

STRATEGIES FOR AGRONOMIC BIOFORTIFICATION OF POTATO TUBERS WITH ZINC

Jagdev Sharma¹, Prince Kumar², VK Dua^{1*}, Manoj Kumar³, Vineeta Sharma¹ and Dipak Kumar¹

ABSTRACT: Current study explored the possibility of increasing zinc (Zn) content in potato tubers by foliar, seed tuber soaking, and soil application of Zn fertilizers. During first year, a single application of 5 kg Zn ha⁻¹ through zinc sulphate (ZnSO₄) increased the Zn concentration by ~30 % followed by split application of ZnSO₄ (19.6%), and a single application of 1 kg Zn as Zn-EDTA (17.6%) in whole tubers. Single and split soil application of either zinc sulphate (5 kg ha⁻¹) or zinc-EDTA (1.0 kg Zn ha⁻¹), foliar application (ZnSO₄) and soaking of seed tubers in zinc sulphate solution before planting also increased its concentration significantly in tuber peels. During 2nd year of experimentation, a single soil application of zinc sulphate (5 to 10 kg Zn ha⁻¹), Zn-EDTA (1 to 2 kg Zn ha⁻¹) increased the Zn concentration in peeled (tuber flesh) as well as unpeeled whole tuber significantly. Application of 2 kg zinc as Zn-EDTA resulted in highest increase of 4.4 mg kg⁻¹ Zn (25.7%) in tuber flesh which was comparable with 10 kg Zn as ZnSO₄ (24.9%). On application rate basis, compared to ZnSO₄, the 5-times lesser quantity of chelated Zn resulted in equivalent increase in tuber Zn concentration. Since, the bioavailability of Zn from potatoes is high, the soil application of Zn fertilizers during the initial crop growth stage, as revealed by this study, can be adopted as a simple strategy to increase its content in tubers for addressing Zn - related malnutrition issues.

KEYWORDS: Biofortification, potato, tuber, flesh, peel, zinc content, zinc fertilizers

INTRODUCTION

Micronutrient malnutrition is the most widespread nutritional problem worldwide (Stein, 2010). Amongst micronutrients, zinc (Zn) is critical to human immune system and affects the function of more than 300 biological enzymes (McCall *et al.*, 2000). Its deficiency is highly prevalent in developing and developed countries (Gibson, 2012). Zn deficiency affects plant development and nutrition in around one-third of the world's soils, and low Zn concentrations in edible plant portions also have an impact on human Zn nutrition (Cakmak and Kutman, 2018).

Potato tubers may have a high zinc bioavailability, making them a key crop in the fight against Zn deficiency (White *et al.*, 2009). Since there are wide variations in Zn content

of tubers among Indian potato cultivars and germplasm (Sharma *et al.*, 2017, Dalamu *et al.*, 2017), the development of genetically biofortified cultivars that are commercially viable takes a lot of time. Zn-deficiency is highly prevalent in developing countries in general, and the rice dominated north-Indian plains in particular (Heba *et al.*, 2021), where potato is an important *Rabi* season crop. Hence, agronomic biofortification through the use of agricultural techniques e.g., use of fertilizers containing nutrients is promoted as a cost-effective and fast approach to support on-going efforts of biofortification with micronutrients (Cakmak, 2008, 2009; Choudhary *et al.*, 2010, 2022). Most of the previous studies have indicated that Zn biofortification of potato tubers may best be achieved with foliar Zn application (Waters

¹ICAR-Central Potato Research Institute, Shimla - 171 001, Himachal Pradesh, India

²ICAR-Central Potato Research Institute, Regional Station, Jalandhar - 144003, Punjab, India

³ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut - 250110, Uttar Pradesh, India

*Corresponding author; email: vkdua65@yahoo.co.in

and Sankaran, 2011; White *et al.*, 2012) and only few studies have reported that potatoes could be fortified by soil application of zinc fertilizers (Peter *et al.*, 2017). The chemical interactions of Zn with the soil and the method of fertilizer application have an impact on the availability of Zn fertilizers to plants. In addition, the response to applied Zn differs depending on the type of variety (Peter *et al.*, 2017). This study was done to improve the content of chelated zinc in potato tubers using various methods, application times, and sources of zinc fertilisers because there are very few studies on the agronomic biofortification of potato tubers using these fertilizers.

MATERIALS AND METHODS

Two field experiments were conducted at ICAR-CPRS, Jalandhar, Punjab (India) during 2015 to 2017 to increase the tuber zinc content using two zinc sources *viz.*, zinc sulphate and Zn-EDTA in Kufri Pukhraj and Kufri Jyoti. Prior to the experiments soil samples were collected to a depth of 30 cm to determine the available nutrient content in soil. The experimental soil was near neutral in pH

(7.3) low in SOC (0.3 to 0.4%) and rich in DTPA-extractable Zn (0.7 to 0.8 mg kg⁻¹), Fe (6.8 to 8.1 mg kg⁻¹), Mn (7.3-9.4 mg kg⁻¹) and copper (0.8-1.0 mg kg⁻¹). Available-P in soil was determined by Olsen's method which ranged from 18.9 to 19.8 mg kg⁻¹. Available-N in soil was low (205 kg ha⁻¹) and other major nutrients available-P and K were in the medium range in soil. The crop was raised by following recommended package of practices. The experiment in the first year was conducted in a drip-irrigated Kufri Pukhraj variety and the treatments included single and split application (25 DAP/earthing up) of zinc fertilizer, foliar application of each source at 45, 60 and 75 days after planting (DAP) and soaking seed tuber in zinc sulphate solution for 30 minutes before planting as described in Table 1. For foliar application, 1000 litres of spray solution was used on per ha basis. No sticker or additive was used for foliar application of Zn. During second year, the experiment was conducted using two varieties (Kufri Pukhraj and Kufri Jyoti) and the treatments included only soil application of zinc at the time of earthing up (25 DAP) and entire dose of Zn was applied (T₁-

Table 1. Effect of zinc application on tuber and leaf zinc content of Kufri Pukhraj.

Treatment	Zinc concentration in tuber and leaf (mg kg ⁻¹ dry weight basis)				Tuber yield (t ha ⁻¹)
	Whole tuber	Tuber flesh	Tuber peels	Leaf	
T ₁ -Control	16.8	16.6	18.9	40.4	30.2
T ₂ -Foliar application of Zn (3g zinc sulphate L ⁻¹)	18.4	17.9	22.6	77.7	28.2
T ₃ -Foliar application of Zn (1g Zn-EDTA L ⁻¹)	17.9	17.5	21.5	61.6	29.4
T ₄ -Single application of Zn (5kg Zn ha ⁻¹ as ZnSO ₄)	21.9	21.4	28.0	51.8	30.1
T ₅ -Split application of Zn (5kg Zn ha ⁻¹ as ZnSO ₄)	20.1	19.2	26.4	51.4	29.2
T ₆ -Single application of Zn (0.5 kg Zn ha ⁻¹ as Zn-EDTA)	19.3	19.1	21.3	44.9	30.4
T ₇ - Split application of Zn (0.5 kg Zn ha ⁻¹ as Zn-EDTA)	17.4	17.2	19.9	43.6	28.9
T ₈ -Single application of Zn (1kg Zn ha ⁻¹ as Zn-EDTA)	19.7	19.3	23.8	46.1	30.8
T ₉ -Split application of Zn (1kg Zn ha ⁻¹ as Zn-EDTA)	18.7	18.3	22.4	45.9	29.6
T ₁₀ - Soaking of seed tuber (2g ZnSO ₄ L ⁻¹)	18.5	18.0	22.9	52.5	30.1
LSD (<i>p</i> =0.05)	2.5	*NS	3.2	6.3	NS

*NS implies non-significant

Control; T₂- ZnSO₄ (5 kg Zn ha⁻¹), T₃- ZnSO₄ (10 kg Zn ha⁻¹) , T₄- Zn-EDTA (1 kg Zn ha⁻¹) and T₅- Zn-EDTA (2 kg Zn ha⁻¹). Leaf and tuber samples were collected from the four middle rows of each plot to avoid border effects. Tubers were peeled single handily to ensure the uniformity of peeling with a food grade stainless steel peeler. Leaf samples were collected 15 days after last Zn application during the experiment i.e. at 90 DAP in the first year and 40 DAP during the second year. Tuber and leaf samples were washed in pure nitric acid followed by distilled water, peeled and oven-dried at 70°C, ground in stainless steel grinder, digested with nitric and perchloric acid for nutrient analysis and the data were statistically analysed using randomized block design.

RESULTS AND DISCUSSION

The present study showed that fertilizer application practices could enhance Zn content in potato tubers. Only data on zinc concentration is presented here, since the concentration of other nutrients were not affected significantly by any of the zinc treatments in this study. For first year, a single soil application of 5 kg Zn ha⁻¹ as ZnSO₄ increased its concentration by 30% (5.0 mg kg⁻¹ on dry wet basis) followed by split application of ZnSO₄ (19.6%) and single application of 1kg Zn as Zn-EDTA (17.6%) over control in whole tubers (unpeeled tubers) (Table 1). A single soil application 5kg Zn (zinc sulphate) increased its concentration by 9.0 mg kg⁻¹ (dry weight basis) in tuber peels which was 1.5 times higher than control (no external zinc application). Differences between single and split applications of Zn were not significant. Other treatments viz. soil application of 5 kg Zn as ZnSO₄ (split application); 1 kg Zn as Zn-EDTA (single or split application); three foliar applications of zinc (zinc sulphate) and soaking of seed tubers with ZnSO₄ also increased the

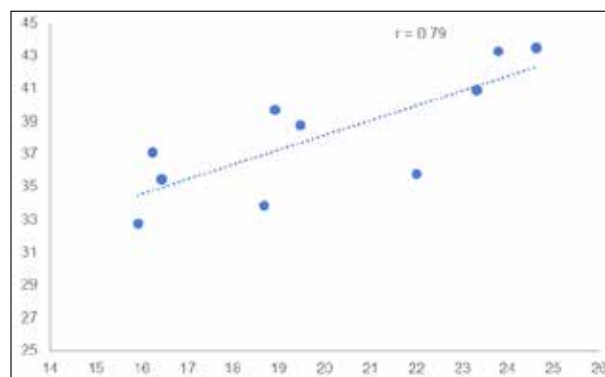
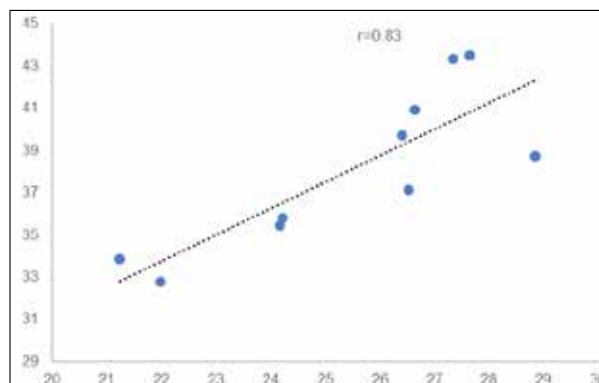
Zn concentration in tuber peels (Table 1). However, the increase was less as compared to single soil application of zinc sulphate. Split application of zinc sulphate also increased the Zn concentration significantly. Single application of 5 kg zinc as zinc sulphate at 25 DAP also increased its concentration by 5.2 mg kg⁻¹ over control treatment (Table 1), the increase, however, was not statistically significant. Foliar applications of zinc, seed tuber soaking, and 5kg Zn ha⁻¹ increased the leaf zinc content significantly (Table 1). According to Peter et al. (2016), foliar and soil applications of Zn fertilizers increased the content of Zn in both the meat and skin of tubers. In our experiments, foliar application of zinc sulphate considerably enhanced the amount of zinc in tuber peels; however, foliar application of zinc in the form of Zn-EDTA only resulted in a non-significant increase, which may be related to the lower rate of Zn-EDTA used in our study. Although every preventative measure was taken to wash the leaves before analysis, it is important to carefully interpret the increased leaf Zn concentration caused by foliar Zn fertilizer application because the concentrations that were reported may have included foliage applied Zn deposited that had not yet passed the plant cuticle.

During the second year, soil application of Zn applied either ZnSO₄ or Zn-EDTA significantly increased its concentration in both peeled and unpeeled tubers in both varieties (Table 2). In tuber flesh highest average increase of 4.4mg kg⁻¹ Zn (25.7%) was with the application of 2 kg zinc as Zn-EDTA which was statistically at par with 10.0 kg Zn applied as ZnSO₄ (24.9%). At lower rate of application, 1kg chelated Zn (Zn-EDTA) increased the zinc content by 14.2% compared to 11.1% increase by 5kg zinc as zinc sulphate. In unpeeled tubers the highest increase of 6.4mg kg⁻¹ Zn (29.9%) was

Table 2. Effect of zinc levels on tuber and leaf zinc content (mg kg⁻¹ dry weight basis) in Kufri Pukhraj and Kufri Jyoti

Treatments	Tuber flesh			Whole tuber			Leaf			Tuber yield (t ha ⁻¹)		
	Kufri Pukhraj	Kufri Jyoti	Mean	Kufri Pukhraj	Kufri Jyoti	Mean	Kufri Pukhraj	Kufri Jyoti	Mean	Kufri Pukhraj	Kufri Jyoti	Mean
Control (no Zn applied)	15.9	18.6	17.3	21.9	21.2	21.6	32.7	33.8	33.3	27.3	22.7	25.0
5 kg Zn ha ⁻¹ (as ZnSO ₄)	16.4	22.0	19.2	24.1	24.2	24.1	35.4	35.8	35.6	28.8	25.2	27.0
10 kg Zn ha ⁻¹ (ZnSO ₄)	19.4	23.7	21.6	28.8	27.3	28.0	38.7	43.3	41.0	29.0	25.2	27.1
1 kg Zn ha ⁻¹ (Zn-EDTA)	16.2	23.3	19.7	26.5	26.6	26.5	37.1	40.9	39.0	28.1	23.4	25.8
2 kg Zn ha ⁻¹ (Zn-EDTA)	18.9	24.6	21.7	26.4	27.6	27.0	39.7	43.5	41.6	29.2	25.4	27.3
Mean	17.3	22.4		25.5	25.4		36.7	39.4		28.5	24.4	
LSD (<i>p</i> =0.05)												
Zn levels		1.3			2.5			1.6			NS	
Variety		0.8		NS (non-significant)				1.0			1.2	
Zn level×variety		1.9						NS			NS	

recorded with the application of 10kg Zn as ZnSO₄ which was statistically at par with 2 kg zinc applied as Zn-EDTA. Zinc sulphate and Zn-EDTA also significantly increased the leaf Zn concentration. A positive correlation (Fig. 1 and 2) was observed between Zn concentration in leaf and Zn concentration in peeled (*r*=0.79) and unpeeled tubers (*r*=0.83). On application rate basis, compared to ZnSO₄ five times lesser amount of Zn (as Zn-EDTA) was needed for equivalent increase in Zn content of potato tubers. Comparable accumulation of Zn in tuber by low rates of Zn-EDTA is attributed to its better mobility into the soil compared to inorganic Zn salt (ZnSO₄) which may be positionally less

**Fig. 1.** Relationship between leaf and tuber flesh Zn content**Fig. 2.** Relationship between leaf and unpeeled tuber Zn content

available to plants (Boawn, 1973; Pooniya *et al.*, 2019). Most of the previous studies have indicated that Zn biofortification of potato tubers may best be achieved with foliar Zn application (Waters and Sankaran, 2011; White and Broadley, 2011; White *et al.*, 2012), however, our study revealed that apart from foliar application, soil application of zinc fertilisers (chelated or inorganic) is also effective as has been reported in few studies conducted elsewhere (Peter *et al.*, 2016).

CONCLUSION

Until Zn rich varieties are developed, soil application of zinc fertilizers during the initial crop growth stage, as revealed by present

study can be adopted as a simple strategy for increasing its content in tubers to fight Zn malnutrition and support ongoing efforts on biofortification.

CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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