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Enhancing Growth and Yield of Chickpea (*Cicer arietinum* L.) Varieties through Foliar Application of Micronutrients under Field Condition

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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

Extensively, it is imperative to address the pervasive issue of nutrient deficiencies among humans and animals in numerous underdeveloped regions. To tackle this challenge, a field experiment was conducted to investigate the impact of foliar applications of Zinc, Boron, and Iron on the growth, yield attributes, and overall yield of chickpea (*Cicer arietinum* L.) varieties during the Rabi seasons of both 2018-19 and 2019-20. The field experiment was meticulously designed using a Split Plot Design, wherein three distinct chickpea varieties (V1-KGD-1168, V2-Radhey, and V3-KWR-108) were assigned to the main plots. The subplots were dedicated to seven micronutrient treatment combinations, namely (M1-Control), (M2-Zinc @ 0.5%), (M3-Boron @ 0.2%), (M4-Iron @ 0.1%), (M5-Zinc @ 0.5% + Boron @ 0.2%), (M6-Zinc @ 0.5% + Iron @ 0.1%), and (M7: Zinc @ 0.5% + Boron @ 0.2% + Iron @ 0.1%). Consequently, a total of 21 treatment combinations were meticulously replicated three times. The findings of the experiment unveiled that the Radhey variety significantly influenced various parameters, including plant height, the number of branches per plant, fresh plant weight, 100-seed weight (17.21, 17.25g), seed yield (2118, 2228 kg ha^{-1}), gross return (112396, 113628 INR ha^{-1}), net return (83154, 83616 INR ha^{-1}), and the benefit-to-cost ratio (B: C ratio) (2.84, 2.79) of chickpea for both the years 2018-19 and 2019-20, respectively. Regarding the micronutrient treatments, the foliar application of Zinc @ 0.5% + Boron @ 0.2% + Iron @ 0.1% exhibited a notably positive impact on plant height, the number of branches per plant, fresh plant weight, 100-seed weight (16.94, 16.97g), seed yield (2162, 2276 kg ha^{-1}), gross return (114634, 116076 INR ha^{-1}), net return (85041, 85712 INR ha^{-1}), and B: C ratio (2.87, 2.82) of chickpea during both the years 2018-19 and 2019-20, respectively. Based on these compelling results, farmers are strongly advised to cultivate the Radhey variety of chickpea while implementing foliar applications of Zinc @ 0.5% + Boron @ 0.2% + Iron @ 0.1% for enhanced growth and higher yields.

Keywords: Chickpea; micronutrients; zinc; boron; iron growth; yield.

1. INTRODUCTION

Pulses hold a special place in Oriental cuisine, particularly in countries like India, where a significant portion of the population follows a vegetarian diet. These humble legumes are not only prized for their high protein content but also for their economical provision of carbohydrates, essential minerals, and a host of vital B-complex vitamins. In the realm of nutrition, pulses are true powerhouses, typically boasting 20-25% protein in their dry seeds—2.5 to 3 times more protein than cereals. This nutritional richness makes grain legumes an indispensable component in safeguarding the nutritional well-being of India's predominantly vegetarian population, often referred to as the "poor man's meat" and the "rich man's vegetables" for their versatility and nutrient density. Beyond their dietary significance, pulses play a pivotal role in sustainable agriculture due to their ability to enrich soil fertility through biological nitrogen fixation, a fact highlighted in the work of [1]. However, despite their importance, pulse production in India has not kept pace with the surging population, leading to a concerning drop in per capita pulse availability, from 71 grams per day in 1995 to a mere 34.4 grams per day in 2009. This decline in consumption can be attributed in part to low productivity, underscoring the urgent need for increased pulse production. Pulses occupy a substantial agricultural footprint, covering approximately 95.16 million hectares globally and contributing 95.97 metric tons to the world's food supply [2].

Among the diverse array of pulse crops, chickpea, scientifically known as *Cicer arietinum* L., holds a prominent position in the Indian subcontinent. Chickpeas are not only consumed as pulses but also find their way into various snacks, sweets, and condiments in their dried form. Furthermore, the fresh green variant of chickpeas serves as a nutritious vegetable. This versatile crop predominantly thrives in semi-arid and tropical climates and carries immense economic significance. India, being the world's largest producer and consumer of chickpeas, contributes a substantial share, accounting for 36.76% of the global pulse area and 26% of pulse production worldwide. India's agricultural prowess in pulses extends to its status as the largest pulse producer on the planet. Covering an extensive area of 34.99 million hectares, India produces a staggering 24.21 million tons of pulses with a productivity rate of 806 kg per hectare, as reported in Agricultural Statistics at a Glance [3]. It's worth noting that as we progress into the 21st century, the global population continues to surge, with a fourfold increase during the 20th century, accompanied by a 4.5-fold growth in economic activity per person. Projections indicate a 50% increase in the world's population in the next four to five decades, necessitating a doubling of food production to meet the demands of this expanding human population, particularly as diets evolve and more people move up the food chain [4].

The selection of the right chickpea variety plays a pivotal role in achieving maximum productivity, given that different varieties exhibit distinct growth and developmental patterns driven by their unique genetic characteristics. However, the advent of modern agricultural practices, characterized by the use of high-yield crop varieties and intensive fertilization, has inadvertently led to the depletion of essential micronutrients in the soil. These micronutrients, including Manganese (Mn), Iron (Fe), Copper (Cu), and Boron (B), are vital for the growth and development of plants. The consequences of micronutrient deficiencies are far-reaching, affecting not only plant growth, metabolism, and reproduction but also posing significant challenges to human and animal health. Notably, deficiencies in Iron and Zinc are prevalent in many developing Asian nations, including India. To address these deficiencies and optimize plant growth and yield, foliar application of micronutrients like Zinc, Iron, Magnesium, Boron, and Manganese has emerged as a promising solution. The most promising outcomes are achieved when these micronutrients are applied in conjunction with nitrogen. Scientific research has demonstrated that foliar application of micronutrient combinations can result in a multitude of benefits, including increased pod and seed production per plant, greater seed weight per plant, higher seed yield per hectare, enhanced harvest index, and greater 100-seed weight. Additionally, the application of Boron through foliar spraying has been found to boost the number of pods per plant and enhance 100-seed weight. It's essential to note that Indian soils often exhibit deficiencies in micronutrients, with a significant portion suffering from deficiencies in Zinc, Iron, Manganese, and Boron—reported in 49%, 12%, 5%, and 3% of soils, respectively. Therefore, foliar application of micronutrients becomes imperative to address these deficiencies and promote optimal chickpea production. In light of these considerations, the objectives of this study encompass an exploration of the impact of micronutrients on chickpea growth and yield attributes, as well as an investigation into the influence of micronutrients on the yield of different chickpea varieties.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted at the Student's Instructional Farm (SIF) situated within the premises of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India. This farm occupies a strategic location within the alluvial expanse of the Indo-Gangetic plains, situated in the central part of Uttar Pradesh. It lies within the geographical coordinates of 25º 26' to 26º 58' North latitude and 79º 31' to 80º 34' East longitude, with an elevation of 125.9 meters above mean sea level. The region encompassing this farm falls under the agro-climatic zone V, commonly referred to as the Central Plain Zone, within the state of Uttar Pradesh. Throughout the duration of the study, the experimental field remained consistent, occupying the same geographical area, as depicted in Fig. 1.

2.2 Climate and Weather Conditions

The study site is situated within a semi-arid climatic zone, featuring fertile alluvial soil. The region experiences an average annual rainfall of approximately 890mm, with the bulk of this precipitation occurring from mid-July to the conclusion of September. During the winter months, the climate turns cooler, marked by intermittent rain and frost, typically spanning from the last week of December to mid-January. Conversely, the months of May and June witness soaring temperatures, soaring as high as 44-47°C or even higher, while winter brings about a noticeable drop in temperature. Relative humidity patterns reveal that, on average, the mornings at 7:00 A.M. maintain a relatively stable humidity level ranging between 80-90% from July through the end of March. However, as April unfolds, the humidity gradually decreases to 40-50% by month's end, only to rebound and stabilize at 80% once more throughout the month of May.

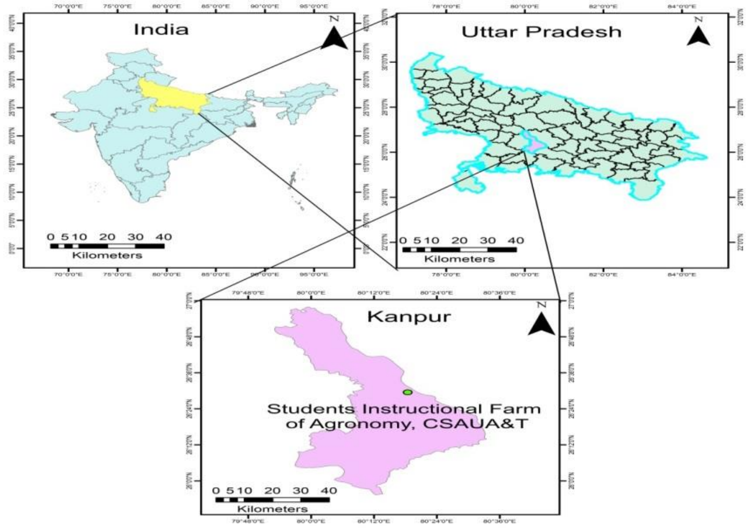

Fig. 1. Location map of the study area

2.3 Soil Characteristics

The characteristics of the soil, which serves as the essential medium for plant growth, wield a profound influence on the pace and ultimate outcome of plant development. In the experimental field, the soil displayed specific attributes, classified as sandy loam in texture, with a pH level ranging between 7.83 to 7.87. The electrical conductivity of the soil at 25ºC stood 0.26 to 0.27 dSm^{-1}, while the bulk density was measured at 1.39 to 1.40 g cm^{-3}. The particle density of the soil fell within the range of 2.64 to 2.63 g cm^{-3}. Additionally, the soil exhibited an organic carbon content of 0.33 to 0.35%, available nitrogen content in the range of 156.22 to 161.32 kg ha^{-1}, and available P_2O_5 content ranging from 17.24 to 18.15 kg ha^{-1}. Furthermore, the available K_2O content was measured between 175.35 to 181.49 kg ha^{-1}, while the available Zn content ranged from 0.56 to 0.58 mg kg^{-1}. The soil also contained available Fe content measuring 8.02 to 8.07 mg kg^{-1}, and lastly, available B content was found to be in the range of 0.28 to 0.38 mg $kg^{-1.}$ These soil properties remained consistent during both the years 2018-19 and 2019-20.

2.4 Experimental Details

The experimental setup followed a split-plot design, meticulously replicated three times for robustness. This design encompassed a total of twenty-one distinct treatment combinations. Within this framework, the primary plots were dedicated to three distinct chickpea varieties, namely V1-KGD-1168, V2-Radhey, and V3-KWR-108. Complementing these, the sub-plots were allocated for the micronutrient treatments, which included seven variations: (M1-Control), (M2-Zinc @ 0.5%), (M3-Boron @ 0.2%), (M4-Iron @ 0.1%), (M5-Zinc @ 0.5% + Boron @ 0.2%), (M6-Zinc @ 0.5% + Iron @ 0.1%), and (M7-Zinc @ 0.5% + Boron @ 0.2% + Iron @ 0.1%). Each individual plot was standardized to a size of 12 square meters, with dimensions measuring 4.0 meters in length and 3.0 meters in width. This carefully structured experimental layout allowed for comprehensive evaluation and comparison of the specified treatments and varieties, ensuring reliable and meaningful results.

2.5 Crop Varieties

a) KGD-1168

KGD-1168, also known as Alok chickpea, was developed in 1996 by Chandra Shekhar Azad University of Agriculture and Technology in Kanpur for cultivation in northwestern India. It has medium plant height, resistance to wilt disease and root node nematode, and key attributes include a 140-145 day duration, 55-60 cm plant height, 19-21 q/ha yield, medium-bold seeds, 14.14% husk, 72% dhal recovery, 23% protein, and a seed index of 15.48g.

b) Radhey

This chickpea variety, released in 1968 by crossing T-197 with 76, is well-suited for Uttar

Pradesh. It has light green, semi-spreading foliage, two-seeded pods, bold light brown grains, pink flowers, and notable characteristics: Plant height (60-70 cm), Yield (26-30 q/ha), Medium-bold seeds, Husk (13.18%), Dhal recovery (78.8%), Protein (21.50%).

c) KWR-108

This chickpea variety, developed in 1996 by Chandra Shekhar Azad University in Kanpur, Uttar Pradesh, is tailored for cultivation in India's northeastern plain regions (Eastern Uttar Pradesh, Bihar, and West Bengal). It has medium plant height, wilt disease resistance, and key features including 130-135 day growth duration, 45-55 cm plant height, 22-23 quintals per hectare yield, small dark brown seeds, 16% husk content, 74% dhal recovery, 24.10% protein, and a 17g seed index.

2.6 Agronomical Practices Adopted

Throughout the experimental phase, the land underwent a series of meticulous preparations. Initially, a tractor-drawn cultivator was employed to plow the field, followed by harrowing. Subsequently, diligent efforts were made to eliminate weeds and stubble, culminating in leveling the field using a leveler in accordance with the experimental layout. The soil was meticulously refined, with the aim of achieving the desired tilth by breaking down sizable soil clumps into finer particles and smoothing the surface. The recommended doses of nitrogen, phosphorus, and potassium (at a ratio of 20:60:60 kg ha-1) were administered using urea, single super phosphate, and muriate of potash, respectively. A portion of P_2O_5 and K_2O, along with half of the nitrogen, was applied as a basal dose. The remaining half of the nitrogen was evenly distributed as a top dressing 30 days after sowing. For micronutrient supplementation, zinc, boron, and iron were meticulously applied as foliar sprays using $ZnSO_4$, boric acid (H_3BO_3), and $FeSO_4$, respectively. These micronutrient treatments were conducted twice, at 25 and 50 days after sowing (DAS), with a fresh solution prepared for each application. The spray solution was prepared by dissolving the precise quantities of micronutrients in distilled water, incorporating a sticker to enhance absorption by cabbage leaves. The spraying procedure was carried out using a knapsack sprayer, with all necessary safety precautions diligently bserved throughout the process.

2.7 Observations Recorded

Throughout the course of the study, biometrical observations were meticulously collected at multiple growth stages, specifically at 25, 50, 75, and 100 days after sowing (DAS), in addition to observations at the point of maturity. To ensure the utmost accuracy and minimize the potential for sampling errors, comprehensive precautions were rigorously observed. The growth-related parameters and yield indicators, including plant height, the number of branches per plant, fresh plant weight, 100-seed weight, and seed yield, were systematically recorded. Subsequently, the acquired data underwent rigorous statistical analysis, following the methodology delineated by Gomez and Gomez in [5], aimed at discerning any discernible distinctions among the treatment means. The LSD (Least Significant Difference) test was employed to compare the treatment means at a 5% significance level. The entire analysis process was executed using SPSS Version 10.0, a statistical software package developed by SPSS, Chicago, IL, renowned for its comprehensive statistical analysis capabilities.

3. RESULTS AND DISCUSSION

3.1 Plant Height

Plant height (Table 1) serves as a reliable indicator of growth and development, reflecting the overall infrastructure buildup over time. The growth characteristics of chickpeas (Table) were significantly influenced by different varieties and micronutrients (Zn, B, and Fe). However, the interaction between varieties and micronutrients did not yield significant effects. Among the varieties, Radhey consistently displayed significantly greater plant height compared to the other treatments in both experimental years. Plant height in chickpeas increased progressively as the crop advanced in age until reaching maturity. Variability in plant height was observed among different varieties, as plant height is a varietal trait that can also be influenced by environmental factors. Similar varietal variations in plant height were reported by [6,7,8]. The increase in plant height could be attributed to the stimulating influence of boron, which enhances the absorption rates of essential nutrients such as N, P, and K, among others. Additionally, boron participates in sugar translocation, which may contribute to increased plant height, as observed in the findings of Kayan *et al*. 2015 in chickpeas. The involvement of zinc, boron, and ferrous elements in cell division and meristematic tissue growth may also contribute to the observed increase in plant height, aligning with similar findings reported by [9]. Micronutrients such as Zn, Fe, and Boron have been reported to improve chickpea plant height, corroborating the results observed by [10].

3.2 Number of Branches Plant^{-1}

The Branching in chickpea, as indicated by the number of branches per plant (Table 2), has been a subject of debate among researchers. Some consider it a growth parameter, while others categorize it as a yield attribute. In this investigation, branching is regarded as a growth parameter. The production of branches exhibited an increasing trend with the advancing age of the crop until maturity, regardless of the plant variety. The interaction between varieties and micronutrients did not yield significant effects. The Radhey variety exhibited the highest number of branches per plant, while the KGD-1168 variety had the lowest, consistent with the findings of previous researchers such as [11,6]. This variation in the number of branches per plant among different varieties may be attributed to their distinct growth behaviors resulting from genetic differences. Similar results were also reported by [12,13]. The application of micronutrients (Zn, B, and Fe) led to an increased number of branches per chickpea plant. This enhancement could be attributed to the promotional effects of micronutrients on vegetative growth, ultimately leading to increased photosynthetic activity. Additionally, it may result from the availability of the required quantity of essential plant nutrients at various growth stages, accelerating plant metabolic processes and consequently leading to the production of more branches. These findings align with the study by [14].

3.3 Fresh Weight of Plant

The fresh weight of chickpeas (Table 3) displayed a progressive increase with the advancing age of the crop until reaching maturity. Notably, the interaction between varieties and micronutrients did not yield significant effects. The Radhey variety exhibited the highest fresh weight production, statistically on par with the KWR-108 variety, while the KGD-1168 variety recorded the lowest fresh weight production in both years. The elevated fresh weight production in the Radhey variety can be attributed to its enhanced growth characteristics, including Crop Growth Rate (CGR), Relative Growth Rate (RGR), photosynthetic rate, and chlorophyll content. Additionally, it demonstrated better utilization of soil moisture and nutrients, showcasing high yield potential and improved attributes compared to other varieties. These findings align with prior studies conducted by [15,16,17]. The fresh weight of chickpeas reflects vigorous plant growth and effective assimilation of photosynthates. Chickpeas fertilized with Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% experienced robust crop growth, thanks to the sufficient availability of micronutrients. Soil enrichment with micronutrients facilitated their efficient utilization, with iron enhancing chlorophyll metabolism, zinc aiding in carbohydrate and protein synthesis, and protecting the chickpea crop against photo-oxidative damage. Boron played a crucial role in regulating sugar transport across membranes and contributed significantly to cell division and development. These results are in line with the findings of Velenciano et al., 2010 and [18].

3.4 100-Seed Weight

The 100-seed weight provides insights into the nature and extent of seed development, reflecting the influence of various production factors on seed development and filling patterns. An analysis of the data presented in Table 4 reveals the impact of different treatments on the 100-seed weight of chickpea. Distinct varieties displayed significant variations in the 100-seed weight of chickpeas, whereas micronutrients (Zn, B, and Fe) exhibited a non-significant effect on the 100-seed weight. Among the varieties, Radhey exhibited significantly higher 100-seed weight (17.21 g and 17.25 g), statistically on par with variety KWR-108 during both experimental years. However, the lowest 100-seed weight was observed in variety KGD-1168. Regarding micronutrients, the application of Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% resulted in a higher 100-seed weight (16.94 g and 16.97 g) compared to other treatments, although the difference was not statistically significant in both years. Conversely, the control treatment yielded the lowest 100-seed weight (16.57 g and 16.61 g). The interaction between varieties and micronutrients did not yield significant effects. These findings align with previous research by [19,7].

3.5 Seed Yield

Crop yield (Table 4) is the outcome of various growth and yield-contributing factors. Significant variations in growth characteristics and yield

Table 1. Effect of varieties and micronutrients (Zinc, Boron, and Iron) on plant height (cm) of chickpea

Treatments	Plant height (cm) at 25 DAS		Plant height (cm) at 50 DAS		Plant height (cm) at 75 DAS		Plant height (cm) at 100 DAS		Plant height (cm) at maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Varieties										
V1: KGD-1168	7.67	7.71	26.78	27.63	50.05	52.59	58.09	58.77	62.19	62.96
V2: Radhey	7.96	7.99	28.62	29.70	53.57	56.11	61.42	62.23	66.35	67.63
V3: KWR-108	7.23	7.28	25.60	26.49	47.26	48.29	54.04	54.62	57.17	57.84
SEm±	0.24	0.25	0.83	0.86	1.68	1.70	2.06	2.09	2.14	2.17
LSD (*p*=0.05)	0.75	0.77	2.55	2.61	5.12	5.19	6.23	6.28	6.44	6.53
Micronutrients										
M1: Control	7.52	7.54	25.41	26.54	46.12	48.34	52.78	53.19	56.98	58.02
M2: Zinc @ 0.5%	7.62	7.65	26.73	27.81	49.41	51.28	57.67	58.27	61.27	62.12
M3: Boron @ 0.2%	7.58	7.61	26.56	27.62	48.99	51.12	56.09	56.97	60.29	61.24
M4: Iron @ 0.1%	7.55	7.59	26.31	27.39	48.37	50.23	55.27	56.11	59.78	60.57
M5: Zinc @ 0.5% **+** Boron @ 0.2 %	7.68	7.72	27.84	28.90	53.51	55.27	60.67	61.37	64.29	65.47
M6: Zinc @ 0.5% **+** Iron @ 0.1 %	7.71	7.74	27.21	28.29	51.09	53.47	58.67	59.48	62.87	63.49
M7: Zinc @ 0.5% **+** Boron @ 0.2 % **+** Iron @ 0.1 %	7.73	7.77	28.96	29.06	54.57	56.61	63.78	64.39	67.84	68.78
SEm±	0.20	0.21	0.72	0.75	1.36	1.39	1.72	1.75	1.91	1.93
LSD (*p*=0.05)	NS	NS	2.21	2.28	4.14	4.22	5.21	5.26	5.78	5.81
Interaction (V x M)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of varieties and micronutrients (Zinc, Boron and Iron) on number of branches plant^{-1} of chickpea

Treatments	Number of Branches Plant^{-1} at 25 DAS		Number of Branches Plant^{-1} at 50 DAS		Number of Branches Plant^{-1} at 75 DAS		Number of Branches Plant^{-1} at 100 DAS		Number of Branches Plant^{-1} at maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Varieties										
V1: KGD-1168	5.65	5.76	9.40	9.74	12.97	14.12	14.30	15.22	15.69	14.12
V2: Radhey	6.30	6.51	11.23	11.56	15.34	16.50	16.85	17.87	18.02	16.50
V3: KWR-108	5.88	5.99	10.02	10.42	14.09	15.21	15.54	16.64	17.12	15.21
SEm±	0.19	0.20	0.34	0.38	0.43	0.50	0.52	0.54	0.56	0.50
LSD (*p*=0.05)	0.58	0.61	1.03	1.16	1.34	1.52	1.56	1.63	1.68	1.52
Micronutrients										
M1: Control	5.72	5.89	8.89	9.20	12.11	13.25	13.57	14.64	14.92	13.25
M2: Zinc @ 0.5%	5.97	6.12	10.24	10.57	14.26	15.39	15.72	16.69	16.97	15.39
M3: Boron @ 0.2%	5.87	5.97	9.87	10.16	13.88	14.99	15.39	16.24	16.56	14.99
M4: Iron @ 0.1%	5.78	5.86	9.58	9.91	13.46	14.58	14.87	15.87	15.99	14.58
M5: Zinc @ 0.5% **+** Boron @ 0.2 %	6.09	6.24	10.99	11.34	14.97	16.11	16.39	17.38	17.97	16.11
M6: Zinc @ 0.5% **+** Iron @ 0.1 %	6.02	6.18	10.58	10.99	14.58	15.72	15.89	16.97	17.65	15.72
M7: Zinc @ 0.5% **+** Boron @ 0.2 % **+** Iron @ 0.1 %	6.15	6.34	11.36	11.84	15.67	16.89	17.11	18.24	18.54	16.89
SEm±	0.15	0.17	0.28	0.30	0.36	0.41	0.42	0.43	0.45	0.41
LSD (*p*=0.05)	NS	NS	0.87	0.92	1.11	1.24	1.27	1.31	1.36	1.24
Interaction (V x M)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of varieties and micronutrients (Zinc, Boron, and Iron) on fresh weight (g) of chickpea

Treatments	**Fresh weight of plant (g) at 25 DAS**		**Fresh weight of plant (g) at 50 DAS**		**Fresh weight of plant (g) at 75 DAS**		**Fresh weight of plant (g) at 100 DAS**		**Fresh weight of plant (g) at maturity**	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Varieties										
V1: KGD-1168	7.75	7.96	49.67	51.10	92.41	94.96	133.82	135.76	174.22	177.07
V2: Radhey	8.47	8.87	55.69	57.94	105.06	107.81	163.81	167.99	213.81	217.91
V3: KWR-108	8.16	8.47	53.35	54.77	101.80	103.22	157.90	159.63	196.64	200.70
SEm±	0.24	0.26	1.69	1.74	3.04	3.12	4.13	4.22	6.17	6.23
LSD (*p*=0.05)	NS	NS	5.11	5.23	9.16	9.37	12.48	12.67	18.52	18.73
Micronutrients										
M1: Control	8.06	8.36	47.23	48.65	80.68	83.74	135.46	136.58	169.12	173.60
M2: Zinc @ 0.5%	8.26	8.57	53.14	54.67	101.69	104.04	152.59	154.12	193.39	196.25
M3: Boron @ 0.2%	8.16	8.47	51.61	53.35	97.51	99.45	148.82	151.47	189.82	193.19
M4: Iron @ 0.1%	7.96	8.36	50.69	52.22	91.19	93.23	143.92	145.15	182.99	185.84
M5: Zinc @ 0.5% **+** Boron @ 0.2 %	8.16	8.47	55.90	57.73	109.85	112.00	160.96	163.02	210.85	214.10
M6: Zinc @ 0.5% **+** Iron @ 0.1 %	8.06	8.36	54.47	56.00	105.98	107.92	155.96	160.22	202.23	207.22
M7: Zinc @ 0.5% **+** Boron @ 0.2 % **+** Iron @ 0.1 %	8.26	8.57	57.32	59.57	111.38	113.73	165.34	170.75	215.85	219.75
SEm±	0.16	0.18	1.09	1.11	2.36	2.41	3.39	3.50	4.76	4.86
LSD (*p*=0.05)	NS	NS	3.27	3.34	7.13	7.28	10.21	10.54	14.29	14.58
Interaction (V x M)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. Effect of varieties and micronutrients (Zinc, Boron, and Iron) on yield and economics of chickpea

Treatments	**100- seed weight (g)**		**Seed yield (kg ha^{-1})**		**Cost of cultivation (₹ ha^{-1})**		**Gross returns (₹ ha^{-1})**		**Net returns (₹ ha^{-1})**		**B: C ratio**	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
Varieties												
V1: KGD-1168	16.18	16.21	1921	2020	29242	30012	101785	103020	72543	73008	2.48	2.43
V2: Radhey	17.21	17.25	2118	2228	29242	30012	112396	113628	83154	83616	2.84	2.79
V3: KWR-108	17.04	17.07	2063	2156	29242	30012	109350	109956	80108	79944	2.74	2.66
SEm±	0.33	0.34	62	65	-	-	-	-	-	-	-	-
LSD (*p*=0.05)	1.01	1.03	187	196	-	-	-	-	-	-	-	-
Micronutrients												
M1: Control	16.57	16.61	1869	1939	28908	29679	99048	98889	70140	69210	2.43	2.33
M2: Zinc @ 0.5%	16.84	16.87	2038	2134	29188	29959	108063	108834	78875	78875	2.70	2.63
M3: Boron @ 0.2%	16.79	16.82	2010	2113	29128	29899	106571	107763	77443	77864	2.66	2.60
M4: Iron @ 0.1%	16.72	16.75	1967	2102	29093	29864	104314	107202	75221	77338	2.59	2.59
M5: Zinc @ 0.5% **+** Boron @ 0.2 %	16.91	16.94	2113	2227	29408	30179	111183	113577	81775	83398	2.78	2.76
M6: Zinc @ 0.5% **+** Iron @ 0.1 %	16.89	16.92	2096	2152	29373	30144	111961	109752	82588	79608	2.81	2.64
M7: Zinc @ 0.5% **+** Boron @ 0.2 % **+** Iron @ 0.1 %	16.94	16.97	2162	2276	29593	30364	114634	116076	85041	85712	2.87	2.82
SEm±	0.24	0.25	37	39	-		-	-	-	-	-	-
LSD (*p*=0.05)	NS	NS	112	119	-	-	-	-	-	-	-	-
Interaction (V x M)	NS	NS	NS	NS	-	-	-	-	-	-	-	-

attributes resulting from different varieties and micronutrient treatments have a notable impact on chickpea crop yields. Notably, the interaction between varieties and micronutrients did not yield significant effects. The highest seed yield was achieved by the Radhey variety, while the lowest seed yield was observed in the KGD-1168 chickpea variety. Radhey's superior performance can be attributed to its higher number of branches, pods per plant, and seeds per pod, along with heavier seeds, collectively contributing to a greater seed yield. Seed yield is consistently positively associated with attributes such as pod number, pod weight, seeds per pod, seed weight, among others. These findings align with previous studies by [20,21,22]. Among the micronutrients, the foliar application of Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% consistently recorded significantly higher seed yields in both years. This increase can be attributed to improved nutrient availability at crucial growth stages due to the application of various micronutrient combinations. Consequently, this enhances metabolic activity rates and efficiency, leading to increased protein and carbohydrate assimilation, facilitating better nutrient absorption by plants and, ultimately, higher yields. These results are in line with studies by [23,24,25] Valenciano et al., 2010.

3.6 Economics

The economic data, including gross returns, net returns, and benefit-cost ratios, influenced by various varieties and micronutrient treatments, are summarized in Table 4. Ultimately, the practicality and effectiveness of a treatment are assessed based on net returns. In both the years 2018-19 and 2019-20, the Radhey variety demonstrated higher gross returns (112,396 INR ha^{-1} and 113,628 INR ha^{-1}, respectively), net returns (83,154 INR ha^{-1} and 83,616 INR ha^{-1}, respectively), and benefit-cost ratios (2.84 and 2.79, respectively) for chickpeas. This can be attributed to its higher seed and straw yields compared to other treatments, resulting in elevated net returns. These findings align with the research conducted by [23,18]. The economic analysis underscores the importance of considering a treatment's practical suitability from the perspective of farmers. Agricultural practices with lower production costs that yield higher net returns and benefit-cost ratios are generally preferred for adoption. The application of micronutrients significantly influenced gross returns, net returns, and benefit-cost ratios for chickpeas. Specifically, the application of Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% resulted in higher gross returns (114,634 INR ha^{-1} and 116,076 INR ha^{-1} for 2018-19 and 2019-20, respectively), net returns (85,041 INR ha^{-1} and 85,712 INR ha^{-1} for 2018-19 and 2019-20, respectively), and benefit-cost ratios (2.87 and 2.82, respectively) due to increased seed and straw yields. These findings are consistent with those of [26,27].

4. CONCLUSIONS

The two-year study yielded the following conclusions. Among the various varieties, the Radhey variety exhibited the most significant improvements in growth, chlorophyll content, relative water content, yield attributes, and overall yield. The foliar application of Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% proved to be superior to other treatments in terms of promoting growth, enhancing chlorophyll content, maintaining relative water content, and increasing chickpea yield. Based on these findings, farmers are advised to cultivate the Radhey chickpea variety and apply Zinc @ 0.5%, Boron @ 0.2%, and Iron @ 0.1% through foliar application to achieve higher yields and improved profitability.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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