*International Journal of Plant & Soil Science*

***Volume 37, Issue 12, Page 240-247, 2025; Article no.IJPSS.149021***
***ISSN: 2320-7035***

# Studies on Effect of Application of Zinc on Yield, Yield Components and Quality of Bhendi (*Abelmoschus esculentus* (L.) Moench)

**Jebisha R [a*], K. Coumaravel [a], U. Bagavathi Ammal [a] and V. Kanthaswamy [b]**

*[a] Department of Soil Science and Agricultural Chemistry, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal,609603, India.*
*[b] Department of Horticulture, Pandit Jawaharlal Nehru college of Agriculture and Research Institute, Karaikal,609603, India.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Author JR carried out the field work and experiment. Authors KC, UBA and VK designed the study, supervised the entire research and contributed to compiling the manuscript. All authors read and approved the final manuscript.*

***Article Information***

DOI: https://doi.org/10.9734/ijpss/2025/v37i125888

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/149021

***Original Research Article***

***Received: 16/10/2025***
***Accepted: 11/12/2025***
***Published: 22/12/2025***

## ABSTRACT

**Aims:** The present study optimizes, the effect of application of zinc on yield and yield components of Bhendi (*Abelmoschus esculentus* (L.) Moench)**:**

**Place and Duration of Study:** A field experiment on the effect of zinc application on the growth and yield attributes of bhendi (*Abelmoschus esculentus* (L.) Moench) was carried out from February to May 2025 in the Eastern (E1) field of the Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal.

**Corresponding author: E-mail: jebishalatimar10@gmail.com;*

***Cite as:** Jebisha R, K. Coumaravel, U. Bagavathi Ammal, and V. Kanthaswamy. 2025. "Studies on Effect of Application of Zinc on Yield, Yield Components and Quality of Bhendi (Abelmoschus Esculentus (L.) Moench)". International Journal of Plant & Soil Science 37 (12):240–247. https://doi.org/10.9734/ijpss/2025/v37i125888.*

**Methodology:** The experiment was conducted in a Randomized Block Design (RBD) with 8 treatments and replicated thrice. The treatments consisted of $T_1$ – Absolute control, $T_2$ – RDF + FYM @ 40 t ha$^{-1}$, $T_3$ – $T_2$ + Zn-EDTA @ 1.0 kg ha$^{-1}$ (SA), $T_4$ – $T_2$ + Zn-EDTA @ 1.25 kg ha$^{-1}$ (SA), $T_5$ – $T_2$ + $ZnSO_4$ @ 15 kg ha$^{-1}$ (SA),$T_6$ – $T_2$ + $ZnSO_4$ @ 20 kg ha$^{-1}$ (SA), $T_7$ – $T_3$ + Zn-EDTA @ 0.1% (FA), $T_8$ – $T_5$ + $ZnSO_4$ @ 0.5% (FA).

**Results:** Results showed that the integrated application of Zn-EDTA @ 1 kg ha$^{-1}$ as basal soil application combined with foliar spray of Zn-EDTA @ 0.1% at 30 DAS (along with the recommended dose of fertilizers and FYM) produced the best outcomes for plant growth (plant height: 109.15 cm, number of branches: 2.95, LAI: 1.40), yield traits (fruit length: 16.78 cm, girth: 7.64 cm, fruit weight: 15.01 g, number of fruits: 16.70) and fresh fruit yield (19.33 t ha$^{-1}$).Quality attributes, namely ascorbic acid (13.51 mg 100 g$^{-1}$) and crude protein (15.28%), were also highest under this treatment, signifying enhanced nutritional value and the lowest crude fiber (10.37%), confirming improved fruit tenderness from zinc supplementation.

**Conclusion:** The study conclusively establishes that integrated zinc management, especially chelated zinc applications, boosts bhendi yield, thereby offering a practical recommendation for elevating productivity and profitability of bhendi under intensive cultivation.

*Keywords: Bhendi; chelated; soil; micronutrient; nutrient management; zinc.*

## 1. INTRODUCTION

Soil fertility has special importance as it decides the potential of soil as a habitat for plant growth and crop production. Crop development depends on the presence of both macronutrients and micronutrients. Maintaining soil health and guaranteeing sustainable agricultural practices require proper soil management, which includes the application of both inorganic and organic fertilizers. Some areas have naturally infertile soils that have little to no potential for agriculture, while other areas have seen a decline in fertility due to soil degradation. Micronutrient depletion has become a major soil fertility concern in intensive cropping systems, particularly the widespread deficiency of zinc, which limits plant growth, nutrient use efficiency and overall productivity. In crops like bhendi, inadequate zinc availability in the root zone leads to poor physiological activity, reduced flowering and ultimately lower yields. Understanding how zinc application improves soil micronutrient balance and crop performance is therefore essential for sustaining productivity in zinc-deficient soils.

Bhendi (*Abelmoschus esculentus* (L.) Moench) belongs to the family Malvaceae. It is an economically important vegetable crop grown in tropical and sub-tropical parts of the world. It is widely cultivated in India in the states of Uttar Pradesh, Assam, Bihar, Orissa, Maharashtra, West Bengal, Karnataka, Tamil Nadu and Andhra Pradesh. Okra originated in Ethiopia (Sathish and Eswar,2013). Bhendi is nutritionally rich in iodine, vitamin A, vitamin B, vitamin C and folic acid, besides carbohydrates, phosphorus, magnesium and potassium. Bhendi is mainly propagated by seeds and has a duration of 90-100 days. More than 50 per cent of the agricultural soil in the world is deficient in zinc (Shukla et al., 2021). Micronutrients are not only needed for better growth, yield and quality of produce but they are as important as the major nutrients in spite of their requirement in micro quantity. Micronutrient imbalance, especially zinc (Zn) deficiency, has emerged as a critical soil fertility issue in many vegetable-growing regions. Okra is particularly sensitive to Zn shortages because the nutrient plays a central role in auxin synthesis, enzymatic activity and membrane integrity. When Zn is insufficient in the soil, okra plants exhibit stunted growth, shortened internodes, reduced leaf expansion and impaired chlorophyll formation. These physiological constraints delay flowering, restrict fruit set and ultimately reduce pod number and pod length. Moreover, Zn deficiency weakens root development, limiting nutrient uptake and water absorption, which further suppresses yield. Therefore, understanding and managing Zn nutrition is essential to improving growth, sustaining flowering and maximizing yield in okra grown under Zn-deficient conditions. Zinc (Zn) is an essential nutrient for all living organisms. It is required in six different classes of enzyme oxidation, including oxidoreductases, transferase, hydrolyze, lyase, isomerase and ligase (Jain et al., 2013).

Generally, $ZnSO_4$ is the most widely applied Zn source for its high solubility and low cost. In addition, Zn-EDTA (Ethylene Diamine Tetra acetic Acid) is also being recommended due to its efficiency of Zn availability for the plants (Quijano-Guerta et al.,2002). The efficiency of $ZnSO_4$ and Zn- EDTA is 0.90% and 3.66% respectively (Ghasal et al., 2017; Saha et al., 2015). Throughout the world it has been observed that zinc application increased grain yield (Potarzycki and Grzebisz, 2009). Zinc deficiency is a chief worldwide problem damaging cultivation of plant and this difficulty is due to exacerbated in alkaline soils these soil types are mostly found in semi-arid and arid parts of the world (Cakmak, 2000). Micronutrient imbalance, particularly zinc (Zn) deficiency, is one of the most widespread soil fertility problems in Indian agriculture. Nearly half of the cultivated soils in India are Zn-deficient due to intensive cropping, limited micronutrient replenishment and the prevalence of calcareous and alkaline soils that reduce Zn availability (Shukla et al., 2021). The application of Zn via soil and foliar method increases crop yield (Mortvedt et al., 1991). Both the soil and foliar application enhanced Zn concentration and uptake in crop grain (Yilmaz et al., 1998).

This study was conducted to evaluate the effect of zinc application on growth, yield components and quality of bhendi.

## 2. MATERIALS AND METHODS

A field experiment was conducted during February-May, 2025 in the eastern (E1) field in the farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal to evaluate the effect of application of zinc on yield and yield components of Bhendi (*Abelmoschus esculentus* (L.) Moench). The bhendi hybrid CO 4 was selected as the test crop for the study. This high-yielding hybrid originates from the cross between BHD 9 and Karamadai local. It has an approximate crop duration of 110 days. A key strength of CO 4 is its tolerance to Bhendi Yellow Mosaic Virus (BYMV), which makes it a dependable option for cultivation in areas where the disease is common. The experiment was conducted in a Randomized Block Design (RBD) with 8 treatments (Table 1) and replicated thrice.

The Bhendi hybrid CO 4 seeds were sown on ridges at a spacing of 60 x 45 cm. The fertilizer application for the different treatments is given through Urea, Single Super Phosphate and Muriate of Potash for N, P, K respectively @ 200:100:100 kg $ha^{-1}$(*Crop Production Guide: Horticulture*, TNAU, 2020). The application of nitrogen as urea was done in two equal splits i.e.,50 per cent as basal and remaining 50 per cent at 30 DAS. The application of FYM @ 40 t $ha^{-1}$ at basal (*Crop Production Guide: Horticulture*, TNAU, 2020). Zinc sulphate and Zinc EDTA was applied at various doses (Table 1) as soil application (basal) and foliar application at 30 days after sowing respectively. Irrigation was done on the third day after sowing and subsequent irrigations followed as and when needed. Gap filling was done on 7 DAS and thinning was carried out on 15 DAS.

**Table 1. Treatment details**

| Treatment No | Treatment Details |
|---|---|
| $T_1$ | Absolute Control |
| $T_2$ | RDF + FYM @ 40 t $ha^{-1}$ |
| $T_3$ | $T_2$ + Zn EDTA @ 1 kg $ha^{-1}$ (SA) |
| $T_4$ | $T_2$ + Zn EDTA @ 1.25 kg $ha^{-1}$ (SA) |
| $T_5$ | $T_2$ + $ZnSO_4$@ 15 kg $ha^{-1}$ (SA) |
| $T_6$ | $T_2$ + $ZnSO_4$ @ 20 kg $ha^{-1}$ (SA) |
| $T_7$ | $T_3$ + Zn EDTA @ 0.1 % (FA) |
| $T_8$ | $T_5$ + $ZnSO_4$ @ 0.5% (FA) |

*RDF – Recommended dose of Fertilizers; FYM – Farmyard Manure; $ZnSO_4$ – Zinc Sulphate; Zn EDTA – Zinc Ethylenediaminetetraacetic Acid; SA – Soil Application; FA- Foliar Application*

The pre-emergence herbicide Pendimethalin 30 EC was sprayed on the third day of sowing and hand weeding was done whenever needed. The matured tender fruits were harvested from 45 DAS on alternate days. Five plants were selected at random from the sampling area and tagged for recording biometric observations. A representative fruit sample from each plot was taken for analyses. Yield components were measured at three different harvest stages, 5th picking (52 DAS), 12th picking (67 DAS) and the final 22nd picking (97 DAS)—to evaluate early, peak and late yield performance. These observations were then averaged to determine the overall yield. For nutrient analysis, representative plant and fruit samples were collected, dried in an oven at 60°C until a constant weight was reached, finely powdered and then analysed for their nutrient composition. The experimental data were subjected to statistical analysis. Analysis of variance (ANOVA) was carried out using the AGRES software to determine the effect of the various treatments. Whenever the results were found to be significant, the critical difference at the 5% probability level was calculated to draw valid statistical inferences.

## 3. RESULTS AND DISCUSSION

### 3.1 Characterization of the Experimental Field Soil and FYM

Characterization of the experimental soil belonging to Sorakudy soil series revealed that the soil had no major constrains limiting crop production except N, P and Zn deficiency. The texture of the soil was found to be sandy clay loam with sand 66 %, silt 8 % and clay 26 % and was taxonomically classified as *Fluventic Haplustept*. The pH and EC were slightly acidic (5.85) and non- saline (0.08 dS $m^{-1}$) respectively. It was dominated by exchangeable bases and follows the order Ca > Mg > Na > K.

The organic carbon content (0.49 %) was low (Walkley and Black, 1984), and with respect to the available nutrient status of the soil, the available N (136 kg $ha^{-1}$) as determined by $KMnO_4$ (Subbiah and Asija, 1956) and the available P (17 kg $ha^{-1}$) as extracted by Bray reagent were low (Bray and Kurtz, 1945). The available K (141 kg $ha^{-1}$) as extracted by $NH_4OAc$ was medium (Standford and English, 1949). The micronutrient content of the soil was estimated as 1.02 mg $kg^{-1}$(Zn),36.37 mg $kg^{-1}$ (Fe), 10.89 mg $kg^{-1}$ (Mn), 0.84 mg $kg^{-1}$ (Cu) (Lindsay and Norvell, 1978).

### 3.2 Effect of Zinc, Inorganic Fertilizers and FYM on the Growth and Yield Parameters of Bhendi

Application of Zn-EDTA @ 1 kg $ha^{-1}$ as soil application combined with foliar spray @ 0.1% at 30 DAS along with RDF and FYM recorded the highest plant height (109.15 cm), number of branches per plant (2.95), LAI (1.40), fruit length (16.78 cm), fruit girth (7.64 cm), individual fruit weight (15.01 g) and fruits per plant (16.70). These values were statistically on par with $ZnSO_4$ @ 15 kg $ha^{-1}$ as soil application plus foliar spray @ 0.5% along with RDF and FYM, which recorded LAI of 1.33, fruit length of 16.42 cm, fruit girth of 7.50 cm, individual fruit weight of 14.86 g and fruits per plant of 16.29. The lowest values were consistently observed in the absolute control with plant height of 50.76 cm, number of branches per plant of 2.10, LAI of 0.62 (Table 2), fruit length of 12.36 cm, fruit girth of 6.18 cm, individual fruit weight of 13.70 g and fruits per plant of 11.58 (Table 3).

The right source and right time of Zn application could result in improving the metabolic functioning, hormone synthesis, enzymatic activity, protein synthesis, chlorophyll formation, thereby producing taller plants with positive influences on all other observations as observed in the results. Similar results were also reported by Polara et al.(2017), who had concluded that, the application of Zn at right source could heighten metabolic activity which supports elongation and structural development, resulting in taller plants. Foliar application of zinc in chelated form has been widely reported to enhance the growth and development of pulses by improving zinc availability and translocation within plant tissues. In 'blackgram', foliar application of Zn-EDTA, particularly in combination with phosphorus fertilization, significantly improved morphological traits such as plant height, number of branches and leaf development (Chama, 2023). Similar findings were reported (Siddique et al., 2025, Sowmiya et al., 2024).

The increase in the number of fruits per plant due to Zn-EDTA application can be attributed to the higher availability and efficient absorption of zinc in chelated form, which enhances its role in metabolic and physiological processes. Zinc stimulates the synthesis of growth-promoting substances, regulates auxin metabolism and activates several enzymes, all of which improve vegetative growth, flower initiation and fruit set. This leads to better retention of flowers and their conversion into fruits, thereby increasing the number of fruits per plant (Naruka et al*.,* 2000). Similar result have also been reported (Anburani and Manivannan, 2002, Yadav et al., 2007).

### 3.3 Effect of Zinc, Inorganic Fertilizers and FYM on the Yield

The statistical analysis revealed that fruit yield was significantly influenced by zinc nutrition in combination with inorganic fertilizers and FYM. The maximum fruit yield (19.33 t $ha^{-1}$) was obtained with the application of Zn-EDTA @ 1 kg $ha^{-1}$ as soil application along with foliar spray @ 0.1% and RDF + FYM. This treatment was closely followed by $ZnSO_4$ @ 15 kg $ha^{-1}$ as soil application with foliar spray @ 0.5% along with RDF + FYM (18.55 t $ha^{-1}$). In contrast, the lowest yield was recorded in the untreated control plot (5.43 t $ha^{-1}$), highlighting the importance of integrated zinc management (Table 3).

**Table 2. Effect of zinc, inorganic fertilizers and FYM on the growth parameters of bhendi**

| T. No | Treatment Details | Plant height (cm) | Number of branches per plant | LAI |
|---|---|---|---|---|
| $T_1$ | Absolute Control | 50.76 | 2.10 | 0.62 |
| $T_2$ | RDF + FYM @ 40 t ha $^{-1}$ | 84.70 | 2.19 | 0.75 |
| $T_3$ | $T_2$ + Zn EDTA 1 kg ha $^{-1}$ (SA) | 89.05 | 2.56 | 0.91 |
| $T_4$ | $T_2$ + Zn EDTA 1.25 kg ha$^{-1}$ (SA) | 95.07 | 2.75 | 1.14 |
| $T_5$ | $T_2$ + $ZnSO_4$ 15 kg ha$^{-1}$ (SA) | 87.37 | 2.45 | 0.85 |
| $T_6$ | $T_2$ + $ZnSO_4$ 20 kg ha$^{-1}$ (SA) | 91.07 | 2.58 | 1.05 |
| $T_7$ | $T_3$ + Zn EDTA 0.1 % (FA) | 109.15 | 2.95 | 1.40 |
| $T_8$ | $T_5$ + $ZnSO_4$ 0.5% (FA) | 96.65 | 2.81 | 1.33 |
| | Mean | 87.98 | 2.55 | 1.01 |
| | S. Ed | 2.81 | 0.06 | 0.04 |
| | C.D. (0.05) | 5.61 | 0.13 | 0.09 |

**Table 3. Effect of zinc, inorganic fertilizers and FYM on the yield and yield parameters of bhendi**

| T. No | Treatment Details | Yield (t ha$^{-1}$) | Fruit length (cm) | Fruit girth (cm) | Individual fruit weight (g) | No. of fruits per plant |
|---|---|---|---|---|---|---|
| $T_1$ | Absolute Control | 5.43 | 12.36 | 6.18 | 13.70 | 11.58 |
| $T_2$ | RDF + FYM @ 40 t ha $^{-1}$ | 13.06 | 15.62 | 6.59 | 13.77 | 12.61 |
| $T_3$ | $T_2$ + Zn EDTA 1 kg ha $^{-1}$ (SA) | 16.96 | 15.78 | 6.90 | 14.64 | 14.47 |
| $T_4$ | $T_2$ + Zn EDTA 1.25 kg ha$^{-1}$ (SA) | 17.33 | 16.07 | 7.31 | 14.82 | 15.59 |
| $T_5$ | $T_2$ + $ZnSO_4$ 15 kg ha$^{-1}$ (SA) | 14.92 | 15.66 | 6.68 | 14.58 | 13.42 |
| $T_6$ | $T_2$ + $ZnSO_4$ 20 kg ha$^{-1}$ (SA) | 17.29 | 15.85 | 7.17 | 14.75 | 14.64 |
| $T_7$ | $T_3$ + Zn EDTA 0.1 % (FA) | 19.33 | 16.78 | 7.64 | 15.01 | 16.70 |
| $T_8$ | $T_5$ + $ZnSO_4$ 0.5% (FA) | 18.55 | 16.42 | 7.50 | 14.86 | 16.29 |
| | Mean | 15.36 | 15.57 | 7.00 | 14.52 | 14.41 |
| | S. Ed | 0.09 | 0.22 | 0.15 | 0.29 | 0.23 |
| | C.D. (0.05) | 0.21 | 0.45 | 0.31 | 0.58 | 0.46 |

**Table 4. Effect of zinc, inorganic fertilizers and FYM on the quality parameters of bhendi**

| T. No | Treatment Details | Ascorbic acid (mg 100 g$^{-1}$) | Crude protein (%) | Crude fiber (%) |
|---|---|---|---|---|
| $T_1$ | Absolute Control | 9.30 | 9.84 | 15.46 |
| $T_2$ | RDF + FYM @ 40 t ha $^{-1}$ | 10.34 | 10.73 | 13.35 |
| $T_3$ | $T_2$ + Zn EDTA 1 kg ha $^{-1}$ (SA) | 11.41 | 13.26 | 12.06 |
| $T_4$ | $T_2$ + Zn EDTA 1.25 kg ha$^{-1}$ (SA) | 12.30 | 14.24 | 10.70 |
| $T_5$ | $T_2$ + $ZnSO_4$ 15 kg ha$^{-1}$ (SA) | 10.95 | 12.36 | 12.61 |
| $T_6$ | $T_2$ + $ZnSO_4$ 20 kg ha$^{-1}$ (SA) | 11.58 | 13.65 | 11.62 |
| $T_7$ | $T_3$ + Zn EDTA 0.1 % (FA) | 13.51 | 15.28 | 10.37 |
| $T_8$ | $T_5$ + $ZnSO_4$ 0.5% (FA) | 12.60 | 14.74 | 10.61 |
| | MEAN | 11.50 | 13.01 | 12.10 |
| | S. Ed | 0.25 | 0.46 | 0.13 |
| | C.D. (0.05) | 0.52 | 0.97 | 0.27 |

The increase in okra yield due to Zn-EDTA application can be attributed to its higher solubility, stability and bioavailability compared to inorganic sources like $ZnSO_4$. Being a chelated form, Zn-EDTA prevents zinc fixation in soil and ensures a continuous supply of available Zn in the rhizosphere, which facilitates efficient root uptake and improved translocation of zinc to growing plant parts leading to higher crop yield (Elayaraja and Singaravel, 2017).

### 3.4 Effect of Zinc, Inorganic Fertilizers and FYM on the Quality Parameters of Bhendi

The quality attributes of bhendi fruits were significantly influenced by zinc nutrition along with fertilizers and FYM. The highest ascorbic acid content (13.51 mg 100 $g^{-1}$) was obtained with Zn-EDTA @ 1 kg $ha^{-1}$ as soil application + foliar spray @ 0.1% in combination with RDF + FYM, followed by $ZnSO_4$ @ 15 kg $ha^{-1}$ + foliar spray @ 0.5% (12.60 mg 100 $g^{-1}$), while the control recorded the lowest value (9.30 mg 100 $g^{-1}$) (Table 4).

Crude protein content was also enhanced, with Zn-EDTA @ 1 kg $ha^{-1}$ + foliar spray @ 0.1%, producing the highest value (15.28%) which was significantly similar to the value recorded in $ZnSO_4$ @ 15 kg $ha^{-1}$ + foliar spray @ 0.5% (14.74%). The minimum protein content was observed in the control (9.84%) (Table 4).

For crude fiber, the lowest content (10.37%) was recorded with Zn-EDTA @ 1 kg $ha^{-1}$ + foliar spray @ 0.1% + RDF + FYM. In contrast, the highest crude fiber was found in the control (15.46%), followed by RDF + FYM (13.35%), indicating that zinc fertilization improved fruit tenderness by reducing fiber accumulation (Table 4).

Adequate zinc nutrition improves the reactive oxygen species (ROS) scavenging mechanism, leading to increased accumulation of ascorbic acid in plant tissues (Broadley et al., 2007). Similar result was reported by Arjun et al. (2018), who reported higher ascorbic acid content in okra fruits with zinc application. Zinc application improved the overall growth and yield of okra, the treatments that promoted higher fruit succulence and nutritive value were associated with relatively lower crude fiber content (Sharma et al., 2018).

## 4. CONCLUSION

The study demonstrated that the integrated application of Zn-EDTA @ 1.0 kg $ha^{-1}$ as soil application with RDF (200:100:100) and FYM @ 40 t $ha^{-1}$, along with 0.1% foliar spray at 30 DAS, significantly enhanced growth and yield parameters of bhendi. The performance of this treatment was on par with $ZnSO_4$ @ 15 kg $ha^{-1}$ + 0.5% foliar spray combined with RDF and FYM. The improvement in yield and yield attributes could be attributed to better zinc availability, which enhanced auxin metabolism, pollen formation, enzymatic activities and efficient translocation of photosynthates. Thus, the adoption of Zn-EDTA @ 1.0 kg $ha^{-1}$ with 0.1% foliar spray in combination with RDF and FYM can be highly effective in improving growth, yield and fruit production of bhendi, while also addressing zinc deficiency in soils. From a practical standpoint, the recommended practice has strong potential for field use, as it can help farmers overcome zinc deficiency while improving productivity. The approach may also be adaptable to different agro-ecological regions, though cost factors and resource availability need to be considered before large-scale adoption.

The findings of this work should be viewed in light of certain limitations, such as its conduct in a single season and at a single location. Future studies across multiple locations and seasons, along with an economic assessment and investigations into long-term soil health, would provide a more comprehensive understanding of the effectiveness and sustainability of zinc-based nutrient management in bhendi.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

**Details of the AI usage are given below:**

1.Copilot
2.Quillbot

## ACKNOWLEDGEMENTS

The authors are grateful to Department of SS&AC, PAJANCOA&RI, Karaikal for providing the resources necessary for conducting the research experiments. The authors are also thankful to the farm workers for their help in sowing and harvesting the crop.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

Anburani, A., & Manivannan, K. (2002). Effect of integrated nutrient management on growth in brinjal (Solanum melongena L.) cv. Annamalai. South Indian Horticulture, 50(4–6), 377–386. https://doi.org/10.5555/20033180699

Arjun, M. A., Singh, T., Shukla, M., & Namdeo, K. (2018). Integrated nutrient management on growth, yield and quality of okra (Abelmoschus esculentus L. Moench). Annals of Plant and Soil Research, 20(4), 344–348. https://www.gkvsociety.com/control/uploads/1325975.pdf

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59(1), 39–46. https://doi.org/10.1097/00010694-194501000-00006

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2007). Zinc in plants. New Phytologist, 173(4), 677–702. https://doi.org/10.1111/j.1469-8137.2007.01996.x

Cakmak, I., Ozkan, H., Braun, H.-J., & Welch, R. M. (2000). Zinc and iron concentrations in seeds of wild, primitive, and modern wheats. Food and Nutrition Bulletin, 21(4), 401–403. https://doi.org/10.1177/156482650002100411

Chama, T., Shanmugasundaram, R., Selvi, D., Chandrasekhar, C., & Srinivasan, K. (2023). Effect of levels of phosphorus and zinc-EDTA on growth and yield of blackgram (Vigna mungo L.) in zinc-deficient Vertisol. International Journal of Plant and Soil Science, 35(19). https://doi.org/10.9734/ijpss/2023/v35i193723

Elayaraja, D., & Singaravel, R. (2017). Effect of different levels and sources of zinc fertilizers on the growth and yield of okra in coastal sandy soil. International Journal of Agricultural Sciences, 13(2), 282–286. https://doi.org/10.15740/HAS/IJAS/13.2/282-286

Ghasal, P. C., Shivay, Y. S., Pooniya, V., Choudhary, M., & Verma, R. K. (2017). Response of wheat genotypes to zinc fertilization for improving productivity and quality. Archives of Agronomy and Soil Science, 63(11), 1597–1612. https://doi.org/10.1080/03650340.2017.1289515

Jain, R., Srivastava, S., Solomon, S., Shrivastava, A. K., & Chandra, A. (2010). Impact of excess zinc on growth parameters, cell division, nutrient accumulation, photosynthetic pigments and oxidative stress of sugarcane (Saccharum spp.). Acta Physiologiae Plantarum. https://doi.org/10.1007/s11738-010-0487-9

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal, 42(3), 421–428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Mortvedt, J. J., Cox, F. R., Shuman, L. M., & Welch, R. M. (Eds.). (1991). *Micronutrients in agriculture* (2nd ed.). Soil Science Society of America. https://doi.org/10.1002/jpln.19921550421

Naruka, I. S., Gujar, K. D., & Lal, G. (2000). Effect of foliar application of zinc and molybdenum on growth and yield of okra (*Abelmoschus esculentus* L. Moench) cv. Pusa Sawani. *Haryana Journal of Horticultural Sciences, 29*(3/4), 266–267.

Polara, K. B., Ponkia, H. P., Sakarvadia, H. L., Vekaria, L. C., & Babariya, N. B. (2017). Effect of Multi-Micronutrients Fertilizers on Yield and Micronutrients Uptake by Okra (Abelmoschus esculentus L.) Grown on Medium Black Calcareous Soils of Saurashtra Region of Gujarat. International Journal of Pure & Applied Bioscience, 5(6), 258–264. https://doi.org/10.18782/2320-7051.5350

Potarzycki, J., & Grzebisz, W. (2009). Effect of zinc foliar application on grain yield of maize and its yielding components. Plant, Soil and Environment, 55(12), 519–527. https://doi.org/10.17221/95/2009-PSE

Quijano-Guerta, C., Kirk, G. J. D., Portugal, A. M., Bartolome, V. I., & McLaren, G. C. (2002). Tolerance of rice germplasm to zinc deficiency. Field Crops Research, 76(2–3), 123–130.

https://doi.org/10.1016/S0378-4290(02)00034-5

Saha, B., Saha, S., Hazra, G. C., Saha, S., Basak, N., Das, A., & Mandal, B. (2015). Impact of zinc application methods on zinc concentration and zinc-use efficiency of popularly grown rice (Oryza sativa) cultivars. Indian Journal of Agronomy, 60(3), 391–402. https://doi.org/10.59797/ija.v60i3.4469

Sathish, D., & Eswar, A. (2013). A review on: *Abelmoschus esculentus* (okra). *International Research Journal of Pharmacy and Applied Sciences, 3*(4), 129–132.

Sharma, R., Bairwa, L. N., Ola, A. L., Lata, K., & Meena, A. R. (2018). Effect of zinc on growth, yield and quality of okra [*Abelmoschus esculentus* (L.) Moench]. *Journal of Pharmacognosy and Phytochemistry, 7*(1), 2519–2521. https://www.phytojournal.com/archives/2018/vol7issue1/PartAI/7-1-5-443.pdf

Shukla, A. K., Behera, S. K., Prakash, C., Tripathi, A., Patra, A. K., Dwivedi, B. S., & Singh, A. K. (2021). Deficiency of phyto-available sulphur, zinc, boron, iron, copper and manganese in soils of India. Scientific Reports, 11, 19760. https://doi.org/10.1038/s41598-021-99040-2

Siddique, M., Bhatti, S., Rajpar, I., & Depar, N. (2025). Comparative efficacy of Zn-EDTA and $ZnSO_4$ in mitigating zinc deficiency in wheat for sustainable production. *Plant Protection*. *9*(2), 251-260. https://doi.org/10.33804/pp.009.02.5552

Sowmiya, K., Shofiya, M., Gopika, K., & Nithika, M. (2024). Impact of Nano DAP and Zn EDTA on Cowpea Growth and Yield. International Journal of Plant & Soil Science, 36(6), 317–326. https://doi.org/10.9734/IJPSS/2024/v36i64634

Standford, S., & English, L. (1949). Use of the flame photometer in rapid soil tests for K and Ca. *Agronomy Journal, 41*, 446–447. https://doi.org/10.2134/agronj1949.00021962004100090012x

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. Current Science, 25, 259–260. https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium_19571900070

Tamil Nadu Agricultural University. (2020). Crop production guide: Horticulture. https://tnau.ac.in/site/research/wp-content/uploads/sites/60/2020/02/Horticulture-CPG-2020.pdf

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38. https://journals.lww.com/soilsci/citation/1934/01000/AN_EXAMINATION_OF_THE_DEGTJAREFF_METHOD_FOR.3.aspx

Yadav, S. K., Rana, J. C., Pradeep, K., Yadav, S. K., Hussain, Z., & Mishra, S. K. (2007). Effect of NPK, FYM and climatic zones on seed yield and quality in tomato (*Lycopersicon esculentum* Mill.). *International Journal of Tropical Agriculture, 25*(4), 867–869.

Yilmaz, A., Ekiz, H., Gültekin, I., Torun, B., Barut, H., Karanlik, S., & Cakmak, I. (1998). Effect of seed zinc content on grain yield and zinc concentration of wheat grown in zinc-deficient calcareous soils. Journal of Plant Nutrition, 21(10), 2257–2264. https://doi.org/10.1080/01904169809365559

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

*© Copyright (2025): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://pr.sdiarticle5.com/review-history/149021*