



Zinc Fertilization in Potato: A Physiological and Bio-chemical Study

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Authors' contributions

This work was carried out in collaboration between all authors. Authors HB and SS designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors SS, PD, IC, KR and SAS analyzed the plant samples. Authors SS and KR performed the statistical analysis. Author HB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: More than 54% of soils in West Bengal are Zinc (Zn) deficient and therefore, Zn-fertilization is assumed to play a key role not only for increasing potato yield but also for combating wide spread deficiency of micronutrients (mainly Zn) in many potato growing areas of the state.

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Place and Duration of Study: A two-year field experiment was conducted during winter 2013-14 and 2014-15 at to assess the advantages of Zn nutrition in potato cv. Kufri Jyoti under alluvial soil (Entisols) of West Bengal, India

Methodology: The experiment was laid out in randomized block design (RBD) having five treatments and four replications The potato was fertilized with five zinc levels (0, 1.5, 3.0, 4.5 and 6.0 kg Zn ha⁻¹) through zinc sulphate heptahydrate i.e. ZnSO₄·7H₂O (commercial grade Multi-Zn contained 21% Zn) at the time of planting. A uniform dose of NPK at 200:150:150 kg ha⁻¹ RDF was applied in all the plots in the form of urea (46% N), single super phosphate (16% P₂O₅), and muriate of potash (60% K₂O).

Results: Application Zn fertilizer at 4.5 kg ha⁻¹ recorded significantly higher germination %, plant height, leaf area index (LAI), dry matter accumulation (DMA) and number of tubers hill⁻¹. Total number and yield of tuber ha⁻¹ were also changed significantly ($P \leq .05$) with the levels of Zn-fertilization. Quality parameters like total soluble solids (TSS), total acidity, ascorbic acid, starch and amount of total sugar contents of fresh potato tuber as well as organoleptic quality of chips (colour) also influenced significantly ($P \leq .05$) with varied levels of Zn fertilization.

Conclusion: Results suggest that application of 4.5 kg Zn ha⁻¹ in combination with recommended dose fertilizer (RDF) of NPK (i.e. 200:150:150 kg ha⁻¹) is vital for optimizing yield components, yield and quality of potato (cv. Kufri Jyoti) in trans-Gangetic plains of West Bengal, India.

Keywords: Ferti-fortification; potato; tuber quality; zinc; yield.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the important global crops in terms of its use in human food and the starch industry. Potato rates fourth among the world's agricultural products in terms of production volume [1] with high total food value per acre. India is the largest potato producer among South and West Asian (SWA) countries [2], and has shown a spectacular growth in area, production and productivity of potato during last five decades. West Bengal is the second largest potato growing state in country, and together with Uttar Pradesh and Bihar contributing about 78.2% to the national potato production [3].

For the last few years, potato growers in West Bengal face some fundamental setbacks causing over-use of macronutrients (N, P and K) in potato production, resulting in serious depletion of different micronutrients in soil reserve [4]. Most of the potato growing areas in West Bengal show multi-nutrient deficiencies, and these deficiencies adversely affect the crop vigour, ultimately result in poor yield, low quality of tubers and less profit [5]. The other reasons for the occurrence of micronutrient deficiency could be the adoption of intensive cropping with high yielding varieties of crops with the increase in irrigation facilities in modern agricultural system [6]. The gradual shift to use of high analyzed chemical fertilizers instead of organic and conventional plant nutrients like FYM, composts

etc. also another contributing factor to this problem [7].

Hence, micronutrient management needs greater attention in crop production systems to combat with wide spread deficiency of micronutrients (mainly Zn) in many potato growing areas, as 49% soils of India is deficient in available Zn [8]. Zinc is considered as the most important micronutrient for potato, and low recovery of applied Zn is the main limitation in enhancing the yield of potato crop [9]. Zinc is involved in the synthesis of growth promoting hormones and the reproductive process of many plants [10]. Zinc plays an important role as a metal component of enzymes (alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase and RNA polymerase) or as a functional, structural or regulator cofactor of a large number of enzymes [11]. Depending upon the duration of variety, potato crop is highly sensitive to Zn application. Further, Zn has been found to increase ascorbic acid content, but reduces the tyrosine and total phenol content in tubers which are the important criteria for processing Industries [5]. The information pertaining to Zn nutrition in potato is meagre for particular pedo-climatic condition of West Bengal. Authors hypothesized that potato responds well with applied Zn fertilizer and Zn plays an important role for physiology, productivity and post-harvest quality of potato. To test this hypothesis, we estimated plant growth, yield and bio-chemical parameters of potato as affected by varied level of Zn application.

2. MATERIALS AND METHODS

2.1 Study Environment

The field trial reported here was carried out at Distract Seed Farm–C Unit, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India (22°58' N latitude, 88°25' E longitude, 8.5 m above mean sea level) in winter 2013–14 and 2014–15. Weather parameters clearly showed that climatic conditions were quite congenial for growth and development of potato crop during both the year of study, as evident in Fig. 1a and 1b. The soil was sandy clay loam (27.4% sand, 44.4% silt and 28.2% clay according to Hydrometer method) and had the following key

properties for the 0–30 cm layer: pH 7.35 (in 1:2.5:: Soil : Water), EC 0.25 dS m⁻¹ (in 1:2.5:: Soil: Water), organic carbon 0.10% (Wet oxidation method), available N 82.1 kg ha⁻¹ (Hot alkaline KMnO₄ Method), available P 78.3 kg ha⁻¹ (0.5 M NaHCO₃ extract), available K 193.2 kg ha⁻¹ (Neutral N NH₄OAc extract) and available Zn 1.10 kg ha⁻¹ (DTPA extraction).

2.2 Treatments and Experimental Design

The experimental treatments comprised of five zinc levels i.e. 0, 1.5, 3.0, 4.5 and 6.0 kg Zn ha⁻¹ (used Multi-Zn as Zn fertilizer containing with 21% Zn). The experimental design was randomized complete block with four replicates.

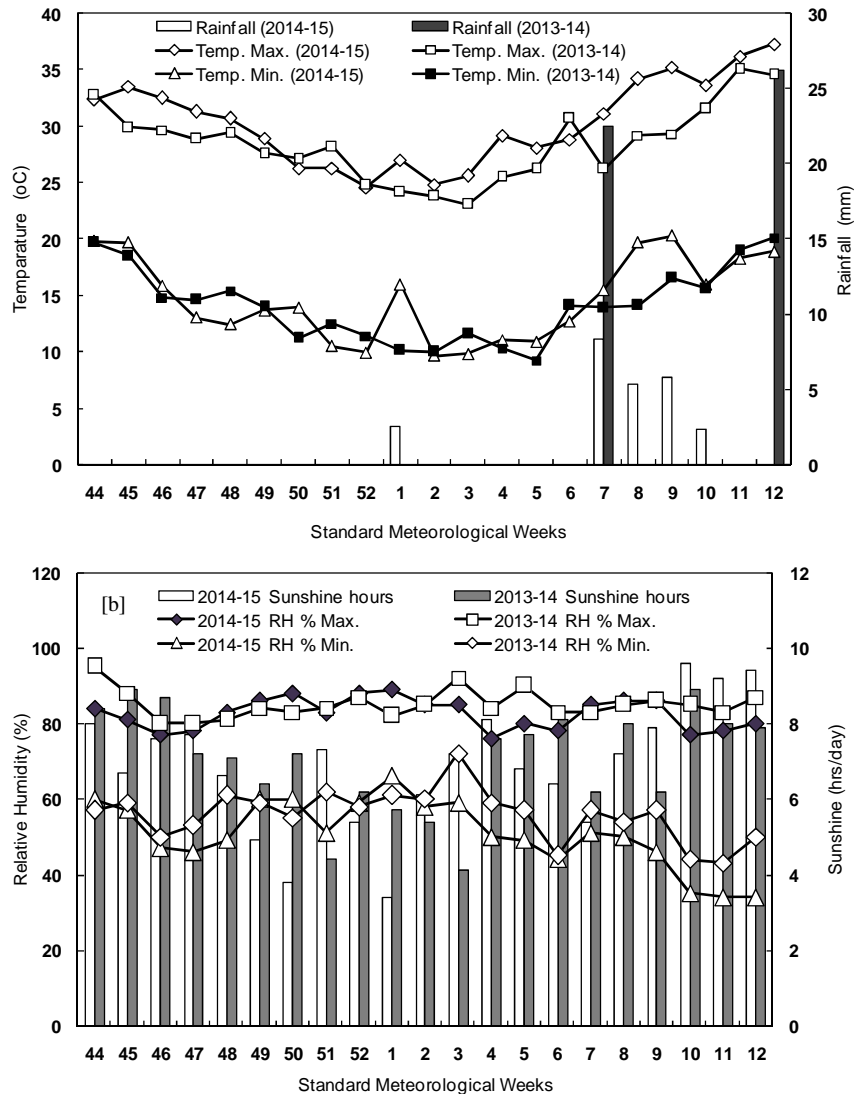


Fig. 1. Meteorological observation on (a) temperature and rainfall, and (b) relative humidity and sunshine hours during experimental period in both years

Individual plot size for each treatment was 3 m × 3 m. Seed tubers [cv. Kufri Jyoti, a medium maturing (90–100 days) high yielding potato variety] weighing about 30–40 g were hand planted on 23 and 25 November of 2013 and 2014, respectively on furrows opened by tyne at a spacing of 60 cm × 20 cm and at a depth of 15 cm, and finally covered with soil. A uniform dose of NPK i.e. 200:150:150 kg ha⁻¹ (RDF) was applied in all the plots through urea [50% before planting and 50% at 30 days after planting (DAP)], single super phosphate (100% before planting), and muriate of potash (100% before planting). Two light irrigations were given at 5 days interval within 12 DAP for good germination and better crop establishment. Then 3 irrigations were given at an interval of 7–8 days. During irrigation the water level was maintained below two-third height of the ridges. Irrigation was completely withheld 12 days before harvest of the crop. The first weed control was through pre-emergence application of Sencor (Metribuzin) @ 0.75 kg a.i. ha⁻¹ at 3 DAP, and the second was done manually with hand-held hoe at 30 DAP in both the years of study. Earthing up was done at 30 DAP and ridges were made by manual labour with the help of spade. No major insect pests and disease were observed during the cropping season. However, as a prophylactic measure moximate (cymoxanil 8% + mancozeb 64% WP) was sprayed (twice) at 2.5 g liter⁻¹ at 40 and 60 DAP to protect the crop against late light disease. In addition, metasystox 25 EC (oxydemeton-methyl) @ 1% was also sprayed (twice) at 45 and 65 DAP for check the incidence of aphids. Haulms were cut by sickle (*dehaulming*) after the crop attained maturity (at least 12–15 days before harvesting). Potato was harvested on 25 and 27 March in 2014 and 2015, respectively.

2.3 Plant Sampling and Observations

In each plot, second rows on either side were marked for destructive sampling and for recording other biometric observations. The middle two rows were marked for the determination of yield. The number of plants germinated was counted at 30 DAP randomly from five rows of each plot and expressed in %. Five plants from each plot were randomly selected and tagged for recording biometrical observations namely plant height; number of haulms hill⁻¹ and number of compound leaves plant⁻¹ at 30, 50, 70 and 90 DAP. Leaf area index (LAI) is the area of leaf surface per unit area of land surface and calculated for each treatment

and plot at 30, 50, 70 and 90 DAP [12]. For recording dry weight, one plant from the penultimate row in each plot were uprooted carefully and then sun-dried. After sun-drying, the plant sample was separated into leaf, stem and tubers and put in electric oven at 70°C for drying to obtain a constant dry weight, and finally expressed in g plant⁻¹. Crop growth rate (CGR) is defined as the increase in dry weight of plant material per unit area of land per unit change of time [13]. Tuber bulking rate (TBR) is defined as the increase in fresh weight of tuber per unit area of land per unit change of time [4]. Tuber yield and tuber number was obtained from two rows of 3 m length in the centre of each treatment plot, avoiding plot borders at harvestable maturity and finally represented in t ha⁻¹.

2.4 Determination of Biochemical Parameters

After lifting of potato tubers, some biochemical estimations were done to judge the quality parameters as influenced by Zn fertilization. The total soluble solids content of fruits were measured with the help of a digital refractometer, by the principle of total refraction. A few drops of muslin cloth strained juice of fresh potato were taken for estimating the total soluble solid which was expressed in °Brix. Ascorbic acid content of the potato was estimated by using 2, 6 *di-chlorophenolindophenol* dye titration method [14]. The total sugar and total starch (dry weight basis) of potato tuber was determined by universal anthrone reagent method as stated by [15]. The concentration of total phenol content from the fresh potato tuber was estimated spectrophotometrically with the help of Folin-Ciocalteu reagent [16]. Specific weight of potato was determined by hydrometer method using a sample of 3.63 kg of processing grade tubers from each plot [17]. Ten processing grade tubers were selected randomly from each plot and used for preparation of potato chips at laboratory scale, which involved peeling of the tubers in abrasive peeler, making 1.75 mm thick slices with an automatic slicer, washed and surface dried. Slices were fried in refined sunflower oil in a thermostatically controlled deep fat fryer at 180° F till bubbling stopped. Fried chips were then evaluated for a particular processing quality attribute i.e. chip colour. For evaluation of chip colour on a 1–10 sensory scale, subjectively with the help of colour cards [18], where 1 denotes a highly acceptable colour, 10 denote a dark brown and unacceptable colour. Chips with colour range of up to 3.0 were considered acceptable.

2.5 Statistical Analysis

All data were analyzed using the analysis of variance (ANOVA) procedure to test the effects of the treatments on the measured parameters, and subjected to Duncan's multiple range tests. The ANOVA of different parameters across the years revealed a non-significant variation between the years at $p \leq 0.05$. Thus, pooled data of two years have been presented. Significance ($P \leq 0.05$) was tested using the Window-based SPSS software version 18.0 (SPSS, Inc., Chicago, IL, USA). The Excel software (version 2007, Microsoft Inc., WA, USA) was used to draw graphs and figures.

3. RESULTS AND DISCUSSION

3.1 Growth Traits

Plant emergence was recorded at 30 DAP in all the plots separately, and ranged between 97.5 to 100% (Table 1). Maximum plant stand was recorded in plots fertilized with 3.0 and 4.5 kg Zn ha⁻¹, respectively. Data also revealed that varied Zn levels did not leave significant effect on germination of tubers, indicating this parameter (germination %) did not interfere in the evaluation of crop growth and variety-specific response to Zn fertilization. Plant height was increased as the age of the crop progresses up to 70 DAP; thereafter height was slightly declined towards maturity (Table 1). The leaf area index (LAI) was increased with the increase of aerial growth of the plant up to 50 DAP, and then declined towards maturity, irrespective of Zn levels. Zinc fertilization effect was detected significant ($P \leq 0.05$) on plant height and LAI at 30 DAP only, however the effect was non-significant for other observation dates. Total dry weight increased with the increase in crop age. Moreover, varied Zn levels exerted significant effect ($P \leq 0.05$) on total dry matter production as evident from the data at different dates (Table 1). At 30 DAP, plants with RDF + 4.5 kg Zn ha⁻¹ recorded higher dry matter (DM) and it was statistically at par with 0 and 3.0 kg Zn ha⁻¹ in combination with RDF. Afterwards, plants with RDF + 4.5 kg Zn ha⁻¹ produced significantly higher DM at 70 and 90 DAP, but only at 90 DAP it was statistically at par with all Zn levels except control (without Zn). It was found that application of RDF + 4.5 kg Zn ha⁻¹ yielded higher DM accounting 10.5, 18.9, 17.6 and 46.4% more than potato crop in control plots at 30, 50, 70 and 90 DAP, respectively.

Data in Table 2 revealed that Zn fertilization to potato crop did not exert significant influence on the production of haulms hill⁻¹ throughout the growth period. Numbers of haulm hill⁻¹ more or less constant up to 70 DAP but decreased towards the end of maturity. There was no significant variations in leaf production plant⁻¹ up to 70 DAP while the variation was significant ($P \leq 0.05$) at maturity stage (90 DAP). Plants fertilized with RDF + 4.5 kg Zn ha⁻¹ had significantly higher number of leaf at 90 DAP accounting 48.5% more than control (-Zn). Rate of growth for potato cultivar 'Kufri Jyoti' reached at peak level during the early growth stage (30-50 DAP), beyond that it showed a declining trend towards maturity (Table 2). Difference in CGR among plants with different Zn levels was not significant ($P \leq 0.05$), although higher rate of growth was recorded with RDF + 6.0 kg Zn ha⁻¹ all throughout the growth period. Zinc fertilization effect was detected non-significant ($P \leq 0.05$) for tuber bulking rate (TBR) of potato at different dates of observation (Table 2). TBR was more between 50-70 DAP and reduced towards maturity (70-90 DAP), irrespective of Zn levels. Application of RDF + 4.5 kg Zn ha⁻¹ resulted higher TBR (42.5 and 51.4% more than control at 50-70 and 70-90 DAP, respectively), but failed to show any significant improvement than rest of the treatments.

Growth of potato plant is highly responsive to micronutrient application, especially Zinc. Foliar feeding Zn helped to improve plant height of potato [19]. However in our study, we did not find any significant effect of Zn fertilization in plant height (except for 30 DAP), number of compound leaves plant⁻¹ as well as number of haulms plant⁻¹. This result is similar to Bari et al. [20] and Islam et al. [21] where they demonstrated non-significant effect of Zn fertilization on plant growth. In the present study, Zn fertilization increased LAI of potato during early stage of growth only (30 DAP) which might be due to higher vegetative growth as influenced by Zn fertilization with a great influence on basic plant life process such as nitrogen metabolism and higher rate photosynthetic activity [22]. The increase of LAI by Zn fertilization in potato and thereby increase in amount of dry matter accumulation and economic yield [23]. In the present study, application of Zn fertilization (4.5 kg Zn ha⁻¹) recorded higher total dry weight of plant. It must be stressed that an increase in the weight of above ground biomass was not accompanied by changes in the number of haulms plant⁻¹. This is indicative of the

considerable increase in cytokinin as well as chlorophyll content in the leaves and finally an enhancement of photosynthetic activity of the plant [24]. Researchers also detected higher dry matter content in potato plant with chelated Zn fertilization [25]. Further, Zn fertilization also increases the tuber dry matter percent by increasing the size of tuber and higher accumulation of starch. Singh et al. [9] found that omission of Zn significantly reduces dry matter (12.2%) of potato.

3.2 Yield Components and Yield

Zinc fertilization had significant ($P \leq .05$) positive impact on tuber number as well as yield of potato (Table 3); this holds true for processing grade as well as total tubers. Application of RDF + 4.5 kg Zn ha⁻¹ produced maximum number of total tuber (4.05×10^5 ha⁻¹) as well as processing grade tuber (2.55×10^5 ha⁻¹) which was significantly ($P = .05$) higher than other Zn levels tested. In harmony to tuber number, the same treatment resulted maximum processing grade tuber (23.95 t ha⁻¹) as well as total tuber yield (28.77 t ha⁻¹) accounting 10.9 and 14.6% higher than control (without Zn).

The tuber yield was linearly and positively correlated with plant height ($R^2 = 0.43$), compound leaves plant⁻¹ ($R^2 = 0.93$), LAI ($R^2 = 0.56$), total dry weight plant⁻¹ ($R^2 = 0.72$) and TBR ($R^2 = 0.59$). The rates of increase in tuber yield per unit increase in plant height, number of compound leaves plant⁻¹, LAI, total dry weight plant⁻¹ and TBR were 12.34, 0.74, 17.66, 13.16 and 18.94 t ha⁻¹, respectively.

Several researchers observed positive influences of Zn fertilization in increasing yield and qualitative parameters of potato crop [25,26]. Application of Zn in potato resulted increase in number of tuber, average tuber weight, yield as well as qualitative and post-harvest indices [19]. Here, the weight of potato tubers per plant mainly increased due to increase in their number. Zinc fertilization might have brought about an increase in the cytokinin content accompanied by increased rate of photosynthesis and respiration, which in turn abolish the apical dominance resulting in to more number of tubers plant⁻¹ [24]. Zinc application significantly increased the tuber yield of potato which might be attributed to the beneficial effect on tuberization [5] and Zn content in tubers [27,28]. The beneficial effect of Zn on growth of plants, greater synthesis of food

material and their translocation to developing tuber, thereby increasing the size of tuber was also reported [19].

3.3 Profitability

Economic analysis was carried out to compare the profitability of producing potato with Zn fertilizer at different levels, wherein the benefit: cost ratio (BCR) of the different treatments was used to assess the economic returns on investments (Table 3). Fertilization with Zn exerted positive effect on net return and benefit: cost ratio (BCR) in potato cultivation. The results documented that all the levels of Zn fertilizer resulted in a benefit-cost ratio of above 1 [benefit-cost ratios of 1 implied a breakeven point], meaning its benefits exceed its cost. Net income and BCR continued to increase till 4.5 kg Zn ha⁻¹ and further addition of Zn (6.0 kg Zn ha⁻¹) resulted in decrease on net return and BCR, indicating low returns on investment and should not be recommended for field application. The use of RDF + 4.5 kg Zn ha⁻¹ gave higher economic returns and BCR (35.6 and 11.5% more than control treatment) because of increased total tuber yield realized at this application rate.

3.4 Zn Concentration in Potato Tuber

Zinc fertilization significantly ($P \leq .05$) increased Zn concentration in potato tuber over control (without Zn). The highest Zn concentration in tuber of potato was recorded (18.46 mg kg⁻¹ of dry weight) with RDF + 6.0 kg Zn ha⁻¹ accounting 28.3% more than control (Fig. 2). Our results, along with those of [29] indicate that potato is one of the highest Zn accumulators compared to cereal crops. White et al. [30] reported that Zn concentration in potato tuber may be as high as 30 mg kg⁻¹ of dry weight though Zn uptake by potato also a genetically controlled trait which may differ cultivar to cultivar. Researchers reported from Iran that foliar application of Zn at 2, 4 and 8 ppt can increase Zn concentration in potato tuber up to 8, 22 and 23%, respectively as compared to control [26]. Zinc plays structural and regulatory roles in large numbers of enzymes and protein synthesis, which directly affects the nutrients absorption from the soil [31]. According to Himanshu et al. [32], the increase in yield might be due to the role of Zn in bio-synthesis of indole acetic acid (IAA), initiation of primordial for reproductive parts and partitioning of photosynthates towards them, which resulted in better.

Table 1. Effect of zinc fertilization on germination, plant height, leaf area index (LAI) and total dry weight of potato (cv. Kufri Jyoti)

Fertilizer treatments	Days after planting															
	Germination %				Plant height (cm)				Leaf area index (LAI)				Total dry weight (g hill ⁻¹)			
	30	30	50	70	90	30	50	70	90	30	50	70	90			
RDF + Zn ₀	97.5 ^a	28.00 ^{ab}	46.25 ^a	50.75 ^a	55.25 ^a	0.78 ^{ab}	3.81 ^a	3.79 ^a	2.71 ^a	12.28 ^{ab}	41.27 ^b	78.35 ^b	86.70 ^b			
RDF + Zn _{1.5}	98.3 ^a	31.25 ^{ab}	50.50 ^a	54.25 ^a	58.50 ^a	0.89 ^{ab}	3.72 ^a	3.64 ^a	2.82 ^a	10.77 ^{ab}	43.78 ^{ab}	89.32 ^b	104.51 ^a			
RDF + Zn _{3.0}	100.0 ^a	33.50 ^a	51.75 ^a	52.50 ^a	56.25 ^a	0.98 ^{ab}	4.05 ^a	3.71 ^a	2.74 ^a	13.41 ^a	43.05 ^{ab}	98.45 ^{ab}	103.39 ^a			
RDF + Zn _{4.5}	100.0 ^a	30.25 ^{ab}	49.25 ^a	53.25 ^a	59.50 ^a	1.13 ^a	4.84 ^a	4.07 ^a	2.98 ^a	13.57 ^a	49.10 ^a	105.07 ^a	114.73 ^a			
RDF + Zn _{6.0}	97.5 ^a	26.00 ^b	50.75 ^a	53.25 ^a	53.75 ^a	0.69 ^b	4.16 ^a	3.73 ^a	2.48 ^a	9.34 ^b	44.45 ^{ab}	105.34 ^a	111.37 ^a			
LSD _{0.05}	NS	4.50	NS	NS	NS	0.32	NS	NS	NS	2.78	6.30	14.06	19.23			

Values are pooled data of 2013–14 and 2014–15

Within columns means followed by the same superscripts are not significantly different at $P \leq .05$

NS Non-significant

Table 2. Effect of zinc fertilization on number of haulms hill⁻¹, number of compound leaves plant⁻¹, crop growth rate (CGR) and tuber bulking rate (TBR) of potato (cv. Kufri Jyoti)

Fertilizer treatments	Days after planting												
	Number of haulms hill ⁻¹				Number of compound leaves plant ⁻¹				Crop growth rate (g m ⁻² day ⁻¹)			Tuber bulking rate (g m ⁻² day ⁻¹)	
	30	50	70	90	30	50	70	90	30–50	50–70	70–90	50–70	70–90
RDF + Zn ₀	4.00 ^a	3.25 ^a	3.75 ^a	2.50 ^a	33.25 ^a	49.00 ^a	49.75 ^a	25.75 ^{ab}	9.33 ^a	1.66 ^a	-2.87 ^a	81.15 ^a	34.15 ^a
RDF + Zn _{1.5}	4.75 ^a	3.00 ^a	4.25 ^a	3.00 ^a	34.00 ^a	51.25 ^a	47.50 ^a	16.00 ^b	10.87 ^a	-1.17 ^a	-0.64 ^a	90.99 ^a	2.79 ^a
RDF + Zn _{3.0}	3.25 ^a	3.00 ^a	3.75 ^a	3.50 ^a	31.25 ^a	54.00 ^a	47.25 ^a	22.75 ^{ab}	9.08 ^a	0.35 ^a	-2.58 ^a	89.26 ^a	36.34 ^a
RDF + Zn _{4.5}	4.25 ^a	3.25 ^a	4.00 ^a	2.00 ^a	35.75 ^a	55.75 ^a	55.25 ^a	38.25 ^a	9.14 ^a	0.47 ^a	-2.00 ^a	115.61 ^a	51.70 ^a
RDF + Zn _{6.0}	3.25 ^a	3.25 ^a	4.00 ^a	2.50 ^a	29.25 ^a	54.25 ^a	47.25 ^a	23.25 ^{ab}	9.99 ^a	2.72 ^a	-3.15 ^a	90.11 ^a	27.66 ^a
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	12.76	NS	NS	NS	NS	NS

Values are pooled data of 2013–14 and 2014–15

Within columns means followed by the same superscripts are not significantly different at $P \leq .05$

DAP Days after planting, NS Non-significant

Table 3. Effect of zinc fertilization on tuber number, yield, processing quality of tuber and economics of potato (cv. Kufri Jyoti)

Fertilizer treatments	Tuber number ($\times 10^5 \text{ ha}^{-1}$)		Tuber yield (t ha^{-1})		Specific gravity (g cm^{-3})	Tuber dry matter (%)	Chip colour score	Total sugar ($\text{mg } 100 \text{ g}^{-1}$ of dry weight)	Net return (₹ ha^{-1})	B:C ratio (BCR)
	Processing grade	Total	Processing grade	Total						
RDF + Zn ₀	1.64 ^c	2.71 ^b	21.6 ^b	25.10 ^c	1.069 ^c	19.85 ^b	7.56 ^a	0.82 ^a	53986	1.56
RDF + Zn _{1.5}	1.85 ^{bc}	3.02 ^b	22.49 ^b	26.21 ^b	1.074 ^{bc}	19.84 ^b	6.11 ^b	0.84 ^a	59718	1.61
RDF + Zn _{3.0}	1.9b ^c	3.16 ^b	22.68 ^b	28.15 ^{ab}	1.077 ^b	20.19 ^b	3.75 ^c	0.83 ^a	70434	1.72
RDF + Zn _{4.5}	2.55 ^a	4.05 ^a	23.95 ^a	28.77 ^a	1.088 ^a	21.88 ^a	2.45 ^d	0.88 ^a	73221	1.74
RDF + Zn _{6.0}	2.05 ^{ab}	3.06 ^b	23.71 ^a	27.21 ^b	1.071 ^{bc}	20.32 ^{ab}	4.08 ^c	0.89 ^a	62934	1.63
LSD _{0.05}	0.29	0.74	0.84	1.48	0.01	0.67	0.72	NS	-	-

Values are pooled data of 2013–14 and 2014–15

Within columns means followed by the same superscripts are not significantly different at $P \leq .05$

NS Non-significant

NB Net return ha^{-1} was calculated as the difference between the gross income and total variable costs; The benefit: cost ratio (BCR) was calculated by dividing the gross income by the total variable costs, wherein price of 1 kg Multi-Zn (Zn fertilizer) is ₹ 130 and sale price of potato (₹ 6000 t^{-1})

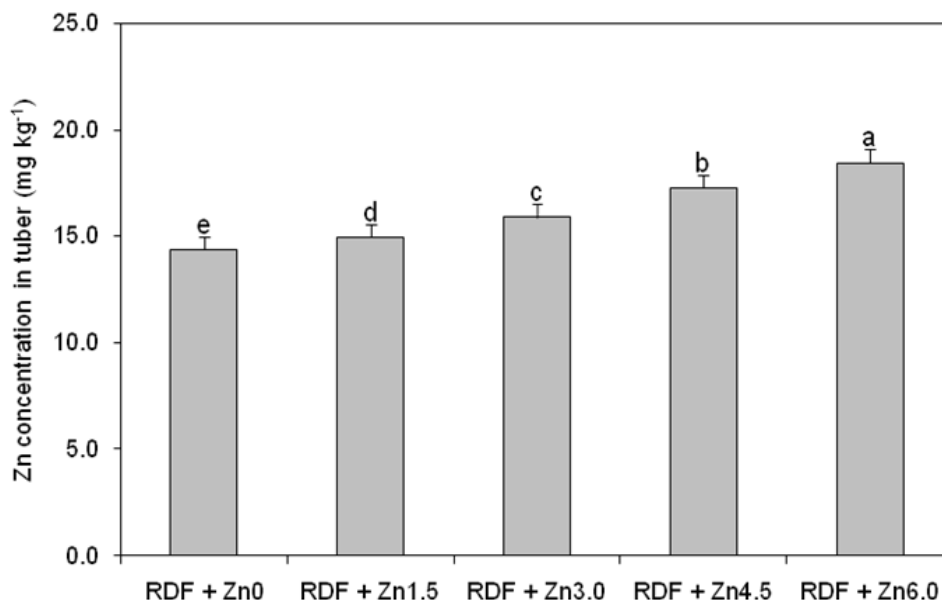


Fig. 2. Zn concentration (mg kg⁻¹) in potato tuber (Kufri Jyoti) as influenced by varied level of Zn fertilization

Vertical columns followed by a different letter are significantly different at $P \leq .05$ (Otherwise statistically at par)

3.5 Quality Parameters of Potato Tubers

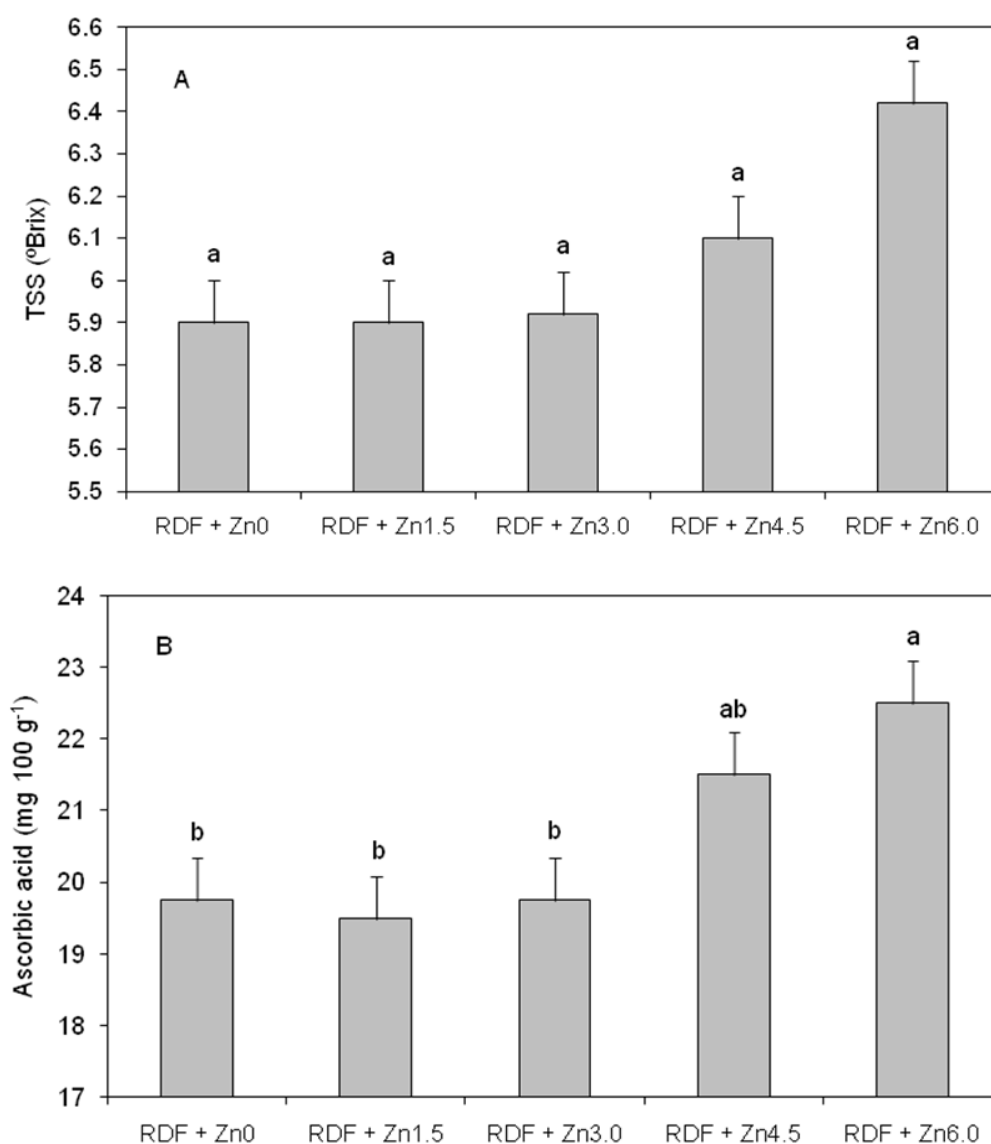
Zinc fertilization exerted positive but insignificant influence on total soluble solid (TSS) in tubers (Fig. 3a). Nevertheless, the TSS was more in tubers harvested from plants treated with RDF + 6.0 kg Zn ha⁻¹, and it was statistically at par with other treatments. Ascorbic acid content in potato tubers was significantly ($P \leq .05$) influenced by Zn fertilization (Fig. 3b). The vitamin C was more (22.5 mg 100 g⁻¹ of dry weight) in potato tubers harvested from plants treated with RDF + 6.0 kg Zn ha⁻¹ (13.9% more than control), and it was statistically at par with vitamin C content in potato tubers those harvested from plants treated with RDF + 4.5 kg Zn ha⁻¹ (19.75 mg 100 g⁻¹ of dry weight). There was significant reduction in the vitamin C content due to reduction of Zn levels, and it was poor with control treatment (without Zn). This result is supporting Mondy et al. [33] who concluded that Zn fertilization have positive impact on ascorbic acid content in potato tuber. In our study, Zn fertilization significantly ($p \leq 0.05$) increased total starch content in potato tubers over no Zn application as evident in Fig. 3c. Potatoes harvested from the plants fertilized with RDF + 6.0 kg Zn ha⁻¹ recorded significantly ($P \leq .05$) higher starch content (58.05 mg 100 g⁻¹ of dry weight) than

those harvested from plants treated with other Zn treatments, accounting 2.4% more than control. Dwivedi and Dwivedi [34] also reported that 10 kg ZnSO₄ was adequate to increase the potato tuber yield and starch content. Zinc fertilization was effective in reducing the total phenol content in tubers as evident in Fig. 3d. The lowest total phenol content (18.95 mg 100 g⁻¹ fresh weight) was recorded in potatoes harvested from the plants fertilized with RDF + 4.5 kg Zn ha⁻¹, and it was statistically at par with total phenol content in potato tubers those harvested from plants treated with RDF + 3.0 kg Zn ha⁻¹ (20.15 mg 100 g⁻¹ of dry weight) and RDF + 6.0 kg Zn ha⁻¹ (19.85 mg 100 g⁻¹ of dry weight). This result supports previous research finding of Mondy and Chandra [35] who also found significant reduction of total phenol content in potato with Zn fertilization.

The specific gravity was significantly ($P \leq .05$) affected with Zn fertilization (Table 3). The specific gravity was more in potato tubers harvested from plants treated with RDF + 4.5 kg Zn ha⁻¹. There was reduction in the specific gravity due to reduction of Zn level, and it was poor with RDF of NPK only (without Zn). Foliar application of ZnSO₄ at the rate of 8 ppm in potato also recorded 1.9% increment in

tuber dry matter content [26]. Zinc fertilization exerted positive and significant ($P \leq .05$) influence on the production of total dry matter in tubers. In addition, RDF + 4.5 kg Zn ha⁻¹ produced tubers with highest total dry matter content accounting 10.2% more than control (-Zn). As evident from Table 3, Zn fertilization significantly ($P \leq .05$) improved the potato chip colour, and potatoes harvested from plants fertilized with RDF of NPK + 6.0 kg Zn ha⁻¹ recorded 67.6% lighter chip colour than those harvested from plants fertilizer with RDF of NPK only (Zn omission). This may be due to less

production of phenol substances in tuber influenced by Zn⁺⁺ ion thus less chances of enzymatic discoloration of potato chips during frying. Reduction of Zn level up to 1.5 kg Zn ha⁻¹ resulted significant increase in chip colour of potatoes. Kumar et al. [19] also find similar results with 'Kufri Chipsona-1' cultivar where three times foliar sprays with ZnSO₄ (0.2%) significantly improved chip colour over control. In the present study, total sugar content in potato tubers was more or less constant and recorded no significant changes with varied levels of Zn fertilization.



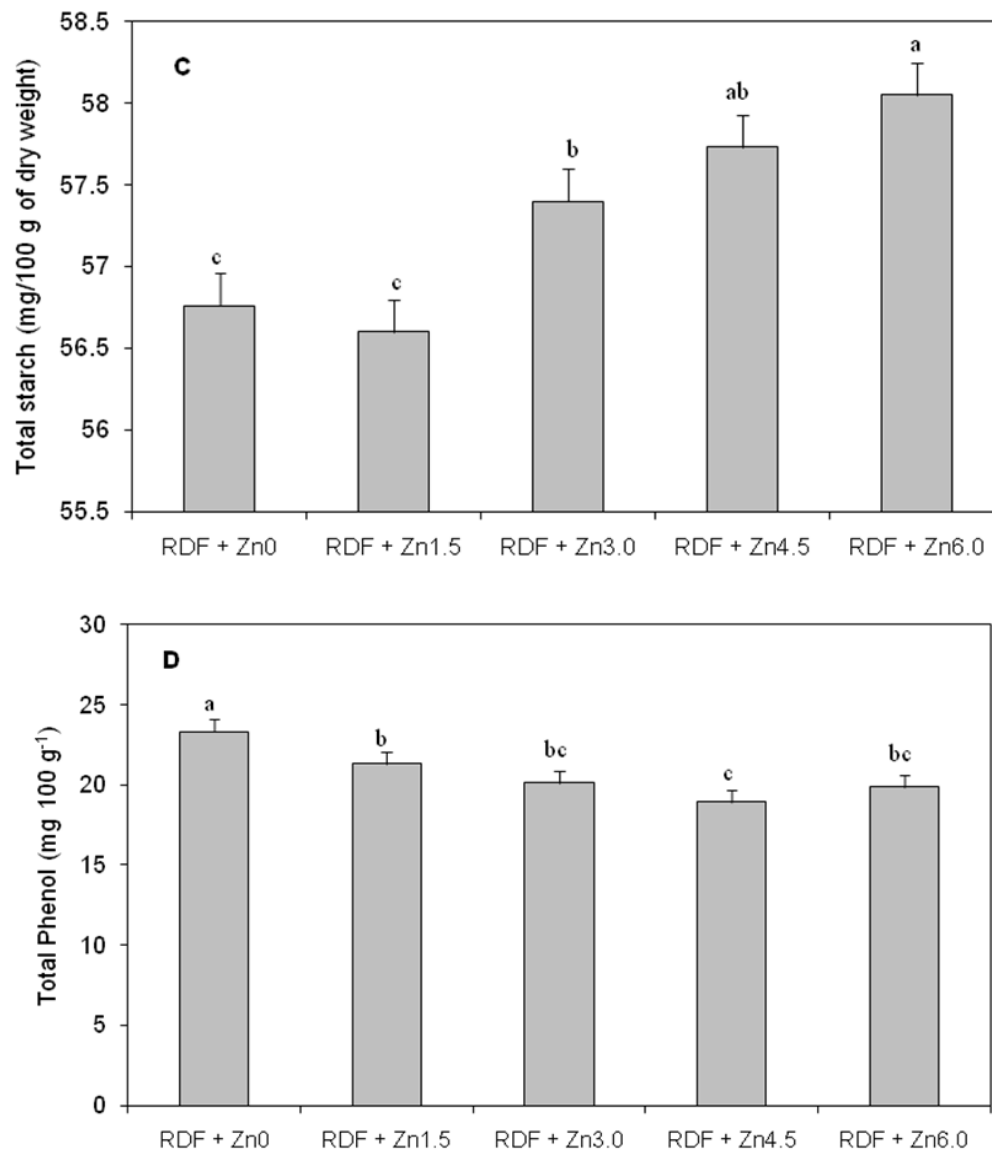


Fig. 3. (A-D). Different quality parameters (A) TSS, (B) Ascorbic acid, (C) Total starch and (D) Total Phenol content of potato tuber (cv. Kufri Jyoti) as influenced by varied level of Zn fertilization

Vertical columns followed by a different letter are significantly different at $p \leq 0.05$ (otherwise statistically at par)

4. CONCLUSION

Results of the present study revealed that Zn bio-fortification in potato production influenced not only the biomass yield of the crop, but also its tuber quality, the quality of processed product, and the overall economics of its cultivation. Soil application of 4.5 kg Zn ha⁻¹ in combination with RDF of NPK (200:150:150 kg ha⁻¹) was found to be productive and economically sound

practice in trans-Gangetic plains of West Bengal, India.

CONSENT

All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images. A copy of the written consent is available for review by the

Editorial office/Chief Editor/Editorial Board members of this journal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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