Enhancing Zinc Concentration in Chickpea *(Cicer arietinum L*.) grains through agronomic Biofortification Under Irrigated Conditions

ABSTRACT

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| An experimental study investigated the effects of zinc fertilization on chickpea (*Cicer arietinum L*.) growth, yield, and protein content through agronomic biofortification under irrigated conditions during the rabi seasons of 2024 Conducted at Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu. The experiment employed a split-plot design with four main treatments (M1-M4) and three zinc treatments (S1-S3). The results showed that 75% RDF (M3) significantly enhanced growth attributes, including plant height (48.03 cm), dry matter production (2360.10 kg ha⁻¹), and leaf area index (0.80). Zinc treatment S3 - Chelated ZnSO4 as soil @ 20 kg ha-1 as basal+ ZnO as foliar application at 30 and 60 DAS produced the highest yields, with grain yield reaching 961.20 kg ha⁻¹ and stover yield at 2306.80 kg ha⁻¹. Improved nutrient uptake and efficient partitioning of biomass contributed to higher productivity and profitability, demonstrating the potential of integrated zinc fertilization strategies for enhancing chickpea yield and nutritional quality. |

*Keywords:* Biofortification, Zinc, Chickpea, Fertilization, Nutrient management

1. INTRODUCTION

The world population is projected to grow from 7.6 billion in 2017 to 8.6 billion by 2030 and reach 9.8 billion by 2050 (United Nations, 2016). At present, anemia affects approximately 40% of pregnant women and 42% of children under the age of five, while 17% of the global population is estimated to be at risk of insufficient zinc intake. (WHO 2021). Meeting the nutritional needs of the expanding global population, including adequate supplies of food, iron (Fe), and zinc (Zn), is a crucial challenge. While dietary diversity is the best approach to ensure proper nutrition, the diets of low-income families in developing nations mainly consist of staple plant-based foods. Unfortunately, many of these foods, such as cereals, are deficient in essential nutrients (Bouis and Welch 2010). Over a span of 120 years of data collection, hard white wheat varieties demonstrated a yield increase of up to 175%. However, this improvement was accompanied by a reduction of 11 to 25% in the concentrations of iron and zinc, respectively Murphy *et al*. (2008). Biofortification seeks to address this imbalance by enhancing not only the agronomic performance of crops but also by improving the iron and zinc content in newly developed varieties. Agronomic biofortification is considered one of the most cost-effective methods for minimizing mineral deficiencies in human diets. Moreover, numerous studies have shown that, beyond enhancing micronutrient levels, biofortification also positively influences the production of other beneficial compounds with nutritional value. (Newman *et al*., 2021).

Zinc deficiency results in reduced pollen viability, alterations in stigma size, morphology, and exudation, ultimately hindering pollen-stigma interaction. Zinc is an essential nutrient required for maintaining proper human health Pandey *et al*. (2009). Approximately 2800–3000 proteins in the human body include zinc prosthetic groups Cakmak *et al*. (2018). zinc is essential for the activity of more than 300 enzymes. Notably, zinc plays a role in all six enzyme classes: hydrolases, lyases, ligases, isomerases, oxidoreductases, and transferases. Zinc is essential for proper physical growth, development, immune response, reproductive health, and cognitive function. Among pulse crops, chickpea is particularly susceptible to zinc deficiency, which is prevalent in major chickpea-growing areas of the country. Zinc also enhances water use efficiency, promotes nodulation, and improves nitrogen fixation in pulses. Roy *et al*. (2013). Eating biofortified crops can help combat micronutrient deficiencies by boosting the daily intake of essential micronutrients, ensuring better nutritional adequacy throughout an individual's life Bouis *et al*. (2011). This study was conducted to identify an eco-friendly, cost-effective, and practical approach to fulfil the nutrient requirements of chickpea crops within cropping systems, ensuring soil fertility and productivity. Developing sustainable and efficient technologies is essential to maintain chickpea productivity in the long term.

2. material and methods

A field study was carried out on sandy clay loam soil during the rabi seasons of 2024 at the South Farm of Karunya Institute of Technology and Sciences, located in Coimbatore, Tamil Nadu, India (10.934°N latitude, 76.75°E longitude, and an elevation of 467 meters above mean sea level). This site is positioned in the western part of Tamil Nadu, which falls under a semi-arid tropical climate zone, characterized by hot, dry summers and moderately cool winters. For the *rabi* seasons, which span from October to January, the average precipitation throughout the crop-growing season was 875.50 mm in 2024 and 925 mm in 2025. Temperatures during the crop-growing season peaked at 27°Cand fell as low as 32.7°C. The soil in the experimental field, characterized as sandy clay loam, exhibited an alkaline pH of 8.9 and moderate electrical conductivity measuring 0.24 dS/m. It contained low available nitrogen (80.06 kg ha⁻¹), medium levels of available phosphorus (0.143 kg ha⁻¹), and potassium (35.0 kg ha⁻¹). The experiment was conducted using a split-plot design, incorporating twelve different treatments consisting of M1- Control (no organics and inorganics), M2- 100 % RDF (NPK- 25:50:20), M3 -75 % RDF, M4 -50 % RDF as main plot. Sub plots comprising of S1 - Chelated ZnSO4 as soil application @ 20 kgha-1 as basal, S2 - ZnO as foliar application @ 0.5% conc. at 30 and 60 DAS, S3 - Chelated ZnSO4 as soil @ 20 kg ha-1 as basal+ ZnO as foliar application at 30 and 60 DAS. Chickpea variety Chickpea NBeG 49 with a duration of 100-110 days was selected for this experiment. Planting was done at a spacing of 30 × 10cm. The prescribed fertilizer rate for Chickpea hybrids was 25:50:20 (N: P: K) kg ha-¹. All yield and growth parameters were assessed following standardized and well-established protocols.

3. results and discussion

**Growth parameters**

The plant height was significantly influenced by the various treatments. The maximum plant height of 48.03 cm was observed with M3 (75% RDF), whereas the minimum height of 44.90 cm was recorded in M1 (Control) in table 1. Among the zinc treatments, the highest plant height (46.83 cm) was achieved with the combination of chelated ZnSO₄ as soil application and ZnO as foliar spray (S3). The participation of zinc and iron in cell division and the growth of meristematic tissues may also account for the observed increase in plant height, consistent with similar results reported by (Hossain, M.D *et al*., 2016)

Dry matter production was significantly affected by the various treatments, with the highest DMP of 2360.10 kg ha⁻¹ observed under M3 (75% RDF) and the lowest at 2077.00 kg ha⁻¹ in M1 (Control). Among zinc treatments, S3 (Chelated ZnSO₄ as soil application + ZnO as foliar spray) resulted in the highest DMP (2251.98 kg ha⁻¹). The enhancement in growth and yield traits through soil or foliar application of zinc could be attributed to improved photosynthetic efficiency, more effective translocation, and better assimilation of metabolites towards the sink. This, in turn, led to increased plant height and dry matter production (Singh *et al*., 2015)

The various treatments had a considerable impact on the leaf area index (LAI), with the greatest LAI (0.80) observed under M3 (75% RDF) and the lowest (0.46) in M1 (Control). Among zinc treatments, S3 (Chelated ZnSO₄ as soil application + ZnO as foliar spray) recorded the highest LAI (0.67). Better nutrient availability and uptake may have contributed to the plant's increased height and leaf area index through boosting the number of functioning leaves per plant (Abiyot *et al*., 2022).

**Yield attributes and Yield parameters**

Test weight was marginally influenced by different treatments, with M3 (75% RDF) recording the highest value (34.34). Among zinc treatments, S3 exhibited the highest test weight (34.31), though the variations were minimal. The 100-seed weight and test weight provide a valuable information about seed development, indicating how different production factors influence seed formation and filling processes. The interaction between varieties and micronutrients showed with no significant effects. These results are consistent with the findings of Siag, R. K., & Yadav, B. S. (2004).

Maximum protein yield (566.20 kg ha⁻¹) was achieved under M3 (75% RDF), while the lowest (526.67 kg ha⁻¹) was observed in M1 (Control). Zinc treatment S3 showed the highest protein yield (552.93 kg ha⁻¹) as shown in (Fig1). Because zinc is a component of several dehydrogenase, proteinase, and peptidase enzymes, the increased synthesis of carbohydrates and fats may be caused by the stimulating effect of sprayed zinc on the activity of these enzymes. Additionally, improved N uptake and increased expression of Zn transporter proteins resulted in maximum nutrient translocation from source to sink, and improved protease enzymes led to higher protein content in seed (Dadkhah *et al*., 2015).

Stover yield was notably higher under M3 (1747.70 kg ha⁻¹) compared to other treatments in table 2. Among zinc applications, S3 recorded the highest stover yield (2306.80 kg ha⁻¹), indicating enhanced biomass accumulation. Grain yield was significantly higher in M3 (977.63 kg ha⁻¹) compared to other treatments, while the lowest was observed in M1 (936.30 kg ha⁻¹). Among zinc treatments, S3 recorded the maximum grain yield (961.20 kg ha⁻¹). Crop yield is the result of the combined influence of various growth and yield-contributing traits. Zinc plays a vital role in starch synthesis, the production of growth regulators such as auxin, seed maturation, and overall productivity. Enhanced zinc availability has been shown to significantly improve growth characteristics, which in turn boosts grain and stover yield (Pal *et al*., 2021).

The harvest index was relatively consistent across treatments, with M3 having the highest value (40.76). The highest harvest index among zinc treatments was recorded under S3 (40.73), indicating efficient partitioning of biomass. Improved plant growth, along with increased seed and straw yield, likely contributed to a higher benefit-cost ratio, harvest index, and net profitability in Zn-treated plots compared to the control. These results regarding the economic advantages of zinc-enriched treatments align with the findings of Singh and Shivay (2015).

**Table 1. Effect of Zinc fertilization on growth attributes of chickpea**

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| **Treatments** | **Plant height** | **Dry Matter Production** | **Leaf area index** |
| M1- Control (no organics and inorganics) | 44.90 | 2077.00 | 0.46 |
| M2-100 % RDF (NPK- 25:50:20) | 46.00 | 2178.00 | 0.58 |
| M3-75 % RDF | 48.03 | 2360.10 | 0.80 |
| M4-50 % RDF | 47.03 | 2265.47 | 0.69 |
| **SE(d)** | **0.02** | **5.79** | **0.006** |
| **CD(P=0.05)** | **0.06** | **14.16** | **0.015** |
| S1-Chelated ZnSO4 as soil application @ 20 kgha-1 as basal | 46.18 | 2187.35 | 0.60 |
| S2- ZnO as foliar application @ 0.5% conc. at 30 and 60 DAS | 46.48 | 2221.10 | 0.63 |
| S3- Chelated ZnSO4 as soil @ 20 kg ha-1 as basal+ ZnO as foliar application at 30 and 60 DAS | 46.83 | 2251.98 | 0.67 |
| **SE(d)** | **0.02** | **3.16** | **0.003** |
| **CD(P=0.05)** | **0.05** | **6.69** | **0.007** |
| M at S |  |  |  |
| **SE(d)** | **0.042** | **7.7** | **0.008** |
| **CD(P=0.05)** | **0.094** | **17.8** | **0.019** |
| S at M |  |  |  |
| **SE(d)** | **0.043** | **6.3** | **0.007** |
| **CD(P=0.05)** | **0.091** | **13.4** | **0.014** |

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| **Table 2: Effect of Zinc fertilization on yield and yield attributes of Chickpea** |  |  |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Treatments** | **Test weight** | **Protein yield** | **Stover yield** | **Grain yield** | **Harvest index** | | M1- Control (no organics and inorganics) | 34.25 | 526.67 | 1706.85 | 936.30 | 40.67 | | M2-100 % RDF (NPK- 25:50:20) | 34.28 | 542.20 | 1717.00 | 948.57 | 40.70 | | M3-75 % RDF | 34.34 | 566.20 | 1747.70 | 977.63 | 40.76 | | M4-50 % RDF | 34.31 | 554.00 | 1730.93 | 963.53 | 40.73 | | **SE(d)** | **1.20** | **1.63** | **5.70** | **1.02** | **1.43** | | **CD(P=0.05)** | **2.95** | **3.98** | **13.95** | **2.50** | **3.50** | | S1-Chelated ZnSO4 as soil application @ 20 kgha-1 as basal | 34.29 | 540.90 | 2295.00 | 952.250 | 40.71 | | S2- ZnO as foliar application @ 0.5% conc. at 30 and 60 DAS | 34.30 | 547.98 | 2300.68 | 956.075 | 40.72 | | S3- Chelated ZnSO4 as soil @ 20 kg ha-1 as basal+ ZnO as foliar application at 30 and 60 DAS | 34.31 | 552.93 | 2306.80 | 961.200 | 40.73 | | **SE(d)** | **1.44** | **0.59** | **1.38** | **0.55** | **1.71** | | **CD(P=0.05)** | **3.04** | **1.25** | **2.92** | **1.17** | **3.61** | | M at S |  |  |  |  |  | | **SE(d)** | **2.64** | **1.89** | **6.13** | **1.36** | **3.13** | | **CD(P=0.05)** | **5.77** | **4.47** | **14.73** | **3.14** | **6.85** | | S at M |  |  |  |  |  | | **SE(d)** | **2.87** | **1.18** | **2.75** | **1.11** | **3.41** | | **CD (p=0.05)** | **6.09** | **2.50** | **5.84** | **2.35** | **7.23** | |  |  |
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**M1- Control (no organics and inorganics), M2- 100 % RDF (NPK- 25:50:20), M3 -75 % RDF, M4 -50 % RDF as main plot.**

**Sub plots comprising of S1 - Chelated ZnSO4 as soil application @ 20 kgha-1 as basal, S2 - ZnO as foliar application @ 0.5% conc. at 30 and 60 DAS, S3 - Chelated ZnSO4 as soil @ 20 kg ha-1 as basal+ ZnO as foliar application at 30 and 60 DAS**

**Fig. 1. Zinc fertilization on yield and yield attributes**

4. Conclusion

The findings indicate that the application of 75% RDF (M3) consistently resulted in superior growth, yield attributes, and overall productivity compared to the control (M1). Zinc treatment S3, involving chelated ZnSO₄ as soil application and ZnO as foliar spray, also demonstrated enhanced performance across various parameters, including plant height, dry matter production, leaf area index, and protein yield. The improved grain and stover yields under M3 and S3 treatments suggest better nutrient availability and assimilation. Additionally, higher harvest indices observed under these treatments highlight efficient biomass partitioning. Overall, integrating RDF with zinc supplementation proved effective in maximizing growth, yield, and profitability.

**Reference**

Abiyot, A., Alemayehu, G., Feyisa, T. (2022). Nodulation, growth and yield of soybean as influenced by biofertilizer and inorganic fertilizers in assosa zone, Western Ethiopia. Indian Journal of Agricultural Research.  56(6): 653-659. doi: 10.18805/IJARe.A-654.

Bouis H.E., Welch R.M. Biofortification-A Sustainable Agricultural Strategy for Reducing Micronutrient Malnutrition in the Global South. Crop Sci. 2010;50:S-20–S-32. doi: 10.2135

Bouis, H.E., Hotz, C., McClafferty, B., Meenakshi, J.V. and Pfeiffer, W.H. (2011). Biofortification: A new tool to reduce micronutrient malnutrition. Food Nutrition Bulletin. 32 (Supplement 1): 31S-40S

Cakmak I., Kutman U.B. Agronomic biofortification of cereals with zinc: A review. Eur. J. Soil Sci. 2018;69: 172–180. doi: 10.111.

Dadkhah, N., Ebadi, A., Parmoon, G.H., Ghlipoori, G.H. and Jahanbakhsh, S. (2015). The effects of zinc fertilizer on some physiological characteristics of chickpea (*Cicer arietinum L*.) under water stress. Iranian Journal of Pulses Research. 6(2): 59-72.

FAO. IFAD. UNICEF. WFP. WHO. The State of Food Security and Nutrition in the World 2020: Transforming Food Systems for Affordable Healthy Diets. FAO; Rome, Italy: 2020.

Hossain MD, Hasan M, Sultana R, Bari AKM. Growth and yieldresponse of ch ickpea to different levels of boron and zinc. Fundamental and Applied Agriculture. 2016;1(2):82 86.

Murphy KM, Reeves PG, Jones SS (2008) Relationship between yield and mineral nutrient Plant 98:229–234. https://doi.org/10.1034/j.1399-3054. 1996.980202.x

Newman RG, Moon Y, Sams CE, Tou JC, Waterland NL (2021) Biofortification of sodium selenate improves dietary mineral contents and antioxidant capacity of culinary herb microgreens. Front Plant Sci 12:716437. <https://doi.org/10.3389/fpls.2021.716437>

Pal, V., Singh, G. and Dhaliwal, S.S. (2021). A new approach in agronomic biofortification for improving zinc and iron content in chickpea (*Cicer arietinum L*.) grain with simultaneous foliar application of zinc sulphate, ferrous sulphate and urea. Journal of soil science and plant nutrition. 21: 883-896.

Pandey M, Gautam JP. Effect of foliar nutrition of boron and molybdenum on chickpea. Indian Journal of Pulses Research. 2009;14 (1):41-43.

Roy, P.D., Narwal, R.P., Malik, R.S., Saha, B.N. and Kumar, S. (2013). Impact of zinc application methods on green gram productivity and grain zinc fortification. Journal of Environmental Biology. 35: 851-854

Siag RK, Yadav BS. Effect of vermicompost and fertilizers on productivity of gram (*Cicer arietinum*) and soil fertility. Indian journal of agricultural science. 2004;74(11):613 615.

Singh A, Shivay YS. Effect of summer green manuring crops and zinc fertilizer sources on productivity, Zn uptake and economics of basmati rice. Journal of Plant Nutrition. 2015; 39:204-218.

Singh, U., Kumar, N., Praharaj, C.S., Singh, S.S. and Kumar, L. 2015. Ferti-fortification: an easy approach for nutritional enrichment of chickpea. The Ecoscan, 9(3&4): 731-736.