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Enhancing biofortification and yield of potato (*Solanum tuberosum* L.) through zinc-enriched soil and foliar applications

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Abstract
An investigation on influence of soil and foliar supplementation of zinc on yield of potato. During the *rabi* season of 2023-2024, a field experiment was carried out at the Zonal Agricultural Research Station, Chhindwara, under Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to examine the effect of applying zinc sulphate on the yield of potato tubers. Seven RDF treatments and varying zinc fertilizer dosages at 25 and 50 DAP make up the experiment. Three replications of the experiment were set up using a Randomised Complete Block Design. Yield attribute such as number of tubers per plant (14.44), tuber weight per plant (1.21 kg), tuber volume (126.79 ml), tuber yield (36.46 t/ha), fresh haulm yield (10.57 t/ha), dry haulm yield (2.14 t/ha), number of tuber grading i.e. 25-50 g (151.27), 50-75 g (140.01) &>75 g (129.04) 000'/ha, yield of tuber grading i.e. 25-50 g (10.13), 50-75 g (13.87), & > 75 g (11.09) t/ha found maximum in T_7 [2.5 kg Zinc/ha from zinc sulphate, at the time of planting + foliar application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP].In terms of economics, application of 2.5 kg Zinc/ha from zinc sulphate, at the time of planting + foliar application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP was found to give more net monetary return (Rs 349725.82/ha), gross monetary return (Rs 433552.22/ha) and a maximum B:C ratio (4.17).

Keywords: Biofortification, zinc, zinc sulphate, potato, *Solanum*, foliar application

Introduction
The potato (*Solanum tuberosum* L.) belongs to the Solanaceae family. A key commercial component, the larger underground stems, sometimes referred to as tubers, are produced by the expanding potato plant (Anonymous, 2011) [5]. Dehydrated potato flakes are used as a component of store-bought mashed potatoes, as well as a culinary additive and snack item. Convenient, safe, and fresh-like potato products that are ready to use or eat have become more and more popular in recent decades. The food business may have a strong chance of increasing market sales with a product that can fully satisfy current customers need for healthy foods provided minimally processed tubers have a balanced fortified mineral profile.

China, the Russian Federation, Poland, India, the Netherlands, Ukraine, and the United States are among the biggest producers of potatoes, which are a key crop in the world. India contributed 2.21 million hectares of land, 53.58 million metric tonnes of production, and a yield of 24.24 metric tonnes per hectare for potatoes in 2021-2022. With an area of 620.44 hectares and a production of 15811.31 metric tonnes, Uttar Pradesh is the largest potato-growing state in India. Bihar, West Bengal, Madhya Pradesh, Punjab, Haryana, and Karnataka are next in line, while potatoes can also be found growing in other states under a variety of circumstances (FAOSTAT, 2023) [11].

Alloway (2009) [9] studied that among all micronutrient deficiencies in crops worldwide, zinc deficiency is the most common. Zinc is a structural component and regulatory co-factor in proteins and enzymes involved in numerous biochemical pathways, making it vital for both plants and animals. Zinc deficiency affects millions of hectares of crop land and poor zinc intake affects about one-third of the world's population. The primary soil factors that impact the availability of zinc to plants are high concentrations of Na, Ca, Mg, bicarbonate and phosphate in the soil solution or in labile forms, low total zinc contents, high pH, high calcite and organic matter contents.

Micronutrient malnutrition, also known as "hidden hunger," affects around 2 billion people worldwide, primarily in underdeveloped nations (Von Grebmer, 2014) [31]. Zinc is an element found in proteins that functions as a structural, functional and regulatory cofactor for numerous enzymes. One of the main effects of zinc deficiency on the body is the disruption of normal enzyme activity, *i.e.*, zinc deficiency-induced inhibition of photosynthesis is correlated with a reduction in the activity of important photosynthetic enzymes. According to recent research, zinc is essential for maintaining the activity of enzymes that synthesise DNA, stabilising the structure of RNA and DNA, and regulating the activity of enzymes that degrade DNA. Zinc may therefore have an impact on the regulation of gene expression (Brown *et al.*, 1993) [7]. Bagci *et al.* (2007) [6] suggested that when plants experienced drought stress, their susceptibility to Zn deficiency stress increased. The idea that effective water uses in a given area is highly dependent on the Zn nutritional status of plants stems from the observation that irrigation had the greatest impact on grain yield when Zn was supplied to a sufficient degree. Low zinc concentrations in most agricultural soils have a detrimental effect on crops, significantly lowering yield and posing health hazards to the general public. Zinc deficiency affects more than one-third of the world's population and increases the risk of immunodeficiency, delayed development, infectious illnesses, and DNA damage. More than 300 biological enzymes depend on zinc for proper operation, and it is essential for the human immune system (McCall *et al*., 2000) [17].

Zinc deficiency is a major issue in India, particularly in the northwest (Shukla *et al*., 2017 and Singh *et al*., 2022) [25, 26]. It poses a significant risk to crop output, particularly in calcareous and light-textured soils (Heba *et al*., 2021) [12]. According to soil and plant studies, 49% of Indian soils may be zinc deficient (Alloway, 2008) [8]. A zinc deficiency affects plant root growth, which lowers soil absorption of water and nutrients and thus lowers plant growth, nutritional composition, and yield. The most typical signs of zinc deficiency include stunted development, shorter internodes, petioles, and small, deformed leaves that produce the "rosette" symptom early in growth.

As the pH of the soil rises, zinc's solubility and plant absorption rapidly decline. Because of its high pH and high reactivity with clay, zinc may occasionally be present in the soil but unavailable to plants (Mousavi *et al*., 2013). Because farmers apply a lot of phosphorous fertilizer at planting, which interferes with the plant's metabolism of zinc, the potato crop is extremely sensitive to zinc. This can lead to a shortage, particularly when soil temperatures are low during the early stages of potato growth. Biofortification can be used to address micronutrient shortages on a wide scale and improve nutrient uptake in plant systems (Dhaliwal *et al*., 2022) [9].

Zinc deficiency is typically sporadic, even within a field. In order to increase biomass and yield, zinc application in a variety of crops has been suggested using a variety of methods, including soil application, foliar spray, and seed priming (Dhaliwal *et al*., 2022) [9]. Through plant breeding or mineral fertilisation, biofortification increases the amount of micronutrients in the edible portions of plants. While the translocation of integrates increases in later growth phases, the administration of micronutrient fertilisers dramatically improves the nutrient content of foliage during crop growth stages, leading to production benefits (Singh *et al*., 2022) [26]. Improvements in tuber output and quality are mostly dependent on zinc.

Only a small portion of the zinc in food may be easily absorbed and accessed by the human digestive system. Due to its high digestibility, potatoes are a crop that is enjoyed by people all over the world. Additionally, they offer a great chance for agronomic biofortification. The ineffective transport of zinc in the phloem and the adsorption of zinc to soil elements make it difficult to raise the zinc content of tubers.

Materials and Methods

The current study was conducted in a field at the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) Zonal Agricultural Research Station, Chhindwara, during the *rabi* season 2023-2024. The location is 657.87 meters above mean sea level and is located at 22°03" North Latitude and 78°92" East Longitude. A randomised block design with seven treatments replicated three times was used for the field experiment, which was carried out in sandy loam soil with homogeneous texture, good drainage properties, and a medium NPK status. Fertilizer dosage recommendations, which are 120:100:100 kg N, P_2O_5, and K_2O per hectare, respectively. Nitrogen was administered in two split doses at planting time, whereas potassium and phosphorus were applied in full dosages. 30 days after planting, half of the nitrogen dose was administered, and the other half was applied 60 days later. Zinc sulphate was used to fertilize the potato crop in accordance with various experimental treatments, including T_1 [No Zinc (control)], T_2 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting], T_3 [5.0 kg Zinc/ha from zinc sulphate @ at the time of planting], T_4 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting], T_5 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting], T_6 [T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting], T_7 [T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting]. In the final week of November, 60 x 20 cm spacing was used to plant the Kufri Lavkar variety of well-sprouted potato tubers. To maintain moisture levels and promote plant emergence, a little amount of light watering was carried out after planting. Subsequent watering was provided using a check basin irrigation system. About 10 to 15 days before the potato tuber is harvested when it becomes yellow, dehaulming is done. The crop was harvested during third week of March. Yield parameters were observed after harvesting of tubers with following procedures:

Number of tubers per plant

The number of tubers of five labeled plants was counted. The mean was recorded as number of tubers per plant**.**

Tuber weight per plant (kg)

Five labelled plants were harvested, and the weight of tubers per plant was measured. The average weight of tubers per plant, measured in grams, was determined by averaging five plants.

Tuber volume (ml)

The volume of the randomly selected five tubers was recorded by water displacement method and average was expressed in milliliter per tuber.

Tuber yield (t/ha)
The tubers obtained from the net plots were separated and the weight was recorded. The tuber yield per hectare was estimated and expressed in kilogram. Tubers were sorted out into four different grades based on their weights. The weights of four grades of tubers were recorded plot wise from each net plot. Total yield per net plot was calculated by adding all the four grades. The grade wise and total yield per hectare were expressed in kilogram were calculated using the following formula.

$$\text{Tuber Yield (t/ha)} = \frac{\text{Yield per net plot (kg)}}{\text{Total net area of the plot (m}^2\text{)}} \times 100$$

Haulm yield (t/ha)
From the net plot area haulm was cut at ground level from each treatment and sun dried and weighed and converted into tonnes per hectare.

Tuber Grading (>75 g, 50-75 g, 25-50 g &< 25 g)
Tubers obtained from the five tagged plants were graded after harvest as: A-grade (> 75 g), B-grade (50-75 g), C-grade (25-50 g) and D-grade (< 50 g) based on weight of tubers.

Economics Parameters
Cost of cultivation (Rs/ha)
The cost of cultivation was calculated by adding the cost of items used in cultivation (Rs/ha), while total expenditure was calculated by adding the cost of cultivation with the treatment cost.

Gross monetary return (Rs/ha)
The value realized from the produce obtained under each treatment was computed on the basis of the existing market price of the produce as the gross income per hectare under different treatments.

Net monetary return (Rs/ha)
The net return per hectare under each treatment was determined by subtracting the cost of cultivation of a particular treatment from the net return of the same treatment.

Net return = Gross returns-Cost of cultivation

Benefit cost ratio
The benefit-cost ratio, also known as profitability, is an index that indicates the monetary gain over each rupee investment under different treatments. It was calculated using the following formula:

$$\text{B: C ratio} = \frac{\text{Net returns}}{\text{Cost of cultivation}}$$

Results
Yield Parameters
Effect of application of different doses of zinc fertilizer studied with respect to the following yield parameters, i.e., number of tubers per plant, tuber weight per plant (kg), tuber volume (cm^3), tuber yield (tonne per ha), haulm yield (tonne per ha), tuber grading (< 25 g, 25-50 g, 50-75 g, &>75 g), were recorded, analyzed, and presented as follows:

Number of Tubers per Plant
The number of tubers produced by each potato plant was significantly impacted by the use of different doses of zinc fertilizer.
Data in Table no. 1 showed that application of different doses of zinc fertilizer were significantly influenced by number of tubers and maximum (14.44) found in the treatment T_7, which is at par with T_5 (12.02), and T_6 (11.83), and the minimum (5.97) was found in the treatment T_1.

Tuber Weight per Plant (kg)
The tuber weight per plant produced by each potato plant was significantly impacted by the use of different doses of zinc fertilizer.
Data in Table no. 1 showed that application of different doses of zinc fertilizer significantly influenced tuber weight per plant (kg) and the maximum (1.21) was found in the treatment T_7, which is at par with T_5 (1.11) and the minimum (0.51) was found in the treatment T_1.

Tuber Volume (ml)
The tuber volume (ml) of each potato was significantly impacted by the use of different doses of zinc fertilizer.
Data in Table no. 1 showed that different doses of zinc fertilizer were significantly influenced by the tuber volume (ml) and the maximum (126.79) was found in the treatment T_7, followed by T_3 (115.16), T_5 (120.71), and T_6 (117.44), and the minimum (97.64) was found in the treatment T_1.

Tuber Yield (tonne per ha)
The tuber yield (t/ha) produced by each potato plant was significantly impacted by the use of different doses of zinc fertilizer.
Data in Table no. 1 showed that different doses of zinc fertilizer significantly influenced tuber yield (t/ha), and the maximum (36.46) was found in the treatment T_7, which is at par with T_3 (32.61), T_5 (34.77), and T_6 (33.16), and the minimum (26.37) was found in the treatment T_1.

Haulm Yield (tonne per ha)
Data in Table no. 1 showed that different doses of zinc fertilizer were significantly influenced on fresh haulm yield and dry haulm yield in tonne per hectare. Maximum fresh haulm yield (t/ha) was found in the treatment T_7 (10.57) which is at par with T_5 (9.51), and the minimum (6.88) was found in the treatment T_1. Maximum dry haulm yield (t/ha) was found in the treatment T_7 (2.14) which is at par with T_5 (1.84), and the minimum (1.35) was found in the treatment T_1.

Grade Wise Number of Tubers (< 25 g, 25-50 g, 50-75 g, &>75 g 000'/ha)
Data in Table no. 2 showed that different doses of zinc fertilizer significantly influenced on grade wise no. of tuber (< 25 g, 25-50 g, 50-75 g, &>75 g).
For <25 g potato tubers, maximum (170.33) was found in the treatment T_5 which is at par with T_6 (153.01), and the minimum (80.47) was found in the treatment T_1.
For 25-50 g potato tubers, maximum (151.27) was found in the treatment T_7 which is at par with T_5 (133.78), and the minimum (102.03) was found in the treatment T_1.
For 50-75 g potato tubers, maximum (140.01) was found in the treatment T_7 which is at par with T_5 (126.63), and T_6

(121.56), and the minimum (55.90) was found in the treatment T_1.

For >75 g potato tubers, maximum (129.04) was found in the treatment T_7 which is at par with T_5 (113.62), and the minimum (52.64) was found in the treatment T_1.

Grade Wise Tuber Yield (< 25 g, 25-50 g, 50-75 g, &>75 g t/ha)

Data in Table no. 3 showed that different doses of zinc fertilizer significantly influenced on grade wise tuber yield (< 25 g, 25-50 g, 50-75 g, &>75 g t/ha).

For <25 g potato tubers, maximum (1.56) was found in the treatment T_5 which is at par with T_7 (1.37), and the minimum (0.88) was found in the treatment T_1.

For 25-50 g potato tubers, maximum (10.13) was found in the treatment T_7 which is at par with T_4 (9.65), and T_5 (8.97), and the minimum (7.03) was found in the treatment T_1.

For 50-75 g potato tubers, maximum (13.87) was found in the treatment T_7 which is at par with T_5 (12.53), and T_6 (12.41), and the minimum (9.99) was found in the treatment T_1.

For >75 g potato tubers, maximum (11.09) was found in the treatment T_7 which is at par with T_3 (10.93), T_5 (11.03), and T_6 (10.73), and the minimum (8.41) was found in the treatment T_1.

Economics

After harvesting economic parameters viz., cost of cultivation, gross monetary return (Rs/ha), net monetary return (Rs/ha), and B:C ratio of potato were calculated. Effect of application of different doses of zinc fertilizer showed significant effects on cost of cultivation, gross monetary return (Rs/ha), net monetary return (Rs/ha), and B:C ratio of potato, as presented in the table no. 4.

The cost of cultivation is (83826.40 Rs/ha) for treatment T_7 (2.5 kg Zinc/ ha from zinc sulphate @ at the time of planting+ Foliar Application of zinc sulphate @ 2 g/ litre (400 PPM Zn) at 25 and 50 DAP) produced the highest net monetary return (349725.82 Rs/ha), gross monetary return (433552.22 Rs/ha), and B:C ratio (4.17), outperforming all other treatments. In potato, treatment T_1 yielded a minimum cost of cultivation (82049.44 Rs/ha), a gross monetary return (318760.00Rs/ha), net monetary return (236710.56 Rs/ha), and B:C ratio (2.88) of potato were significantly influenced by the application of different doses of zinc fertilizer treatments.

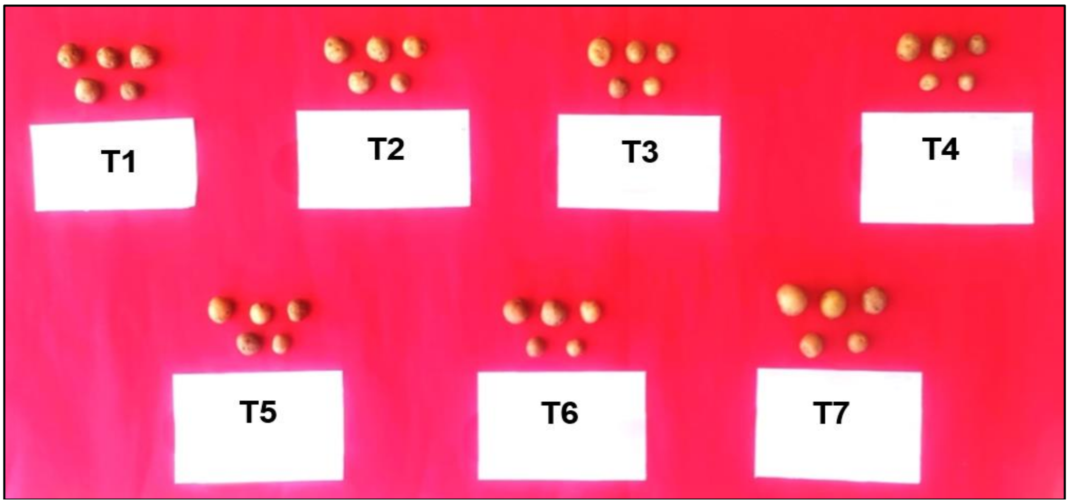

Plate 1: Potato Tuber (D Grade, <25 G)

Plate 2: Potato Tuber (C Grade, 25-50 G)

Plate 3: Potato Tuber (B Grade, 50-75 G)

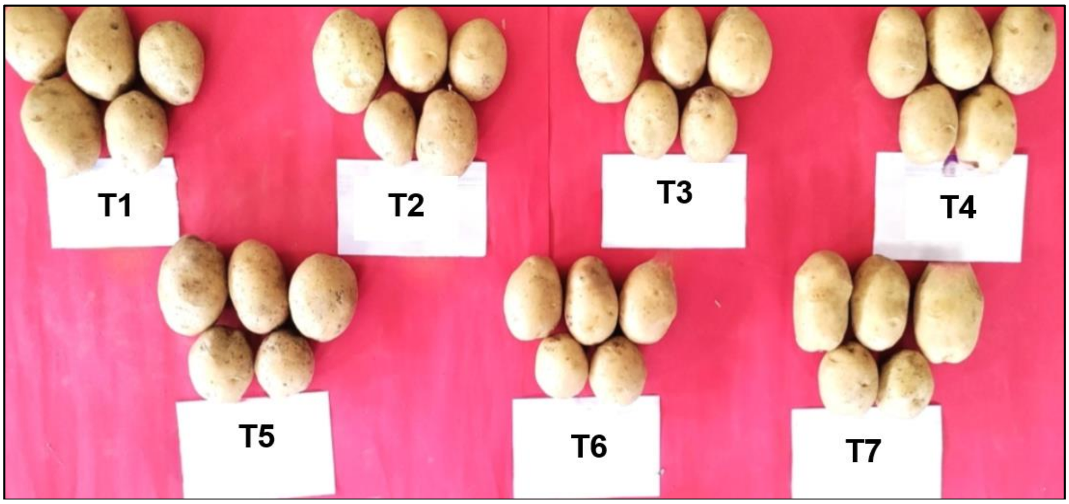

Plate 4: Potato Tuber (A Grade,>75 G)

Table 1: Effect of Zinc Application on Different Yield Parameters in Potato Tubers

Treatments		Number of Tubers per Plant	Tuber weight per plant (kg)	Tuber volume (ml)	Tuber Yield (t/ha)	Haulm Fresh weight (t/ha)	Haulm Dry weight (t/ha)
T_1	No Zinc (control)	5.97	0.51	97.64	26.37	6.88	1.35
T_2	2.5 kg Zinc/ha from zinc sulphate @ at the time of planting	7.10	0.69	108.88	28.04	8.45	1.49
T_3	5.0 kg Zinc/ha from zinc sulphate @ at the time of planting	8.46	0.80	115.16	32.61	8.97	1.75
T_4	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	8.40	0.66	112.10	29.80	8.65	1.48
T_5	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	12.02	1.11	120.71	34.77	9.51	1.84
T_6	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	11.83	0.90	117.44	33.16	8.93	1.70
T_7	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	14.44	1.21	126.79	36.46	10.57	2.14
	SE m±	1.02	0.04	4.75	2.04	0.51	0.11
	C.D. at 5% level	3.15	0.11	14.62	6.27	1.58	0.32

Table 2: Effect of Application of Different Doses of Zinc Fertilizer on Grade Wise Number of Tubers (< 25 g, 25-50 g, 50-75 g, &>75 g) of Potato

Treatments		Grade wise no. of Tubers (000'/ha)			
		< 25 g	25-50 g	50-75 g	>75 g
T_1	No Zinc (control)	80.47	102.03	55.90	52.64
T_2	2.5 kg Zinc/ha from zinc sulphate @ at the time of planting	110.56	117.87	99.77	60.63
T_3	5.0 kg Zinc/ha from zinc sulphate @ at the time of planting	121.87	120.90	112.77	69.12
T_4	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	111.31	125.89	95.27	63.19
T_5	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	170.33	133.78	126.63	113.62
T_6	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	153.01	127.15	121.56	101.96
T_7	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	151.80	151.27	140.01	129.04
	SE m±	5.80	6.46	6.64	5.45
	C.D. at 5% level	17.88	19.92	20.44	16.79

Table 3: Effect of Application of Different Doses of Zinc Fertilizer on Grade Wise Tuber Yield (< 25 g, 25-50 g, 50-75 g, &>75 g t/ha) of Potato

Treatments		Grade Wise Tuber Yield (t/ha)			
		< 25 g	25-50 g	50-75 g	>75 g
T_1	No Zinc (control)	0.88	7.03	9.99	8.59
T_2	2.5 kg Zinc/ha from zinc sulphate @ at the time of planting	0.95	7.86	10.43	8.88
T_3	5.0 kg Zinc/ha from zinc sulphate @ at the time of planting	1.12	8.76	11.80	10.93
T_4	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	1.08	7.94	11.05	9.73
T_5	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	1.56	9.65	12.53	11.03
T_6	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	1.05	8.97	12.41	10.73
T_7	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	1.37	10.13	13.87	11.09
	SE m±	0.07	0.41	0.51	0.44
	C.D. at 5% level	0.22	1.27	1.58	1.61

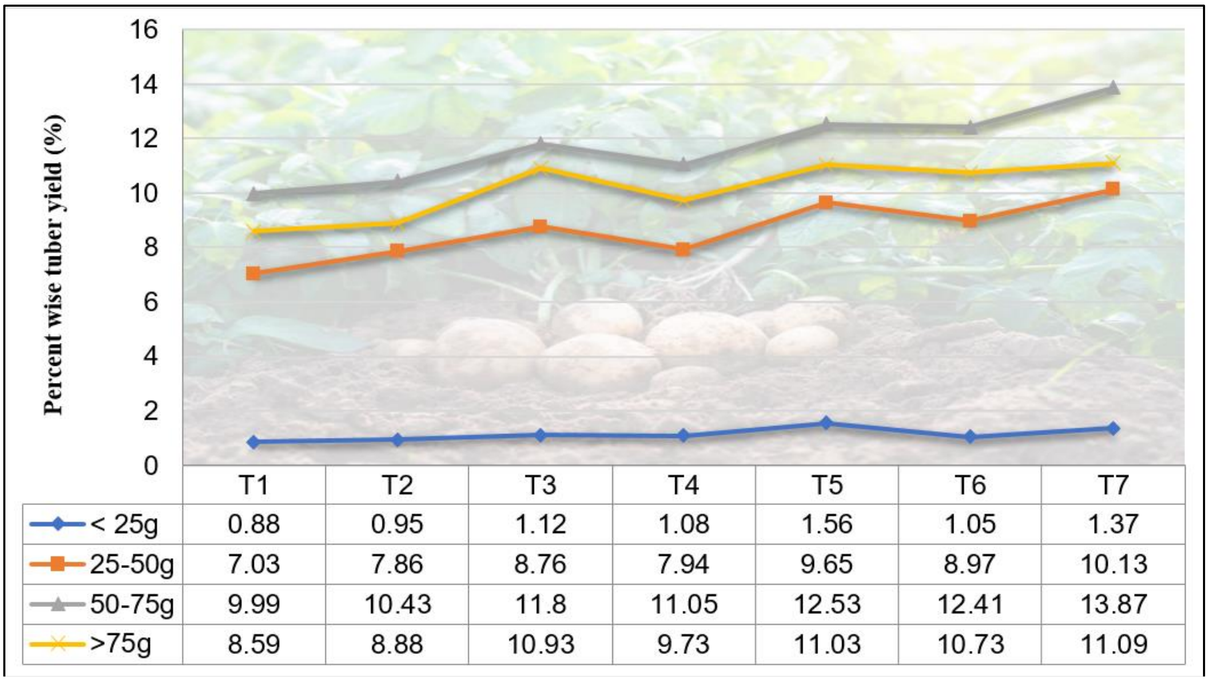

Fig 1: Effect of Application of Different Doses of Zinc Fertilizer on Grade Wise Tuber Yield (< 25 g, 25-50 g, 50-75 g, & >75 g t/ha) of Potato

Table 4: Effect of application of different doses of zinc fertilizer on gross monetary return (Rs/ha), net monetary return (Rs/ha), and B:C ratio of potato

Treatments		Gross monetary return (Rs/ha)	Net monetary return (Rs/ha)	B:C ratio
T_1	No Zinc (control)	318760.00	236710.56	2.88
T_2	2.5 kg Zinc/ha from zinc sulphate @ at the time of planting	332726.78	250129.41	3.03
T_3	5.0 kg Zinc/ha from zinc sulphate @ at the time of planting	391289.60	308144.32	3.71
T_4	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	357568.24	274903.91	3.33
T_5	Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	417188.02	333909.54	4.01
T_6	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting	397920.00	314707.76	3.78
T_7	T_2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting	433552.22	349725.82	4.17

Discussion

The number of tubers produced by each potato plant was significantly impacted by the use of different doses of zinc fertilizer, maximum (14.44) found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (5.97) was found in the treatment T_1 (No Zinc control). Since zinc affects the hormonal condition of potato plants, treating them with zinc increased the total number of tubers per plant. Zinc, on the other hand, increases the ratios of cytokinin/ABA and IAA/ABA, which encourages the growth and development of stolons primarily because it increases gibberellin content in plants while decreasing ABA content (Puzina, 2004) [22]. These conclusions were corroborated by the research conducted by Taheri *et al*. (2012) [28], Al-Jobori and Al-Hadithy (2014) [2], and Raghav and Singh (2003) [23].

Application of different doses of zinc fertilizer significantly influenced tuber weight per plant and the maximum (1.21 kg) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (0.51 kg) was found in the treatment T_1 (No Zinc control). Although zinc increases both the number and size of tubers per plant, applying zinc caused the weight of tubers per plant to increase. Furthermore, there was a positive association found between the number and size of tubers per plant as well as the weight of tubers per plant. When zinc was given as basal dose, medium and large sized tubers' weight increased (Raghava and Singh, 2003) [23]. Similar results were reported by Puzina (2004) [22], Thakare *et al*. (2007) [29] and Ahmed *et al*. (2011) [1].

Different doses of zinc fertilizer were significantly influenced by the tuber volume and the maximum (126.79 ml) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (97.64 ml) was found in the treatment T_1 (No Zinc control). Due to zinc stimulates photosynthesis, phloem loading and translocation, and the synthesis of large molecules within the storage organ, all of which contribute to the tubers volume (Joshi *et al*., 2007) [13]. This may have contributed to the potato crop's balanced nutrition of zinc in addition to supplying other necessary elements. The increase in tuber volume with Fe and Zn-enriched organics may also be the result of enhanced physiological activity, such as photosynthesis and food material translocation. It also contributed to the transition of tubers from small to medium and medium to large grade by raising the average weight of each tuber. These findings are consistent with the findings published by Koodi *et al*. (2017) [14] and Mousavi *et al.* (2007) [18].

Different doses of zinc fertilizer significantly influenced tuber yield and the maximum (36.46 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP] and the minimum (26.37 t/ha) was found in the treatment T_1 (No Zinc control). The role zinc plays in the metabolism of carbohydrates could be the main cause of the increase in tuber yield linked to zinc intake. Because this element is involved in the production of RNA polymerase enzymes and carboxyl phosphate, which enhances yield, plant tissue contains higher levels of glucose and starch. The result was similar to which Namini *et al.* (2021) [21] found.

Different doses of zinc fertilizer were significantly influenced on fresh haulm yield and dry haulm yield in tonnes per hectare. Maximum fresh haulm yield (10.57 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (6.88 t/ha) was found in the treatment T_1 (No Zinc control). Maximum dry haulm yield (2.14 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP] and the minimum (1.35 t/ha) was found in the treatment T_1 (No Zinc control). A higher harvest output could have been attributed to a considerable improvement in growth and yield-related indicators, such as plant height, number of shoots, number of leaves per plant. The results were consistent with the observations and findings of Choudhary *et al.* (2021) [8].

Different doses of zinc fertilizer significantly influenced on grade wise no. of tuber. For <25 g potato tubers, maximum (170.33) was found in the treatment T_5 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting], and the minimum (80.47) was found in the treatment T_1 (No Zinc control). For 25-50 g potato tubers, maximum (151.27) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (102.03) was found in the treatment T_1 (No Zinc control). For 50-75 g potato tubers, maximum (140.01) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (55.90) was found in the treatment T_1 (No Zinc control). For >75 g potato tubers, maximum (129.04) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (52.64) was found in the treatment T_1 (No Zinc control). Improvements in grade wise potato tuber size and number per unit area may have led to better photosynthetic accumulation and translocation to potato tubers, which in turn may have directly contributed to an increase in yield (Sati *et al*., 2017 and Kromann *et al*., 2017) [24, 15].

Different doses of zinc fertilizer significantly influenced on grade wise tuber yield (< 25 g, 25-50 g, 50-75 g, &>75 g t/ha). For <25 g potato tubers, maximum (1.56 t/ha) was found in the treatment T_5 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting], and the minimum (0.88 t/ha) was found in the treatment T_1 (No Zinc control). For 25-50 g potato tubers, maximum (10.13 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (7.03 t/ha) was found in the treatment T_1 (No Zinc control). For 50-75 g potato tubers, maximum (13.87 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (9.99 t/ha) was found in the treatment T_1 (No Zinc control). For >75 g potato tubers, maximum (11.09 t/ha) was found in the treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting

+ Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP], and the minimum (8.41 t/ha) was found in the treatment T_1 (No Zinc control). That could be attributed to zinc being applied by soil application and foliar application, which increased grade-wise tubers yield. An appropriate supply of nutrients leads to higher yields and tubers, according to Nagar *et al*. (2024) [20] as well as Singh *et al*. (2022) [26]. It is associated with increasing the grade wise yield of potato tubers by activating a number of plant enzymes involved in protein synthesis, and glucose metabolism. The same results were published by Ehsanullah *et al*. (2015) [10]. This resulted from increasing zinc levels increasing the amount of ground covered by leaves, which favoured a high rate of photosynthesis. Additionally, photosynthate partitioning was higher towards tubers that were comparatively earlier formed through the stolon than tubers that were initiated later. This result matches up with Trehan (2005) [30] and Kumar *et al*. (2006) [16] findings.

After harvesting economic parameters viz., cost of cultivation, gross monetary return (Rs/ha), net monetary return (Rs/ha) and B:C ratio of potato were calculated. Effect of application of different doses of zinc fertilizer showed significant effects on cost of cultivation, gross monetary return (Rs/ha), net monetary return (Rs/ha) and B:C ratio of potato. The cost of cultivation is (83826.40 Rs/ha) for treatment T_7 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP] at 25 and 50 DAP) produced the highest net monetary return (349725.82 Rs/ha), gross monetary return (433552.22 Rs/ha) and B:C ratio (4.17), outperforming all other treatments. In potato, treatment T_1 (No Zinc control) yielded a minimum cost of cultivation (82049.44 Rs/ha), a gross monetary return (318760.00 Rs/ha), net monetary return (236710.56 Rs/ha) and B:C ratio (2.88) of potato were significantly influenced by the application of different doses of zinc fertilizer treatments. Joshi and Raghav (2007) [13] discovered that the kind of fertilization and treatment levels had an impact on the overall cost of farming. According to their data, while total tuber yields increased, it also increased the cost of labour and the bags needed for post-harvest processing of harvested tubers. This led to an increased the overall cost of production when Zn treatments were applied. Because zinc fertilization had a positive correlation with tuber quality and total production, it also boosted net return, gross return and benefit: cost ratio.

Conclusion

On the basis of the findings of present experiments, yield attributes viz., number of tubers per plant, tuber weight per plant (kg), tuber volume (ml), tuber yield (t/ha), haulm yield (t/ha), tuber grading (< 25 g, 25-50 g, 50-75 g, &>75 g) and economic parameters are also were found maximum in the treatment where 2.5 kg Zinc/ha from zinc sulphate @ at the time of planting + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 DAP were applied along with 120: 100: 100 NPK kg/ha can be recommended to improve the yield of potato tubers. The process of biofortification, which can help address the issue of hidden hunger or malnutrition, primarily entails the biologically available concentration of nutrients in the edible portions of plants through agronomic or genetic selection. The recent studies have demonstrated the beneficial effects of zinc on enhancing potato quality.

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References

1. Ahmed AA, Abd El-Baky MMH, Zaki MF, Abd El-Aal FS. Effect of foliar application of active yeast extract and zinc on growth, yield and quality of potato plant (*Solanum tuberosum* L.). Journal of Applied Sciences Research. 2011;7:2479-2488.
2. Al-Jobori KMM, Al-Hadithy SA. Response of potato (*Solanum tuberosum*) to foliar application of iron, manganese, copper and zinc. International Journal of Agriculture and Crop Sciences. 2014;7:358-363.
3. Alloway BJ. Micronutrients and crop production: An introduction. In: Robson AD, editor. *Micronutrient deficiencies in global crop production*. Perth, Western Australia: Kluwer Academic Publishers; 2008. p. 1-2.
4. Alloway BJ. Soil factors associated with zinc deficiency in crops and humans. Environmental Geochemistry and Health. 2009;31:537-548.
5. Anonymous. Potato Nutrition. Lima, Peru: International Potato Center; 2011.
6. Bagci SA, Ekiz H, Yilmaz A, Cakmak I. Effects of zinc deficiency and drought on grain yield of field-grown wheat cultivars in Central Anatolia. Journal of Agronomy and Crop Science. 2007;193:198-206.
7. Brown PH, Cakmak I, Zhang Q. Form and function of zinc in plants. In: Robson AD, editor. *Zinc in soils and plants*. Developments in Plant and Soil Sciences. Dordrecht: Springer; 1993. Vol. 55. p. 341-343.
8. Choudhary RS, Yadav SK. Studies on effect of zinc application on quality and yield of soybean (*Glycine max* L.) under typic haplotypes soil. Indian Journal of Pure and Applied Biosciences. 2021;9(1):188-193.
9. Dhaliwal SS, Sharma V, Shukla AK, Shivay YS, Hossain A, Verma V, *et al*. Agronomic biofortification of forage crops with Zn and Cu for enhancing nutritive potential-A systematic review. Journal of the Science of Food and Agriculture. 2022;103:1631-1643.
10. Ehsanullah, Mahmood AT, Shakeel RA, Anjum MN, Muhammad N. Exploring the role of zinc in maize (*Zea mays* L.) through soil and foliar application. Universal Journal of Agricultural Research. 2015;3(3):69-75.
11. FAOSTAT. World Food and Agriculture-Statistical Yearbook. Rome: Food and Agriculture Organization of the United Nations; 2023.
12. Heba MN, Rana DS, Choudhary AK, Rajanna GA, Pande P. Influence of sulphur and zinc nutrition on productivity, quality and biofortification in groundnut in south-Asian alluvial soil. Journal of Plant Nutrition. 2021;44(8):1151-1174.
13. Joshi N, Raghav M. Growth and yield of potato as affected by zinc sulphate and their method of application. Progressive Horticulture. 2007;39:189-193.
14. Koodi S, Singh SP, Rolaniya MK, Gathala S, Choudhary R. Effect of NPK, FYM and vermicompost on growth, yield and quality of sweet potato (*Ipomoea batatas* Lam.). Chemical Science Review and Letters. 2017;6(21):495-499.

15. Kromann MA, Dalia AS, Khalil AA. Effect of application methods of potassium and some micronutrients on yield and quality of potato. Journal of Soil Science and Agricultural Engineering. 2017;1(3):211-223.
16. Kumar M, Trehan SP, Singh SK, Singh SN. Growth-period specific nitrogen requirement of potato in the Indo-Gangetic plains of Bihar. Potato Journal. 2006;33(3-4):166-167.
17. McCall KA, Huang C, Fierke CA. Function and mechanism of zinc metalloenzymes. Journal of Nutrition. 2000;130(5):1437S-1446S.
18. Mousavi SR, Galavi M, Ahmadvand G. Effect of zinc and manganese foliar application on yield, quality and enrichment on potato (*Solanum tuberosum* L.). Asian Journal of Plant Science. 2007;6:1256-1260.
19. Mousavi SR, Galavi M, Rezaei M. Zinc (Zn) importance for crop production-A review. International Journal of Agronomy and Plant Production. 2013;4(1):64-68.
20. Nagar BL, Singh J, Yadav DL, Verma HP, Meena RR. Agronomic zinc biofortification of potato (*Solanum tuberosum*) through soil and foliar zinc sulphate application in Rajasthan. The Indian Journal of Agricultural Sciences. 2024;94(10):16-20.
21. Namini SKA, Malakouti MJ, Ghavidel A. The effect of zinc chelates and potassium sulfate topdressing on alleviating the cadmium (Cd) and nitrate (NO_3^-) toxicity in potato tubers of Ardabil province, Iran. International Journal of Agricultural Science and Food Technology. 2021;7(1):34-42.
22. Puzina TI. Effect of zinc sulfate and boric acid on the hormonal status of potato plants in relation to tuberization. Russian Journal of Plant Physiology. 2004;51:209-214.
23. Raghav M, Singh NP. Effect of zinc on yield of potato under Tarai Region. Bhartiya Krishi Anusandhan Patrika. 2003;18:135-138.
24. Sati K, Raghav M, Sati U, Lavlesh. Effect of zinc sulphate application on quality of potato. Research on Crops. 2017;18:98-102.
25. Shukla AK, Sinha NK, Tiwari PK, Prakash C, Behera SK, Lenka NK, *et al*. Spatial distribution and management zones for sulphur and micronutrients in Shiwalik Himalayan region of India. Land Degradation and Development. 2017;28:959-969.
26. Singh NP, Singh J, Singh S, Gill PPS. Soil-leaf nutrient relationships with fruit quality and yield of litchi (*Litchi chinensis*) in northern India. The Indian Journal of Agricultural Sciences. 2022;92(12):1453-1457.
27. Singh P, Verma P, Ravi A, Singh S, Kumar L, Kairovin E, *et al*. Determining the effect of zinc fortification on growth, yield and economics of wheat (*Triticum aestivum* L.) under irrigated condition. Asian Journal of Agricultural Extension, Economics & Sociology. 2022;40:114-118.
28. Taheri N, Sharif-Abad HH, Yousefi K, Mousavi SR. Effect of compost and animal manure with phosphorus and zinc fertilizer on yield of seed potatoes. Journal of Soil Science and Plant Nutrition. 2012;12:705-714.
29. Thakare RG, Jadhao BJ, Nandre DR, Ghawade SM, Khewale AP. Effect of zinc and iron levels on growth and yield of potato. Plant Archives. 2007;7:275-276.
30. Trehan SP. Comparative efficiency of ten potato cultivars to use nitrogen from green manured soil. Potato Journal. 2005;32(3-4):151-152.
31. Von Grebmer K, Saltzman A, Birol E, Wiesmann D, Prasai N, Yin S, *et al*. Global Hunger Index: Armed Conflict and the Challenge of Hidden Hunger. Bonn, Germany: International Food Policy Research Institute and Concern Worldwide; 2014.