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Agronomic zinc biofortification of potato (*Solanum tuberosum*) through soil and foliar zinc sulphate application in Rajasthan

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ABSTRACT

An experiment was conducted during winter (*rabi*) seasons of 2020–21 and 2021–22 at Agricultural Research Station, Kota, Rajasthan to assess agronomical biofortification of potato (*Solanum tuberosum* L.) through soil and foliar zinc sulphate application The experiment consisted of 7 treatment combination of soil and foliar applications in a randomized block design with 4 replications. The results revealed that the application of $ZnSO_4$ @2.5 kg/ha at the time of planting and foliar application of zinc sulphate @0.2% at 25 and 50 DAP (T_7) gave significantly higher total tuber yield, and number of tubers. A significantly higher tuber zinc content was observed under treatment T_7, where soil application of $ZnSO_4$ @12.5 kg/ha at planting + 0.2% foliar application of $ZnSO_4$ at 25 and 50 days after planting (DAP) compared to control, indicating more Zn accumulation. The benefit-cost analysis of tuber production under different basal soil application levels and foliar application revealed highest benefit-cost ratio of 2.59 with treatment T_7 followed by T_6 (2.39) and T_3 (2.35). The apparent recovery efficiency and partial factor productivity were also higher with combined application of $ZnSO_4$ through soil as well as foliar application. The experiment highlights the importance of soil and foliar zinc sulphate application for improved tuber yield and zinc fortification in a sustainable and cost-effective manner.

Keywords: Biofortification, Correlation matrix, Potato, Tuber yield, Zinc

The potato (*Solanum tuberosum* L.) is a significant crop in Indian agriculture that can supply nourishment to the nation's ever-increasing population. The major potato producing states are Madhya Pradesh, Uttar Pradesh, Bihar, Assam, Gujarat, Punjab, Haryana, West Bengal, Jharkhand and Chhattishgarh. In India, Zn deficiency is the serious problem especially in the north western region (Shukla *et al.* 2017, Singh *et al.* 2022) posing serious risk to crop production, especially in light textured and calcareous soils (Heba *et al.* 2021). Thus, application of zinc through different modes such as soil application, foliar spray and seed priming has been recommended in various crops for improving biomass and yield (Dhaliwal *et al.* 2022a). The potato crop is highly responsive to zinc, as the farmers apply high amount of phosphorous fertilizer at planting that interferes with the plant's metabolism of Zn resulting in the deficiency, especially when soil temperatures are low during the early growth of potatoes.

The easiest and latest interventions to deal with deficiencies of micronutrient in crops is the application of micronutrient fertilizers (Dhaliwal *et al.* 2011). The improvement in nutrient uptake in plant system may be achieved through the biofortification to overcome micronutrient deficiencies on a large scale (Dhaliwal *et al.* 2022b). Biofortification, raise micronutrients in the edible parts of the plants, either through mineral fertilization or plant breeding. The application of micro-nutrients fertilizers significantly increases nutrient content of foliage during stages of crop growth, while the translocation of integrates increase during later growth phases (Singh *et al.* 2022), resulting in yield improvements. Zinc plays a very significant role in realizing better tuber yield as well as quality. Application of zinc to potato through foliar application increases the concentration of Zn in potato tubers several times, which is higher than that of conventional crops and appears to be a sustainable and cost-effective way to achieve zinc biofortification. To improve Zn content in potato tubers and its bioavailability for consumer, the study was initiated with objective to improve the yield and zinc content in tuber production for biofortification.

MATERIALS AND METHODS

The present experiment was conducted during winter (*rabi*) seasons of 2020–21 and 2021–22 at Agricultural Research Station, Kota, Rajasthan situated in the humid south eastern plain zone of Rajasthan. The mean annual

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rainfall of the district is 732.4 mm. The soil was characterised as clay loam soil, neutral in soil reaction (7.59) and non-saline (0.34 dS/m), medium in organic carbon (0.42%), available N (150.5 kg) and high in available phosphorus (20.86 kg) and sufficient available potassium (250.1 kg). The initial status of soil micronutrient such as available zinc, iron, manganese and copper was 0.575, 2.314, 1.79 and 0.85 g/kg respectively. The experiment comprised of 7 treatment combinations replicated four times i.e. T_1, control (no Zinc application); T_2, Soil application of zinc sulphate ($ZnSO_4$) @12.5 kg/ha at planting; T_3, Soil application of $ZnSO_4$ @25 kg/ha at planting; T_4, 0.2% foliar application of $ZnSO_4$ 25 days after planting (DAP); T_5, 0.2% foliar application of $ZnSO_4$ at 25 and 50 DAP; T_6, soil application of $ZnSO_4$ @12.5 kg/ha at planting + 0.2% foliar application of $ZnSO_4$ at 25 DAP; T_7, soil application of $ZnSO_4$ @12.5 kg/ha at planting + 0.2% foliar application of $ZnSO_4$ at 25 and 50 DAP were arranged in randomized complete block design.

The crop was planted on ridges 60 cm apart and plant to plant spacing of 20 cm, at a depth of 5–6 cm using potato cultivar Kufri Bahar at 25 q seeds/ha in the field during 2nd week of November, during 2020–21 and 2021–22. The gross plot size of 12.96 m^2 was sown and net plot of 7.68 m^2 was harvested removing borders rows while harvesting. The doses of NPK @187.5 kg N, 125 kg P and 125 kg K/ha were applied through inorganic fertilizers (i.e Urea as source of N, single super phosphate (SSP) for phosphorus and muriate of potash (MOP) for potassium). The urea (as source of N) was applied in two splits i.e. half at planting and remaining half at 30–35 DAP as per the dose of each treatment. The entire amount of potassium and phosphorus fertilizers were applied in furrows at the time of planting as per treatment. The tubers of potato were treated with fungicides mencozeb at 0.2% solution before planting. The package of practices recommended for the zone were followed for the management of weed, insect-pest, diseases and irrigation. The crop was dehaulmed during the third week of February and harvested in the first week of march during the year 2020–21 and 2021–22.

The plant observations, viz. emergence count (%), plant height and numbers of shoots per plant at 60 days after planting were taken. After harvest the crop, tubers were graded according to their size (i.e. 0–25, 25–75 and more than 75 g) for each category of grades as well as all sizes of tubers were counted and weighted separately. The tubers were oven dried at 65°C for 48 h to achieve constant weight and ground and sieved through 1 mm sieve to get fine powder. A known weight of powdered tuber was digested using diacid and analyzed for zinc using atomic absorption spectrophotometer (AAnalyst 200, Perkin Elmer Pvt. Ltd.). The Zn uptake was calculated as the product of zinc concentration in tuber and total tuber yield.

The net return was calculated as the difference between the cultivation cost and gross realization for each treatment and expressed in ₹/ha. The benefit cost ratio (B:C ratio) was calculated as ratio of gross returns and cost of cultivation. The agronomic efficiency, physiological efficiency and apparent recovery efficiency (Dobermann 2007) were calculated as:

$$\text{Agronomic efficiency} = \frac{TY_f - TY_0}{\text{Zn applied}}$$

$$\text{Apparent recovery efficiency} = \frac{ZnUT_f - ZnUT_0}{\text{Zn applied}}$$

$$\text{Partial factor productivity} = \frac{ZnU_f - ZnU_0}{\text{Zn applied}}$$

where, TY_f, tuber yield from fertilized plot; TY_0, tuber yield from Zn unfertilized plot; $ZnUT_f$, tuber zinc uptake in fertilized plot; $ZnUT_0$, tuber zinc uptake in unfertilized plot; Zn applied is amount of zinc applied.

Bartlett's test was applied to test the homogeneity of variances and found homogenous for both the years. The statistical analysis of the two-year data generated was carried out through the analysis of variance of pooled data as per the randomized complete block design and analyzed using PROC ANOVA in SAS 9.4 (SAS Online, SAS, CA). The Duncan multiple range test was employed for comparison of treatment means. The PSYCH package was used for correlation analysis using RStudio (RStudio team 2019).

RESULTS AND DISCUSSION

The plant height was found to be significantly affected by the application of zinc sulphate to crop, either soil application as well as foliar, or combined soil and foliar application in potato. The plant height was higher in the treatment T_7 (62.4 cm) that was at par with the treatment T_6 (59.4 cm) and T_3 (57.8 cm) significantly superior to control (43.6 cm) as well as treatment T_2 (48.6 cm) (Table 1). Al-Jobory and Al-Hadithy (2014) and Rakshya and Arjun (2019) also reported increase in plant height with adequate supply of zinc in potato (either through soil application or foliar application) resulted from increased internodal distance. The number of shoots per plant were also significantly influenced by the zinc application. The highest number of shoots (8.8) were recorded in the treatment T_7, statistically at par with T_6 (7.9) and T_3 (7.8) and significantly higher than the control treatment. The number of shoots in treatment T_7 were 12.8% higher than T_3 treatment i.e with additional two foliar spray and 11.3% higher than T_6 i.e with additional one foliar spray of zinc sulphate (Table 1). The soil application of zinc sulphate at planting was not found to affect significantly the emergence of tuber sprouts. However, rate of emergence was more where zinc was applied to soil @25 kg/ha at the time of planting.

The zinc fertilizer application had positive affect on the total number of tubers, where highest number of tubers were observed in the treatment T_7 (497.9) followed by T_5 (474.5) and T_3 (471.2), significantly higher than the control (390.7) (Table 1). The number of tubers of >75 g size improved by 32.6% in T_7 compared to control treatment, and increased by 5.16% in T_7 than T_3 treatment that included two additional zinc spray at 25 and 50 DAP. The number of tubers of

Table 1 Effect of various treatments of zinc application on mean emergence, plant height, no of shoot/plant and grade wise number of tubers in potato

Treatment	Emergence (%)	Plant height (cm)	Shoots/plant	Grade-wise number of tubers (000'/ha)			
				0–25 g	25–75 g	>75 g	Total
T_1	93.4^{a}	43.6^{d}	4.7^{c}	210.8^{d}	89.4^{a}	90.6^{d}	390.7^{d}
T_2	93.8^{a}	48.6^{cd}	5.8^{bc}	219.2^{cd}	107.9^{a}	102.4^{c}	429.5^{cd}
T_3	95.5^{a}	57.8^{ab}	7.8^{a}	253.2^{ab}	103.6^{a}	114.3^{ab}	471.2^{abc}
T_4	93.5^{a}	51.6^{bc}	5.9^{b}	233.3^{bcd}	98.4^{a}	106.2^{bc}	437.9^{bc}
T_5	94.8^{a}	53.6^{bc}	6.0^{b}	243.3^{bc}	98.5^{a}	108.8^{bc}	450.6^{bc}
T_6	95.8^{a}	59.4^{ab}	7.9^{a}	259.8^{ab}	98.3^{a}	116.4^{ab}	474.5^{ab}
T_7	95.8^{a}	62.4^{a}	8.8^{a}	277.1^{a}	100.6^{a}	120.2^{a}	497.9^{a}
CV (%)	6.17	9.30	10.78	7.08	11.25	6.01	5.98
Pr>F	ns	**	**	**	ns	**	**

Treatment details are given under Materials and Methods.

25–75 g grade size was not significantly affected by the zinc application, however number of tubers with weight <25 g followed similar trend as that of total number of tubers (Table 1). Al-Jobory and Al-Hadithy (2014) attributed the improved number of tubers due to production of more photosynthates, better mobilization of photosynthates from shoots to roots, higher plant height and number of shoots.

The tuber yield of various size grades and total tuber yield was significantly affected by the soil and foliar application of zinc to the potato crop. The yield of tuber of <25 g grade size was significantly higher with treatment T_3 compared to control, however <25 g grade size tuber yield in T_3 was statistically at par with T_7 (Table 2). Whereas the yield of tuber 25–75 g grade size was statistically similar in treatment T_7, T_6 and T_3 and significantly higher than the control. The yield of tuber >75 g grade size was statistically higher in treatment T_7, that was statistically similar in treatment T_3, T_4, T_5, and T_6, and significantly higher than the control treatment. That may be attribute to soil application and foliar application of zinc which improved the tuber yields. Nagar *et al.* (2023) also reported that the adequate supply of nutrients results in improved yields/tubers (Singh *et al.* 2022).

The total tuber yield was significantly higher with the treatment T_7 statistically at par with T_6 and T_3 compared to control. The tuber yield under T_7 was 22.8% higher than T_2, where similar basal zinc fertilizer was applied except two 0.2% $ZnSO_4$ foliar spray was done at 25 and 50 DAP. Parmar *et al.* (2016) also reported that foliar application of zinc improves the tuber yield of potato (Table 2). The improvement in tuber yield may be due to improved accumulation and translocation of photosynthates to potato tubers resulted from improved size of potato tuber and number of tubers per unit area, contributing directly to yield increase (Sati *et al.* 2017, Kromann *et al.* 2017). The data further revealed that soil application (T_2 and T_3) or foliar application (T_4 and T_5) alone did not produce yield comparable to combined application of soil + foliar application (T_6 and T_7).

The data on tuber zinc content revealed significantly highest tuber zinc content under treatment T_7, where soil application of $ZnSO_4$ @12.5 kg/ha at planting + 0.2% Foliar application of $ZnSO_4$ at 25 and 50 DAP was given compared to control. The tuber zinc uptake followed similar trend where, significantly high zinc uptake was observed in the treatment T_7 compared to control (T_1), T_2, T_3, T_4,

Table 2 Effect of various treatments of zinc application on potato tuber yield, zinc content and zinc uptake

Treatment	Grade-wise yield of tubers (t/ha)			Total tuber yield (t/ha)	Tuber zinc content (ppm)	Tuber zinc uptake (kg/ha)
	0–25 g	25–75 g	>75 g			
T_1	2.63^{e}	14.19^{e}	9.12^{c}	25.95^{d}	6.84^{e}	177.6^{d}
T_2	3.06^{d}	17.19^{d}	10.49^{bc}	30.74^{c}	9.71^{d}	298.3^{c}
T_3	4.16^{a}	19.73^{abc}	11.32^{ab}	35.21^{ab}	12.50^{c}	440.1^{b}
T_4	3.29^{cd}	17.87^{cd}	10.71^{ab}	31.87^{bc}	13.80^{bc}	439.8^{b}
T_5	3.42^{bcd}	18.49^{bcd}	10.81^{ab}	32.72^{bc}	14.70^{ab}	480.8^{b}
T_6	3.68^{bc}	20.44^{ab}	11.41^{ab}	35.53^{ab}	15.20^{ab}	540.1^{ab}
T_7	3.81^{ab}	21.58^{a}	12.36^{a}	37.75^{a}	16.40^{a}	619.1^{a}
CV (%)	7.55	7.92	9.43	7.22	8.71	16.16
Pr>F	**	**	*	**	**	**

Treatment details are given under Materials and Methods.

Table 3 Effect of various treatments of zinc application on economics of potato cultivation, agronomic efficiency, apparent recovery and partial factor productivity

Treatment	Total cost of production (cost of inputs + cultivation cost) (₹/ha)	Net returns (₹/ha)	B:C ratio	Agronomic efficiency (t/ha/kg)	Apparent recovery efficiency (t/ha/kg)	Partial factor productivity (t/ha/kg)
T_1	62453	93231	1.49	-	-	-
T_2	62768	121666	1.94	0.38	9.7	2.46
T_3	63083	148167	2.35	0.37	10.5	1.41
T_4	62603	128627	2.05	11.84	524.6	63.74
T_5	62753	133556	2.13	6.77	303.2	32.72
T_6	62918	150266	2.39	0.75	28.5	2.80
T_7	63068	163436	2.59	0.91	34.2	2.93

Treatment details are given under Materials and Methods.

Input: Seed tuber, ₹9600/tonnes; Urea, ₹6.5/kg; SSP, ₹7.5/kg; $ZnSO_4$, ₹50/kg; Mandays, ₹56.92/ h; tractor, 455/h; Tuber sold @₹6000/tonne (Average over grades).

T_5 and statistically at par with T_6. The zinc uptake through tuber in T_7 was 107.5% higher compared to T_2 treatment. However, zinc uptake in T_7 was 14.6% higher compare to T_6, whereas additional 0.2% $ZnSO_4$ foliar spray at 50 days after planting was made.

The data reveals that the foliar application was more efficient in biofortification of tubers as evident from the agronomic efficiency and partial factor productivity under T_4 treatment, followed by T_5 (Table 3). The apparent recovery efficiency revealed that zinc uptake efficiency was quite higher under the treatments receiving foliar spray of zinc sulphate. The highest apparent recovery efficiency was observed in treatment T_4 followed by T_5. The apparent recovery efficiency in treatment T_7 was 252.5% higher compared to T_2, both the treatments received similar basal doze of zinc sulphate except T_7 treatment received two foliar sprays of 0.2% $ZnSO_4$ at 25 and 50 DAP, i.e. foliar application improves apparent recovery than that of

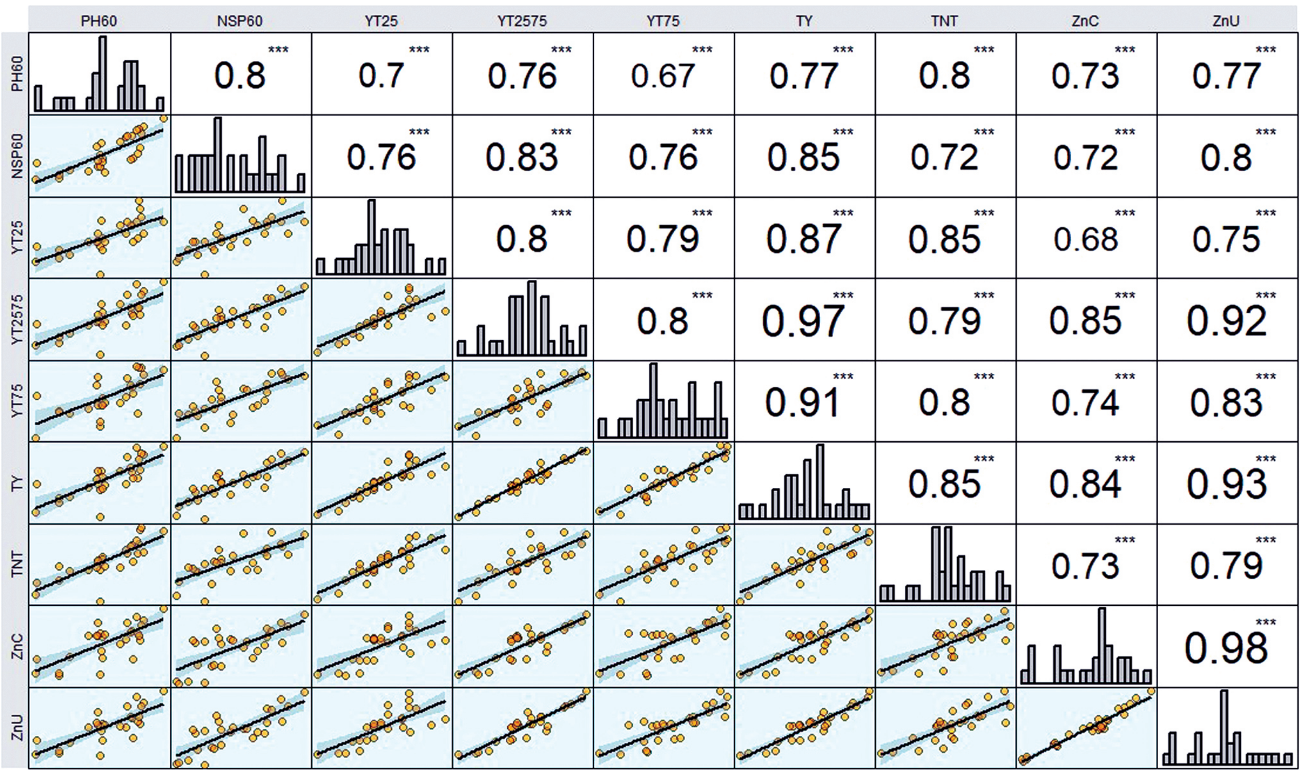

Fig. 1 Correlation matrix of different quantitative and quality parameters of potato.

PH60, Plant height; NSP60, number of shoots per plant; YT25, tuber yield of <25 g tuber size grade; YT2575, tuber yield of 25–75 g tuber size grade; YT75, tuber yield of >75 g tuber size grade; TY, total tuber yield; TNT, total number of tubers per hectare; ZnC, tuber zinc content, ZnU is zinc uptake.

*** correlation is significant at P≤0.01.

increasing the rate of soil fertilizer application. Thus, foliar application was found to be more efficient in accumulation of zinc in tubers (White *et al.* 2012), leading to Zn biofortified tubers. The higher agronomic efficiency, apparent recovery efficiency and partial factor productivity was due to the use of 50 times (0.5 kg $ZnSO_4$ for spray of 0.2% $ZnSO_4$ at 25 DAP) and 25 times (1.0 kg $ZnSO_4$ for spray of 0.2% $ZnSO_4$ at 25 and 50 DAP) lesser use of zinc sulphate during foliar application under treatment T_4 and T_5 respectively compared to soil application of 25 kg/ha zinc sulphate.

The benefit-cost analysis of tuber production under different basal soil application levels and foliar application revealed highest benefit-cost ratio of 2.59 with T_7 treatment followed by T_6 (2.39) and T_3 (2.35) (Table 3). There was 33% higher economic benefit under T_7 treatment compared to T_2 with two additional foliar application of zinc sulphate may be due to higher tuber yield.

The Pearson's correlation analysis of growth, quantitative and qualitative parameters revealed significant positive correlation among themselves (Fig. 1). The tuber yield has significant positive correlation with plant height (0.77), number of shoots per plant (0.85), total number of tubers (0.85) and zinc content (0.84). Thus, correlation analysis revealed that zinc application positively affects the plant growth, tuber yield and zinc uptake resulted from better accumulation and translocation of photosynthates under tuber production.

It is concluded from the present study that application of zinc sulphate improves tuber yield and associated quality parameters. The foliar application of zinc sulphate along with soil application was found to be better option for improving yield and biofortification of zinc in potato production for sustainable tuber production.

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