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Zinc Application Enhances Tuber Quality and Zinc Bioavailability in Potato (*Solanum tuberosum* L.) in the Tarai Region of Uttarakhand

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As evident from plant and soil investigations, 49 per cent of Indian soils are deficient in zinc. This could affect the production and quality of potato (*Solanum tuberosum* L.) as the crop is moderately sensitive to zinc deficiency. Zinc is considered to be the most important micronutrient for potato and its reduced availability in the plant is the major constraint to obtaining good tuber quality. However, repeated practice of rice-wheat cropping system in the *tarai* region of

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Uttarakhand has led to zinc deficiency in the soil, and thereby, its availability in the tubers. Therefore, the present investigation was undertaken at the Vegetable Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Uttarakhand) during the *rabi* season of 2021-22 with the objective to enhance the quality of potato tubers, and at the same time, increase the bioavailability of zinc in the tubers. The experiment was laid out in a randomised complete block design with twelve treatments and four replications. The results of the experiment revealed that foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 days after planting recorded the highest dry matter content (20.73%), specific gravity (1.07 g cm^{-3}) and starch content (17.10%) in the tubers. The zinc content in tubers (47.58 ppm) and zinc uptake by tubers (2.85 kg ha^{-1}) were also found to be maximum in the same treatment combination. Hence, the same treatment combination can be recommended for getting better quality of potato tubers as well as increasing zinc bioavailability in potato under the *tarai* region of Uttarakhand.

Keywords: Potato; zinc deficiency; zinc bioavailability; tuber quality; zinc uptake.

1. INTRODUCTION

Zinc is, undisputably, one of the most essential trace elements for human health and nutrition. It has three chief biological roles–as catalyst, structural ion and regulatory ion [1]. Deficiency of zinc, as confirmed by several studies, is fairly prevalent in developing countries like India, and might be the reason behind retarded growth observed in these countries [2]. It is more prevalent in regions of high cereal and low animal food consumption [3]. The diet may not be necessarily low in zinc, however, its bioavailability plays an important role in its absorption.

Potato (*Solanum tuberosum* L.), popularly known as the "king of vegetables", can supplement the food needs of the country in a substantial way as it produces more dry matter, balanced proteins and calories from unit area of land and time than other major food crops. There is no doubt, the problem of malnutrition and undernutrition can be largely solved if potato is accepted as a major food and not merely as a vegetable in our country. However, production of potato is limited in soils deficient in zinc as potato is moderately sensitive to zinc deficiency. Zinc plays a crucial role in the overall growth and development of potato by enhancing the synthesis of growth hormones and chlorophyll [4,5]. Around 49 per cent of Indian soils are deficient in zinc [6] and the repeated practice of paddy-wheat crop rotation in the *tarai* region of Uttarakhand has further led to diminution of zinc in the soil [7].

Furthermore, heavy and injudicious fertiliser use in Indian agriculture has depleted the soils of micronutrients, such as zinc [8]. It has been proved through recent studies that mineralisation of potato with zinc is heritable and, therefore, can be enhanced through breeding [9]. Zinc can be applied to the plant through soil, or directly through the leaves by foliar fertilisation, or both. In this paper, we have aimed to determine whether application of zinc would enhance tuber quality and zinc bioavailability of potato.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out at the Vegetable Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar (29°N and 79.30°E, and 243.84 m above msl) during the *rabi* season of 2021-22. The site is located in the sub-mountainous region of the Shivalik, known as *Tarai*, and receives an annual rainfall of approximately 1,300 mm. The average minimum and maximum temperature in Pantnagar are 29°C and 35°C, respectively.

Daily weather data for the growing season were obtained from the meteorological observatory of Department of Agrometeorology, G. B. Pant University of Agriculture and Technology, Pantnagar. Maximum and minimum temperatures (°C), relative humidity (%), bright sunshine hours and rainfall (mm) were recorded each day during the course of investigation and the weekly weather data (average) have been graphically depicted in Fig. 1.

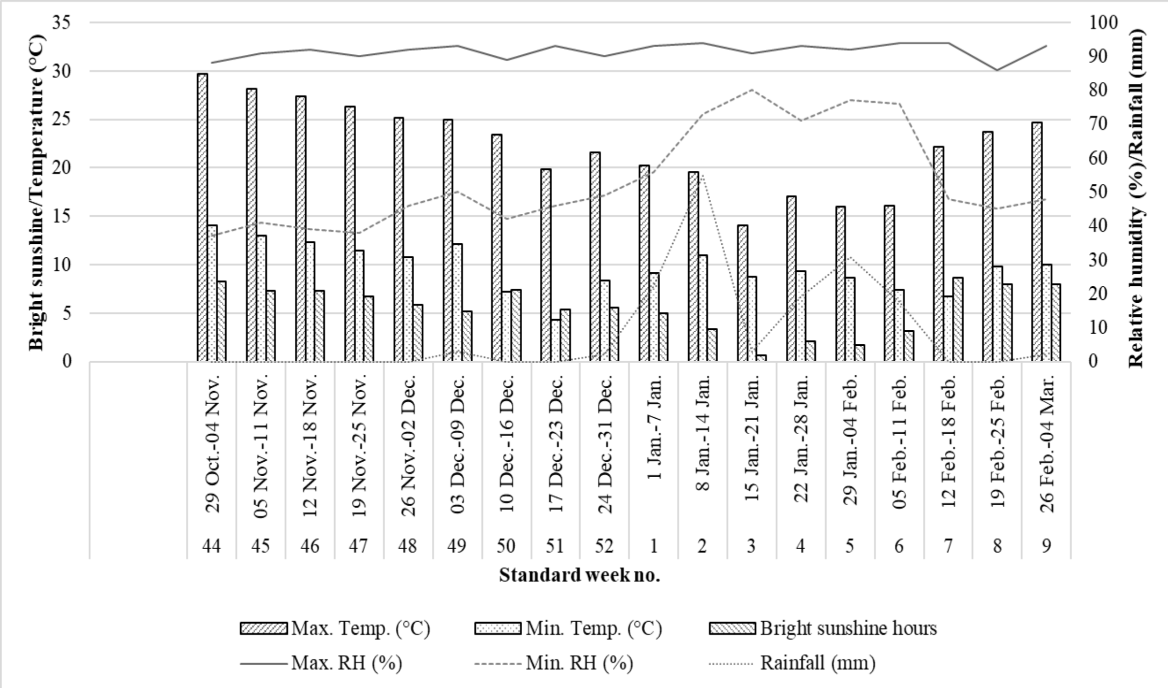

Fig. 1. Average weekly meteorological data recorded during the cropping period

The physico-chemical properties of the experimental soil were determined by adopting standard analytical methods. The soil was sandy loam in texture and neutral in reaction (pH 7.30). It was low in available nitrogen (178.65 kg ha^{-1}), medium in available phosphorus (18.71 kg ha^{-1}), medium in available potassium (184.45 kg ha^{-1}), high in organic carbon (0.85%) and medium in available zinc (0.80 ppm).

2.2 Experimental Design and Cultural Practices

The experiment, comprising twelve treatment combinations, was laid out in a randomised complete block design. The treatments were replicated four times, giving a total of 48 plots with individual experimental plots measuring 7.68 m^2 (2.4 m × 3.2 m). The rows were spaced 60 cm apart and the plants were spaced 20 cm apart. Inorganic fertilisers were applied at the time of planting at a rate of 80 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1} through urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively. Well-sprouted, healthy and whole potato (cv. Kufri Surya) tubers of 50-75 g weight and 2.5-5.0 cm size were selected and planted manually on the ridges. Each experimental plot consisted of six rows having 18 plants each.

The different doses of zinc were applied through zinc sulphate monohydrate ($ZnSO_4.H_2O$) containing 33% Zn (min.). The details of the treatment combinations and symbols used to represent them have been given in Table 1. Half of the nitrogen, *i.e.*, 80 kg N ha^{-1} was top-dressed through urea, 30 days after planting. All the plots were uniformly irrigated (twice). Earthing up was done 35 days after planting and dehaulming, 82 days after planting. Manual weeding and spraying of fungicide [Three sprays of Matco fungicide (Metalaxyl 8% WP + Mancozeb 64% WP) @ 2.5 L $plot^{-1}$] were carried out to keep the plots weed-free and disease-free throughout the cropping season. The fungicide had no phytotoxic effect on normal growth of plant and tubers or their contents either.

2.3 Dry Matter Content (%)

Five samples of 100 g tubers from each treatment plot were taken, cut into thin slices and shade-dried for a day. These samples were oven-dried at 40±20°C for 48 hours and then at 60°C for 24 hours till a constant weight was achieved. After drying, the samples were weighed and the dry matter content was determined using the following formula:

$$\text{Dry matter content (\%)} = \frac{\text{Oven-dried weight (g)}}{\text{Fresh weight (g)}} \times 100$$

Table 1. Details of the treatments and symbols used

Symbols	Treatment combination
T_1	Control (RDF without zinc)
T_2	Zinc @ 2.5 kg ha^{-1} at the time of planting
T_3	Zinc @ 5 kg ha^{-1} at the time of planting
T_4	Zinc @ 7 kg ha^{-1} at the time of planting
T_5	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 days after planting (DAP)
T_6	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 DAP
T_7	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP
T_8	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP
T_9	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP
T_{10}	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP
T_{11}	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP
T_{12}	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP

2.4 Specific Gravity (g cm^{-3})

A representative sample of tubers was taken from each treatment plot after harvesting and the volume of the tubers was determined by the water displacement method. The specific gravity of the tubers was calculated using the following formula:

$$\text{Specific gravity of tuber } (g\ cm^{-3}) = \frac{\text{Weight of tuber (g)}}{\text{Volume of tuber } (cm^3)} \times 100$$

2.5 Starch Content (%)

A representative sample of tubers was taken from each treatment plot after harvesting. The tubers were chopped into small pieces and made into a fine paste using mortar and pestle. The starch content in the tubers was determined from this paste using the procedure outlined by Lane and Eynon [10].

Potato tuber paste (50 g) was mixed with 100 ml distilled water and neutralised with 0.1 N NaOH solution using phenolphthalein as indicator, and allowed to stand for 10 minutes. Then, 8 ml of potassium oxalate solution was added to the mixture and the total volume was made up to 250 ml by adding distilled water. This was followed by titration of 5 ml of the extract against 10 ml of mixed Fehling solution (5 ml of Fehling solution A + 5 ml of Fehling solution B) in a burette using methylene blue as indicator, till end point (indicated by decolorisation of the solution) was achieved. The following formula was used to compute the total sugars and then, starch content:

$$\text{Total sugars (\%)} = \frac{\text{Factor for Fehling solution} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight of sample taken} \times 100}$$

$$\text{Starch content (\%)} = \text{Total sugars (\%)} \times 0.9$$

Where, 0.9 = factor for starch conversion

2.6 Determination of Zinc Content in Tuber

For the determination of zinc content, tubers were collected after harvesting of the crop from each treatment plot. The tuber samples were washed repeatedly with distilled water and dried under shade for three days. The samples were oven-dried at 60°C and then at 75°C, till a constant weight was achieved. After drying, the samples were ground using an electric mixer-grinder. One gram of finely ground tuber sample was taken into a 150 ml conical flask. To the flask, 10 ml of conc. HNO_3 was added and kept still overnight followed by heating the flask for 30 minutes on a hot plate. After cooling, 10 ml of the diacid digestion mixture (HNO_3 and $HClO_4$ in 4:1 v/v ratio) was added and the contents were digested at 40°C till the brown fumes changed to white fumes (about 90 minutes later), which marked the end of digestion. After digestion, the flask was removed from the hot plate and allowed to cool, followed by addition of 5 ml of 6 N HCl along with a little volume of distilled water. The contents were boiled gently and transferred to a 50- or 100-ml volumetric flask, and the volume was made up using distilled water. This volume was used for the estimation of zinc by atomic absorption spectrophotometer (Biogen digital spectrophotometer) and recorded in parts per million (ppm) [11].

2.7 Determination of Zinc Uptake by Tuber

Zinc uptake by tuber was calculated using the following formula:

$$\text{Zinc uptake } (kg\ ha^{-1}) = \frac{\text{Zinc (\%) in tuber} \times \text{tuber yield } (kg\ ha^{-1})}{100}$$

2.8 Statistical Analysis

The data recorded during the course of experimentation were subjected to analysis through computer using OP Stat software designed and developed by the Computer Section, CCS HAU, Hisar. The 'F' test of significance was used for testing the null hypothesis and the critical difference (CD) at 5 per cent probability level was worked out for testing the significance of treatment differences wherever the effects were found significant.

3. RESULTS AND DISCUSSION

3.1 Dry Matter Content, Specific Gravity and Starch Content in Tubers

Dry matter content was significantly influenced due to the different treatments, as evident from the data (Table 2). The maximum dry matter content (20.73%) was recorded in treatment T_6 (RDF + Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting) followed by T_5 (20.30%), T_{10} (20.24%) and T_{11} (20.01%), which were statistically at par, while T_1 (RDF without zinc) recorded the minimum dry matter content (15.86%).

Data presented in Table 2 shows that application of zinc did not have any significant effect on the specific gravity of tubers. The maximum specific gravity (1.07 g cm^{-3}) was observed in treatment T_6 (RDF + Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting), while the minimum value (1.03) was observed in T_1 (RDF without zinc). This is in conformity with the findings of Mousavi et al. [12] and Sati et al. [13] who observed that foliar application of zinc reduced the specific gravity of potato tubers relative to soil application. Kanwar [14] also reported non-significant effect of zinc sulphate on the specific gravity of potato tubers.

Perusal of data presented in Table 2 indicated that starch content in tubers was significantly influenced by different treatments of zinc application. The maximum starch content (17.10%) was recorded under treatment T_6 (RDF + Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting), whereas T_1 (RDF without zinc) recorded the minimum value (13.18%). The higher amount of starch accumulation may be attributed to the increased rate of photosynthesis with application of zinc, translocation of photosynthates (sucrose, glucose and fructose) from source (leaves) to sink (tubers) and their subsequent conversion to starch [15,16]. Also, zinc activates enzymes such as aldolase and carbonic anhydrase, which help in translocation of carbohydrates from leaves to tubers. Puzina [17] reported that zinc increases the isodiametric cell diameter of perimedullary tuber zone; these cells are characterised by the most intense starch accumulation. These results are in agreement with the findings of Banerjee et al. [18], Eggadi Ramesh et al. [19] and Sati et al. [13].

3.2 Zinc Content and Zinc Uptake

The data regarding effect of zinc application on zinc content in potato tuber have been presented in Table 3. It can be figured out from the data, that the treatment T_6 (RDF + Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting) registered the highest zinc content in tuber (47.58 ppm), while T_1 (RDF without zinc) registered significantly lower zinc content in tuber (31.39 ppm) except T_2 (37.37 ppm). It is evident that application of zinc increased the zinc content in tuber as compared to no-zinc application. This might be attributed to the fact that the soil of the experimental field was low in zinc, and application of zinc improved the root biomass, which further increased the zinc uptake efficiency of the plant. Ahmed et al. [20] reported that zinc concentration in tubers varied significantly with levels of zinc fertilisation as well as cultivars.

As indicated in Table 3, it is clear that different zinc fertilisation treatments had a significant impact on the zinc uptake by the tuber, the values of which ranged between 1.05 and 2.85 kg ha^{-1}. The highest value for zinc uptake by tuber was recorded in treatment T_6 (RDF + Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting), however, it remained statistically at par with the treatments T_7 (Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP) and T_4 (Zinc @ 7 kg ha^{-1} at the time of planting). The lowest value of zinc uptake by tuber was registered by treatment T_1 (RDF without zinc). Higher value recorded with foliar application of $ZnSO_4$ may be ascribed to the fact that foliar feeding has high absorption rate, and thereby, increased its uptake by tubers. Similar results were also recorded by Banerjee et al. [18].

Table 2. Effect of zinc application on quality parameters of potato

Treatments		Dry matter content (%)	Specific gravity of tubers (g cm^{-3})	Starch content (%)
T_1 :	Control (RDF without zinc)	15.86	1.03	13.18
T_2 :	Zinc @ 2.5 kg ha^{-1} at the time of planting	16.55	1.05	14.14
T_3 :	Zinc @ 5 kg ha^{-1} at the time of planting	18.07	1.06	15.24
T_4 :	Zinc @ 7 kg ha^{-1} at the time of planting	19.07	1.05	15.47
T_5 :	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 days after planting (DAP)	20.30	1.05	14.48
T_6 :	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 DAP	20.73	1.07	17.10
T_7 :	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP	19.54	1.06	16.53
T_8 :	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP	18.83	1.06	15.16
T_9 :	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP	19.54	1.05	16.28
T_{10} :	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP	20.24	1.05	16.27
T_{11} :	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP	20.01	1.03	16.00
T_{12} :	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP	18.78	1.04	14.99
CD (p=0.05)		0.30	NS	1.09

Table 3. Effect of zinc application on tuber zinc content and zinc uptake

Treatments		Zinc content in tubers (ppm)	Zinc uptake by tubers (kg ha^{-1})
T_1 :	Control (RDF without zinc)	31.39	1.05
T_2 :	Zinc @ 2.5 kg ha^{-1} at the time of planting	37.37	1.45
T_3 :	Zinc @ 5 kg ha^{-1} at the time of planting	41.43	1.81
T_4 :	Zinc @ 7 kg ha^{-1} at the time of planting	43.68	2.43
T_5 :	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 days after planting (DAP)	44.85	1.77
T_6 :	Foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 DAP	47.58	2.85
T_7 :	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP	43.15	2.79
T_8 :	Zinc @ 2.5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP	42.28	1.72
T_9 :	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP	42.75	1.69
T_{10} :	Zinc @ 5 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 DAP	43.35	1.72
T_{11} :	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 25 and 50 DAP	44.12	1.77
T_{12} :	Zinc @ 7 kg ha^{-1} at the time of planting + Foliar application of $ZnSO_4$ @ 2 g L^{-1} at 50 DAP	12.13	1.68
CD (p=0.05)		8.22	0.67

4. CONCLUSION

The study showed that foliar application of zinc sulphate @ 2 g L^{-1} at 25 and 50 days after planting registered higher values for dry matter content, specific gravity, starch content, zinc content and zinc uptake. Clearly, application of zinc has the potential of enhancing quality of tubers as well as bioavailability of zinc in potato and, therefore, we recommend the same treatment, in addition to RDF, for commercial potato cultivation under the *tarai* region of Uttarakhand.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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