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# EVALUATING THE IMPACT OF ZINC AND IRON BIOFORTIFICATION ON PIGEONPEA, CONCERNED WITH A BENEFIT-COST ASSESSMENT

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**ABSTRACT**

Nutritional security is a primary goal of India's 2030 Vision and aligns with the UN Sustainable Development Goal 3. Pigeonpea, a climate-resilient legume, is highly nutritious and significantly combating malnutrition in regions like Asia, Africa and the Caribbean. However, the yield and nutritional quality of pigeonpea are frequently limited by deficiencies in essential micronutrients, especially zinc (Zn) and iron (Fe). This study examines the impact of agronomic fortification with zinc (Zn) and iron (Fe) on growth, yield parameters, overall yield, and economic benefits of pigeonpea. The experiment was conducted over two years i.e., during 2022-23 and 2023-24 using a Randomized Block Design (RBD) with nine treatments and three replications. Agronomic fortification included the foliar application of zinc (Zn) and iron (Fe) during the flowering and pod development stages were applied to pigeonpea (*Cajanus cajan* L.) in sandy loam soil. Two years were treated as replication, and the pooled data were analyzed to evaluate the effects of different modes of micronutrient application on growth and yield. The results show that among the nine treatments, $T_8$ (foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation) recorded the highest values for plant height (183.83 cm), branches per plant (14.34), pods per plant (144.50), grains per pod (4.33), 100-grain weight (8.95 g), grain yield (2840.74 kg/ha), biological yield (8358.02 kg/ha) and harvest index (34.35%). Additionally, $T_3$ (foliar application of 0.50% $FeSO_4$ at flower initiation) resulted in a significantly higher plant population. Meanwhile, $T_7$ (foliar application of 0.50% $FeSO_4$ at flower and pod initiation) recorded the highest benefit-cost (B: C) ratio among all treatments, including the control. The combined use of zinc and iron significantly improved the growth and yield of pigeonpea, demonstrating its potential as a sustainable solution to micronutrient deficiencies and increased crop productivity. Additionally, it positively impacted economic conditions by raising the benefit-cost (B: C) ratio.

***Key words :*** Biofortification, Benefit-cost, Foliar, Micronutrients, Pigeonpea.

## Introduction

Micronutrient deficiency, also called "Hidden Hunger" occurs when the body lacks essential vitamins and minerals needed in small amounts for proper growth, development, and health. This issue is common in developing countries, where limited access to a diverse, nutritious diet makes it challenging to obtain necessary micronutrients. Unlike cereals, Legumes offer a nutritious and balanced source of calories and protein, making them vital for food security, especially in semi-arid regions (Varshney *et al*., 2022).

Pigeonpea [*Cajanus cajan* (L.) Millsp.], or red gram or Tur, is a versatile legume widely grown in tropical and subtropical regions for its high protein content and nitrogen-fixing ability, which improves soil fertility. It is grown for food, fodder, fuel wood, hedges, windbreaks, soil conservation, green manuring, medicinal properties, and roofing (Ratnaparkhe *et al*., 2007; Gaur *et al*., 2021). Nutritionally, pigeonpea grain is rich in protein, Ca, Mn, and crude fiber (Saxena *et al*., 2010). Furthermore, the nutrient accumulation varied with the seed developmental stage, Fe and Zn are rich at the green stage, whereas protein, starch, Mn, and Ca are high at the grain stage (Singh *et al*., 1984). Unlike cereals, Zn and Fe are enriched in the cotyledons; thus, the processing does not affect the availability of these minerals (Susmitha *et al*., 2022). However, pigeonpea often suffers from mineral nutrient deficiencies, particularly in zinc (Zn) and iron (Fe), essential for plant growth, development, overall yield, and economic enhancement. Deficiencies in zinc and iron in pigeonpea can result in stunted growth, reduced yields, and diminished nutritional quality, creating major challenges for food security and economic stability in regions dependent on this crop.

Zinc is an essential micronutrient for both plants and humans, supporting a range of vital physiological processes such as immune function, protein and DNA synthesis, wound healing, and the metabolism of carbohydrates, proteins, and fats. In plants, zinc is vital for growth, yield and disease resistance, and its deficiency can result in stunted growth and decreased productivity. In humans, it acts as a cofactor for enzymes crucial to metabolism, immune function, and DNA synthesis, and its deficiency impairing these processes. Zinc deficiency in soil affects plant growth, yield in pigeonpea (Behera *et al*., 2021). Thus, maintaining sufficient zinc levels in both plant nutrition and human diets is essential for promoting sustainable agriculture and supporting human health.

Iron is a vital micronutrient for nearly all living organisms due to its critical role in metabolic processes like DNA synthesis, respiration, and photosynthesis. Additionally, iron activates various metabolic pathways and serves as a prosthetic group in many enzymes. Iron is crucial for various physiological and biochemical processes in plants, serving as a component of essential enzymes like cytochromes in the electron transport chain, and is vital for chlorophyll synthesis as well as the maintenance of chloroplast structure and function (Gyana *et al*., 2015). In humans, iron is vital for producing red blood cells and transporting oxygen throughout the body. It also supports the immune system, provides energy and helps maintain healthy skin, hair and nails (Avnee *et al*., 2023). Therefore, ensuring sufficient iron availability in soil for plants and in human diets is essential for sustainable agriculture and overall well-being. It was observed that pigeonpea genotypes with increased iron and zinc content exhibited improved agronomic traits, including higher grain yield. To enhance micronutrient levels in the edible parts of plants, organic or inorganic fertilizers and biofertilizers containing micronutrients are applied through foliar or soil methods. This suggests the potential to develop varieties with both enhanced nutritional value and yield (Singh *et al*., 2019).

Therefore, efforts have been made to develop pigeonpea varieties with enhanced nutritional value, primarily through multi-nutrient fortification, aimed at improving food security and public health. In response to widespread zinc and iron deficiencies, this study was conducted to assess the impact of foliar application of Fe and Zn salts on their concentration in pigeonpea (Amar variety) and to evaluate the economic benefits by analyzing the benefit-cost ratio.

## Materials and Methods

### Experimental site

The study aimed to investigate how different applications of micronutrient fortification affect the yield of pigeonpea (*Cajanus cajan* L.) in a field and make it economically profitable. The experiment was conducted at Crop Experimental Research Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kalyanpur, Kanpur in 2022-23 and 2023-24. The soil of the experimental field was sandy loam having 0.03% O.C., 196.00 kg ha$^{-1}$ available N, 25.20 kg ha$^{-1}$ available $P_2O_5$ and available $K_2O$ was 175.00 kg ha$^{-1}$ with 7.98 pH.

### Experimental design and Treatment details

Amar variety of pigeonpea was grown in a randomized block design (R.B.D.) in three replications along with 9 treatments. Total of 9 treatments was used *viz*., $T_1$ [RDF *i.e.*, Absolute Control (NPKS)], $T_2$ (Foliar application of 0.50% $ZnSO_4$ at flower initiation), $T_3$ (Foliar application of 0.50% $FeSO_4$ at flower initiation), $T_4$ (Foliar application of 0.50% $ZnSO_4$ at pod initiation), $T_5$ (Foliar application of 0.50% $FeSO_4$ at pod initiation), $T_6$ (Foliar application of 0.50% $ZnSO_4$ at flower and pod initiation), $T_7$ (Foliar application of 0.50% $FeSO_4$ at flower and pod initiation), $T_8$ (Foliar application of 0.50% $ZnSo_4$ + 0.50% $FeSO_4$ at flower and pod initiation), $T_9$ (Water spray control), respectively.

It was raised in 8 lines with a row-to-row distance of 75 cm and a plant-to-plant distance of 25 cm as a gross plot (24 m$^2$). The seed rate is 18 kg/ha and the seed material status is good for raising a good crop. The two-year study was treated as a replication and the pooled data were analyzed to assess the effects of various micronutrient application methods on the growth, yield, and overall economic prosperity of pigeonpea cultivation.

Growth and yield parameters were recorded at harvest, and the economic analysis was conducted based on input costs, labor expenses and output prices throughout the study. The analysis of variance and all data analysis were done using the open-source software OPSTAT.

## Result and Discussion

### Effect of different Treatments on different Parameters of Pigeonpea

This study examined the impact of different foliar applications on plant growth, yield attributes and economic returns in a controlled field setting. Observations across treatments highlighted variations in plant population, growth parameters, yield components and financial gains, revealing significant effects due to the foliar applications of zinc (Zn) and iron (Fe) at different growth stages.

### Effect of Treatments on Plant Population, Branches per plant and Grains per pods

The study measured plant population across all treatments, revealing no significant differences. Plant population values ranged narrowly from 63.00 to 65.33 plants per plot (Table 1), with most treatments ($T_1 – T_9$) showing similar results. These small variations suggest that foliar applications of zinc and iron at different stages (flower and pod initiation) had no significant impact on plant population, indicating that differences in application timing and combinations of treatments were non-significant (Fig. 1) in influencing plant population/density.

Similarly, the number of branches per plant showed minimal variation, with values ranging from 13.17 to 14.34 (Table 1). Although treatments such as $T_4$, $T_5$, $T_6$, $T_7$ and $T_8$ showed slightly higher branch counts, these differences were not statistically significant (Fig. 1), suggesting that the foliar sprays did not have a meaningful effect on branching. In contrast to the above results, Rehaman *et al.* (2024) observed a significantly higher number of branches per plant with the foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ applied at both flower and pod initiation stages, recording notably increased values. Whereas, Saakshi *et al.* (2020) observed significantly higher number of branches was recorded with RDF + soil application of $ZnSO_4$ @ 15 kg $ha^{-1}$ fb foliar application of 0.5% Zn EDTA.

The grains per pod also exhibited minor variation, ranging from 3.50 to 4.33 (Table 1), with $T_8$ (a combination of $ZnSO_4$ and $FeSO_4$ applied at flower and pod initiation) showing the highest grain count. However, this difference was also non-significant (Fig. 1), indicating that treatment variations had little effect on grain production per pod. Similar findings in pigeonpea were reported by Kailas *et al.* (2019).

### Effect of different Treatments on Plant height

The results for plant height across treatments showed

**Table 1 :** Effect of various Treatments on Growth parameters and Yield attributes of Pigeonpea.

| Treatments | Plant population | Plant height(cm) | Branches / plant | Pods per plant | Grains per pod | 100 grain wt. (g) |
|---|---|---|---|---|---|---|
| **$T_1$:** RDF (absolute control) | 63.33 | 176.67 | 13.50 | 130.00 | 3.67 | 8.25 |
| **$T_2$:** Foliar application of 0.50% $ZnSO_4$ at flower initiation | 64.67 | 177.50 | 13.50 | 136.83 | 3.50 | 8.53 |
| **$T_3$:** Foliar application of 0.50% $FeSO_4$ at flower initiation | 65.33 | 178.17 | 13.67 | 136.34 | 3.67 | 8.54 |
| **$T_4$:** Foliar application of 0.50% $ZnSO_4$ at pod initiation | 63.00 | 178.84 | 14.00 | 137.83 | 3.84 | 8.61 |
| **$T_5$:** Foliar application of 0.50% $FeSO_4$ at pod initiation | 63.00 | 179.67 | 14.17 | 140.00 | 3.67 | 8.62 |
| **$T_6$:** Foliar application of 0.50% $ZnSO_4$ at flower and pod initiation | 65.33 | 180.50 | 14.17 | 142.00 | 4.00 | 8.74 |
| **$T_7$:** Foliar application of 0.50% FeSo4 at flower and pod initiation | 63.00 | 182.67 | 14.00 | 142.00 | 3.84 | 8.79 |
| **$T_8$:** Foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation | 63.67 | **183.83** | 14.34 | **144.50** | 4.33 | **8.95** |
| **$T_9$:** Water spray (control) | 64.33 | 179.50 | 13.17 | 133.00 | 3.50 | 8.47 |
| C.D. | **N/A** | 3.076 | **N/A** | 4.380 | **N/A** | 0.191 |
| SE(m) | 1.61 | 0.929 | 0.251 | 1.323 | 0.148 | 0.058 |
| SE(d) | 2.276 | 1.314 | 0.355 | 1.871 | 0.209 | 0.082 |
| C.V. | 4.359 | 0.731 | 2.567 | 1.355 | 5.541 | 0.950 |

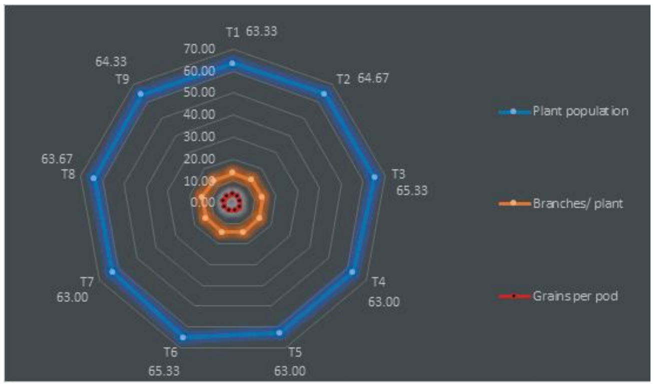


**Fig. 1 :** Non-significant characters.

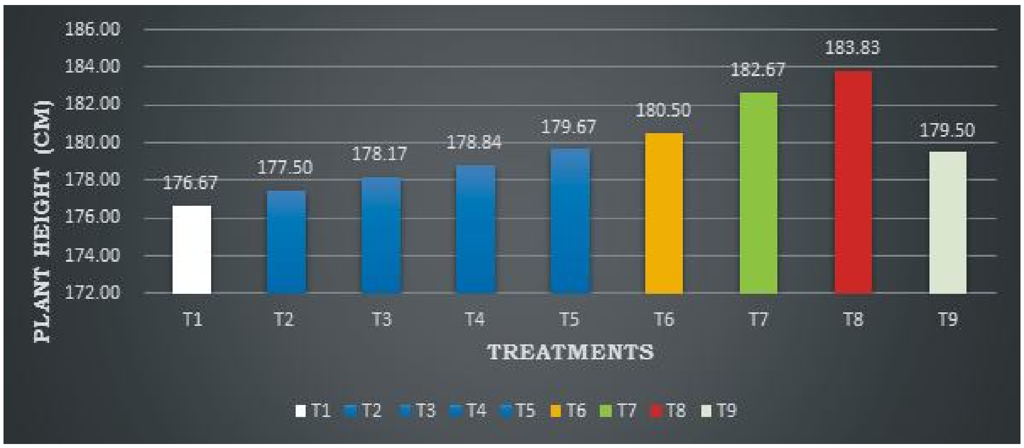


**Fig. 2 :** Plant height(cm).

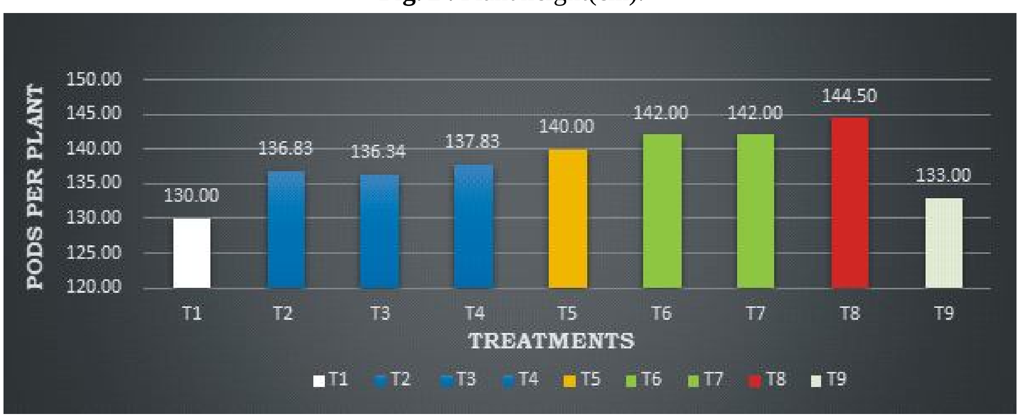


**Fig. 3 :** Pods per plant.

a range from 176.67 cm to 183.83 cm (Table 1). Foliar applications of $ZnSO_4$ and $FeSO_4$ at different stages, either separately or in combination, resulted in progressively taller plants. The highest plant height was recorded in $T_8$ (183.83 cm), (Fig. 2), where a combination of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ was applied at both flower and pod initiation stages followed by $T_7$ (182.67 cm) with 0.50% $FeSO_4$ and $T_6$ (180.50 cm) with 0.50% $ZnSO_4$ at flower and pod initiation. In contrast, the lowest plant height was observed in $T_1$ (176.67 cm), the RDF (absolute control) treatment. Similar findings in pigeonpea were reported by Rehaman *et al.* (2024) and Hanumanthappa *et al.* (2018).

**Effect of different Treatments on Pods per plant**

The results indicated that the number of pods per plant across the treatments ranged from 130.00 to 144.50 (Table 1). The highest value was observed in $T_8$ (foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation) with 144.50 pods per plant *(Fig 3)*, followed by $T_7$ (0.50% $FeSO_4$ at flower and pod initiation) and $T_6$ (0.50% $ZnSO_4$ at flower and pod initiation), both showing 142.00 pods per plant (Fig. 3). $T_5$ (foliar application of 0.50% $FeSO_4$ at pod initiation) resulted in 140.00 pods per plant, showing a moderate increase in pod production compared to the controls ($T_1$ and $T_9$), suggesting a positive effect of $FeSO_4$ application at pod initiation. These findings suggest that the combined foliar application of zinc and iron at flower and pod initiation significantly increased the number of pods per plant.

Similar results were observed by *Rehaman et al. (2024)*. However, Saakshi *et al*. (2020) found that RDF + Soil application of $ZnSO_4$ at 15 kg $ha^{-1}$ resulted in the highest number of pods per plant. Whereas, Meena *et al*. (2020) observed that RDF combined with a multi-

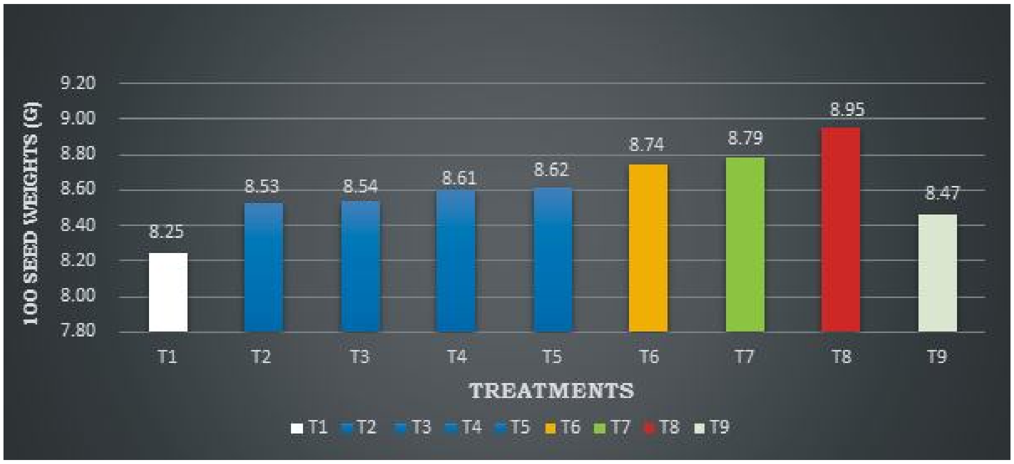


**Fig. 4 :** 100 grain wt. (g).

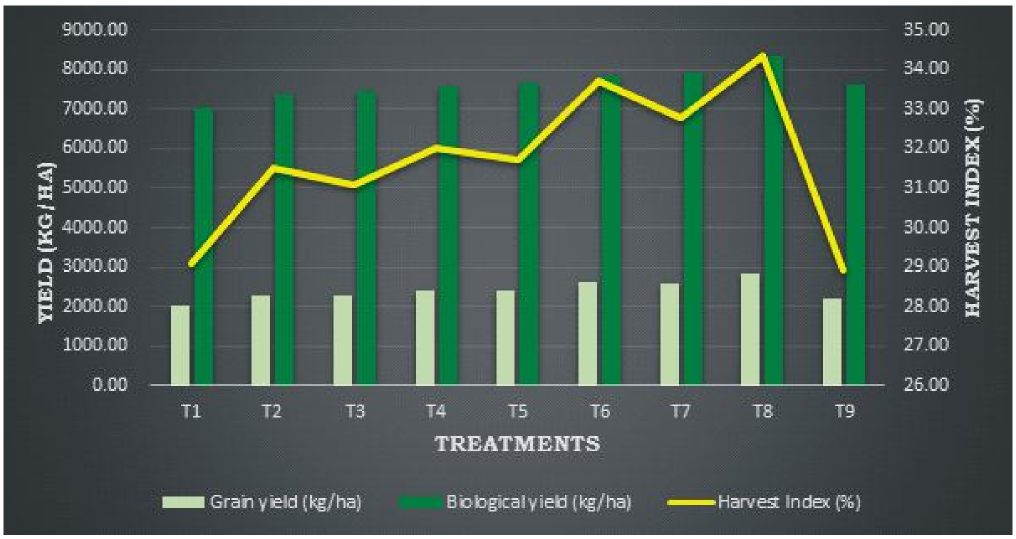


**Fig. 5 :** Yield.

micronutrient spray (Zn 5.0%, Mn 2.0%, Fe 2.0%, B 0.5%, Cu 0.5% and Mo 0.05%) at 2 ml $L^{-1}$ applied at 50% flowering resulted in the highest number of pods per plant.

**Effect of different Treatments on 100 grain wt. (g)**

The 100-grain weight across treatments ranged from 8.25 to 8.95 g (Table 1). The highest value was observed in $T_8$ with a 100-grain weight of 8.95 g (Fig. 4), followed by $T_7$ (8.79 g) and $T_6$ (8.74 g). In contrast, the control treatment $T_1$ (8.25 g) had a lowest 100-grain wt. (Fig. 4).

These results indicate that the combined foliar application of zinc and iron at flower and pod initiation led to the greatest increase in 100-grain weight. Similar results were also reported by Borah *et al.* (2021) with a 0.50% Zn application (23.8 g $ZnSO_4$/L water) in garden pea and by Elumle Priyanka *et al.* (2019) in pigeonpea.

**Effect of different treatments on Yield of Pigeonpea**

The study results show that grain yield, biological yield, and harvest index were highest in $T_8$ (foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation) with values of 2840.74 kg/ha, 8358.02 kg/ha and 34.35%, respectively (Table 2, Fig. 5). While the control treatment $T_1$ showed the lowest grain yield and harvest index at 2030.86 kg/ha and 29.10%, respectively. Similar result was also observed by Rehaman *et al.* (2024); Farooq (2022). This treatment was followed by $T_6$ (0.50% $ZnSO_4$ at flower and pod initiation) with a grain yield of 2623.46 kg/ha, biological yield of 7851.85 kg/ha and harvest index of 33.71%. Yashona *et al.* (2020) also reported that application of zinc 5/ 2.5 kg/ha + FYM @ 5 t/ha with foliar application of $ZnSO_4$ @ 0.5% at flowering initiation and pod initiation significantly increased the yield of pigeonpea. Similar result is also observed by Behera *et al.* (2021). Meanwhile, $T_7$ (0.50% $FeSO_4$ at flower and pod initiation) also showed relatively high values, with a grain yield of 2580.25 kg/ha, biological yield of 7925.92 kg/ha and harvest index of 32.80% (Fig. 5). In contrast, the study

**Table 2 :** Effect of various Treatments on Yield and Economics of pigeonpea.

| Treatment | Grain yield (kg/ha) | Biological yield (kg/ha) | Harvest Index (%) | Gross income (Rs. /ha) | B:C Ratio |
|---|---|---|---|---|---|
| **$T_1$:** RDF (absolute control) | 2030.86 | 7049.38 | 29.10 | 180308.50 | 2.09 |
| **$T_2$:** Foliar application of 0.50% $ZnSO_4$ at flower initiation | 2296.29 | 7395.05 | 31.52 | 203456.60 | 2.25 |
| **$T_3$:** Foliar application of 0.50% $FeSO_4$ at flower initiation | 2286.42 | 7462.96 | 31.10 | 203160.30 | 2.27 |
| **$T_4$:** Foliar application of 0.50% $ZnSO_4$ at pod initiation | 2401.24 | 7575.30 | 32.03 | 214456.60 | 2.37 |
| **$T_5$:** Foliar application of 0.50% $FeSO_4$ at pod initiation | 2419.75 | 7691.35 | 31.73 | 215802.30 | 2.41 |
| **$T_6$:** Foliar application of 0.50% $ZnSO_4$ at flower and pod initiation | 2623.46 | 7851.85 | 33.71 | 233888.70 | 2.46 |
| **$T_7$:** Foliar application of 0.50% $FeSO_4$ at flower and pod initiation | 2580.25 | 7925.92 | 32.80 | 233456.60 | **2.51** |
| **$T_8$:** Foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation | **2840.74** | **8358.02** | **34.35** | **250901.00** | 2.48 |
| **$T_9$:** Water spray (control) | 2191.36 | 7617.28 | 28.93 | 199691.20 | 2.29 |
| C.D. | 190.194 | 396.902 | 1.912 | 16,634.255 | — |
| SE(m) | 57.430 | 119.846 | 0.577 | 5,501.085 | — |
| SE(d) | 81.218 | 169.488 | 0.816 | 7,779.709 | — |
| C.V. | 3.373 | 2.213 | 2.576 | 4.431 | — |

by Rai *et al.* (2023) found that the foliar application of RDF + 0.5% $FeSO_4$ at Flower initiation, resulted in a decrease in yield in pigeonpea.

These results indicate that combined foliar applications of Zn and Fe at flower and pod initiation stages positively influenced yield parameters, especially in $T_8$, compared to control and other treatments.

### Effect of different treatments on Economics of Pigeonpea

The results indicate that the highest gross income was achieved with $T_8$ (foliar application of 0.50% $ZnSO_4$ + 0.50% $FeSO_4$ at flower and pod initiation), yielding Rs. 250,901 per hectare with a B:C ratio of 2.48. However, the highest benefit-cost (B:C) ratio was recorded in $T_7$ i.e., 2.51 (foliar application of 0.50% $FeSO_4$ at flower and pod initiation), demonstrating that while $T_8$ maximized gross income, $T_7$ offered the most cost-effective return. Almost similar result found by Rehaman *et al.* (2024) with foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ at flower and pod initiation and Saakshi *et al.* (2020) with RDF + soil application of $ZnSO_4$ @ 15 kg $ha^{-1}$ fb foliar application of 0.5% Zn EDTA in pigeonpea.

## Conclusion

In conclusion, all treatments had similar effects on plant population, branches per plant, and grains per pod, indicating that foliar applications of zinc and iron at various growth stages did not significantly alter these growth parameters. However, foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ at both flower and pod initiation was effective in enhancing the growth, yield and economic return of pigeonpea. Based on this study, it is recommended that pigeonpea be fertilized with 100% RDF combined with a 0.5% foliar spray of $ZnSO_4$ + 0.5% $FeSO_4$ at flower and pod initiation stages to achieve optimal yield and profitability.

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