***Original Research Article***

**Effect of Zinc and Iron Biofortification on Yield and Quality of Chickpea (*Cicer arietinum* L.)**

**Abstract**

A field experiment was conducted during the *Rabi* season of 2024-25 at Agricultural Farm Mewar University Gangrar, Chittorgarh, Rajasthan, to investigate the "Effect of Zinc and Iron Biofortification on Yield and Quality of Chickpea (*Cicer arietinum* L.)". Nine different treatments involving soil and foliar applications of zinc sulfate (ZnSO4​) and ferrous sulfate (FeSO4​) were evaluated in a Randomized Block Design (RBD) with three replications. The study revealed that agronomic biofortification significantly enhanced growth attributes, yield parameters, nutrient content, and economic returns of chickpea. Specifically, the combined application of ZnSO4​ @ 25 kg/ha (soil application) + 0.5% FeSO4​ (foliar application) consistently resulted in the highest plant height (67.76 cm), dry matter accumulation (22.46 g/plant), number of branches/plant (5.63), pods/plant (61.83), seeds/pod (2.12), 100-seed weight (24.95 g), seed yield (1855 kg/ha), and straw yield (3518 kg/ha). This treatment also led to the highest NPK content in seed and straw, maximum protein content (21.06%), and the highest net return (₹66925/ha) with a benefit-cost ratio of 1.91. The findings underscore the potential of zinc and iron biofortification as a viable strategy to improve chickpea productivity, nutritional quality, and farmer profitability, particularly in regions prone to micronutrient deficiencies.

**Keywords:** Chickpea, Fe, Zn, growth, biofortification

**1. Introduction**

Chickpea (*Cicer arietinum* L.) is the world's third most important pulse crop after dry beans and peas, serving as a vital primary source of protein for vegetarian populations (Kaur et al., 2020). India plays a crucial role in global chickpea production, contributing over 62-67% of the total global output, with an area of 10.17 million hectares and a production of 11.35 million tonnes (Anonymous, 2023; Anonymous, 2024). Beyond its nutritional value, chickpea is integral to sustainable agriculture due to its ability to improve soil physico-chemical and biological properties. Its deep root system enhances soil aeration, and significant leaf drop increases organic matter content. Furthermore, chickpea can fix approximately 25-30 kg N ha−1 through symbiosis, thereby reducing reliance on synthetic nitrogen fertilizers (Pujitha et al., 2022).

Despite its importance, global productivity of chickpea is often constrained by micronutrient deficiencies in the soil, particularly zinc (Zn) and iron (Fe). According to the World Health Organization (WHO, 2016) and Cakmak (2008), zinc deficiency ranks 11th among the twenty most important global factors contributing to micronutrient deficiencies, while zinc and iron deficiencies collectively rank 5th and 6th in developing countries. India, Pakistan, China, Iran, and Turkey are among the countries significantly affected by zinc deficiency (Lockyer et al., 2018). A comprehensive analysis of three lakh soil samples across India revealed that nearly 49% of soils were deficient in zinc and 12% in iron (Singh and Behera, 2011).

Zinc is an essential trace element vital for plant growth and reproduction, involved in signal transduction, DNA/RNA regulation, and phytohormone synthesis (Hassan et al., 2020). Its deficiency can lead to stunted growth and reduced crop development. Similarly, iron plays a critical role in chlorophyll synthesis, respiration, photosynthesis, and nitrogen fixation, being a structural component of hemes and leghaemoglobin (Larson et al., 2018). Although iron is abundant in the earth's crust, its low solubility, especially in saline and alkaline soils, limits its bioavailability to plants, leading to chlorosis and impaired pod or grain formation (Vadlamudi et al., 2020; Abbaspour et al., 2014).

Micronutrient deficiencies in crops directly translate to human health issues, affecting more than half of the world's population, particularly in developing countries (Harvest Plus, 2021; Yadava et al., 2018). Iron deficiency leads to anemia, impacting pregnant women and pre-school children, and reducing work capacity in adults (Sheftela et al., 2011). Zinc deficiency is linked to impaired immune function and metabolic disorders (Chasapis et al., 2020; Chistiakov et al., 2014).

Biofortification, derived from Greek ("bios" meaning life) and Latin ("fortificare" meaning making strong), is a process of increasing micronutrient concentrations in edible crop portions. Agronomic biofortification, through the application of mineral fertilizers, offers a compatible and easy solution to combat these deficiencies (Majeed et al., 2020; Meena et al., 2017). Soil and foliar applications of zinc and iron are key agronomic approaches that not only nourish crops but also enhance the accumulation of these micronutrients in edible parts, thereby improving nutritional security (Athar et al., 2020; Sharma et al., 2017; Kayan et al., 2015; Cakmak, 2008).

Considering the critical role of zinc and iron in alleviating malnutrition and enhancing chickpea quality, the present investigation was undertaken with the objectives to assess the effect of zinc and iron on the yield and quality of chickpea, to determine the compatibility of zinc and iron for biofortification, and to evaluate the economic viability of different treatments.

**2. Materials and Methods**

**2.1. Experimental Site and Climate**

The field experiment was conducted during the Rabi season of 2024-25 at the Agricultural Farm of Mewar University, Gangrar, Chittorgarh, Rajasthan, India. The experimental site is located at 10°57′ N latitude and 75°20′ E longitude, at an altitude of 267 meters above mean sea level. This region falls under Agro-climatic Zone IV (Humid South Plains) of Rajasthan. The climate is subtropical, characterized by an average annual rainfall ranging from 750 to 1005 mm. Mean annual maximum and minimum temperatures are 40.2°C and 18.5°C, respectively. During the experimental period (*Rabi* 2024-25), the mean weekly maximum and minimum temperatures fluctuated between 19.8°C and 36.1°C and 5.6°C and 18.9°C, respectively. Total rainfall during the growing season was 17.9 mm over 2 rainy days.

**2.2. Soil Characteristics**

Prior to sowing and fertilization, soil samples (0-15 cm depth) were collected from different spots of the experimental field to determine its physico-chemical properties. The soil was classified as clay loam in texture, slightly saline in reaction (pH 7.6, EC 0.96 dS/m). It was medium in available nitrogen (314 kg ha−1), medium in available phosphorus (22.3 kg ha−1), and high in available potassium (398 kg ha−1), with sufficient DTPA extractable micronutrients. The organic carbon content was 0.58%.

**2.3. Experimental Design and Treatments**

The experiment was laid out in a Randomized Block Design (RBD) with three replications. Nine different treatment combinations of zinc and iron biofortification were evaluated:

* **T1:** Control (no fertilizer application)
* **T2:** ZnSO4​ @ 12.5 kg/ha (Soil Application - SA)
* **T3:** FeSO4​ @ 12.5 kg/ha (SA)
* **T4:** ZnSO4​ @ 25 kg/ha (SA)
* **T5:** FeSO4​ @ 25 kg/ha (SA)
* **T6:** ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (Foliar Application - FA)
* **T7:** ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)
* **T8:** FeSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)
* **T9:** FeSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)

Zinc sulphate heptahydrate (ZnSO4​⋅7H2​O) with 21% zinc content and ferrous sulphate (FeSO4​) with 19.5% iron and 10.5% sulphur were used.

**2.4. Crop Management and Data Collection**

Chickpea variety RSG-1581 was used as the test crop. Seeds were sown on October 25, 2024, at a rate of 80 kg/ha, with a row spacing of 30 cm and a depth of 8 cm. Field preparation involved ploughing, harrowing, and planking. Thinning was performed to maintain uniform plant stand. Hand weeding was done at 40 and 60 DAS. The first irrigation was applied 50 DAS, with subsequent irrigations at the pod development stage. Harvesting occurred on March 22, 2025, at physiological maturity.

Data were systematically collected on:

* **Growth attributes:** Plant population (no./mrl) at 30 DAS and harvest, plant height (cm) at 30, 60, 90 DAS and harvest, dry matter accumulation (g/plant) at 30, 60, 90 DAS and harvest, and number of branches/plant at 90 DAS.
* **Yield attributes and yield:** Number of pods/plant, number of seeds/pod, 100-seed weight (g), seed yield (kg/ha), straw yield (kg/ha), and harvest index (%).
* **Quality parameters:** Protein content (%), protein yield (kg/ha).
* **Nutrient content and uptake:** Nitrogen (N), phosphorus (P), and potassium (K) content (%) in seed and straw, and NPK uptake (kg/ha) by seed and straw.
* **Economics:** Net returns (₹/ha) and Benefit: Cost (B:C) ratio.

**2.5. Statistical Analysis**

All collected data were subjected to statistical analysis using Fisher's analysis of variance technique (Panse and Sukhatme, 1985). Critical Difference (CD) at 5% level of significance (P=0.05) was calculated for treatment comparisons where the F-test was significant. Standard Error of Mean (S.Em.±) was also reported.

**3. Results and Discussion**

The experimental results consistently demonstrated the significant positive impact of zinc and iron biofortification on various parameters of chickpea.

**3.1. Growth Attributes**

The application of agronomic biofortification treatments significantly influenced growth parameters such as plant height, dry matter accumulation, and number of branches per plant. Plant population, however, did not show significant differences among treatments (Table 1).

The highest plant height was recorded with treatment T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)) at all growth stages: 17.75 cm at 30 DAS, 38.87 cm at 60 DAS, 60.42 cm at 90 DAS, and 67.76 cm at harvest. This treatment was statistically at par with T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)). Similarly, dry matter accumulation was significantly higher in T7 (0.51 g/plant at 30 DAS, 5.94 g/plant at 60 DAS, 18.14 g/plant at 90 DAS, and 22.46 g/plant at harvest), also statistically at par with T6. The maximum number of branches per plant at 90 DAS (5.63) was observed in T7, followed by T6 (5.15), with the control (T1) showing the lowest (3.55).

The observed increments in plant height and dry matter production can be attributed to the enhanced availability of zinc and iron, which are crucial for auxin formation and overall plant metabolism. Zinc's role in promoting cell division and iron's involvement in chlorophyll synthesis likely contributed to increased photosynthetic efficiency and biomass production. These findings are consistent with previous research by Pal et al. (2019), Habib et al. (2018), and Kuldeep et al. (2018). The increased branching due to Zn and Fe application is likely a result of improved nutrient availability leading to enhanced lateral meristematic differentiation, as supported by Haider et al. (2018) and Kuldeep et al. (2018).

**3.2. Yield Attributes and Yield**

Yield attributes, including number of pods/plant, number of seeds/pod, and 100-seed weight, were significantly influenced by the biofortification treatments (Table 2). Treatment T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)) consistently recorded the highest values: 61.83 pods/plant, 2.12 seeds/pod, and a 100-seed weight of 24.95 g. This treatment was statistically at par with T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)). The lowest values for these attributes were observed in the control (T1).

The improvements in yield attributes are likely due to the combined application of Zn and Fe, which enhanced the availability of both macro and micronutrients. This, in turn, promoted early root growth and cell multiplication, leading to better absorption of nutrients from deeper soil layers. The increased supply of micronutrients, particularly at the reproductive stage, encouraged cell differentiation, resulting in more pods and seeds per pod, and heavier seeds. These results align with findings from Parmar and Poonia (2020), Banjara and Majgahe (2019), Saini and Singh (2017), and Shivay et al. (2014).

Regarding actual yield T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)) recorded significantly higher seed yield (1855 kg/ha) and straw yield (3518 kg/ha) compared to the control and other treatments. T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)) also showed good yields (1710 kg/ha seed yield, 3278 kg/ha straw yield) and was statistically at par with T7. Harvest index, however, did not show significant variation among treatments. The enhanced seed and straw yields are a direct consequence of improved growth and yield attributes, reflecting efficient photosynthetic activity and nutrient translocation to the economic parts of the plant. These findings are consistent with Sajid et al. (2016), Jha et al. (2020), Pandey et al. (2013), and Parimala et al. (2013).

**3.3. Nutrient Content and Uptake**

The NPK content in both chickpea seeds and straw was significantly influenced by the biofortification treatments. The highest NPK content in seed (3.37% N, 0.52% P, 2.38% K) and straw (0.99% N, 0.16% P, 1.45% K) was observed in T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)), statistically at par with T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)). The control (T1) showed the lowest NPK content.

Similarly, NPK uptake by both seed and straw was maximized by T7 (seed: 62.51 kg/ha N, 9.65 kg/ha P, 43.78 kg/ha K; straw: 34.83 kg/ha N, 5.63 kg/ha P, 51.01 kg/ha K), followed by T6. These results are in conformity with Pal et al. (2019), Shivay et al. (2015), Ali et al. (2014), and Shivay et al. (2014). The increased nutrient uptake is attributed to the positive interaction between Zn and Fe, which enhances nutrient availability and absorption. Zinc directly participates in nitrogen metabolism, while iron, a key component of chlorophyll, regulates photosynthesis and nitrogen fixation, leading to higher nitrogen acquisition (Pal et al., 2019; Hidoto et al., 2017).

**3.4. Quality Parameters**

The protein content and protein yield in chickpea seeds were significantly improved by the nutrient applications. The maximum protein content (21.06%) and protein yield (390.71 kg/ha) were recorded in T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)), significantly higher than the control (18.81% protein content, 233.28 kg/ha protein yield). T7 was statistically at par with T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)). This enhancement is primarily due to the higher nitrogen content in seeds under these treatments, as nitrogen is actively involved in protein synthesis. These findings are supported by Bhadoria (2018) and Chaudhari et al. (2021).

**3.5. Economics**

The economic analysis revealed that agronomic biofortification of zinc and iron significantly improved the net returns and benefit-cost (B:C) ratio of chickpea cultivation. The highest net return (₹66925/ha) and B:C ratio (1.91) were obtained with T7 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% FeSO4​ (FA)). This treatment was statistically at par with T6 (ZnSO4​ @ 25 kg/ha (SA) + 0.5% ZnSO4​ (FA)). The control (T1) recorded the lowest net return (₹43300/ha) and B:C ratio (1.74).

The superior economic performance of T7 is attributed to its ability to produce significantly higher grain and straw yields while maintaining a relatively efficient cost structure. This demonstrates that the combined soil and foliar application of zinc and iron is an economically viable approach for chickpea production. These economic findings are consistent with previous studies by Pal et al. (2019), Pal (2018), Kapilashiv (2017), Shivay et al. (2014), Jat et al. (2015), and Naik and Das (2008).

**4. Conclusion**

The present investigation unequivocally demonstrates that agronomic biofortification of chickpea with zinc and iron significantly enhances growth, yield, quality, and economic returns under irrigated conditions. The integrated application of ZnSO4​ @ 25 kg/ha (soil application) + 0.5% FeSO4​ (foliar application) (T7) emerged as the most effective treatment. This holistic approach led to significant improvements in plant height, dry matter accumulation, branching, pods per plant, seeds per pod, 100-seed weight, and ultimately, higher grain and straw yields. Beyond quantitative gains, T7 also improved the nutritional quality of chickpea seeds by increasing NPK content and protein content.

Economically, the application of T7 resulted in the highest net return and a favorable benefit-cost ratio, proving its economic viability and profitability for farmers. While the results are based on one year of experimentation, they strongly suggest that zinc and iron biofortification is a promising strategy for sustainable chickpea production, addressing both yield enhancement and nutritional security. Further validation through multi-year trials would solidify these recommendations for broader agricultural adoption.

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**Table 1 Effect of Zinc and Iron Biofortification on growth attributes and quality of chickpea**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Treatments | Plant height (cm) | DMA (g/mrl) | No. of branches/plant | Protein content (%) |
| Control | 53.24 | 16.80 | 3.55 | 18.81 |
| ZnSO4 @ 12.5 kg/ha (SA) | 58.13 | 19.42 | 4.33 | 20.13 |
| FeSO4 @ 12.5 kg/ha (SA) | 57.17 | 18.16 | 4.16 | 19.94 |
| ZnSO4 @ 25 kg/ha (SA) | 60.84 | 20.35 | 4.62 | 20.38 |
| FeSO4 @ 25 kg/ha (SA) | 59.32 | 19.62 | 4.44 | 20.25 |
| ZnSO4 @ 25 kg/ha (SA) + 0.5% ZnSO4 (FA) | 64.25 | 21.37 | 5.15 | 21.00 |
| ZnSO4 @ 25 kg/ha (SA) + 0.5% FeSO4 (FA) | 67.76 | 22.46 | 5.63 | 21.06 |
| FeSO4 @ 25 kg/ha (SA) + 0.5% ZnSO4 (FA) | 62.21 | 20.36 | 4.91 | 20.94 |
| FeSO4 @ 25 kg/ha (SA) + 0.5% FeSO4 (FA) | 61.81 | 19.92 | 4.73 | 20.81 |
| S.Em.+ | 1.19 | 0.47 | 0.14 | 0.18 |
| CD (P=0.05) | 3.58 | 1.43 | 0.43 | 0.53 |

**Table 2 Effect of Zinc and Iron Biofortification on yield attributes and yield of chickpea**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Pods/plant (No.)** | **Seeds/pod (No.)** | **Seed index (g)** | **Seed yield (kg/ha)** | **Straw yield (kg/ha)** |
| Control | 44.14 | 1.74 | 23.31 | 1240 | 2625 |
| ZnSO4 @ 12.5 kg/ha (SA) | 51.33 | 1.89 | 23.94 | 1460 | 2895 |
| FeSO4 @ 12.5 kg/ha (SA) | 49.66 | 1.87 | 23.85 | 1425 | 2840 |
| ZnSO4 @ 25 kg/ha (SA) | 52.92 | 1.91 | 24.29 | 1550 | 3040 |
| FeSO4 @ 25 kg/ha (SA) | 52.04 | 1.90 | 24.12 | 1525 | 3015 |
| ZnSO4 @ 25 kg/ha (SA) + 0.5% ZnSO4 (FA) | 57.75 | 2.06 | 24.64 | 1710 | 3278 |
| ZnSO4 @ 25 kg/ha (SA) + 0.5% FeSO4 (FA) | 61.83 | 2.12 | 24.95 | 1855 | 3518 |
| FeSO4 @ 25 kg/ha (SA) + 0.5% ZnSO4 (FA) | 56.06 | 1.93 | 24.59 | 1630 | 3170 |
| FeSO4 @ 25 kg/ha (SA) + 0.5% FeSO4 (FA) | 54.35 | 1.92 | 24.46 | 1590 | 3110 |
| S.Em.+ | 1.74 | 0.04 | 0.12 | 51.66 | 78.33 |
| CD (P=0.05) | 5.22 | 0.12 | 0.36 | 155 | 235 |

**Fig. 1 Effect of Zinc and Iron Biofortification on economics of chickpea**