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Effect of different doses of zinc on growth and yield of potato (*Solanum tuberosum* L.) cv. Kufri Khyati under Chhattisgarh plain condition

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Abstract
Potato (*Solanum tuberosum* L.), a vital tuberous crop of the Solanaceae family with an auto-tetraploid chromosome number (2n = 4x = 48), holds significant importance in India's agricultural economy. Originating from the Andes of South America, potato is a major cash crop cultivated extensively for its starchy tubers. A field experiment was conducted during the Rabi seasons of 2023-2024 and 2024-2025 at the Research cum Demonstrational Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, to evaluate the effect of different doses of zinc on growth and yield parameters of potato. The experiment was laid out in randomized block design with three replication and eleven treatments *viz*., T_1: No Zn (Control),T_2:2.5 kg zinc /ha from zinc sulphate @ at the time of planting, T_3:5.0 kg zinc /ha zinc from zinc sulphate at the time of planting, T_4:Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 days after planting, T_5: Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 and 50 days after planting, T_6: T_2+Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 days after planting, T_7: T_2+Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 and 50 days after planting, T_8: 7.5 kg zinc /ha from zinc sulphate @ at the time of planting, T_9: 10 kg zinc /ha from zinc sulphate @ at the time of planting, T_{10}: T_3+Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 days after planting, T_{11}: T_3+Foliar application of Zinc sulphate @ 2g/liter (400 ppm Zn) at 25 and 50 days after planting.Results revealed that zinc application significantly influenced growth and yield traits. The highest values for plant height, number of compound leaves per plant, number of shoots per plant, fresh and dry weight of shoots were recorded under treatment T_{11} (5.0 kg Zn/ha from $ZnSO_4$ at planting + foliar application of $ZnSO_4$ @ 2 g/L at 25 and 50 days after planting). Similarly, yield and yield-attributing characters such as number of tubers per plant, total tuber count, marketable tuber yield, and total tuber yield were maximized under T_{11}. Economic analysis showed that T_{11} also resulted in the highest gross return, net return, and benefit-cost (B:C) ratio. Based on these findings, the combined soil and foliar application of zinc at these doses is recommended to enhance vegetative growth, yield, and profitability in potato cultivation under Chhattisgarh plain conditions.

Keywords: Potato (*Solanum tuberosum* L.), zinc application, growth parameters, yield attributes, foliar spraying, zinc sulphate ($ZnSO_4$), biofortification, benefit-cost ratio, Chhattisgarh plains and micronutrient fertilization

Introduction
Potato (*Solanum tuberosum* L.), a member of the family *Solanaceae*, is one of the most important staple food crops worldwide. It is recognized for its high yield potential, nutritional value, and adaptability to diverse agro-climatic conditions. Being a heavy nutrient-demanding crop, potato requires an adequate and balanced supply of both macro- and micronutrients for optimum growth and productivity. Although micronutrients are required in small quantities, their deficiency can significantly limit yield and quality. In India, zinc (Zn) has emerged as the most deficient micronutrient, with approximately 52% of soils lacking sufficient levels to meet crop demands.

Zinc plays a crucial role in plant physiological and biochemical processes, including the biosynthesis of indole acetic acid (IAA), initiation of primordia for reproductive parts, and partitioning of photosynthates towards them, thereby enhancing flowering, fruit set, and yield

(Himanshu *et al*., 2008) [13]. It also functions as a structural and catalytic component of numerous enzymes, influencing protein synthesis, membrane integrity, and hormonal balance. Zinc deficiency in crops not only reduces productivity but also adversely impacts the nutritional quality of edible parts, contributing to "hidden hunger" or micronutrient malnutrition in humans. Inadequate dietary zinc intake can result in stunted growth, impaired immune function, and reproductive issues.

Biofortification through Zn fertilization is an effective, sustainable approach to address both productivity constraints and nutritional deficiencies. The application of Zn-fertilizers to crops capable of absorbing and storing Zn in edible tissues offers dual benefits—enhancing crop yield on Zn-deficient soils and improving human dietary zinc intake (Graham *et al*., 2007) [11]. Potato is particularly suitable for biofortification due to its wide consumption and favorable nutrient profile. For example, 200 g of fresh weight (FW) unpeeled potato tubers can provide approximately 5.5% of the daily Zn requirement for an adult male (11 mg/day) (White *et al*., 2009) [34]. Furthermore, the bioavailability of Zn in potato tubers is relatively high, owing to the presence of organic compounds that enhance Zn absorption and the low levels of inhibitors such as phytates (Burlingame *et al*., 2009; Kärenlampi & White, 2009; White *et al*., 2009) [9, 18, 34].

Enhancing tuber Zn concentration through Zn fertilization, therefore, represents a practical and impactful strategy to improve both agricultural productivity and public health. This research aims to evaluate the effect of different doses of zinc on the growth, yield, and quality of potato under Chhattisgarh plain conditions, with a view to identifying optimal Zn management practices for maximizing both agronomic and nutritional benefits.

Methods and Materials

The experiment was conducted at Research cum Demonstration Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during year 2023-24 and 2024-25 *rabi* season to investigate the effect of different doses of zinc on growth and yield of potato (*Solanum tuberosum* L.) cv. Kufri Khyati under Chhattisgarh plain condition. The soil of the experimental field is clay-loam, which is locally known as "Dorsa". Soil samples of experimental field were gathered at random using an auger from 4-5 locations upto a depth of 20 cm and properly mixed to create a composite sample. The composite sample was analysed to determine the soil initial fertility status.

Table 1: Physico-chemical properties of experimental soil

	Particulars	2023-24	2024-25	Method Employed
I	**Mechanical analysis**			
	Sand (%)	56.43	57.28	International Pipette method (Black, 1965) [8]
	Silt (%)	17.22	18.46	
	Clay (%)	26.35	24.26	
II	**Chemical analysis**			
	Soil pH	6.89	7.1	Glass electrode pH meter (Piper, 1967) [26]
	EC (dsm^{-1} At 25°C)	0.18	0.24	Systronics electrical conductivity meter (Richards, 1954) [28]
	Organic carbon (%)	0.18	0.43	Walkley and Black method (1934) [33]
	Available N (kg ha^{-1})	210	233.42	Alkaline permanganate method (Subbiah and Asija, 1956) [30]
	Available P_2O_5 (kg ha^{-1})	18.5	21.70	Olsen's method (Olsen *et al*.,1954) [23]
	Available K_2O (kg ha^{-1})	239	271.23	Flame photometric method (Jackson, 1967) [14]
	Available Zn (kg ha^{-1})	0.7	1.1	DTPA (Lindsay and Norvell,1978) [20]

The field was prepared by ploughing with a mouldboard plough, followed by two cross harrowings, and finally brought to a fine tilth using a rotavator. Well-decomposed farmyard manure (FYM) @ 20 t ha^{-1} was applied before layout.

The plots were labelled uniformly and were laid down as per the design of the experiment. The trial was laid down in a randomized block design (RBD) corresponding to 11 treatments and three replications. The experimental area was divided into 33 plots, each measuring 4.8 m × 3.4 m, and ridges of 20 cm height were prepared at 60 cm spacing with a tractor-mounted ridger. Nitrogen, phosphorus, and potassium were applied in the form of urea, diammonium phosphate (DAP), and muriate of potash (MOP), respectively. Half of the nitrogen along with the full dose of phosphorus and potassium was applied as a basal dose at planting, and the remaining nitrogen was top-dressed at 30 days after planting (DAP) during earthing-up. For uniform sprouting, seed tubers were kept under diffused light for seven days after removal from cold storage. To prevent fungal contamination, sprouted tubers were dipped in Dithane M-45 solution @ 2.5 g L^{-1} for 15 minutes, shade-dried, and planted on ridges at 20 cm spacing. Gap filling was done at 15 DAP using treated sprouted tubers. Earthing-up was carried out at 30 and 60 DAP, coinciding with top-dressing. The crop was irrigated using the furrow method, with a pre-emergence irrigation applied immediately after planting and subsequent irrigations at 12-day intervals. Weeding was done manually at 30 DAP during earthing-up. Haulm cutting was done at 90 DAP, and harvesting was carried out manually seven days later using spades and kudali. After harvest, tubers were graded into three categories: small (<25 g), medium (25-75 g), and large (>75 g), with marketable tubers defined as >25 g.

Observations were recorded on growth and yield parameters from five randomly selected plants per plot. Growth observations included plant emergence percentage at 30 DAP, plant height, number of shoots, number of compound leaves, total leaves, and fresh and dry shoot weights. Yield attributing traits included number of tubers per plant, fresh and dry tuber weights, grade-wise tuber yield and number, marketable and unmarketable yield, total tuber yield, and tuber counts. Economic analysis was carried out by calculating cost of cultivation, gross return (yield × market price), net return (gross return - cost of cultivation), and benefit:cost ratio (gross return ÷ cost of cultivation). The yield data collected from field and those recorded in the laboratory were subjected to statistical analysis. The analysis of variance approach was used to examine the analytical data in this experiment as described by Gomez and Gomez (1984) [12].

Results and Discussion

Effect of zinc application on growth attributes of potato

Effect of zinc application on Plant Emergence (%)

Plant emergence at 30 DAP was not significantly affected by basal or foliar $ZnSO_4$ application during both years and in the pooled analysis (Table 2). In 2023-24, emergence ranged from 91.00% (T_6) to 94.03% (T_{11}), while in 2024-25 it ranged from 88.57% (T_1) to 93.38% (T_{11}). Pooled means showed the highest emergence in T_{11} (93.71%) and the lowest in the control (91.12%).The lack of statistical significance suggests that emergence was primarily influenced by tuber physiological status rather than external zinc application, owing to adequate carbohydrate reserves enabling uniform sprouting. Similar findings were reported by Banerjee *et al*., (2016) [5] and Miyu *et al*., (2019) [21], who found no significant effect of Zn on potato germination.

Effect of zinc application on Plant Height (cm)

Plant height was recorded at 45, 60, and 75 DAP (Table 3). At 45 DAP, differences were non-significant across years and pooled data, though T_{11} showed the highest plant height (36.28 cm pooled) and the lowest was in the control (T_1, 28.97 cm). At 60 DAP, significant differences were observed, with T_{11} recording the maximum height in pooled data (63.00 cm), statistically at par with T_{10} (62.16 cm), T_5 (61.82 cm), T_7 (60.79 cm), and T_6 (60.05 cm), while T_1 had the lowest (44.59 cm). At 75 DAP, the highest plant height was again in T_{11} (65.41 cm pooled), at par with T_{10}, T_7, T_6, and T_9, and the lowest height was recorded in T_1 (45.30 cm).". The increase in height under combined basal + foliar zinc application could be due to improved auxin synthesis, chlorophyll content, and metabolic activity, enhancing cell division and elongation. These findings similar with Kalaiselvan *et al*., (2021) [16], who reported that adequate Zn supply promotes rapid cell division in apical meristems, increasing vegetative growth.

Effect of zinc application on Number of Shoots per Plant

Zinc plays an essential role in plant growth by influencing auxin metabolism and protein synthesis. The number of shoots per plant was recorded at 45, 60, and 75 DAP (Table 4; Fig. 1.3). At 45 and 60 DAP, differences were non-significant across years and pooled data, with T_{11} recording the highest values (5.02 and 5.57 pooled) and the control (T_1) the lowest (3.75 and 4.55 pooled). At 75 DAP, significant variation was observed, with pooled means showing T_{11} having the highest number of shoots (6.76), statistically at par with T_{10} (6.70) and T_7 (6.68), while T_1 had the lowest (4.60). The increased shoot production under integrated Zn application indicates enhanced shoot initiation, in agreement with findings of Kamboj *et al*. (2019) [17] and Miyu *et al.* (2019) [21]."

Effect of zinc application on Number of Compound Leaves per Plant

The number of compound leaves per plant at 45 and 60 DAP did not differ significantly across years or in pooled data (Table 5). The highest pooled values at 45 DAP were recorded in T_{11} (38.27) and the lowest in the control (T_1, 31.78). At 60 DAP, T_{11} recorded 46.09 leaves (pooled), while the control had 37.52. At 75 DAP, significant differences were observed, with T_{11} recording the highest pooled number of leaves (59.01), statistically at par with T_{10}, T_7, T_6, T_9, and T_8, whereas the control had the lowest (40.20). The increased leaf production under basal + split foliar Zn application could be due to continuous Zn availability during critical vegetative stages, promoting sustained photosynthetic activity. These observations agree with Kaur *et al*., (2018) [19], who highlighted zinc's role in auxin production and vegetative growth stimulation. Overall, the results indicate that plant emergence was not affected by zinc application, whereas vegetative growth parameters—plant height, number of shoots, and compound leaves—were significantly improved under combined basal and foliar $ZnSO_4$ application (5.0 kg Zn/ha + foliar sprays at 25 and 50 DAP, T_{11}). These findings highlight the synergistic effect of integrated zinc nutrition in enhancing potato vegetative growth.

Effect of zinc application on yield attributes of potato

Effect of different doses of zinc application on total tuber number and weight of tuber(g)

Zinc sulphate application significantly influenced tuber number and weight during both years and in pooled analysis (Table 6), highlighting zinc's key role in tuberization and bulking. The combined treatment of 5.0 kg Zn/ha from $ZnSO_4$ at planting plus foliar spray @ 2 g/L at 25 and 50 DAP (T_{11}) consistently produced the highest tuber number (607.4) and weight (198.5 g), statistically at par with T_{10} and superior to other treatments. The improvement is attributed to zinc's involvement in auxin synthesis, enzyme activation, carbohydrate metabolism, and efficient photosynthate translocation during critical growth stages. Similar enhancements in tuber yield due to zinc and other micronutrients have been reported by Das and Jena (1973) [10], Sharma *et al*., (1988) [29], Awad *et al*., (2010) [4], Al-Jobori and Al-Hadithy (2014) [3], and Al-Fadhly (2016) [2].

Effect of different doses of zinc application on grade wise tuber yield of potato

Zinc fertilization significantly improved yields in all tuber size grades, with the highest pooled (Table 7), yields for small (6.96 kg/plot), medium (9.83 kg/plot), and large (7.41 kg/plot) tubers recorded in T_{11} (T_3 + foliar $ZnSO_4$ @ 2 g/L at 25 & 50 DAP). This treatment outperformed or matched other Zn-supplemented treatments, while control and low-Zn rates gave the lowest yields. Results suggest combined basal and foliar Zn maximizes tuber size distribution and total yield, consistent with Awad *et al*., (2010) [4], Al-Jobori & Al-Hadithy (2014) [3], and Al-Fadhly (2016) [2].

Effect of different doses of zinc application on unmarketable yield (t ha^{-1}), marketable yield (t ha^{-1}), total yield (t ha^{-1}) and grade wise number of tuber (000' ha^{-1})

Unmarketable yield, comprising misshapen, diseased, undersized, or cracked tubers, was significantly influenced by zinc sulphate treatments across both years and pooled data(Table 1.8). The lowest yields were recorded under T_2 (2.5 kg Zn/ha at planting) in 2023-24 and pooled analysis, while the control (T_1) had the lowest in 2024-25. The highest unmarketable yields occurred in T_{11} (T_3 + foliar $ZnSO_4$ @ 2 g/L at 25 & 50 DAP), statistically comparable to other high-dose or combined treatments. Higher unmarketable yields in these treatments likely resulted from increased total tuber production, consistent with Banerjee *et al*., (2016) [6].

Marketable yield improved markedly with integrated soil and foliar Zn application. T_{11} consistently produced the highest yields across years and pooled data (Table 9), statistically similar to T_{10}. Control (T_1) and foliar-only at 25 DAP (T_4) produced the lowest yields. These results align with Banerjee *et al*., (2016) [5], confirming Zn's role in enhancing tuber size and weight.

Total tuber yield followed the same trend, with T_{11} producing the maximum yields across seasons and pooled data (Table 9), statistically at par with T_{10}. Control and low-Zn treatments yielded significantly less. Previous studies (Raghav & Singh, 2004; Mondal *et al*., 2007; Taya *et al*., 1994; Parmar *et al*., 2016; Thakare *et al*., 2007; Bari *et al*., 2001; Ahmed *et al*., 2011) [27, 22, 31, 25, 32, 7, 1] similarly reported increased yields with integrated Zn management.

Zinc application influenced tuber size distribution in potato (Table 7). For the 0-25 g grade, the highest pooled number (368.8) was recorded in T_{11} (T_3 + foliar $ZnSO_4$ @ 2 g/L at 25 & 50 DAP), statistically at par with most Zn-supplemented treatments, while the lowest (223.7) occurred in T_2 (2.5 kg Zn/ha), likely due to insufficient Zn for early tuber initiation. In the 25-75 g grade, maximum counts were observed in T_2 (158.6), followed by T_{10} (155.5) and T_{11} (155.1), indicating that moderate Zn rates favored development of medium-sized tubers. The lowest number (104.7) in T_4 (foliar @ 25 DAP) suggests that a single foliar application was inadequate for sustained bulking. For the >75 g grade, T_{11} recorded the highest count (82.4), statistically at par with T_{10} (81.2) and T_3 (80.0), reflecting the positive effect of integrated Zn (basal + foliar) on assimilate supply and tuber enlargement, while the control (T_1) produced the fewest tubers (60.1). Overall, integrated basal and foliar Zn application (T_{11}) maximized total yield and favored both small and large tuber grades, while moderate Zn rates (T_2) enhanced medium-sized tuber production.

Effect of zinc application on economics of potato

Effect of different doses of zinc application on economics of potato (Pooled mean basis)

The economics of potato production varied significantly with zinc application methods in (Table 10). The result revealed that the cost of cultivation ranged from Rs 81,909 ha^{-1} in the control (T_1) to Rs 83,409 ha^{-1} in T_{11} (T_3 + foliar $ZnSO_4$ @ 2 g/L at 25 & 50 DAP). Higher costs in T_{11} and T_{10} were due to combined basal and foliar Zn applications, increasing fertilizer and labour inputs (Joshi & Raghav, 2007; Parmar *et al*., 2007) [15, 24].Gross returns were maximum in T_{11} (Rs.3,15,450 ha^{-1}), followed by T_{10} (Rs 3,10,317 ha^{-1}) and T_7 (Rs 2,80,433 ha^{-1}), mainly due to significantly higher tuber yields from integrated Zn supply enhancing nutrient uptake and tuber bulking (Joshi & Raghav, 2007) [15].Net returns peaked in T_{11} (Rs 2,32,041 ha^{-1}), with T_{10} (Rs 2,27,658 ha^{-1}) and T_7 (Rs 2,29,226 ha^{-1}) close behind. The lowest net return (Rs 1,53,391 ha^{-1}) was in the control (T_1), reflecting lower yields without Zn input. B:C ratio was highest in T_{11} (3.78), followed by T_{10} (3.75) and T_7 (3.41), while the lowest was in T_1 (2.93). Overall, T_{11} emerged as the most profitable and cost-effective treatment, with superior economic returns due to sustained Zn availability during critical growth phases, leading to maximum yield and profitability.

Table 2: Effect of different doses of zinc application on plant emergence (%) at 30 days after planting

Treatments	Plant emergence (%)		
	2023-24	2024-2025	Pooled
T_1: No Zn (Control)	93.67	88.57	91.12
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	92.11	90.67	91.39
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	91.34	91.33	91.34
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	92.16	91.18	91.67
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	93.56	90.53	92.05
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	91.00	91.63	91.32
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	91.33	92.52	91.93
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	91.50	91.50	91.50
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	91.47	91.03	91.25
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	93.72	92.10	92.91
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	94.03	93.38	93.71
SEm (±)	1.34	1.64	1.16
CD (p=0.05)	NS	NS	NS
CV (%)	2.52	3.11	2.18

Table 3: Effect of different doses of zinc application on plant height at 45, 60 and 75 days after planting

Treatments	Plant height in cm (45 days)			Plant height in cm (60 days)			Plant height in cm (75 days)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	28.4	29.7	28.9	43.4	45.47	44.59	45.1	45.45	45.30
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	30.7	32.0	31.4	47.8	50.51	49.17	50.1	51.83	51.00
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	32.3	33.0	32.6	55.1	58.14	56.67	56.1	58.26	57.22
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	29.5	31.1	30.3	53.0	55.01	54.04	55.0	56.07	55.57
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	32.2	33.2	32.7	61.5	62.08	61.82	56.0	58.09	57.09
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	33.1	35.6	34.43	59.5	60.57	60.05	62.8	63.52	63.19
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	34.8	36.2	35.5	60.2	61.37	60.79	63.4	64.77	64.08
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	31.7	33.0	32.4	55.0	59.09	57.09	59.0	61.09	60.09
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	32.3	33.5	32.9	53.2	55.45	54.33	56.8	59.21	58.05
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	35.0	36.4	35.7	61.7	62.59	62.16	64.3	65.49	64.94
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	35.2	37.2	36.2	62.0	63.95	63.00	64.6	66.20	65.41
SEm (±)	2.40	2.61	2.48	3.91	3.69	2.99	4.02	4.10	3.96
CD (p=0.05)	NS	NS	NS	11.5	10.88	8.81	11.8	12.10	11.69
CV (%)	12.8	13.37	13.01	12.1	11.08	9.12	12.0	12.03	11.77

Table 4: Effect of different doses of zinc application on number of shoots per plant at 45, 60 and 75 days after planting

Treatments	Number of shoot (45 days)			Number of shoot (60 days)			Number of shoot (75 days)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	3.67	3.83	3.75	4.50	4.60	4.55	4.46	4.73	4.60
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	4.31	4.40	4.36	4.70	4.83	4.77	5.47	5.82	5.65
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	4.37	4.57	4.47	4.80	5.01	4.90	5.60	5.89	5.74
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	4.23	4.30	4.27	4.73	4.77	4.75	5.45	5.57	5.51
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	4.35	4.50	4.43	4.60	4.96	4.78	5.63	6.10	5.87
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	4.57	4.80	4.68	4.73	5.23	4.98	6.40	6.70	6.55
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	4.63	4.93	4.78	4.87	5.33	5.1	6.52	6.84	6.68
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	4.50	4.73	4.62	4.77	5.13	4.95	6.26	6.57	6.41
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	4.40	4.64	4.52	4.73	5.07	4.9	6.10	6.35	6.23
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	4.87	5.03	4.95	5.37	5.51	5.44	6.60	6.80	6.70
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	4.97	5.07	5.02	5.53	5.60	5.57	6.63	6.90	6.76
S.Em (±)	0.45	0.36	0.29	0.37	0.43	0.33	0.42	0.43	0.36
CD (p=0.05)	NS	NS	NS	NS	NS	NS	1.24	1.27	1.06
CV (%)	17.6	13.6	11.0	13.3	14.4	11.6	12.3	12.1	10.3

Table 5: Effect of different doses of zinc application on number of compound leaves per plant at 45, 60 and 75 days after planting

Treatments	Number of compound leaves $plant^{-1}$(45 days)			Number of compound leaves $plant^{-1}$ (60 days)			Number of compound leaves $plant^{-1}$ (75 days)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	29.83	30.40	31.78	36.63	38.40	37.52	39.33	41.07	40.20
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	33.97	34.40	35.85	40.27	41.72	41.00	48.81	49.84	49.32
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	34.63	35.07	34.85	42.73	43.84	43.29	49.87	50.92	50.40
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	32.63	33.97	33.3	39.33	41.29	40.31	46.79	47.82	47.30
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	34.31	34.73	33.85	40.07	43.33	41.70	48.97	50.00	49.48
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	36.47	37.13	36.8	43.20	44.27	43.73	55.73	57.08	56.41
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	36.80	37.47	37.13	43.26	44.92	44.09	56.17	57.84	57.01
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	35.07	36.30	37.35	41.13	43.84	42.49	51.92	53.03	52.48
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	34.97	35.64	36.97	40.27	43.33	41.80	52.10	53.64	52.87
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	37.47	38.13	37.8	44.52	45.52	45.02	58.05	59.46	58.76
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	37.93	38.60	38.27	45.42	46.75	46.09	58.16	59.85	59.01
SEm (±)	1.85	2.84	1.90	3.43	2.96	3.01	3.66	3.69	3.67
CD (p=0.05)	NS	NS	NS	NS	NS	NS	10.79	10.90	10.83
CV (%)	9.18	13.79	9.18	14.31	11.82	12.27	12.31	12.12	12.20

Table 6: Total tuber numbers per plant and Weight of tubers per plant(g) as influenced by different doses of zinc application

Treatments	Total no. of tubers per plant			Weight of tubers per plant (g)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	496.2	506.2	501.2	122.2	124.6	123.4
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	440.3	453.6	447.0	152.7	167.9	160.3
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	528.2	534.9	531.5	168.3	172.8	170.6
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	538.0	545.3	541.6	152.7	157.4	155.0
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	530.3	539.9	535.1	159.6	172.3	165.9
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	547.9	570.1	559.0	183.1	190.6	186.9
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	559.0	581.3	570.1	191.5	197.7	194.6
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	541.3	560.3	550.8	175.0	183.4	179.2
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	533.9	552.6	543.3	166.7	180.9	173.8
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	586.5	610.4	598.5	188.3	195.4	191.9
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	598.9	615.8	607.4	197.0	200.0	198.5
SEm (±)	27.64	29.88	28.09	14.11	14.13	11.59
CD (p=0.05)	81.52	88.15	82.86	41.63	41.69	34.20
CV (%)	8.92	9.38	8.94	14.48	13.86	11.63

Table 7: Effect of different doses of zinc application on grade wise tuber yield of potato

Treatments	Yield of tuber 0-25g (kg/plot)			Yield of tuber 25-75g (kg/plot)			Yield of tuber >75g (kg/plot)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	5.62	4.83	5.22	7.68	8.04	7.86	5.07	5.51	5.29
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	4.06	5.29	4.67	9.06	8.82	8.94	5.75	6.24	6.00
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	6.35	6.48	6.42	6.30	7.97	7.14	6.75	6.77	6.76
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	6.79	6.80	6.80	6.02	7.08	6.55	5.80	6.27	6.03
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	6.36	6.45	6.40	6.81	7.95	7.38	6.03	6.54	6.29
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	6.57	6.60	6.59	7.00	8.60	7.80	6.57	7.01	6.79
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	6.57	6.64	6.61	7.30	8.88	8.09	6.58	7.12	6.85
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	6.50	6.54	6.52	6.99	8.41	7.70	6.55	6.92	6.74
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	6.44	6.49	6.46	6.91	8.08	7.50	6.50	6.82	6.66
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	6.81	6.97	6.89	9.10	10.27	9.69	7.15	7.38	7.27
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	6.86	7.06	6.96	9.32	10.35	9.83	7.33	7.49	7.41
SEm (±)	0.51	0.45	0.37	0.56	0.61	0.53	0.43	0.37	0.38
CD (p=0.05)	1.51	1.32	1.10	1.64	1.79	1.56	1.27	1.10	1.13
CV (%)	14.16	12.17	10.21	12.88	12.22	11.38	11.67	9.59	10.08

Table 8: Effect of different doses of zinc application on unmarketable yield, marketable yield and total yield (t ha^{-1}).

Treatments	Unmarketable tuber yield (t ha^{-1})			Marketable tuber yield (t ha^{-1})			Total tuber yield (t ha^{-1})		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	7.31	6.28	6.80	15.87	17.68	21.83	23.92	24.01	23.97
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	5.28	6.88	6.08	18.63	19.60	24.88	24.57	26.48	25.52
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	8.14	8.44	8.29	18.90	19.19	24.79	25.25	27.63	26.44
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	8.84	8.85	8.85	15.39	17.36	21.32	24.22	26.21	25.22
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	8.28	8.39	8.34	16.72	18.86	23.15	24.97	27.25	26.11
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	8.56	8.93	8.75	17.66	20.32	24.72	26.21	28.91	27.56
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	8.55	8.64	8.60	18.08	20.82	25.31	26.64	29.45	28.04
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	8.46	8.51	8.49	17.62	19.95	24.45	26.09	28.47	27.28
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	8.38	8.44	8.41	17.46	19.40	23.99	25.85	27.83	26.84
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	8.86	9.07	8.97	21.16	22.99	28.72	30.01	32.05	31.03
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	8.93	9.19	9.06	21.68	23.23	29.23	30.68	32.41	31.55
SEm (±)	0.62	0.59	0.53	1.26	1.22	1.28	1.45	1.60	1.49
CD (p=0.05)	1.82	1.75	1.57	3.71	3.59	3.77	4.26	4.73	4.38
CV (%)	13.12	12.32	11.21	12.02	10.57	8.93	9.55	9.83	9.45

Table 9: Effect of different doses of zinc application on grade wise number of tuber (000' ha^{-1})

Treatments	Number of tuber 0-25g (000' ha^{-1})			Number of tuber 25-75g (000' ha^{-1})			Number of tuber >75g (000' ha^{-1})		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: No Zn (Control)	301.8	306.1	304.0	134.7	139.7	137.2	59.78	60.44	60.1
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	220.4	227.0	223.7	157.6	159.6	158.6	62.32	67.02	64.7
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	337.2	338.5	337.9	111.3	116.0	113.7	79.66	80.33	80.0
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	366.4	368.1	367.2	102.4	107.0	104.7	69.21	70.21	69.7
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	339.4	343.7	341.6	119.9	123.9	121.9	70.98	72.32	71.7
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	352.1	355.1	353.6	121.6	139.8	130.7	74.20	75.23	74.7
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	353.3	361.3	357.3	126.1	141.4	133.7	76.28	78.61	77.4
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	348.8	354.0	351.4	121.6	133.8	127.7	70.88	72.41	71.6
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	345.5	355.7	350.6	121.3	126.2	123.8	70.38	70.65	70.5
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	362.1	368.7	365.4	147.7	159.3	155.5	80.06	82.39	81.2
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 and 50 DAP	367.0	370.6	368.8	149.0	161.3	155.1	80.94	83.94	82.4
SEm (±)	23.5	24.0	20.3	10.2	7.7	10.3	4.5	4.6	4.2
CD (p=0.05)	69.2	70.9	59.7	30.1	22.9	30.4	13.3	13.5	12.3
CV (%)	12.1	12.2	10.4	13.7	9.8	13.4	10.8	10.7	9.9

Table 10: Effect of different doses of zinc application on economics of potato (Pooled mean basis)

Treatments	Yield (t ha^{-1})	Cost of cultivation (Rs ha^{-1})			Cost (Rs ha^{-1})		Sale price (Rs t^{-1})	Net returns (Rs ha^{-1})	B:C ratio
		Seed	Fertilizers	Cultivation	Inputs	Produce			
T_1: No Zn (Control)	23.97	40000	9189	32720	81909	239650	10000	253391	2.93
T_2: 2.5 kg Zn/ha from $ZnSO_4$ at the time of planting	25.52	40000	9314	32720	82034	255233	10000	261946	3.11
T_3: 5.0 kg Zn/ha $ZnSO_4$ at the time of planting	26.44	40000	9439	32720	82159	264433	10000	271481	3.22
T_4: Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	25.22	40000	9289	32720	82009	252167	10000	257211	3.07
T_5: Foliar Application of $ZnSO_4$@ 2g/l at 25 & 50 DAP	26.11	40000	9389	32720	82109	261117	10000	267891	3.18
T_6: T_2+ Foliar Application of $ZnSO_4$@ 2g/l at 25 days DAP	27.56	40000	9414	32720	82134	275617	10000	284946	3.36
T_7: T_2+ Foliar Application of $ZnSO_4$ @ 2g/l at 25& 50 DAP	28.04	40000	9514	32720	82234	280433	10000	290726	3.41
T_8: 7.5 kg Zn /ha from $ZnSO_4$ at the time of planting	27.28	40000	10314	32720	83034	272817	10000	189783	3.29
T_9: 10 kg Zn /ha from $ZnSO_4$ at the time of planting	26.84	40000	10689	32720	83409	268433	10000	185024	3.22
T_{10}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP	31.03	40000	9939	32720	82659	310317	10000	227658	3.75
T_{11}: T_3+ Foliar Application of $ZnSO_4$ @ 2g/l at 25 DAP and 50 DAP	31.55	40000	10689	32720	83409	315450	10000	232041	3.78

Conclusion

Integrated application of zinc through basal $ZnSO_4$ along with foliar sprays at critical growth stages significantly enhanced potato growth, yield, and profitability. Treatments receiving combined basal and foliar Zn applications (particularly T_{11}) recorded the highest plant height, shoot number, and dry matter accumulation, indicating improved physiological activity due to Zn's role in auxin metabolism, protein synthesis, and photosynthetic efficiency. Yield attributes such as tuber number, size, and weight improved markedly, resulting in the maximum total tuber yield and marketable produce. Economically, T_{11} achieved the highest net returns (Rs.2,32,041 ha^{-1}) and B:C ratio (3.78), demonstrating that integrated Zn management not only boosts productivity but also maximizes profitability in potato cultivation under Chhattisgarh plain conditions

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