



Effect of Agronomic Biofortification of Zn and Fe on Growth, Yield and Economics of Pigeonpea

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Pigeonpea (*Cajanus cajan*) is a major leguminous crop providing substantial nutritional benefits, especially protein to millions of people worldwide. However, its yield and nutritional quality are often constrained by micronutrient deficiencies, particularly zinc (Zn) and iron (Fe). This study investigates the effects of agronomic fortification with Zn and Fe on the growth, yield parameters and overall yield of pigeonpea. The experiment was conducted through a randomized complete block design with nine treatments and replicated thrice. Agronomic fortification involved foliar application of Zn and Fe at flowering and pod development stages. Results indicated that among different treatments the combined foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation recorded significantly higher plant height (156.7 cm), number of branches per plant

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(16.8), number of pods per plant (98.5), number of seeds per pod (5.4), pod weight per plant (128.5 g), seed weight per plant (83.5 g), seed yield (1056 kg ha⁻¹) and stalk yield (2503 kg ha⁻¹) in the fortified treatments compared to the control. Notably, the combined Zn-Fe fortification exhibited the most pronounced effects on growth and yield parameters. Overall, agronomic fortification with Zn and Fe positively influenced the growth, yield parameters and yield of pigeonpea, suggesting its potential as a sustainable strategy to alleviate micronutrient deficiencies and enhance crop productivity in pigeonpea cultivation systems.

Keywords: Pigeonpea; fortification; zinc; iron; growth; yield.

1. INTRODUCTION

Pigeonpea (*Cajanus cajan*) is an important legume crop cultivated in many tropical and subtropical regions, primarily for its high protein content and ability to fix atmospheric nitrogen, which enhances soil fertility. However, pigeonpea often suffers from mineral nutrient deficiencies, particularly zinc (Zn) and iron (Fe), which are essential for plant growth, development, and overall yield. Zinc and iron deficiencies in pigeonpea can lead to stunted growth, reduced yield, and lower nutritional quality, posing significant challenges to food security and economic prosperity in regions reliant on this crop.

Zinc (Zn) plays a crucial role in both plant physiology and human nutrition. In plants, zinc is an essential micronutrient involved in various biochemical and physiological processes, including enzyme activation, protein synthesis, photosynthesis, and hormone regulation. Zinc deficiency in plants can lead to stunted growth, reduced yield, and susceptibility to diseases. Moreover, zinc is also important for human health, where it functions as a cofactor for numerous enzymes involved in metabolism, immune function and DNA synthesis. Zinc deficiency in humans can result in impaired growth and development, weakened immune system or increased susceptibility to infections. Therefore, ensuring an adequate supply of zinc in both plant nutrition and human diets is crucial for sustainable agriculture and human health.

Iron (Fe) is an essential micronutrient critical for both plant growth and human health. In plants, iron plays a key role in photosynthesis, respiration, DNA synthesis, and nitrogen fixation. Iron deficiency in plants can result in chlorosis, reduced growth, and decreased yield. In human nutrition, iron is vital for oxygen transport as a component of hemoglobin in red blood cells and as a cofactor for various enzymes involved in energy metabolism. Iron deficiency in humans leads to anemia, fatigue, impaired cognitive

function, and compromised immune response. Therefore, ensuring adequate iron availability in soil for plants and in diets for humans is crucial for sustainable agriculture and human well-being reported by Briat et al. [1].

Agronomic biofortification of zinc (Zn) and iron (Fe) in pigeonpea (*Cajanus cajan*) involves targeted nutrient management strategies to enhance the levels of these essential micronutrients in the edible parts of the crop. Pigeonpea, being a valuable legume crop rich in protein and important nutrients, can benefit significantly from biofortification practices to improve its nutritional value reported by Media et al. [2]. Studies have shown that optimizing soil nutrient availability through fertilization techniques can increase the uptake and accumulation of Zn and Fe in pigeonpea plants, leading to enhanced levels of these micronutrients in seeds of pigeonpea reported by Kumar et al. [3]. Agronomic biofortification not only contributes to addressing Zn and Fe deficiencies in soils but also offers a sustainable solution to improve the dietary intake of these vital nutrients, especially in regions where pigeonpea is a dietary staple. Research efforts focusing on agronomic biofortification in pigeonpea hold promise for enhancing food and nutritional security, particularly in populations reliant on pigeonpea-based diets.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

The field experiment took place during the *Kharif* season of 2023 in red sandy loam soil at the Zonal Agricultural Research Station, Gandhi Krishi Vigyana Kendra, University of Agricultural Sciences, Bangalore. This research site located in the Eastern Dry Zone (Zone-V) of Karnataka, known for its characteristic red soils and primarily rainfed ecosystem. Initially, the soil pH measured 6.3, with an electrical conductivity of 0.16 dS m⁻¹. The organic carbon content was

found to be 0.43 per cent, indicating a moderate level. The soil found to have exhibited medium levels of available nutrients, with nitrogen at 285.4 kg ha⁻¹, phosphorus at 38.2 kg ha⁻¹ and potassium at 258.2 kg ha⁻¹.

2.2 Design of Experiment and Treatment Details

The field experiment was laid out in Randomized complete block design (RCBD) replicated thrice with 9 treatments viz., T₁: RDF (Absolute control); T₂: Foliar application of 0.5% ZnSO₄ at flower initiation; T₃: Foliar application of 0.5% FeSO₄ at flower initiation; T₄: Foliar application of 0.5% ZnSO₄ at pod initiation; T₅: Foliar application of 0.5% FeSO₄ at pod initiation; T₆: Foliar application of 0.5 % ZnSO₄ at flower and pod initiation; T₇: Foliar application of 0.5% FeSO₄ at flower and pod initiation; T₈: Foliar application of 0.5% ZnSO₄ + 0.5% FeSO₄ at flower and pod initiation; T₉: RDF +Water spray (control).

2.3 Methodology

The land was ploughed and made to fine seed bed. The recommended dose of fertilizers (25:50:25 NPK kg ha⁻¹) was given for the crop in the form of urea, diammonium phosphate and muriate of potash as basal dose. Healthy and bold, certified seeds of pigeonpea (BRG-4) were used for sowing with spacing of 90×15 cm. Weeding and plant protection measures were undertaken as per need and required plant population was maintained by thinning and gap filling. The crops were harvested at their physiological maturity. Growth and yield parameters and yield were recorded at harvest and the economics was worked out based on the cost of inputs, labour costs and price of output during the course of study. Fischer's method of analysis of variance was used for analysis and interpretation of the data as outlined by Gomez and Gomez [4].

3. RESULTS AND DISCUSSION

3.1 Effect of Foliar Application of Zn and Fe on Growth Parameters of Pigeonpea

The data pertaining to growth attributes of pigeonpea at harvest as influenced by agronomic fortification of pigeonpea with Zn and Fe are presented in Table 1. Among the

different treatments, the treatments (T₈) foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation recorded significantly higher values of growth contributing characters of pigeonpea viz., plant height (156.7 cm), total branches per plant (16.8), leaf area (5542.2 cm² plant⁻¹) and total dry matter production (118.2 g plant⁻¹) followed by treatment (T₆) foliar application of 0.5 % ZnSO₄ at flower and pod initiation (155.8 cm, 16.3 plant⁻¹, 5216.5 cm² plant⁻¹ and 112.6 g plant⁻¹, respectively). Whereas, significantly lower values noticed in application of RDF only (Absolute control).

The observed outcomes can be attributed to the enhanced availability of zinc and iron in deficient soil, facilitated through foliar application of zinc sulphate and iron sulphate. This process involves their better absorption and translocation within the plant. The foliar spray of zinc (Zn) and iron (Fe) in a bioavailable form is readily taken up by the aerial parts of the plant, subsequently moving towards the growing tip. This action stimulates auxin activity at the crop's growth point, thereby enhancing quality of the young shoot. Zinc plays a crucial role in regulating chlorophyll and carotenoid synthesis, vital for optimal functioning of the photosynthetic system. The application of zinc promotes activity in meristematic cells and cell elongation, positively impacting metabolic processes. The heightened metabolic activity, facilitated by increased nutrient supply, leads to greater accumulation of dry matter in leaves. This accumulation aids in maintaining an active photosynthetic area for an extended period, contributing significantly to overall plant growth in terms of dry matter production. The higher dry matter production due to the application of zinc is ascribed to the vigorous and enhanced plant growth and also to higher leaf area development that aided in the effective interception of light leading to higher dry matter production. This result is in conformity with the findings of Sharma et al. [5] in pigeonpea and Verma et al. [6] in lentil. The lower growth in Absolute control due to poor nutrient uptake compared to lack of synergistic effect in absence of micronutrient. Similar results were also reported by Kaur et al. [7] in lentil, Farooq [4] in pigeonpea, Borah et al. [8] in pea, Behera et al. [9] in pigeonpea, Saakshi, [10] in pigeonpea Uma [11] in maize and Kailas et al. [12] in pigeonpea.

Table 1. Effect of foliar application of Zn and Fe on growth parameter of pigeonpea at harvest

Treatments	Plant height (cm)	Total number of branches plant ⁻¹	Total leaf area (cm ² plant ⁻¹)	Total dry matter accumulation (g plant ⁻¹)
T ₁ : RDF (Absolute control)	149.1	12.4	2786.6	78.7
T ₂ : Foliar application of 0.5 % ZnSO ₄ at flower initiation	153.3	15.7	4615.2	104.5
T ₃ : Foliar application of 0.5 % FeSO ₄ at flower initiation	151.8	14.7	3994.5	88.5
T ₄ : Foliar application of 0.5 % ZnSO ₄ at pod initiation	152.8	15.1	4012.4	97.4
T ₅ : Foliar application of 0.5 % FeSO ₄ at pod initiation	151.1	14.2	3546.2	85.2
T ₆ : Foliar application of 0.5 % ZnSO ₄ at flower and pod initiation	155.8	16.3	5216.5	112.6
T ₇ : Foliar application of 0.5 % FeSO ₄ at flower and pod initiation	154.2	16.0	4968.4	110.5
T ₈ : Foliar application of 0.5 % ZnSO ₄ + 0.5 % FeSO ₄ at flower and pod initiation	156.7	16.8	5542.2	118.2
T ₉ : RDF +Water spray (control)	150.5	13.5	2946.6	74.5
S.Em. ±	5.46	1.13	97.58	2.26
C.D. at 5%	16.37	3.38	280.77	6.49

Table 2. Effect of foliar application of Zn and Fe on yield attributes of pigeonpea

Treatments	No of pods plant ⁻¹	No of seeds pod ⁻¹	Pod yield (g plant ⁻¹)	Seed yield (g plant ⁻¹)	Stalk yield (g plant ⁻¹)	Test weight (g)
T ₁ : RDF (Absolute control)	87.2	4.3	84.5	52.5	62.6	14.0
T ₂ : Foliar application of 0.5 % ZnSO ₄ at flower initiation	96.1	5.1	115.0	73.0	102.0	14.9
T ₃ : Foliar application of 0.5 % FeSO ₄ at flower initiation	92.7	4.8	103.1	65.0	93.0	14.6
T ₄ : Foliar application of 0.5 % ZnSO ₄ at pod initiation	94.8	5.0	110.6	69.7	97.2	14.7
T ₅ : Foliar application of 0.5 % FeSO ₄ at pod initiation	91.2	4.7	99.1	62.2	87.5	14.5
T ₆ : Foliar application of 0.5 % ZnSO ₄ at flower and pod initiation	97.7	5.3	124.3	80.8	112.1	15.6
T ₇ : Foliar application of 0.5 % FeSO ₄ at flower and pod initiation	97.2	5.2	122.4	78.3	108.4	15.5
T ₈ : Foliar application of 0.5 % ZnSO ₄ + 0.5 % FeSO ₄ at flower and pod initiation	98.5	5.4	128.5	83.5	116.2	15.7
T ₉ : RDF + Water spray (control)	89.2	4.5	91.2	57.0	76.8	14.2
S.Em. ±	2.89	0.19	5.05	3.31	2.23	0.39
C.D. at 5%	8.67	0.58	15.13	9.93	6.42	1.17

Table 3. Effect of foliar application of Zn and Fe on yield of pigeonpea

Treatments	Seed yield (kg ha ⁻¹)	Stalk yield (kg ha ⁻¹)	Harvest Index
T ₁ : RDF (Absolute control)	972	2090	0.32
T ₂ : Foliar application of 0.5 % ZnSO ₄ at flower initiation	1007	2336	0.30
T ₃ : Foliar application of 0.5 % FeSO ₄ at flower initiation	991	2220	0.31
T ₄ : Foliar application of 0.5 % ZnSO ₄ at pod initiation	998	2285	0.30
T ₅ : Foliar application of 0.5 % FeSO ₄ at pod initiation	987	2181	0.31
T ₆ : Foliar application of 0.5 % ZnSO ₄ at flower and pod initiation	1035	2432	0.30
T ₇ : Foliar application of 0.5 % FeSO ₄ at flower and pod initiation	1018	2377	0.30
T ₈ : Foliar application of 0.5 % ZnSO ₄ + 0.5 % FeSO ₄ at flower and pod initiation	1056	2503	0.30
T ₉ : RDF +Water spray (control)	981	2158	0.31
S.Em. ±	18.06	61.11	0.06
C.D. at 5%	54.14	183.20	NS

Table 4. Effect of foliar application of Zn and Fe on economics of pigeonpea

Treatments	Cost of cultivation (Rs)	Gross returns (Rs)	Net returns (Rs)	B:C Ratio
T ₁ : RDF (Absolute control)	36127	64152	28025	1.78
T ₂ : Foliar application of 0.5 % ZnSO ₄ at flower initiation	36481	66462	29981	1.82
T ₃ : Foliar application of 0.5 % FeSO ₄ at flower initiation	36443	65406	28963	1.79
T ₄ : Foliar application of 0.5 % ZnSO ₄ at pod initiation	36481	65868	29387	1.81
T ₅ : Foliar application of 0.5 % FeSO ₄ at pod initiation	36443	65142	28699	1.79
T ₆ : RDF + Foliar application of 0.5 % ZnSO ₄ at flower and pod initiation	36781	68310	31529	1.86
T ₇ : RDF + Foliar application of 0.5 % FeSO ₄ at flower and pod initiation	36743	67188	30445	1.83
T ₈ : RDF +Foliar application of 0.5 % ZnSO ₄ + 0.5 % FeSO ₄ at flower and pod initiation	36837	69696	32859	1.89
T ₉ : RDF +Water spray (control)	36967	64746	27779	1.75

3.2 Effect of Foliar Application of Zn and Fe on Yield Attributes of Pigeonpea

The data related to yield attributes viz., number of pods per plant, number of seeds per pod, pod yield per plant (g), seed yield per plant (g), stalk yield (g plant⁻¹) and test weight of pigeonpea as influenced by agronomic fortification with Zn and Fe are presented in Table 2. The foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation resulted in significantly higher number of pods (98.5 plant⁻¹), number of seeds (5.4 pod⁻¹), pod yield (128.5 g plant⁻¹), seed yield (83.5 g plant⁻¹), stalk yield (116.2 g plant⁻¹) and test weight (15.7 g) followed by T₆, whereas lower number of pods per plant, number of seeds per pod, pod yield per plant, seed yield per plant, stalk yield per plant and test weight (87.2, 4.3, 84.5, 52.5, 62.5 and 14.0, respectively) were recorded with application of RDF only (T₁). "This might be due to lower availability of major and micronutrient in soil, lower nutrient uptake, reduced photosynthates production which causes lower yield attributing characters and resulted in lower yield and Higher seed yield plant⁻¹ may be due to fulfillment of the demand of crop by higher assimilation and translocation of photosynthates from source to sink and better role of zinc during reproductive phase of crop growth. Seed yield plant⁻¹ was governed by number of pods plant⁻¹, number of seeds pod⁻¹ and 100 seed weight" [13,14]. Similar results were also reported by Kaur et al. [13] in lentil, Rathod et al. [14] in chickpea, Hanumanthappa et al. [15] in pigeonpea, Elumle Priyanka [16] in pigeonpea and Pandey et al. [17].

3.3 Effect of Foliar Application of Zn and Fe on Yield of Pigeonpea

The data relating to yield of pigeonpea that differed significantly due to influence of agronomic fortification with Zn and Fe are depicted in Table 3. Significantly higher seed yield (1056 kg ha⁻¹) and stalk yield (2503 kg ha⁻¹) were recorded with the foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation followed by foliar application of 0.5 % ZnSO₄ at flower and pod initiation (1035 and 2432 kg ha⁻¹, respectively). Whereas, significantly lower yield was noticed in application of RDF only (972 and 2090 kg ha⁻¹, respectively). The harvest index of pigeonpea was not influenced by agronomic fortification with Zn and Fe.

"The increasing in the yield and yield attributes might be due to foliar application of micronutrients which were directly absorbed by plants thereby increasing the metabolism of the plants resulting in increased synthesis of photosynthetic products. These micronutrients also helped in efficiently transferring photosynthetic products from source to sink, thereby increasing seed weight in pods ultimately resulting in higher seed yield. Higher seed weight might be due to higher dry matter accumulation, better nutrient uptake (N, P, K, Zn and Fe) and translocation to reproductive parts and involvement of zinc in various enzymatic processes which helps in catalyzing reaction for growth finally leading to development of more yield attributing characters like number of pods per plant, pod weight, 100 seed weight, and seed yield" [18,19,20,21]. Similar findings were reported by Tribhuwan et al. [20] in greengram, Kaur et al. [18] in maize, Soni et al. [19] in mungbean and Yashona et al. [21] in pigeonpea.

3.4 Effect of Foliar Application of Zn and Fe on Economics of Pigeonpea

Effect of agronomic fortification with Zn and Fe on economics of pigeonpea is described in Table 4. Maximum gross returns (Rs. 69696 ha⁻¹), net returns (Rs. 32859 ha⁻¹) and B:C ratio (1.89) were recorded with foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation (T₈). The marginal increase in cost of production compared to rest of the treatment with higher magnitude of yield enhancement resulted in higher yields, gross returns, net return and benefit cost ratio. Almost similar result found in Kailas et al. [12] in pigeonpea. Mukundgouda et al. [22] in pigeonpea, Rathod et al. [23] in pigeonpea and Jha et al. [24] in blackgram [25].

4. CONCLUSION

Based on the results it can be concluded that foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation was found to be effective for growth and yield of pigeonpea and economics. Pigeonpea crop fertilized with 100 per cent RDF + foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation the higher yield. On the basis of one year experiment, it is recommended that pigeonpea crop should be fertilized with 100% RDF + foliar application of 0.5 % ZnSO₄ + 0.5 % FeSO₄ at flower and pod initiation to obtain the higher pigeonpea yield.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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