the number of pods per plant at harvest, resulting in 676.03 pods per plant (Table 6). The fact that this can be explained by, zinc plays a role in auxin synthesis by activating the enzyme tryptophan aminotransferase (Castillo *et al.*, 2018). Auxins promote cell elongation and division, which are vital for the development of pods and zinc enhances the activity of enzymes like nitrate reductase and glutamate synthetase, which support nitrogen assimilation as nitrogen is crucial for seed protein content and pod filling (Hansch and Mendel, 2009). Through the activation of antioxidant enzymes such as superoxide dismutase, zinc helps to reduce oxidative stress. This reduces cellular damage during pod formation, particularly under stressful environmental conditions, ensuring better pod quality and quantity. Additionally, the same treatment (T_2) resulted in early flower initiation, allowing the plants to begin the reproductive phase sooner. However, it also took longer to achieve 100 per cent flowering, which extended the overall flowering duration. This extended flowering period increased the chance of successful pollination and pod formation by giving flowers more time to develop and mature.

Significant variation was observed in the number of seeds per pod at harvest (Table 6). The highest number of seeds per pod (3.98) was recorded in plants treated with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.25% at 30 and 60 DAS (T_8). This may be attributed to the synergistic effect of optimal micronutrient levels in supporting key physiological and biochemical processes involved in seed development. Zinc and copper enhance phloem loading and assimilate transport, while iron plays a critical role in photosynthesis and respiration by participating in the electron transport chain and serving as a cofactor in key enzymes such as nitrate reductase and ferrochelatase (Rout and Sahoo, 2015). These functions support energy generation, nitrogen assimilation, and chlorophyll biosynthesis, all of which contribute to effective seed filling and development.

In contrast, the lowest number of seeds per pod (2.84) was observed in plants sprayed with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50% (T_9), likely due to micronutrient toxicity. Elevated concentrations of zinc, copper, and iron may impair metabolic activities, disrupt chloroplast membrane integrity, and reduce photosynthetic efficiency (Kaur and Garg, 2021). Excess copper induces oxidative stress and excess zinc interferes with enzyme activity, cell division, and root function, ultimately restricting water and nutrient uptake essential for seed formation.

Pod length varied significantly among treatments at harvest (Table 6). The maximum pod length (1.92 cm) was recorded in plants treated with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.25% at 30 and 60 DAS (T_8). The balanced supply of these micronutrients likely enhanced pod elongation by supporting key physiological processes. Zinc regulates auxin synthesis and protein formation, which influence cell division and elongation (Cakmak, 2000). Copper activates enzymes involved in protein metabolism and lignin biosynthesis, contributing to pod structural integrity and efficient nutrient uptake through improved root metabolism (Kashyap*et al.*, 2022).

Seed yield varied significantly across treatments (Table 7). The highest yield (2.12 g per plant, 192.92 g per plot, and 4.82 q ha^{-1}) was recorded in plants treated with $ZnSO_4$ @ 0.25% at 30 and 60 DAS (T_2). This can be attributed to a higher number of pods per plant, supported by enhanced vegetative growth and increased branching, which led to more flowers and improved pod set. Zinc plays a key role in promoting early flowering and effective pod development by regulating metabolic and hormonal pathways, including auxin and gibberellin synthesis, as well as photoperiod and vernalization responses (Pandey*et al.*, 2013).In contrast, the lowest seed yield (1.21 g per plant, 110.11 g per plot, and 2.74 q ha^{-1}) was recorded in T_9 ($ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.50%), possibly due to micronutrient toxicity, reduced photosynthesis, and lower pod formation. The suboptimal yield may also be influenced by off-season cultivation, as traditionally grown Rabi crops yield 5–7 q ha^{-1}.

Quality parameters

Protein Content (%)

Protein content varied significantly across treatments (Table 8). The highest value (9.76%) was recorded in plants treated with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.25% at 30 and 60 DAS (T_8). This increase is attributed to the synergistic role of these micronutrients in nitrogen metabolism and protein synthesis. Zinc and copper are essential for enzyme activation, RNA polymerase function, and amino acid metabolism, while iron supports chlorophyll formation and energy production. Their optimal concentration enhanced enzymatic activities, protein biosynthesis, and overall metabolic efficiency (Singh *et al*., 2013). In contrast, the lowest protein content (7.56%) was observed in the control (T_1), likely due to micronutrient deficiencies impairing metabolic pathways and protein accumulation.

Trigonelline Content (%)

Significant differences were observed in trigonelline content across treatments (Table 8). The highest content (0.25%) was recorded in plants treated with $ZnSO_4$ + $CuSO_4$ + $FeSO_4$ @ 0.25% at 30 and 60 DAS (T_8). This enhancement is likely due to zinc's role in promoting tryptophan synthesis, a precursor of nicotinic acid, which in turn enhances trigonelline production. Zinc also supports the transcription of biosynthetic enzymes and methylation efficiency, while copper, via superoxide dismutase (SOD) activity, helps maintain redox balance, facilitating secondary metabolite synthesis (Xu*et al*., 2024). The lowest trigonelline content (0.16%) was found in plants treated with $FeSO_4$ @ 0.25% (T_6), possibly due to iron's limited direct involvement in trigonelline biosynthesis and its potential to induce oxidative stress at elevated levels.

Conclusion

The comprehensive analysis of the study reveals that, a significant improvement in the growth, yield and quality of Kasurimethi due to the foliar spray of micronutrients. For leaf production, the foliar spray of $FeSO_4$ @ 0.25 per cent at 30 and 60 DAS (T_6) emerged as the most effective treatment, recording the highest fresh leaf yield, making it the preferred choice for foliage harvesting.For seed production, the foliar spray of $ZnSO_4$ @ 0.25 per cent at 30 and 60 DAS (T_2) proved to be the best approach by promoting optimal growth and yield, ensuring better seed development. Overall, these findings provide valuable insights for optimizing Kasurimethi cultivation practices, emphasizing the importance of foliar spray of micronutrients for enhanced growth, yield and quality attributes.

Table 1 : Influence of foliar spray of micronutrients on plant height (cm) of Kasurimethi at different growth stages

Treatments	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	120 DAS
T_1	**19.59**	36.22[ab]	38.12[b]	39.40[b]
T_2	15.67	**37.18[a]**	**44.16[a]**	**46.91[a]**
T_3	17.26	31.06[c]	32.80[cd]	33.80[cd]
T_4	**15.36**	29.23[cd]	30.90[de]	31.60[de]
T_5	17.61	27.92[d]	29.77[e]	30.66[e]
T_6	15.80	28.98[cd]	32.52[d]	33.43[de]
T_7	18.20	31.19[c]	33.10[cd]	33.83[cd]
T_8	17.69	34.40[b]	35.30[c]	36.83[bc]
T_9	17.38	**24.32[e]**	**26.06[f]**	**27.33[f]**
T_{10}	19.21	30.96[c]	31.43[de]	31.59[de]
S.Em ±	**1.62**	**0.91**	**0.87**	**1.04**
CD at 5%	**NS**	**2.73**	**2.59**	**3.09**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test (P < 0.05).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 2 : Influence of foliar spray of micronutrients on number of branches per plant at different growth stages

Treatments	Number of branches per plant			
	30 DAS	60 DAS	90 DAS	120 DAS
T_1	**10.80**	16.73[b]	18.53[b]	19.73[b]
T_2	10.40	**18.00[a]**	**21.13[a]**	**22.20[a]**
T_3	10.66	14.00[f]	15.13[f]	16.66[d]
T_4	10.00	14.80[d]	16.80[d]	17.20[d]
T_5	10.66	14.40[e]	16.33[e]	17.80[d]
T_6	10.**13**	15.66[c]	17.13[c]	18.53[c]
T_7	10.60	14.86[d]	15.33[f]	16.86[d]
T_8	10.33	14.13[f]	16.26[e]	17.93[d]
T_9	10.33	**13.80[g]**	**15.13[f]**	**16.40[e]**
T_{10}	10.73	14.13[f]	16.26[e]	17.53[d]
S.Em ±	**0.33**	**0.04**	**0.08**	**0.07**
CD at 5%	**NS**	**0.13**	**0.24**	**0.20**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test (P < 0.05).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 3 : Influence of foliar spray of micronutrients on plant spread (cm^2) at different growth stages

Treatments	Plant spread (cm^2)			
	30 DAS	60 DAS	90 DAS	120 DAS
T_1	**52.90**	417.50^{b}	432.61^{b}	248.39^{b}
T_2	51.75	$\mathbf{469.91^{a}}$	$\mathbf{489.96^{a}}$	$\mathbf{303.37^{a}}$
T_3	51.87	272.24^{e}	285.26^{d}	108.75^{h}
T_4	52.36	212.37^{g}	268.59^{e}	188.42^{d}
T_5	51.92	227.76^{f}	257.55^{f}	182.17^{e}
T_6	51.78	347.36^{c}	393.50^{c}	214.82^{c}
T_7	51.68	189.76^{h}	104.90^{i}	94.97^{i}
T_8	52.05	272.49^{e}	230.20^{g}	145.15^{f}
T_9	**51.59**	$\mathbf{171.33^{i}}$	$\mathbf{100.20^{j}}$	$\mathbf{90.06^{j}}$
T_{10}	51.78	297.67^{d}	208.54^{h}	130.22^{g}
S.Em ±	**0.31**	**0.68**	**0.62**	**0.57**
CD at 5%	**NS**	**2.03**	**1.85**	**1.70**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 4 : Influence of foliar spray of micronutrients on fresh leaf yield

Treatments	Fresh leaf yield (g $plant^{-1}$)		Fresh leaf yield (kg $plot^{-1}$)		Fresh leaf yield (T ha^{-1})	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
T_1	39.03^{de}	18.06^{de}	3.55^{de}	1.64^{de}	8.88^{de}	4.10^{de}
T_2	46.45^{b}	23.83^{abc}	4.22^{b}	2.16^{abc}	10.56^{b}	5.40^{abc}
T_3	43.47^{bc}	20.03^{cde}	3.95^{bc}	1.82^{cde}	9.88^{bc}	4.55^{cde}
T_4	39.60^{de}	23.40^{bc}	3.60^{de}	2.12^{bc}	9.00^{de}	5.30^{bc}
T_5	42.60^{cd}	22.01^{cd}	3.87^{cd}	2.00^{cd}	9.68^{cd}	5.00^{cd}
T_6	$\mathbf{52.15^{a}}$	$\mathbf{26.30^{a}}$	$\mathbf{4.74^{a}}$	$\mathbf{2.39^{a}}$	$\mathbf{11.85^{a}}$	$\mathbf{5.98^{a}}$
T_7	40.70^{cde}	23.50^{bc}	3.70^{cde}	2.13^{bc}	9.25^{cde}	5.32^{bc}
T_8	47.58^{b}	25.98^{ab}	4.32^{b}	2.36^{ab}	10.80^{ab}	5.90^{ab}
T_9	$\mathbf{38.36^{e}}$	$\mathbf{18.86^{e}}$	$\mathbf{3.49^{e}}$	$\mathbf{1.71^{e}}$	$\mathbf{8.72^{e}}$	$\mathbf{4.28^{e}}$
T_{10}	41.18^{cd}	20.16^{cde}	3.74^{cd}	1.83^{cde}	9.37^{cd}	4.58^{cde}
S.Em ±	**0.11**	**0.05**	**0.03**	**0.03**	**0.08**	**0.06**
CD at 5%	**0.33**	**0.16**	**0.11**	**0.09**	**0.26**	**0.20**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 5 : Influence of foliar spray of micronutrients on dry leaf yield

Treatments	Dry leaf yield (g plant^{-1})		Dry leaf yield (g plot^{-1})		Dry leaf yield (T ha^{-1})	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
T_1	4.93^{de}	2.12^{e}	448.63^{cde}	192.92^{e}	1.121^{e}	0.48^{e}
T_2	5.50^{bc}	2.92^{abc}	500.50^{bc}	265.72^{abc}	1.251^{bc}	0.66^{bc}
T_3	5.10^{bcd}	2.50^{cde}	464.10^{bcd}	227.50^{cde}	1.160^{bcd}	0.57^{cde}
T_4	4.95^{e}	2.65^{bcd}	450.45^{e}	241.15^{bcd}	1.126^{e}	0.60^{bcd}
T_5	5.00^{cde}	2.40^{bcde}	455.00^{bcd}	218.40^{bcde}	1.137^{cde}	0.55^{bcde}
T_6	**6.50^{a}**	**3.30^{a}**	**591.50^{a}**	**300.30^{a}**	**1.474^{a}**	**0.75^{a}**
T_7	5.05^{de}	2.55^{bcd}	459.55^{de}	232.05^{bcd}	1.148^{de}	0.58^{bcd}
T_8	5.90^{b}	2.85^{ab}	537.90 ^{b}	259.35^{ab}	1.342^{ab}	0.65^{ab}
T_9	**4.90^{e}**	**2.10^{e}**	**445.90^{e}**	**191.10^{e}**	**1.114^{e}**	**0.47^{e}**
T_{10}	4.92^{e}	2.20^{de}	447.72^{e}	200.20^{de}	1.119^{e}	0.50^{de}
S.Em ±	**0.04**	**0.03**	**1.38**	**0.66**	**0.01**	**0.001**
CD at 5%	**0.14**	**0.10**	**4.10**	**1.97**	**0.03**	**0.003**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 6 : Influence of foliar spray of micronutrients on number of pods per plant, number of seeds per pod and length of pod (cm) of Kasurimethi

Treatments	Number of pods per plant at harvest	Number of seeds per pod at harvest	Length of podat harvest (cm)
T_1	364.48^{bc}	3.18^{d}	**1.67^{b}**
T_2	**676.03^{a}**	3.76^{ab}	1.77^{b}
T_3	307.84^{c}	3.52^{bc}	1.73^{b}
T_4	302.97^{c}	3.50^{bc}	1.71^{b}
T_5	320.45^{c}	3.76^{ab}	1.74^{b}
T_6	287.82^{c}	3.45^{c}	1.68^{b}
T_7	328.11^{bc}	3.40^{cd}	1.71^{b}
T_8	431.28^{b}	**3.98^{a}**	**1.92^{a}**
T_9	**260.64^{c}**	**2.84^{e}**	1.71^{b}
T_{10}	281.47^{c}	3.18^{d}	1.75^{b}
S.Em ±	**36.60**	**0.08**	**1.75**
CD at 5%	**108.77**	**0.26**	**0.10**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 7 : Influence of foliar spray of micronutrients on seed yield and test weight

Treatments	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per hectare (q)
T_1	1.53^{b}	139.23^{abc}	3.49^{b}
T_2	**2.12^{a}**	**192.92^{a}**	**4.82^{a}**
T_3	1.36^{c}	123.04^{bcd}	3.10^{c}
T_4	1.35^{c}	123.85^{cd}	3.07^{c}
T_5	1.41^{bc}	128.31^{abcd}	3.20^{bc}
T_6	1.32^{c}	120.12^{cd}	3.01^{c}
T_7	1.43^{c}	130.03^{bcd}	3.26^{c}
T_8	1.71^{b}	155.61^{ab}	3.89^{b}
T_9	**1.21^{c}**	**110.11^{d}**	**2.74^{c}**
T_{10}	1.23^{c}	111.93^{cd}	2.80^{c}
S.Em ±	**0.04**	**2.02**	**0.04**
CD at 5%	**0.14**	**6.01**	**0.13**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

Table 8 : Influence of foliar spray of micronutrients on protein (%) and Trigonelline (%) content in seeds

Treatments	Protein (%)	Trigonelline (%)
T_1	**7.56^{c}**	0.22^{bc}
T_2	9.60^{a}	0.19^{d}
T_3	9.30^{ab}	0.20^{d}
T_4	7.73^{c}	0.19^{d}
T_5	8.03^{c}	0.19^{d}
T_6	9.36^{a}	**0.16^{f}**
T_7	8.43^{bc}	0.23^{b}
T_8	**9.76^{a}**	**0.25^{a}**
T_9	7.80^{c}	0.18^{e}
T_{10}	7.83^{c}	0.22^{c}
S.Em ±	**0.30**	**0.003**
CD at 5%	**0.91**	**0.01**

*DAS: Days after sowing

Note: NS- Non-significant. Means with the same letter in each column are not significantly different, as indicated by the DMRT test ($P < 0.05$).

Treatment details:

T_1 - Control (Distilled water spray)
T_2 - $ZnSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_3 - $ZnSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_4 - $CuSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_6 - $FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_7 - $FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS
T_8 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.25 % foliar spray at 30 and 60 DAS
T_9 - $ZnSO_4 + CuSO_4 + FeSO_4$ @ 0.50 % foliar spray at 30 and 60 DAS

References

Anonymous. (2004). *Trigonella corniculata* L. In Wealth of India: Raw materials (Vol. **5**, pp. 252–258). Council of Scientific and Industrial Research (CSIR), New Delhi.

Anupama, G., Hegde, L. N., Hegde, N. K., Devappa, V., Mastiholi, A. B., & Nishani, S. (2017). Effect of nitrogen and spacing levels on physiological and yield parameters of Kasuri methi (*Trigonella corniculata* L.). *International Journal of Current Microbiology and Applied Sciences*, **6**(9), 723–733.

Balafrej, H., Bogusz, D., Triqui, Z. E. A., Guedira, A., Bendaou, N., Smouni, A., & Fahr, M. (2020). Zinc hyperaccumulation in plants: A review. *Plants*, **9**(5), 562.

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2007). Zinc in plants. *New Phytologist*, **173**(4), 677–702.

Cakmak, I. (2000). Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytologist*, **146**(2), 185–205.

Castillo-Gonzalez, J., Ojeda-Barrios, D., Hernandez-Rodriguez, A., Gonzalez-Franco, A. C., Robles-Hernandez, L., & Lopez-Ochoa, G. R. (2018). Zinc metalloenzymes in plants. *Interciencia*, **43**(4), 242–248.

Cho, Y. Y., Oh, S., Oh, M. M., & Son, J. E. (2007). Estimation of individual leaf area, fresh weight, and dry weight of hydroponically grown cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value. *Scientia Horticulturae*, **111**(4), 330–334.

Hansch, R., & Mendel, R. R. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion in Plant Biology*, **12**(3), 259–266.

Harmanjit, K., & Neera, G. (2021). Zinc toxicity in plants: A review. *Planta*, **253**(6), 129.

Jeong, J., & Connolly, E. L. (2009). Iron uptake mechanisms in plants: Functions of the FRO family of ferric reductases. *Plant Science*, **176**(1), 709–719.

Kalidasu, G., Sarada, C., & Reddy, T. Y. (2008). Influence of micronutrients on growth and yield of coriander (*Coriandrum sativum*) in rainfed vertisols. *Journal of Spices and Aromatic Crops*, **17**(2), 187–189.

Kashyap, C., Bainade, S., Kumar, V., & Singh, A. (2022). Foliar application of macro and micronutrient in field crops and their effect on growth, yield, quality, and economics. *The Pharma Innovation Journal*, **11**(5), 970–976.

Kaur, H., & Garg, N. (2021). Zinc toxicity in plants: A review. *Planta*, **253**(6), 129.

Kinaci, E., & Gulmezoglu, N. (2007). Grain yield and yield components of triticale upon application of different foliar fertilizers. *Interciencia*, **32**(9), 624–628.

Krohling, C. A., Eutropio, F. J., Bertolazi, A. A., Dobbss, L. B., Campostrini, E., Dias, T., & Ramos, A. C. (2016). Ecophysiology of iron homeostasis in plants. *Soil Science and Plant Nutrition*, **62**(1), 39–47.

Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry*, **193**(1), 265–275.

Mengel, K., Kirkby, E. A., Kosegarten, H., & Appel, T. (2001). Further elements of importance. In *Principles of plant nutrition* (Vol. **5**, pp. 639–655).

Pasricha, V., & Gupta, R. K. (2014). Nutraceutical potential of methi (*Trigonella foenum-graecum* L.) and Kasuri methi (*Trigonella corniculata* L.). *Journal of Pharmacognosy and Phytochemistry*, **3**(4), 47–57.

Patil, B., & Chetan, H. T. (2018). Foliar fertilization of nutrients. *Marumegh*, **3**(1), 49–53.

Pilon, M., Abdel-Ghany, S. E., Cohu, C. M., Gogolin, K. A., & Ye, H. (2006). Copper cofactor delivery in plant cells. *Current Opinion in Plant Biology*, **9**(3), 256–263.

Reinhardt, D., Pesce, E. R., Stieger, P., Mandel, T., Baltensperger, K., Bennett, M., Traas, J., Friml, J., & Kuhlemeier, C. (2003). Regulation of phyllotaxis by polar auxin transport. *Nature*, **426**(6964), 255–260.

Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolism. *Reviews in Agricultural Science*, **3**, 1–24.

Silva Lobato, A. K., Lima, E. J. A., Lobato, E. M. S. G., Maciel, G. M., & Marques, D. J. (2016). Tolerance of plants to toxicity induced by micronutrients. In *Abiotic and biotic stress in plants: Recent advances and future perspectives* (pp. 20–57).

Singh, J., Singh, M., Jain, A., Bhardwaj, S., Singh, A., Singh, D. K., Bhushan, B., & Dubey, S. K. (2013). An introduction to plant nutrients and foliar fertilization: A review. In *Precision farming: A new approach* (pp. 252–320). Daya Publishing Company, New Delhi.

Singh, M. V. (2008). Micronutrient deficiencies in crops and soils in India. *Micronutrient Deficiencies in Global Crop Production*, **68**(2), 93–125.

Sundararaj, N., Nagaraj, S., Venkataramu, A. N., & Jagannath, N. K. (1972). *Design and analysis of field experiments*. University of Agricultural Sciences, Bengaluru.

Tayade, V. D., Bhople, S. R., Jawarkar, A. K., Dalal, S. R., & Ghawade, S. M. (2021). Effect of pre-treatments on dehydrated Kasuri methi (*Trigonella corniculata* L.). *The Pharma Innovation Journal*, **10**, 1034–1037.

Woolhouse, H. W., & Walker, S. (1981). *The physiological basis of copper toxicity and copper tolerance in higher plants* (pp. 235–262). CRC Press.

Xu, E., Liu, Y., Gu, D., Zhan, X., Li, J., Zhou, K., Zhang, P., & Zou, Y. (2024). Molecular mechanisms of plant responses to copper: From deficiency to excess. *International Journal of Molecular Sciences*, **25**(13), 6993.

Yadav, A. K., Singh, S. P., Yadav, D. K., Yadav, G. K., Singh, K., & Yadav, M. K. (2021). Influence of phosphorus and foliar nitrogen on the growth, quality, and yield of Kasuri methi (*Trigonella corniculata* L.). *Legume Research: An International Journal*, **1**(7), 63–65.

Yruela, I. (2009). Copper in plants: Acquisition, transport, and interactions. *Functional Plant Biology*, **36**(5), 409–430.

Zhang, C., Yu, K., Li, F., & Xiang, J. (2017). Acute toxic effects of zinc and mercury on survival, standard metabolism, and metal accumulation in juvenile ridgetail white prawn (*Exopalaemon carinicauda*). *Ecotoxicology and Environmental Safety*, **145**, 549–556.