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RESEARCH ARTICLE

Soil and foliar application of zinc for improving nutritional quality in potato (*Solanum tuberosum* L.)

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Abstract

In order to investigate the response of application of zinc sulphate on the quality of potato tubers, a field experiment was conducted during *rabi* season 2023-24 in a field at the Zonal Agricultural Research Station, Chhindwara, under Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). The experiment consists of 7 treatments with RDF and different doses of zinc fertilizer at 25 and 50 DAP. The experiment was laid out in a randomized complete block design with three replications. The results indicated that treatment T7 [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] give maximum total soluble solids (6.37 °Brix), starch (30.96%), total sugar (5.50%), reducing sugar (0.92%), non- reducing sugar (4.58%), dry matter of tubers (75.48 g/plant) and Zn content of potato tuber (24.79 mg/kg) as compare to other treatments. Based on the present investigation, it can be concluded that soil with foliar application of zinc sulphate improved potato tuber quality under the present agro-climatic conditions as a biofortified crop.

Key words: Potato, Zinc, Quality, Biofortification

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Introduction

Potato (*Solanum tuberosum* L.) is a member of the Solanaceae family. The growing potato plant generates bigger subterranean stems, sometimes known as tubers, which are a valuable economic component (Anonymous, 2011). Potato is a major crop worldwide, with countries such as China, the Russian Federation, Poland, India, the Netherlands, Ukraine, and the USA being major producers. For potato, in 2021-22, India contributed 2.21 million ha of land, 53.58 million metric tonnes of production and a yield of 24.24 metric tonnes per hectare. In India, the major potato-growing states are Uttar Pradesh, with a 620.44 ha area and production of 15811.31 metric tonnes, followed by Bihar, West Bengal, Madhya Pradesh, Punjab, Haryana, and Karnataka although it can also be seen growing in other states under diverse conditions (FAOSTAT, 2023). As compared to major cereal crops, potatoes produce more dry matter and protein per unit area (Singh et al., 2010), besides being an important source of starch (Birch et al., 2012; Luthra et al. 2023). Further, potatoes are a good source of carbohydrates (75% of total dry matter), protein, vitamins, dietary fibre, and some minerals (Struik et al., 2007). Potatoes have the following nutrient constituents: carbohydrate (20.13 g), protein (1.87 g), fibre (1.8 g), fat (0.1 g), potassium (379 mg), phosphorus (44 mg), vitamin C (13 mg), iron (0.4 mg), zinc (0.3 mg), calcium

(5 mg), riboflavin (0.02 mg), thiamine (0.10 mg) and niacin (1.44 mg) (Anonymous, 2011). Around the world, nearly 2 billion people, mostly in developing countries, suffer from micronutrient malnutrition, often referred to as 'hidden hunger' (Von Grebmer, 2014). In another related research, the higher bioavailability of minerals in potato tubers and other major food crops was reported owing to the high concentrations of promoter chemicals such as ascorbic acid that promote micronutrient absorption by the body (US Department of Agriculture, 2007) and the low level of inhibitor chemicals (Phillippy, 2004).

Zinc is essential for human health because it is required in trace amounts for a number of vital metabolic processes, such as enzyme activation, protein and carbohydrate synthesis, DNA replication, RNA transcription and chromatin structure (Das *et al*., 2023). Over one-third of people worldwide suffer from zinc deficiency, which raises the risk of infectious diseases, DNA deterioration, delayed development, and immunodeficiency in individuals (Kumar et al., 2017). Soil and plant analysis showed that 49% of Indian soils are potentially deficient in Zn (Alloway, 2008). The solubility of Zn in soils and its uptake by plants decrease rapidly as the soil pH increases. Sometimes, Zn may be present in the soil but not available to the plants due to its high pH and high reactivity with clay (Mousavi et al., 2013). The potato crop is highly responsive to zinc, as the farmers apply a high amount of phosphorous fertilizer at planting that interferes with the plant's metabolism of zinc, resulting in a deficiency, especially when soil temperatures are low during the early growth of potatoes. The improvement in nutrient uptake in plant systems may be achieved through biofortification to overcome micronutrient deficiencies on a large scale (Dhaliwal et al., 2022a). Biofortification raises micronutrients in the edible parts of plants, either through mineral fertilization or plant breeding (Singh et al., 2023). The human digestive system can readily absorb and access only a small percentage of the Zn present in meals. Potatoes are a crop that is widely consumed by people worldwide and has excellent digestibility. They also present a significant opportunity for agronomic biofortification. It is challenging to increase the zinc content of tubers due to the inefficient movement of this element in the phloem and the adsorption of zinc to soil constituents.

Materials and Methods

The present study was conducted during the *rabi* season 2023-24 in a field at the Zonal Agricultural Research Station, Chhindwara under Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). The site is situated at 22°03′ North Latitude, and 78°92′ East longitude at an altitude of 657.87 m above mean sea level. A field experiment was conducted under sandy loam soil with good drainage properties, a medium NPK status, and uniform texture, and laid out in a randomized block design with 7 treatments replicated thrice. The recommended dose of fertilizers i.e., 120:100:100 kg N, P_2O_5 and K_2O per ha, respectively. At the time of planting, a full dose of phosphorus and potassium was applied, and nitrogen was applied in two split doses. Half the dose of nitrogen was applied at 30 days after planting, and the remaining half dose was applied at 60 days after planting. Potato crop was fertilized with zinc sulphate according to different treatments of experiments viz., T1 [No Zinc (control)], T2 [2.5 kg Zinc/ha from zinc sulphate @ at the time of planting], T3 [5.0 kg Zinc/ha from zinc sulphate @ at the time of planting], T4 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting], T5 [Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting], T6 [T2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 days after planting], T7 [T2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting]. Well-sprouted potato tubers variety Kufri Lavkar were planted during last week of November with 60 × 20 cm spacing. After planting, a little light irrigation was done to maintain moisture levels and help the plants emergence. A check basin method of irrigation system was used to supply subsequent irrigation. Dehaulming is conducted approximately 10 to 15 days prior to the potato tuber being harvested when it turns yellow. The crop was harvested during third week of March. Quality parameters were observed after harvesting of tubers with following procedures:

TSS (^{0}Brix)

The TSS content of potato tuber was measured by using an Erma Hand Refractometer of a 0–32 ^{0}Brix range, following the procedure described in A.O.A.C. (1970). Few drops of juice were put on the prism of the refractometer with the help of a clean glass rod. The cover of the refractometer was folded lightly and looked through eyepiece with projection inlet facing towards light. The point where the boundary line of the shaded area interacts with the unshaded area of the scale was noted. The specimen chamber was cleaned with a muslin cloth after every use. The readings were taken at room temperature.

Starch (%)

The starch content of potato tuber was measured by using anthrone reagents. Homogenize 0.1 to 0.5 g of the sample in hot 80% ethanol to remove sugars. Centrifuge and retain the residue. Wash the residue repeatedly with hot 80% ethanol till the washings do not give colour with anthrone reagent. Dry the residue well over a water bath. To the residue, add 5.0 mL of water and 6.5 mL of 52% perchloric acid. Extract at 0°C for 20 min. Centrifuge and save the supernatant. Repeat the extraction using fresh perchloric acid. Centrifuge and pool the supernatants and make up to 100 mL. Pipette out 0.1 or 0.2 mL of the supernatant and make up the volume to 1-mL with water. Prepare the standards by taking 0.2, 0.4, 0.6, 0.8 and 1-mL of the working standard and make up the volume to 1-mL in each tube with water. Add 1-mL of anthrone reagent to each tube. Heat for 8 min in boiling water bath. Cool rapidly and read the intensity of green to dark green colour at 630 nm. Find out the glucose content in the sample using the standard graph. Multiply the value by a factor 0.9 (Powell Gains, 1973) to arrive at the starch content and it was expressed in percentage.

Total Sugar (%)

For the estimation of total sugars, 20 mL of juice was taken in a beaker and 5 mL of concentrated HCl was added. The solution was then boiled for five minutes in a water bath to allow the hydrolysis to convert the non-reducing sugar to reducing sugar. The excess acid was neutralized by the sodium carbonate solution after cooling. The solution was transferred to a 100 mL volumetric flask and the volume was made up to the mark by adding distilled water. This solution was taken in a burette and titrated with Fehling's solutions A and B, similar to what was done in reducing sugar. The total sugar percentage was calculated with the help of the following formula:

$$\text{Total Sugar (\%)} = \frac{1.25}{\textit{Burette Reading}} X\ 100$$

Reducing Sugar (%)

Reducing sugar in fruit juice were estimated by the method as suggested by Nelson (1944). 5 mL each of Fehling's 'A' and 'B' solution were taken in a 300 mL conical flask and diluted with 40 mL of distilled water. The juice solution taken in a burette was added slowly in hot (boiling) Fehling solution till the appearance of slight red colour. Now three drops of methylene blue indicator were added, and titration was continued till a brick red precipitate appeared by destroying the blue colouration. The reducing sugar in percentage was calculated with the help following formula:

$$\text{Reducing Sugar (\%)} = \frac{0.25}{\textit{Burette Reading}} X\ 100$$

Non-reducing Sugar (%)

Non reducing sugar is estimated by subtracting the reducing sugar from total sugar content of the sample.

Non reducing sugars (%) = Total sugar –Reducing sugars

Dry Matter of Tubers (g/plant)

The dry matter produced per plant on oven dry weight basis was recorded for tubers and they were dried to constant weight at 65°C in the hot air oven and expressed in grams. The average of five plant tubers was considered as the dry matter produced.

Zinc Content in Tuber at Harvest (mg/kg)

Determination of zinc content in potato tuber is done by the use of atomic absorption spectrophotometry (AAS) method (Lindsay and Norvell, 1978). Firstly, prepare a stock standard solution by using their foil or wire (AR grade). After that, make a working standard solution. Standard solutions should be made in DTPA extracting solution by taking a known volume of the working standard solution in 50 mL volumetric flask and making the volume with 0.005 m DTPA solution. The concentration ranges usually required for Zn are 0, 0.2, 0.4, 0.8 and 1.2 (µg/mL). Using a diacid mixture for digestion. To the beaker containing the 1.0 g plant sample, add 10 mL of the diacid mixture. Then, place the beaker on a hot plate to heat it quickly. To let the gases out, leave a portion of the beaker's mouth open. Heat the mixture until the thick, white fumes that are evaporating stop, leaving behind approximately 3 mL of colourless solution in the beaker that turns white when cooled. Then prepare a plant sample test solution. The atomic absorption spectrophotometer should be calibrated by feeding standards of the element to be determined into it after it has been set to zero with a blank. This will allow the instrument to read the absorbance and/or concentration in samples containing the given element within the standardised range. After that, feed the filtrate (potato sample), then note the zinc absorbance and concentration.

Results and Discussion

The maximum pulp TSS (6.37) recorded in treatment T7 [T2 + Foliar Application of zinc sulphate @ 2 g/L (400 PPM Zn) at 25 and 50 days after planting] and the lowest TSS (4.00) recorded in treatment T1 [No Zinc (control)]. It is evident from the data (Table 1; Fig. 1) that tryptophan, a precursor of auxin, is synthesized by zinc. Auxins aid in the mobilization of carbohydrates from source to sink, which ultimately increases TSS. Zinc is a part of the carbonic anhydrase enzyme's molecular structure, which is involved in photosynthesis and raises the concentration of soluble sugars (Dube *et al.,* 2004). These outcomes could be attributed to zinc's ability to stimulate plant growth

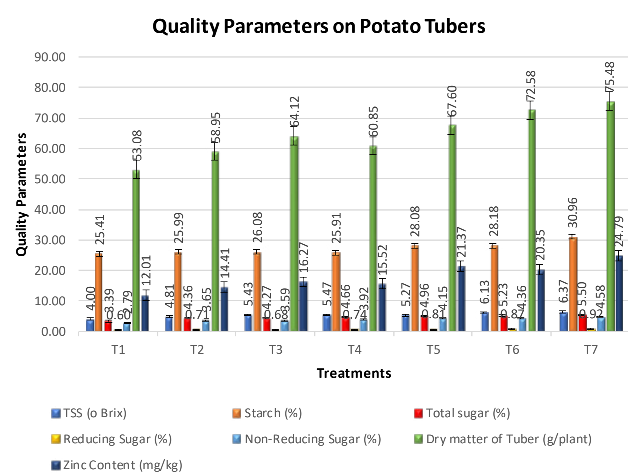

Fig. 1: Effect of zinc on quality parameters of potato tubers

and starch generation. Growth-promoting hormones, the activity of enzymes that support photosynthesis, the quicker transfer of photosynthates to potato tubers, and the synthesis of proteins and carbohydrates are all positively impacted by zinc (Ewais *et al*., 2010). Mohamadi (2000) and Al-Jobori and Al-Hadithy (2014) also reported similar outcomes, observing that zinc applied topically enhances the quality of potato tubers.

Starch (%) content of potato was significantly influenced by the application of different doses of zinc fertilizer. The highest starch (30.96%) was recorded in treatment T7 [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 starch (25.41%) was recorded in treatment T1 (No Zinc control) showed in Table 1. The starch content of potato tubers increased as zinc sulphate levels increased because zinc stimulated enzymes like aldolase and carbonic anhydrase that helped move carbs from leaves to tubers. Puzina (2004) reported that the highest starch accumulation was indicative of isodiametric peri-medullary tuber zone cells, which widened when exposed to zinc. These findings are in some ways consistent with those of Mousavi *et al.* (2007), Panitnok *et al.* (2013) and Ahmed *et al*. (2011).

Application of different doses of zinc fertilizer significantly impacted the total sugar (%) content of the potato tuber. In Table 1 showed maximum total sugar (5.50%) was recorded in treatment T7 [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 total sugar (3.39%) was recorded in the treatment T1 (No Zinc control). The reducing sugar (%) significant influence, and the maximum reducing sugar (0.92%) were recorded in treatment T7 [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], while the minimum reducing sugar (0.60%) was recorded in the treatment T1 (No Zinc control) showed in Table 1. Non- reducing sugar (%) significant influence, and the maximum non-reducing sugar (4.58%) were recorded in treatment T7 [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], while the minimum non-reducing sugar (2.79%) was recorded in treatment T1 (No Zinc control) showed in Table 1. According to Parmer *et al.* (2016), zinc is essential for protein synthesis, enzyme activation, oxidation, revival processes and the metabolism of carbohydrates. It also increases total sugar, reducing sugar and non-reducing sugar. Similar result found by Ahmed *et al*. (2011).

The dry matter of tubers (g/plant) at harvest as significantly influenced by the application of different doses of zinc fertilizer.T7 [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] treatment recorded significantly higher dry matter of tubers at harvest (75.48 g/plant), while lower dry matter of tubers was recorded in T1 (No Zinc control) treatment (53.08 g/plant) at harvest showed in Table 1. Because dry matter and starch content of the tuber have a positive link, the dry matter content of the potato tuber increased as the quantity of zinc sulphate increased. Conversely, a balanced zinc administration enhances the assimilates transfer from shoots to tubers. The collection of dry materials increased as a result of taller plants and larger leaves. Similar findings were made by Bashir *et al*. (2021), who found that the application of chelated zinc increased the crop's dry matter content.

The application of different doses of zinc fertilizer significantly impacted the zinc content in potato tuber, maximum zinc content (24.79 mg/kg) were recorded in treatment T7 [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], while the minimum zinc content (12.01 mg/kg) was recorded in treatment T1 (No Zinc control) showed in Table 1. The amount of zinc

Table 1: Effect of zinc application on different quality parameters in potato tubers

Treatments	*TSS (° Brix)*	*Starch (%)*	*Total sugar (%)*	*Reducing Sugar (%)*	*Non-Reducing Sugar (%)*	*Dry matter of Tuber (g/plant)*	*Zinc Content (mg/kg)*
T1	4.00	25.41	3.39	0.60	2.79	53.08	12.01
T2	4.81	25.99	4.36	0.71	3.65	58.95	14.41
T3	5.43	26.08	4.27	0.68	3.59	64.12	16.27
T4	5.47	25.91	4.66	0.74	3.92	60.85	15.52
T5	5.27	28.08	4.96	0.81	4.15	67.60	21.37
T6	6.13	28.18	5.23	0.87	4.36	72.58	20.35
T7	6.37	30.96	5.50	0.92	4.58	75.48	24.79
SE m±	0.23	1.14	0.19	0.06	0.33	2.68	1.41
C.D. at 5%	0.70	3.51	0.59	0.19	1.04	8.25	4.35

that was easily accessible in potato tubers increased along with zinc levels at the time of planting. This happened as a result of the experimental plot's soil lacking zinc. By adding zinc, the root biomass developed, and the potato plant's absorption efficiency of zinc increased. Zinc's restricted phloem mobility may affect potato tuber zinc content, as suggested by White *et al.* (2012). The zinc content of tubers was found to be significantly impacted by cultivar and zinc fertilization, according to Sharma and Grewal (1990). Similar results were precisely noted by Ahmed *et al.* (2011).

Conclusion

On the basis of the findings of present experiments, quality attributes TSS, starch, total sugar, reducing sugar, non-reducing sugar, dry matter of potato tubers and Zn content of potato tuber 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 quality 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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सारांष

आलू कंदों की गुणवत्ता पर जिंक सल्फेट के प्रयोग की प्रतिक्रिया की जांच करने के लिए, रबी सीजन 2023-24 के दौरान जवाहरलाल नेहरू कृ»ाि विष्वविद्यालय, जबलपुर (म.प्र.) के अंतर्गत आंचलिक कृ»ाि अनुसंधान केंद्र, छिंदवाडा के खेत में क्षेत्र प्रयोग किया गया। इस प्रयोग में त्क्थ् के साथ 7 उपचार और 25 और 50 क्ा।च् पर जिंक उर्वरक की विभिन्न खुराक षामिल हैं। प्रयोग को तीन प्रतिकृतियों के साथ त्ठक् डिजाइन में रखा गया था। परिणामों से पता चला कि उपचार ज्7 ख्रोपण के समय जिंक सल्फेट से 2.5 किग्रा जिंकध्हेक्टेयर. 2 ग्रामध्लीटर (400 पीपीएम जिंक) जिंक सल्फेट का 25 और 50 क्ा।च् पर पत्तियों पर छिडकाव,, अन्य उपचारों की तुलना में अधिकतम टीएसएस (6.37 °ब्रिक्स), स्टार्च (30.96ः), कुल षर्करा (5.50ः), कम करने वाली षर्करा (0.92ः), गैर-कम करने वाली षर्करा (4.58ः), कंद का सूखा पदार्थ (75.48 ग्रामध्पौधा) और आलू कंद में जिंक की मात्रा (24.79 मिलीग्रामध्किग्रा) देता है। वर्तमान जांच के आधार पर, यह नि»कर्»ा निकाला जा सकता है कि जिंक सल्फेट के पत्तियों पर छिडकाव से मिट्टी ने वर्तमान कृ»ाि-जलवायु परिस्थितियों में जैव-प्रबलित फसल के रूप में आलू कंद की गुणवत्ता में सुधार किया है।