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Effect of zinc, iron and biofertilizer application on growth, yield and quality of chickpea (*Cicer arietinum* L.)

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Abstract
The research was conducted at the Central Research Farm of the Department of Soil Science and Agricultural Chemistry, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology, and Sciences (SHUATS) in Prayagraj during the Rabi season of 2022-23. The experimental design employed was a Randomized Block Design (RBD), with application of Zn, Iron along with standard fertilizer dose (RDF). This design aimed to systematically assess the combined effects of these factors on the specified parameters, providing valuable insights into the potential benefits of using micronutrients on growth and yield of chickpea, variety the "Sadabahar" variety.The details of treatment given are T_1 (Absolute control); T_2 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_3 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_4 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_5 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 0 kg ha^{-1}); T_6 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_7 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_8 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_9 (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 0 kg ha^{-1}); T_{10} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_{11} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_{12} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}); T_{14} (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) and T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}).The treatment T_{15} was found to be the best for growth and yield parameters, followed by treatment T_{14}in chickpea. Treatment T_1 had the lowest results, demonstrating that farmers should apply the full recommended dosage of NPK, Fe, Zn, and biofertilizer. As a rapid fix for the Zn/Fe deficiency issue in soil and human populations, fertiliser strategy should be implemented nationwide in India, where a high incidence of Zn/Fe deficiency is observed. When the research programmes were first started, they were primarily focused on developing the most effective ways to apply zinc and ferrous iron to enhance their absorption in soil and maximise their accumulation in grain. In addition to organic matter, biofertilizer is applied to the soil to promote long-term soil fertility and sustainability. In order to address Zn and Fe deficiencies linked to soil and human health issues in India, it would be highly desirable and practical to investigate the bioavailability of grain Zn/Fe derived from applications.

Keywords: Chickpea, zinc, iron, biofertilizers, protein content

Introduction
Pulse crops possess distinct characteristics that render them essential, if not irreplaceable. Firstly, pulses contribute significantly to the agricultural economy of India by their ability to fix atmospheric nitrogen in symbiotic association with Rhizobium bacteria. Each pulse plant acts as a miniature fertilizer factory, enriching the soil with organic nitrogen, thus offering an advantage over chemical fertilizers, which can be lost through nutrient leaching. Secondly, pulses feature deep-root systems, enabling them to efficiently utilize limited moisture resources compared to many other crops, including cereals. Additionally, they contribute substantially to soil aeration. Thirdly, pulses have been crucial in the Indian diet as a protein source due to their high protein content, ranging from 20% to 30%, nearly three times that of cereals. They serve as an essential replacement for cereal-based diets. Moreover, the amino acid composition of pulses complements that of cereal protein. A mixed diet of cereals and pulses exhibits a higher biological value compared to either component alone (Bajracharya *et al.*, 2009) [3].

Chickpea also known as Bengal gram is a self-pollinated pulse crop which is grown in all the parts of India. It is the most important pulse crop grown. Chickpea followed by Pigeon pea and green gram. It accounts 29.60% of the total pulse acreage. Botanically Chickpea is known as *Cicer arietinum* L. belongs to family Leguminosae, sub-family Papillionaceae. Chickpea probably originated from Near East. It is mainly cultivated in China, India, Burma, and other parts of south-east Asia. Madhya Pradesh ranks first in area and production of chickpea in year 2021-22 followed by Uttar Pradesh and Rajasthan. The area under production of chickpea in Uttar Pradesh is 6.11thousand hectares and the production is 75.59 tonnes for year 2021-22. Chickpea is considered as quality pulses due to its excellent digestibility and rich protein (25-28%) content. It is also used as fodder for livestock and incorporated in soil for enrichment of organic matter. Chickpeas are usually rapidly boiled for 10 minutes and then simmered for longer. Chickpeas are a popular ingredient in vegetarian dishes, such as chana masala and chole. Chickpeas are also used to make a popular snack called chana chaat, which consists of boiled chickpeas, chopped onions, tomatoes, and spices, in India. Chickpea is well adapted crop for many diversified cropping systems and rotations. It grown as sole crop and fodder crop as well as mixed crop in *Rabi* seasons in India. It has high capacity of nitrogen fixation. It is well suited to cold climate with annual rainfall of 60-75 cm. Chickpea is grown in all types of well-drained soil but is sensitive to water logging. They are a rich source of protein (18–22 percent), carbohydrates (52–70 percent), fats (4–10 percent), minerals (such as calcium, phosphorus, iron), and vitamins. They serve as excellent animal feed, and their straw holds significant forage value. Chickpeas come in two main types: Desi and Kabuli. The Kabuli variety is predominantly cultivated in the Mediterranean region, North Africa, Southern Europe, Central and North America. Farmers are often drawn to cultivate Kabuli chickpeas due to the extra bold and bold-seeded varieties, which offer the potential for higher earnings.

One of the seventeen essential elements required for plants to grow and develop normally is zinc. With enzymes and proteins involved in protein synthesis, gene expression, auxin (growth regulator) metabolism, pollen formation, biological membrane maintenance, defence against heat stress and photooxidative damage, and resistance to infection by specific pathogens, zinc is essential for plants (Alloway, 2008) [2]. Application of zinc affects the synthesis of auxin, nodulation, and nitrogen fixation, all of which improve crop development and plant growth and eventually affect seed yield (Kasthurikrishna and Ahlawat, 2000) [8]. The secret to healthy soil and plants is balanced fertilisation, which is the application of inorganic and organic fertilisers in equal amounts and coordination to maximise the benefits to the plants. Therefore, crop growth is aided by the inoculation of biofertilizers with inorganic fertiliser. Rhizobium inoculation can raise pulse crop grain yields from 10% to 15% (Ali and Chandra, 1985) [1]. The physical and biological characteristics of the soil, such as the bulk density, particle density, macropore space, pH, microbial population, and soil enzyme activities, are also improved by the application of biofertilizers. Biofertilizers are an economical and environmentally responsible way to nourish plants. By fixing atmospheric nitrogen, solubilizing insoluble soil phosphates, and releasing plant growth substances into the soil, biofertilizers like Rhizobium culture and phosphorus solubilizing bacteria (PSB) contribute to the increased productivity and profitability of pulse crops (Bajracharya *et al.*, 2009) [3]. Thus, the current study's goal is to examine how Zn, Fe, and biofertilizer affect the growth and yield of chickpea

Materials and Methods

The research was conducted at the Central Research Farm of the Department of Soil Science and Agricultural Chemistry, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology, and Sciences (SHUATS) in Prayagraj during the Rabi season of 2022-23 and 2023-24. The experimental design employed was a Randomized Block Design (RBD), with application of Zn, Iron along with standard fertilizer dose (RDF). This design aimed to systematically assess the combined effects of these factors on the specified parameters, providing valuable insights into the potential benefits of using micronutrients in the cultivation of chickpea, particularly the "Sadabahar" variety. The Fisher and Yates, 1963 method was used to statistically analyse the data. The software used for analysis was OPSTAT. In the study, plant height was taken at 60 DAS and harvest stage using measuring tape from shoot above the soil till tip of principal branch. The number of branches per plant were counted at harvest stage. Similarly, number of pods were also counted. Weighing was done on electronic balance. The details of treatment given are T_1 (Absolute control); T_2 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_3 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_4 (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_5 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 0 kg ha^{-1}); T_6 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_7 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_8 (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_9 (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 0 kg ha^{-1}); T_{10} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}); T_{11} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 5 kg ha^{-1}); T_{12} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}); T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1} + Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}); T_{14} (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) and T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}).

Results and Discussion

Plant height

Over the course of the two years, different treatments had different plant height in the chickpea observed at 60 DAS and harvest stage (Table 1).The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest plant height (31.34, and 55.53 cm)at 60 DAS and harvest stage in 2022 and (31.82 and 55.59 cm)at 60 DAS and harvest stage for 2023 followed by treatment T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 30.94, and 54.61 cm observedat 60 DAS and harvest stage for the year 2022 and 30.37and 55.16 cm observed at 60 DAS and harvest stage for the year 2023 came next to T_{15}.Treatment T_1 (Absolute control) had the lowest plant height with values 26.14and 43.43 cm observed at 60 DAS and harvest stagefor 2022 and for 2023 of 24.47and 45.16 observed at 60 DAS and harvest stage respectively. The improved plant height of chickpea was influenced by the application of Zinc, Iron, and Biofertilizers, particularly in the treatment combination of RDF 100% + Zinc @ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg. Zinc and Iron play essential roles in plant growth and development, including cell division and elongation processes, which contribute to increased plant height. Additionally, Rhizobium, as a nitrogen-fixing biofertilizer, enhances overall plant vigour and root development, leading to more robust and taller plants. Furthermore, Rhizobium stimulates soil microbial activity, promoting nutrient cycling and availability, which supports sustained plant growth and height. The synergistic effect of these inputs ensures optimal nutrient uptake and utilization, resulting in taller and healthier chickpea plants. This enhanced plant height not only improves crop yield potential but also enhances the overall resilience and productivity of chickpea cultivation systems. These findings are supported by the results reported by Hussain *et al.,* (2022) [7], Yadav *et al.,* (2021) [11], Dangi *et al.,* (2020) [5], and Vasava *et al.,* (2020) [10].

Number of branches per plant

Over the course of the two years, different treatments had different number of branches per plant in the chickpea observed at harvest stage (Table 2). The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest number of branches per plant (15.83 branches) in 2022 and (15.55 branches) for 2023 followed by treatment T_{14} (RDF 100% + Zinc @ 6.67 kg ha^{-1} + Iron @ 5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) were 14.42 branches observed at harvest stage for the year 2022 and 14.60 branches for the year 2023. Treatment T_1 (Absolute control) had the lowest number of branches per plant with 11.43 branches for 2022 and for 2023 with 11.60 branches. The increased number of branches per plant in chickpea was influenced by the application of Zinc, Iron, and Biofertilizers, particularly in the treatment combination of RDF 100% + Zinc @ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg. Zinc and Iron play crucial roles in plant metabolism and hormone regulation, which influence branching patterns and lateral shoot development. Additionally, Rhizobium, as a nitrogen-fixing biofertilizer, promotes overall plant vigour and growth, including lateral branching. Rhizobium also stimulates root development, leading to increased nutrient uptake, which supports the development of more branches. Moreover, Rhizobium enhances soil microbial activity, improving nutrient availability and cycling, further contributing to enhanced branching. The synergistic interaction of these inputs ensures optimal nutrient uptake and utilization, resulting in increased branching in chickpea plants. This enhanced branching not only improves the plant's ability to capture sunlight and produce more yield but also enhances overall plant architecture and productivity. These findings are supported by the results reported by Hussain *et al.*, (2022) [7], Yadav *et al.*, (2021) [11], *Dangi et al.*, (2020) [5], and Vasava *et al.*, (2020) [10].

Number of pods per plant

Over the course of the two years, different treatments had different number of pods per plant in the chickpea observed at harvest stage (Table 2). The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest number of pods per plant (119.03pods) in 2022 and (116.67pods) for 2023 followed by treatment T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 115.00pods observed at harvest stage for the year 2022 and 116.08pods for the year 2023. Treatment T_1 (Absolute control) had the lowest number of pods per plant with 87.45pods for 2022 and for 2023 with 87.39pods.The application of Zinc, Iron, and Biofertilizers, specifically in the treatment combination of RDF 100% + Zinc @ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg, had an impact on the increased number of pods per plant in chickpea. The development of flowers and pods is just one of the many metabolic processes in plants where zinc and iron are essential. These micronutrients play a critical role in hormone regulation and enzyme activity, both of which are necessary for the initiation of flowers and the subsequent formation of pods. Furthermore, as a nitrogen-fixing biofertilizer, Rhizobium increases the vigour and reproductive growth of plants, which increases the production of flowers and pods. Additionally, rhizobium increases the availability of nutrients, especially nitrogen, which is critical for pod development and reproductive growth. Increased pod set is the outcome of these inputs working in concert to ensure optimal nutrient uptake and utilisation. These findings are supported by the results reported by Hussain *et al.*, (2022) [7], Yadav *et al.*, (2021) [11], *Dangi et al.*, (2020) [5], and Vasava *et al.*, (2020) [10].

Test weight

Over the course of the two years, different treatments had different test weight in the chickpea observed at harvest stage (Table 3). The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest test weight (131.26grams) in 2022 and (134.52grams) for 2023 followed by treatment T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 127.45grams observed at harvest stage for the year 2022 and 130.62grams for the year 2023. Treatment T_1 (Absolute control) had the lowest test weight with 109.19grams for 2022 and for 2023 with 107.29 grams. Zinc, iron, and biofertilizers were applied; in particular, the treatment combination of RDF 100% + Zinc @ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg had an impact on the improved test weight of chickpea. Test weight is directly impacted by a number of physiological processes, including grain filling and development, for which zinc and iron are vital. These micronutrients are essential for hormone regulation and enzyme activation, which guarantees effective assimilate utilisation for grain formation. Rhizobium is a nitrogen-fixing biofertilizer that also improves plant vigour and reproductive growth, which results in increased test weight and better grain filling. Additionally, rhizobium increases the availability of nutrients, especially nitrogen, which is critical for grain quality and development. Test weight is increased because of the synergistic interaction of these inputs, which guarantees optimal nutrient uptake and utilisation. These findings are supported by the results reported by Hussain *et al.*, (2022) [7], Yadav *et al.*, (2021) [11], *Dangi et al.*, (2020) [5], and Vasava *et al.*, (2020) [10].

Yield per hectare

Over the course of the two years, different treatments had different seed and stover yield per hectare in the chickpea observed at harvest stage (Table 3 and 4). The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest seed yield per hectare (17.28 kg/ha) in 2022 and (18.10kg/ha) for 2023 followed by treatment T_{14} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 16.49 kg/ha observed at harvest stage for the year 2022 and 17.54 kg/ha for the year 2023. Treatment T_1 (Absolute control) had the lowest seed yield per hectare with 13.00 kg/ha for 2022 and for 2023 with 13.73 kg/ha. The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest stover yield per hectare (31.99 kg/ha) in 2022 and (31.41kg/ha) for 2023 followed by treatment T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 29.97 kg/ha observed at harvest stage for the year 2022 and 28.70 kg/ha for the year 2023. Treatment T_1 (Absolute control) had the lowest stover yield per hectare with 23.00 kg/ha for 2022 and for 2023 with 24.36 kg/ha. The enhanced yield of chickpea was influenced by the application of Zinc, Iron, and Biofertilizers, particularly in the treatment combination of RDF 100% + Zinc

@ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg. Zinc and Iron play pivotal roles in various metabolic processes essential for plant growth, development, and reproduction, including photosynthesis, enzyme activation, and hormone regulation. These micronutrients ensure optimal plant health and vigour, leading to improved yield potential. Additionally, Rhizobium, as a nitrogen-fixing biofertilizer, enhances nitrogen availability and promotes overall plant growth and development, resulting in increased biomass accumulation and ultimately, higher yield. Rhizobium also improves nutrient uptake efficiency and soil fertility, further contributing to yield enhancement. The synergistic interaction of these inputs ensures optimal nutrient availability, utilization, and plant performance, culminating in better yield outcomes for chickpea cultivation. These findings are supported by the results reported by Hussain *et al.*, (2022) [7], Yadav *et al.*, (2021), *Dangi et al.*, (2020) [5], and Vasava *et al.*, (2020) [10].

Protein content

Over the course of the two years, different treatments had different protein content in the chickpea observed at harvest stage (Table 4). The treatment T_{15} (RDF 100% + Zinc @ 13.34 kg ha^{-1} + Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}) had the highest protein content (22.99%) in 2022 and (23.34%) for 2023 followed by treatment T_{13} (RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}) were 22.72% observed at harvest stage for the year 2022 and 23.23% for the year 2023. Treatment T_1 (Absolute control) had the lowest protein content with 18.25% for 2022 and for 2023 with 18.66%.Zinc, iron, and biofertilizers were applied; in particular, the treatment combination of RDF 100% + Zinc @ 13.34 kg/ha + Iron @ 7.5 kg/ha + Rhizobium 20 g/kg had an impact on the increased protein content of chickpea. In numerous biochemical pathways related to nitrogen metabolism and protein synthesis, zinc and iron are crucial components. In order to ensure that absorbed nitrogen is efficiently converted into proteins, these micronutrients are essential for enzyme activation and nitrogen assimilation. Furthermore, as a nitrogen-fixing biofertilizer, rhizobium increases the availability of nitrogen and fosters general plant growth and vigour, which increases the amount of protein in chickpea seeds. In addition to increasing soil fertility and nutrient uptake efficiency, rhizobium also contributes to the enhancement of protein. Higher protein content results from the synergistic interaction of these inputs, which guarantees optimal nutrient availability, utilisation, and plant performance. These findings are supported by the results reported by Hussain *et al.*, (2022) [7], Yadav *et al.*, (2021), *Dangi et al.*, (2020) [5], and Vasava *et al.*, (2020) [10].

Table 1: Effect of different levels of zinc, iron and biofertilizers on plant heightof chickpea

Plant height (cm)							
Treatment details		60 DAS			Harvest		
		2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	Absolute control	26.14	24.47	25.81	43.43	45.16	44.30
T_2	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	28.61	26.20	27.40	47.46	48.98	48.22
T_3	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	28.51	25.10	26.80	45.31	46.96	46.13
T_4	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	27.53	26.12	26.83	45.16	45.52	45.34
T_5	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	29.13	26.40	27.77	47.41	47.04	47.22
T_6	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	28.25	26.20	27.22	51.72	47.42	49.57
T_7	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	30.23	28.15	29.19	49.56	50.69	50.12
T_8	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	29.02	26.20	27.61	50.73	54.14	52.44
T_9	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	28.55	27.24	27.89	51.84	49.17	50.50
T_{10}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	29.50	29.05	29.28	53.22	54.37	54.89
T_{11}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	30.79	28.42	29.60	52.36	53.36	52.86
T_{12}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	29.81	28.48	29.14	52.97	52.15	52.56
T_{13}	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}	30.94	30.37	30.66	54.61	55.16	54.03
T_{14}	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	29.73	29.37	29.55	51.64	53.01	52.33
T_{15}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	31.34	31.82	31.58	55.53	55.59	55.56
'F' test		S	S	S	S	S	S
SE. m (±)		0.33	0.52	0.31	0.80	0.95	0.72
CD@5%		0.96	1.50	0.89	2.32	2.75	2.09

Table 2: Effect of different levels of zinc, iron and biofertilizers on number of branches and pods per plantof chickpea

Treatment details		No of branches per plant			No of pods per plant		
		2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	Absolute control	11.43	11.78	11.60	87.45	87.32	87.39
T_2	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	11.89	11.96	11.92	102.65	102.73	102.69
T_3	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	12.37	12.29	12.33	98.58	100.20	99.39
T_4	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	13.10	13.15	13.12	95.52	97.27	96.40
T_5	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	13.15	13.22	13.18	101.80	103.64	102.72
T_6	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	12.42	12.55	12.48	103.78	105.30	104.54
T_7	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	14.07	13.92	14.00	106.08	105.80	105.94
T_8	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	12.79	13.06	12.93	105.74	106.57	106.15
T_9	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	14.26	14.11	14.19	108.41	107.27	107.84
T_{10}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	13.45	13.46	13.45	107.01	107.81	107.41
T_{11}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	13.36	13.61	13.48	107.79	108.21	108.00
T_{12}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	14.48	14.45	14.47	110.81	112.04	111.43
T_{13}	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}	13.65	13.70	13.68	115.00	116.08	115.54
T_{14}	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	14.42	14.60	14.51	112.44	112.54	112.49

T_{15}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	15.83	15.55	15.69	119.03	116.67	117.85
'F' test		S	S	S	S	S	S
SE. m (±)		0.33	0.27	0.24	0.65	1.20	0.80
CD@5%		0.96	0.78	0.69	1.87	3.47	2.33

Table 3: Effect of different levels of zinc, iron and biofertilizers on test weight and seed yield per hectare of chickpea

Treatment details		Test weight (g)			Seed yield per hectare		
		2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	Absolute control	109.19	107.29	108.24	13.00	13.73	13.37
T_2	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	112.03	115.10	113.56	14.32	15.26	14.79
T_3	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	114.52	114.98	114.75	14.15	14.73	14.44
T_4	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	109.92	112.91	111.42	14.49	15.35	14.92
T_5	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	116.49	118.48	117.49	14.38	15.20	14.79
T_6	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	112.86	116.39	114.62	15.30	16.37	15.84
T_7	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	121.80	121.07	121.44	15.67	15.98	15.83
T_8	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	115.55	118.04	116.80	15.82	16.81	16.31
T_9	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	118.81	120.33	119.57	14.71	15.21	14.96
T_{10}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	124.86	124.23	124.55	15.67	16.96	16.31
T_{11}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	119.79	122.86	121.32	15.87	16.83	16.35
T_{12}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	125.79	126.21	126.00	16.04	17.03	16.53
T_{13}	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}	127.45	130.62	129.04	15.87	16.68	16.28
T_{14}	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	120.92	133.15	127.03	16.49	17.54	17.01
T_{15}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	131.26	134.52	132.89	17.28	18.10	17.69
'F' test		S	S	S	S	S	S
SE. m (±)		0.70	1.36	0.77	0.40	0.34	0.24
CD@5%		2.03	3.94	2.24	1.15	0.98	0.70

Table 4: Effect of different levels of zinc, iron and biofertilizers on stover yield per hectare and protein content of chickpea

Treatment details		Stover yield per hectare			Protein content (%)		
		2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	Absolute control	23.00	24.36	23.68	18.25	18.66	18.46
T_2	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	26.29	26.12	26.21	18.66	19.08	18.87
T_3	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	25.20	26.15	25.67	18.93	19.23	19.08
T_4	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	25.19	24.93	25.06	18.60	18.96	18.78
T_5	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	26.04	25.41	25.73	18.98	19.33	19.16
T_6	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	24.79	24.77	24.78	19.81	20.16	19.99
T_7	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	26.73	29.19	27.96	20.21	20.51	20.36
T_8	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	27.29	28.62	27.96	20.41	20.81	20.61
T_9	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 0 kg ha^{-1}	26.55	25.63	26.09	19.16	19.45	19.31
T_{10}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}	28.06	27.83	27.95	20.32	20.61	20.47
T_{11}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 5 kg ha^{-1}	27.81	27.85	27.83	19.47	19.80	19.64
T_{12}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1}	29.33	26.87	28.10	21.11	21.45	21.28
T_{13}	RDF 100% + Zinc @ 0 kg ha^{-1}+ Iron @ 2.5 kg ha^{-1}+ Rhizobium 20 g kg^{-1}	29.97	28.70	29.33	22.36	22.50	22.43
T_{14}	RDF 100% + Zinc @ 6.67 kg ha^{-1}+ Iron @ 5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	28.77	26.87	27.82	22.72	23.23	22.98
T_{15}	RDF 100% + Zinc @ 13.34 kg ha^{-1}+ Iron @ 7.5 kg ha^{-1} + Rhizobium 20 g kg^{-1}	31.99	31.41	31.70	22.99	23.34	23.17
'F' test		S	S	S	S	S	S
SE. m (±)		0.46	0.87	0.52	0.43	0.44	0.82
CD@5%		1.35	2.51	1.49	1.26	1.28	1.59

4. Conclusion
The treatment T_{15} was found to be the best for growth and yield parameters, followed by treatment T_{14}in chickpea. Treatment T_1 had the lowest results, demonstrating that farmers should apply the full recommended dosage of NPK, Fe, Zn, and bio-fertilizer. As a rapid fix for the Zn/Fe deficiency issue in soil and human populations, fertiliser strategy should be implemented nationwide in India, where a high incidence of Zn/Fe deficiency is observed. When the research programmes were first started, they were primarily focused on developing the most effective ways to apply zinc and ferrous iron to enhance their absorption in soil and maximise their accumulation in grain. In addition to organic matter, biofertilizer is applied to the soil to promote long-term soil fertility and sustainability. In order to address Zn and Fe deficiencies linked to soil and human health issues in India, it would be highly desirable and practical to investigate the bioavailability of grain Zn/Fe derived from applications.

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