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ZINC INDUCED MODULATION OF GROWTH AND YIELD IN SPROUTING BROCCOLI (*BRASSICA OLERACEA* L. PLENCK VAR. *ITALICA*)

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ABSTRACT

Sprouting broccoli, a nutrient rich cole crop has gained prominence due to its health benefits and market demand. However, its productivity under semi-arid conditions remains sub-optimal, largely due to inadequate micronutrient management, particularly zinc. To address this challenge, a field experiment was conducted during the *Rabi* seasons of 2022-23 and 2023-24 at the Horticulture Farm of S.K.N. College of Agriculture, Jobner, Rajasthan, to study the impact of different zinc concentrations on the growth and yield of sprouting broccoli cultivar Palam Samridhi. The experiment followed a split-plot design with three replications and included 5 zinc treatments: Z_0 (control-water spray), Z_1 (100% recommended dose of zinc sulphate), Z_2 (two foliar sprays of nano zinc @100 ppm), Z_3 (75% zinc sulphate + one foliar spray of nano zinc) and Z_4 (75% zinc sulphate + two foliar sprays of nano zinc). The observations were recorded using 5 randomly selected and tagged plants for several growth and yield attributes, which showed that the application of the treatment Z_4 significantly influenced these traits. Most of the growth and yield parameters *viz.,* plant height (53.32 cm), number of leaves (22.03) leaf area (1190 cm^2), secondary curd weight (224.4 g), diameter (9.78 cm) and total curd yield (9.01 kg/plot) were significantly influenced by the treatment Z_4, showing an improvement of over 20% compared to control. These enhancements are attributed to zinc's critical role in enzymatic activation, auxin synthesis, nutrient uptake and photosynthesis. The study demonstrates that integrated application of zinc sulphate and nano zinc optimizes plant growth and curd yield in broccoli and might be recommended in cultivation practices under semi-arid conditions.

Key words: Growth and yield, Nano zinc, Nutrient, Sprouting broccoli and Zinc sulphate.

Introduction

Sprouting broccoli [*Brassica oleracea* L. var. *italica* Plenck] is a highly nutritiously valuable vegetable crop commonly known as Hari gobhi. It is an important member of cole group belonging to family Brassicaceae having diploid chromosome number 2n=18 (Netwal *et al.,* 2023). It is considered to be originated from wild cabbage syn. *Brassica oleracea* var. *sylvestris,* which is found wild in the Mediterranean Sea (Farhan *et al.,* 2023). The word broccoli comes from the Italian word broccola, which means the flowering crest of cabbage (Thamburaj and Singh, 2001). Sprouting broccoli possesses abundant fleshy green flower heads arranged in a tree like fashion on branches sprouting from a thick, edible stalk. It can be easily distinguished from cauliflower by having a head composed of differentiated flower bud rather than a curd (Pankaj *et al.,* 2018). It is one of the most nutritious cole crop as it contains vitamin A (130 times and 22 times higher than cauliflower and cabbage, respectively). It also contains carbohydrates (5.5%), proteins (3.3%), vitamin A (3500 IU), vitamin B2 (0.12 mg), vitamin C (137 mg), calcium (0.80 mg) and phosphorus (0.79 mg), magnesium and iron (Hazra and Som, 1999; Thamburaj and Singh, 2001). It is also a rich source of sulphoraphane and glucoraphanin a compound associated with reducing the risk of cancer (Asif *et al.*, 2023).

The commercial cultivation of broccoli has increased day by day due to its ever-increasing demand. However, production and productivity of broccoli in the major agri-export zones is uncertain and low or not considered under current cropping system (Parmar *et al.*, 2023). One of the primary reasons for low yield is poor nutrient management practice and secondarily very few researches have been conducted in recent past based on the nutrient management protocol for this crop. Micronutrients play an active role in the plant metabolic process from cell wall development to respiration, photosynthesis, chlorophyll formation, enzymes activity, nitrogen fixation etc. (Alam *et al.*, 2010). Nano fertilizers are the important tools in agriculture to improve crop growth, yield and quality parameters, reduce wastage of fertilizers and cost of cultivation. Present day's nano fertilizers are emerging as an alternative to conventional fertilizers (Veronica *et al.*, 2015). Zinc plays a significant role in various enzymatic and physiological activities in the plant system. It is the most important nutrient in the building blocks of some enzymes like alcohol dehydrogenase, carbonic anhydrase, superoxide dismutase, etc. and is needed for the formation of plant enzymes and many enzymatic reactions that become active with zinc (Narayanamma *et al.*, 2007). Furthermore, it is important for the overall growth and development of plants. Keeping all those points in view, the present investigation was conducted to access the impact of different concentrations of zinc on the growth and yield of sprouting broccoli under semi-arid conditions of Rajasthan.

Materials and Methods

A field experiment was conducted during the *Rabi* seasons of 2022-23 and 2023-24 at the Horticulture Farm, S.K.N. College of Agriculture, Jobner, Jaipur (Rajasthan), situated in Agro-climatic Zone-IIIA (Semi-Arid eastern plain zone). The experiment aimed to evaluate the impact of different concentrations of zinc on the growth and yield of sprouting broccoli cultivar 'Palam Samridhi'. The soil of the experimental site was loamy sand, slightly alkaline (pH 8.15-8.20), low in organic carbon, nitrogen, phosphorous and sulphur and medium in potassium content. Irrigation water was slightly saline with EC ranging from 1.01 to 1.02 dS/m. The experiment was laid out in a split-plot design with three replications. Five zinc treatments were applied as: Z_0 (control-water spray), Z_1 (100% recommended dose of zinc sulphate), Z_2 (two foliar sprays of nano zinc @100 ppm), Z_3 (75% zinc sulphate + one foliar spray of nano zinc) and Z_4 (75% zinc sulphate + two foliar sprays of nano zinc). Each plot measured 1.8 m × 1.8 m, accommodating 16 plants spaced at 45 × 45 cm. Standard agronomic practices were followed. Farmyard manure at 20 t/ha and basal doses of NPK (100:80:60 kg/ha) were uniformly applied. Zinc sulphate was incorporated into the soil before transplanting, while nano zinc was applied as a foliar spray at 25 and 55 days after transplanting (DAT). Nano zinc solution was prepared by dissolving 1 mg of nano Zn in 1 L of water to make a 1000 ppm stock, from which a 100-ppm solution was prepared for spraying. Data were recorded on several growth parameters (plant height, number of leaves per plant, leaf area and plant spread), yield and its attributing traits (number of days from transplanting to curd formation, weight of secondary curds/plant, volume of secondary curd, diameter of secondary curd and curd yield using 5 randomly selected and labelled plants. The recorded data on growth, yield, and quality traits were analyzed using ANOVA (Fisher, 1950; Fisher and Yates, 1963). Treatment differences were tested by 'F' test (Panse and Sukhatme, 1985) for split plot design. Significant differences were separated by critical difference (CD), and pooled analysis was done assuming yearly data homogeneity (Gomez and Gomez, 1984).

Results and Discussion

Impact of zinc on plant growth characteristics of spouting broccoli

It is obvious from the data (table 1 and 2) that plant height, number of leaves per plant, leaf area and plant spread of sprouting broccoli showed the significant response to the application of different combination of zinc during both the years and in pooled mean analysis. The significantly maximum plant height (23.63, 24.52 and 24.08 cm at 30 DAT) were recorded with application of Z_1-zinc sulphate @ 100% RD, over control during investigation year and in pooled mean analysis. However, maximum plant height (52.37, 54.27 and 53.32 cm at 60 DAT) were recorded with application of Z_4-zinc sulphate @ 75% RD + two foliar application of nano Zn @ 100 ppm during the year 2022-23 and 2023-24 as well as in pooled mean analysis, respectively. Notably, treatment Z_3 exhibited statistically similar results to Z_4 at 60 DAT stages during the investigation. Overall, the application of Z_4 led to an increase plant height of 21.95% at 60 DAT compared to the control in the pooled mean analysis. The application of Z_1-zinc sulphate @ 100% RD recorded significantly higher number of leaves per plant at 30 DAT (7.80, 7.91 and 7.85) over control, respectively. However,

Table 1: Impact of zinc on plant growth characteristics of spouting broccoli.

Treatments	Plant height (cm) at 30 DAT			Plant height (cm) at 60 DAT		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Z_0-Control	19.79	19.94	19.87	42.35	44.09	43.72
Z_1-Zn (Zinc sulphate-100% RD)	23.63	24.52	24.08	48.31	49.83	48.57
Z_2-Two foliar application of nano Zn (100 ppm)	20.34	20.96	20.65	43.49	46.63	45.06
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	22.37	23.10	22.74	51.88	52.69	52.28
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	22.55	23.26	22.91	52.37	54.27	53.32
SEm$\pm$	0.32	0.34	0.23	1.10	1.13	0.79
CD (P=0.05)	1.04	1.10	0.70	3.59	3.69	2.37
Treatments	**Number of leaves/ plants at 30 DAT**			**Number of leaves/ plants at 60 DAT**		
Z_0-Control	6.40	6.56	6.48	17.77	18.85	18.31
Z_1-Zn (Zinc sulphate-100% RD)	7.80	7.91	7.85	20.09	21.13	20.61
Z_2-Two foliar application of nano Zn (100 ppm)	6.73	6.88	6.81	19.20	20.20	19.70
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	7.12	7.24	7.18	21.27	22.10	21.68
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	7.20	7.32	7.26	21.64	22.43	22.03
SEm$\pm$	0.16	0.17	0.12	0.20	0.17	0.13
CD (P=0.05)	0.51	0.53	0.37	0.66	0.55	0.40

Table 2: Impact of zinc on plant growth characteristics of spouting broccoli.

Treatments	Leaf area (cm^2) at 30			Leaf area (cm^2) at 60 DAT		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Z_0-Control	513	524	519	964	985	975
Z_1-Zn (Zinc sulphate-100% RD)	616	648	632	1058	1107	1083
Z_2-Two foliar application of nano Zn (100 ppm)	523	543	533	998	1002	1000
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	554	578	566	1134	1153	1143
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	568	589	579	1165	1215	1190
SEm$\pm$	11	11	8	27	27	19
CD (P=0.05)	37	37	24	88	88	57
Treatments	**Plant spread (cm^2) East-West**			**Plant spread (cm^2) North-South**		
Z_0-Control	53.30	55.20	54.25	59.62	62.18	60.90
Z_1-Zn (Zinc sulphate-100% RD)	58.65	59.90	59.27	65.44	68.12	66.78
Z_2-Two foliar application of nano Zn (100 ppm)	55.52	56.43	55.98	63.10	66.75	64.93
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	64.10	66.41	65.25	67.22	70.13	68.67
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	65.22	67.80	66.51	69.87	73.37	71.62
SEm$\pm$	1.15	1.17	0.82	1.24	1.48	0.96
CD (P=0.05)	3.75	3.81	2.46	4.04	4.82	2.89

the maximum number of leaves at 60 DAT (21.64, 22.43 and 22.03) were recorded with application of zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm (Z_4). However, treatment Z_3 was found statistically at par to Z_4 at 60 DAT during the investigation. The enhancement in the number of leaves per plant by 20.32 per cent at 60 DAT were recorded in the treatment Z_4 over Z_0 of sprouting broccoli in pooled mean analysis, respectively. The significantly maximum leaf area per plant at 30 DAT (632 cm^2) were recorded with soil application of zinc sulphate @ 100% RD (Z_1) over control, respectively. However, maximum leaf area at 60 DAT (1190 cm^2), were observed with the application of zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm (Z_4). Treatment Z_4 was found significantly higher over Z_0, Z_1 and Z_2 but remained statistically at par with treatment Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) at 60 DAT was found in pooled mean. The enhancement in the leaf area by 20.05 per cent at 60 DAT of sprouting broccoli were recorded in the treatment Z_4 over Z_0 in pooled mean analysis, respectively. The maximum 66.51 cm^2 and 71.62 cm^2 plant spread from E-W and N-S at final harvest in pooled mean analysis, respectively was recorded with the treatment Z_4 (Zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm), which was found significantly superior over rest of the treatments except treatments Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) which was found statistically at par to it in pooled results. The application of zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm results an increase in plant spread E-W and N-S at final harvest of sprouting broccoli, with an increase of 22.60 and 17.60 per cent over control in pooled analysis.

The application of zinc sulphate and nano zinc enhanced the growth and growth contributing parameters of broccoli when applied either alone or in combinations during the experimentation. Zinc sulphate supports a number of enzymes that power the crop's metabolic processes and are involved in the synthesis of plant hormones like auxin and carbohydrate formation (Pankaj *et al.*, 2018). Additionally, they are essential for maintaining the structure and functionality of chloroplasts, which supports plant growth activity. These results obtained might be due to the stimulating effect of zinc sulphate in cell division and cell elongation. It is effective for the synthesis of plant hormones like auxin and carbohydrate formation (Pankaj *et al.*, 2018). It plays a fundamental role in several critical functions in the cell such as protein metabolism, gene expression, structural and functional integrity of bio-membranes and photosynthetic metabolism (Sainju *et al.*, 2003). Zinc is a constituent of ribosomes and essential for their structural integrity (Trivedi and Dhumal, 2013). Zinc regulates the auxin concentration in plants and is an essential component of enzymes *viz.*, alcohol dehydogenase, carbonic anhydrase, super oxide dismutase which are needed for root development and increasing the absorption of CO_2 per leaf area unit and thus increases the chlorophyll content and photosynthesis. Besides this, zinc also helps in increasing the absorption of essential element by increasing the cation exchange capacity of roots. Hence, application of zinc in soil with lower zinc content improves the plant growth and development of sprouting broccoli. The enhancement in plant growth parameters could be attributed to the role of zinc in chlorophyll synthesis, which affects cell division, meristematic activity in plant tissues, cell expansion and cell wall formation through the active synthesis of aromatic amino acids like tryptophan (Ghritlahare *et al.,* 2015). Tryptophan acts as the primary precursor of auxin, promoting plant tissue growth *via.,* cell elongation and division (Singh *et al.*, 2017). The increased availability of auxin likely contributed to greater internodal length and enhanced apical dominance and ultimately facilitating maximum plant spread. The results obtained from the present study are in accordance with the earlier findings of Lal *et al.* (2015), Singh *et al.* (2018), Tudu *et al.* (2020) and Al-Bayati *et al.* (2021) in broccoli, Chethana *et al.* (2019) in cauliflower.

Impact of zinc on yield and its attributing characteristics of spouting broccoli

Data (table 3) pertaining to the application of different levels of zinc on number of days from transplanting to curd formation, weight of secondary curds/plant, volume of secondary curd, diameter of secondary curd, and curd yield indicated that all the treatments evaluated for their efficacy were noted to have positive significant impacts on all the yield and attributing traits during both the years of investigation and in pooled mean analysis. The results revealed that application of zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm (Z_4) was found statistically at par with application of zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm (Z_3) significantly improved all the above yield and attributing parameters as compared to other treatments. The data indicated that optimum days to curd formation (55.08 days) in pooled mean analysis were recorded under application of zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm (Z_4), respectively. Treatment Z_4 recorded 15.78 per cent minimum days from transplanting to curd formation over control in the individual years as well as in pooled mean analysis, respectively.

The weight of secondary curd was recorded

Table 3: Impact of zinc on yield and its attributing characteristics of spouting broccoli.

Treatments	Number of days from Leaf area (cm^2) at 60 DAT formation			Weight of secondary curds/plant (g)			Volume of secondary curd (cc)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Z_0-Control	65.19	62.35	63.77	181.2	189.4	185.3	78.12	80.94	79.53
Z_1-Zn (Zinc sulphate-100% RD)	61.82	58.38	60.10	194.6	200.6	197.6	81.01	81.24	81.13
Z_2-Two foliar application of nano Zn (100 ppm)	63.11	60.00	61.56	186.7	192.6	189.7	78.63	78.21	78.42
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	58.26	56.12	57.19	210.4	219.2	214.8	93.84	96.72	95.28
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	56.78	53.38	55.08	220.5	228.3	224.4	95.38	99.32	97.35
SEm±	1.53	1.45	1.05	5.5	5.7	3.9	2.39	2.48	1.72
CD (P=0.05)	4.99	4.73	3.16	17.8	18.6	11.8	7.78	8.10	5.16
Treatments	**Diameter of secondary curd (cm)**			**Curd yield (g/plant)**			**Curd yield (kg/plot)**		
Z_0-Control	8.24	8.48	8.36	460.5	475.1	467.8	7.37	7.60	7.48
Z_1-Zn (Zinc sulphate-100% RD)	8.66	8.80	8.73	486.5	501.2	493.8	7.78	8.02	7.90
Z_2-Two foliar application of nano Zn (100 ppm)	8.57	8.75	8.66	469.9	484.6	477.3	7.52	7.75	7.64
Z_3-Zinc sulphate (75 % RD) + One foliar application of nano Zn (100 ppm)	9.18	9.59	9.38	532.6	553.2	542.9	8.52	8.85	8.69
Z_4-Zinc sulphate (75 % RD) + Two foliar application of nano Zn (100 ppm)	9.59	9.98	9.78	551.4	575.3	563.4	8.82	9.21	9.01
SEm±	0.24	0.25	0.17	13.1	13.0	9.2	0.24	0.23	0.17
CD (P=0.05)	0.24	0.25	0.17	13.1	13.0	9.2	0.24	0.23	0.17

maximum (224.4 g) under treatment Z_4 (Zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm). Treatment Z_4 was found significantly higher over Z_0, Z_1 and Z_2 but remained statistically at par with treatment Z_3 during both the years. The maximum volume of secondary curd (97.35 cc) was noticed under treatment Z_4 (zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm), it was found significantly higher over rest of the treatment except treatment Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) registered 95.28 cc during both the years and in pooled mean. The increase in volume of curd in treatment Z_4 was 22.40 per cent higher over control, respectively in the pooled mean. Application of (Z_4) zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm (9.78 cm), being at par with Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) registered (9.38 cm) significantly higher diameter of secondary curd of sprouting broccoli which was significantly higher over control. The corresponding increase in diameter of secondary curd of sprouting broccoli due to zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm was registered 16.98 per cent over control in the individual years as well as in pooled mean analysis. Maximum curd yield (551.4, 575.3 and 563.4 g/plant) during both the years and pooled mean, respectively was recorded with the application of treatment Z_4 (Zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm). This treatment was found significantly superior over rest of the treatments except treatment Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) registered 532.6, 553.2 and 542.9 g/plant during both the years and in pooled mean. The curd yield per plant was enhanced by 20.43 per cent with the application of treatments Z_4 over control on pooled mean basis. Maximum curd yield (8.82, 9.21 and 9.01 kg/plot) during both the years and pooled mean, respectively was recorded with the application of treatment Z_4 (Zinc sulphate @ 75 % RD + two foliar application of nano Zn @ 100 ppm). This treatment was found significantly superior over rest of the treatments except treatment Z_3 (Zinc sulphate @ 75 % RD + one foliar application of nano Zn @ 100 ppm) registered 8.52, 8.85 and 8.69 kg/plot during both the years and in pooled mean. The curd yield per plot was enhanced by 20.45

per cent with the application of treatments Z_4 over control on pooled mean basis.

The soil application of zinc may have enhanced the effectiveness of added chemicals and fertilizers, improved humification rates and increased the availability of both natural and applied nutrients in the soil and ultimately boosting the yield of sprouting broccoli. The improved yield attributes with zinc sulphate application could be linked to the plant's better utilization of resources, as zinc promotes starch formation, seed production and maturation, seed viability and seedling vigor. Zinc also supports plant reproduction and enzymatic activities, playing a critical role in sulphur and nitrogen metabolism (Dube *et al.,* 2003). Zinc facilitates the absorption of essential nutrients by improving the cation exchange capacity (C.E.C.) of roots. It also promotes the accumulation of photosynthates in the plant, resulting in significantly higher curd weight and diameter (Raghav and Singh, 2004). Zinc's function as a metal activator for enzymes such as dehydrogenase, proteinase and peptidases are crucial for processes like carbohydrate and nitrogen metabolism, enhancing nitrogen uptake (Trivedi and Dhumal, 2013). Additionally, zinc plays a direct or indirect role in regulating various physiological processes in plants (Shah *et al.*, 2010). The results of present experiment were closely followed by findings of Yadav *et al.* (2015) in cauliflower, Singh and Kumar (2017) in cabbage, Sharma *et al.* (2018) in okra, Netwal *et al.* (2023) and Upasna *et al.* (2023) in broccoli and Preeti *et al.* (2024) in radish.

Conclusion

The present study clearly demonstrates that the combined application of 75 % recommended dose of zinc sulphate along with two foliar sprays of nano Zn @ 100ppm, 25 and 55 days after transplanting significantly enhances the growth, physiological attributes and yield of sprouting broccoli under semi-arid conditions. This integrated zinc management approach led to increased chlorophyll content, leaf area, curd size and total yield indicating improved photosynthetic efficiency and nutrient use. The synergistic effect of soil and foliar applied zinc ensures better bio-availability and uptake, addressing zinc deficiency more effectively than conventional methods. This strategy might be recommended for sustainable and profitable broccoli cultivation in zinc deficient semi-arid agro-ecological conditions.

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