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Agronomic fortification of zinc in potato production in Indian context: A review

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Abstract
Micronutrient has received greater attention in crop production because the widespread deficiency of micronutrient is coming forward gradually. The key reasons for such deficiency are an intensification of cropping system, adoption of high yielding cultivars of crops and modern irrigation facilities. The greater use of high analysis chemical fertilizers instead of organic sources of plant nutrients (farmyard manure, composts etc.) is also another contributing factor to this problem. This modern technology of crop production causes a serious depletion of different micronutrients reserve in soil resulting in their severe deficiency in many countries. Potato is the widely cultivated vegetable crops throughout India. In potato cultivation, the application of some micro-nutrients (zinc/Zn, boron/B etc.) causes significant increase in foliage at the initial stage of crop growth, while the translocation of assimilates become higher in later stages, ultimately leads to higher yield. Zinc plays a very important role in increasing the production as well as the quality of potato tubers. Zinc loading in potato through foliar as well as soil-applied Zn increases Zn concentration in potato tuber up to 3-4 times which is quite higher than most of the commonly known crops. Zn fertilization has been found to increase ascorbic acid content, but it reduces the tyrosine and total phenol content in tubers, and thereby improves the processing quality. Finally, Zn-fortified potato can be a potential option for mitigating wide spread Zn-driven malnutrition in the Asian countries.

Keywords: Ferti-fortification, *Solanum tuberosum,* Tuber quality, Yield, Zinc

INTRODUCTION

Potato (*Solanum tuberosum* L.) ranks just behind the cereals rice and wheat, achieved 3rd position among the food crops worldwide (Birch *et al.,* 2012). Potato is a staple food for more than a billion people worldwide, and considered as a critical crop in terms of food security to combat population growth and increased hunger rates. Potato is one of the most important crops throughout India (Fig. 1). India now ranks 2nd in potato production (45.34 m t) after China (Fig. 2), but the productivity of the crop in India (22.9 t ha^{-1}) is quite low compared to other leading potato growing countries in the world (FAOSTAT, 2015). Potato crop demands greater attention because of its exceptionally high productivity coupled with high food value. As compared to major cereal crops, potato produces more dry matter and protein per unit area (Singh *et al.,* 2010), besides an important source of starch (Birch *et al.,* 2012). Further, potatoes are a good source of carbohydrates (75% of total dry matter), protein, vitamins, dietary fibre and some minerals (Struik *et al.,* 2007).

Recently, a greater attention has been paid to micronutrient use in crop production system to overcome wide-spread deficiency. Several investigators from all over India have already reported significant response of many crops to micronutrient application. The key reasons for such deficiency are intensification of cropping system, adoption of high yielding cultivars of crops and modern irrigation facilities. The greater use of high analysis chemical fertilizers instead of organic sources of plant nutrients (farm yard manure, composts etc.) is also another contributing factor to this problem (Murmu *et al.,* 2014). This modern technology of crop production causes a serious depletion of different micronutrients reserve in soil resulting in their severe deficiency in many areas of the country. Reports are there that potato plants require micronutrient to produce optimum yield (Murmu *et al.,* 2014). In potato cultivation some minor plant nutrients like Zn, B can help in increasing the foliage at initial stage of growth and in the later stages, the translocation of assimilates is responsible for higher yield (Trehan and Grewal, 1981; Mondal *et al.,* 1993).

Low recovery of applied Zn is the main constraint in augmenting the yield of potato (Singh *et al.,* 2014), which signifies the importance of Zn in potato cultivation. Depending upon the duration of variety, potato crop is highly sensitive to Zn application. Zn fertilization has been found to increase ascorbic acid content, but it reduces the tyrosine and total phenol content in tubers and thereby improves the processing quality (Mondal *et al.,* 2015). Besides yield increase, micronutrients are also influencing the quality of potato by increasing protein content and some antioxidants. Antioxidant, scavengers of free radicals of our body due to oxidative stress, are known to be associated with ageing, heart disease mortality, incidence of cancer (mouth, pharynx and colon) and other degenerative diseases. Therefore, the key objective of this paper is to focus on the advantages of adopting zinc fertilization for the agronomic fortification of potato crop. In this paper, we compiled the specific role of zinc in plant growth *vis-a-vis* soil health improvement status by enhanced use of zinc-fertilizer and finally the implications for redesigning Zn fertilization practice in potato cultivation in terms of dose, time and method.

Zn deficient soils in India: Zinc deficiency is extensively reported on major soil types in India. The common basis for determination of Zn deficiency is soil and plant testing. In India, Nene (1966) while growing rice on an alkali soil first recognised zinc deficiency. The distribution of Zn deficient soils was further reviewed by Takkar (1991) by analysing more than 113,000 soil samples for available Zn (mostly DTPA extractable) and about 20,000 plant analyses from 15 states and territories in India, and he concluded that 44-46% soils are Zn-deficient. The deficiency ranged between 60-70% in the states of Haryana, Madhya Pradesh and Uttar Pradesh; 50-59% in Andhra Pradesh and Punjab; 30-49% in Kerala, Bihar and Tamil Nadu; 20-29% in Delhi, Gujrat, Karnataka and Rajasthan, and less than 20% in Jammu and Kashmir and Pondicherry. He found the greater incidence of Zn deficiency in calcareous, coarse textured soils; in high water table as well as flood plain soils; and in saline and sodic or low organic matter soils. In India, presently about 1.6 million ha is receiving 5 kg Zn ha^{-1} yr^{-1}. With current removal pattern the Zn-deficiency is likely to increase from the present level of 50 to 63% in 2025 in India (Singh *et al.,* 2010). A widespread Zn-deficiency in Gangetic alluvium plains of West Bengal has been identified by analyzing 6,547 soil samples from which 36% samples receded very high deficit in available Zn (Singh, 2007).

Role of Zn in potato plants: Raulin in 1869 first identified the biological role of Zn, who observed that common bread mould (*Aspergillus niger*) did not grow due to lack of Zn. Consequently, Zn was identified as a ubiquitous component of both animal and plant tissue. This observation stimulated Zn research in crops and leads to the establishment of the essentiality of Zn in plant nutrition. Presently, zinc deficiency is accepted as one of the most common micronutrient deficiencies and has been increasing significantly in the crop production system. During the early part of 20th century, the agricultural significance of Zn was recognized, but till late 1960's the specific role for Zn in plants was not identified. Since then a series of Zn -containing enzymes have been identified and significant progress has been made in determining the chemical form and physiological effects of Zn deficiency in plants. Though the precise mode of action of Zn in enzymes is still not fully understood, the involvement of Zn in the activity of various enzymes would indicate that it has profound effects on normal plant metabolism. Generally, Zn deficiency severely causes an interruption in the metabolism of carbohydrates, proteins, auxin, and reproductive process.

Different role of Zn in various processes in potato plants has been discussed below.

Carbohydrate metabolism: The specific effect of Zn nutrition on photosynthesis and sugar transformations confirms the involvement of Zn in carbohydrate metabolism. Generally, Zn status does not affect respiration in plants.

Photosynthesis: Depending on plant species and extent of deficiency, Zn deficiency causes 50-70% reduction in net photosynthesis. Several mechanisms can contribute to this reduction as carbonic anhydrase (CA) activity, ribulose 1,5-bisphosphate carboxylase (RuBPC) activity, stabilizing carbamate formation, maintaining chlorophyll content and chloroplast structure of leaf.

Sucrose and starch formation: Zn deficiency greatly depresses the activity of aldolase in plant tissue, which then impairs the conversion of fructose 1-6-diphosphate to its subsequent compounds. Zn may play a role in the metabolism of starch.

Protein metabolism: General, Zn-deficient plant exhibited dramatic reduction in the amount of protein content, while the composition remains almost unchanged. Cakmak *et al.* (1989) reported that the concentration of free amino acids in Zn-deficient bean leaves, measured by HPLC is increased by a factor of 6.5, decreased to 5.1, 2.7, and 1.4 after a resupply of Zn to deficient plants

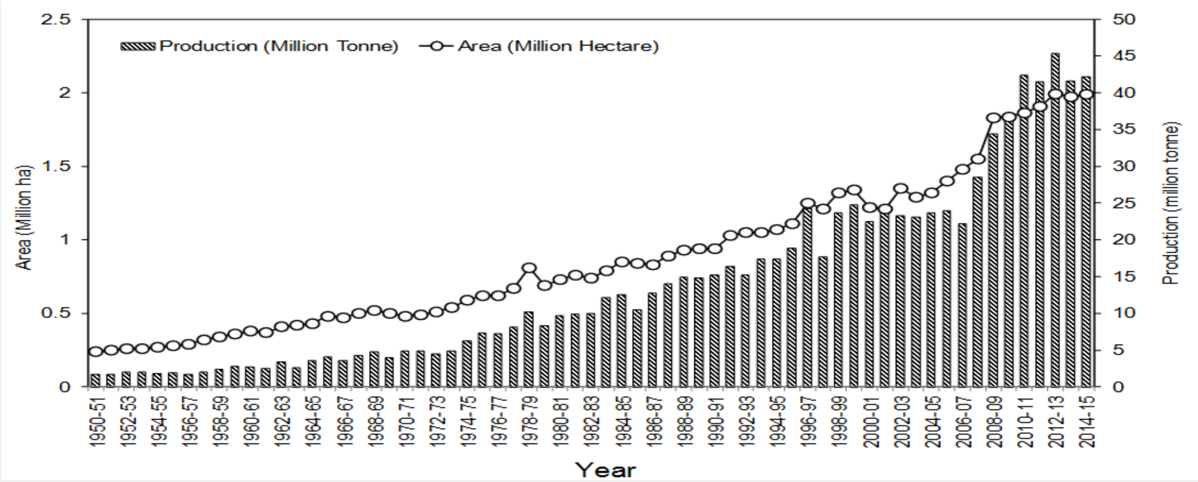

Fig. 1. *Trend in production and area of potato in India during last 50 years (Source: INDIASTAT, 2015).*

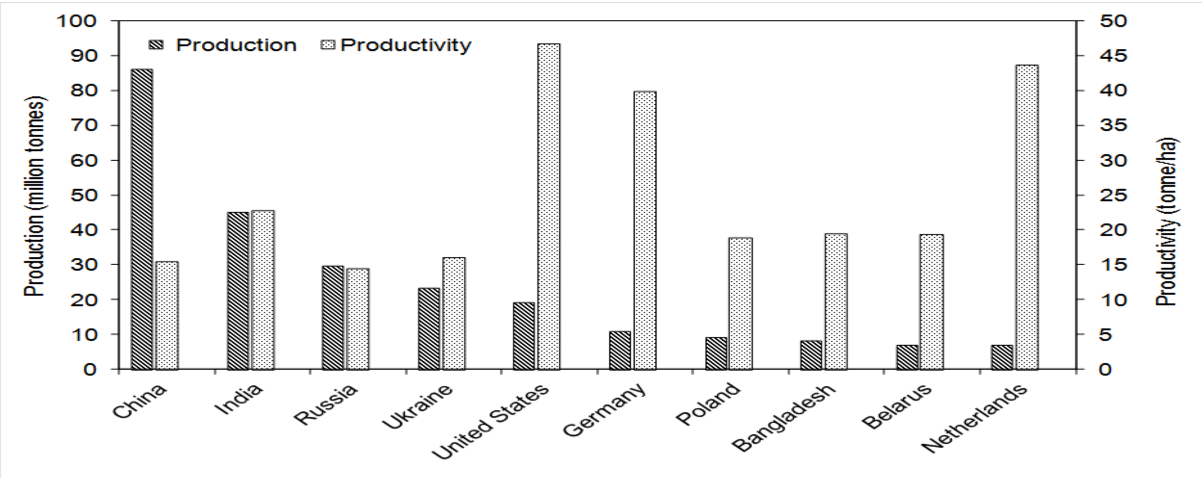

Fig. 2. *Major potato growing countries in the world with their productivity (Source: FAO Stat, 2015).*

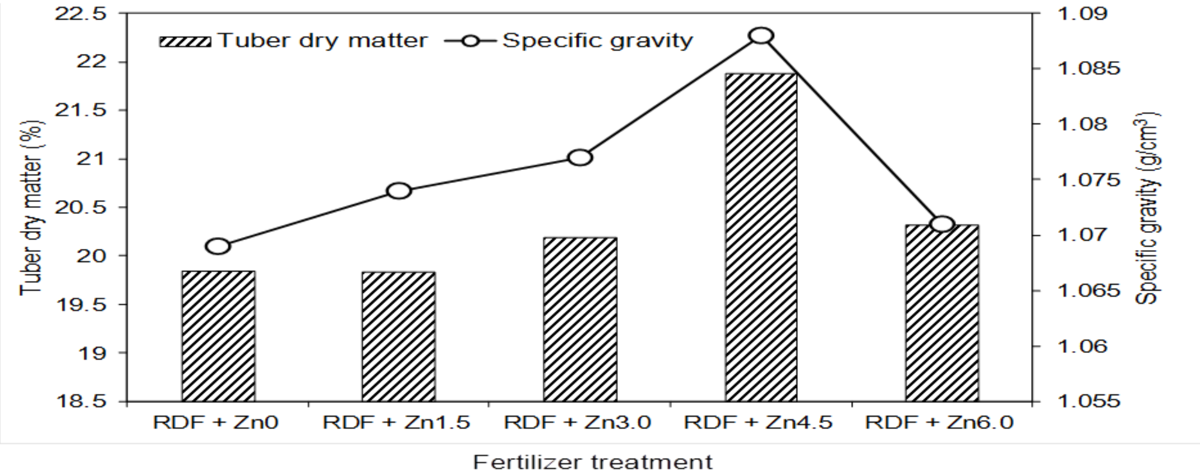

Fig. 3. *Effect of Zn-fertilizer levels on tuber specific gravity and dry matter content of potato (Source: Banerjee et al., 2015).*

for 24 h, 48 h, and 72 h, respectively compared with control plants.

Membrane integrity: The evidence of Zn involvement in membranes of higher plants has been demonstrated indirectly. Using root exudates as an indicator of root plasma membrane permeability, Welch *et al.* (1982) found greater leakage of ^{32}P from roots of Zn-deficient wheat than from Zn-adequate roots.

Auxin metabolism: Zn played a key role for maintaining auxin in an active state and that enhanced oxidation caused the decreased indole acetic acid

Table 1. Zinc containing fertilizers.

Compound	Formula	Zinc content (%)
Inorganic Compounds		
Zinc sulphate monohydrate	$ZnSO_4.H_2O$	36
Zinc sulphate heptahydrate	$ZnSO_4.7H_2O$	22
Zinc oxysulphate	$ZnO.ZnSO_4$	20-50
Basic zinc sulphate	$ZnSO_4.4Zn(OH)_2$	55
Zinc oxide	ZnO	50-80
Zinc carbonate	$ZnCO_3$	50-56
Zinc chloride	$ZnCl_2$	50
Zinc nitrate	$Zn(NO_3)_2.3H_2O$	23
Zinc phosphate	$Zn_3(PO_4)_2$	50
Zinc frits	Fritted glass	10-30
Ammoniated zinc	$Zn(NH_3)_4\ SO_4$	10
Organic Compounds		
Disodium zinc EDTA	$Na_2ZnEDTA$	8-14
Sodium zinc HEDTA	NaZnHEDTA	6-10
Sodium zinc EDTA	NaZnEDTA	9-13
Zinc polyflavonoid	--	5-10
Zinc lignosulphonate	--	5-8

Source: Das (2007)

Table 2. Germination, yield and economics of potato (cv. Kufri Jyoti) as influenced by different Zn levels.

Zinc levels (kg ha^{-1})	Germination %	Total tuber yield (t ha^{-1})	Average tuber number (×10^5 ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio
RDF + Zn_0	97.5^a	25.98^d	316.3^c	59266	1.61
RDF + $Zn_{1.5}$	97.5^a	26.54^b	325.3^b	61698	1.63
RDF + $Zn_{3.0}$	98.3^a	27.84^a	333.5^a	68574	1.70
RDF + $Zn_{4.5}$	100.0^a	27.93^a	342.4^a	68181	1.69
RDF + $Zn_{6.0}$	100.0^a	26.06^c	309.4^d	56034	1.56

RDF of NPK i.e. 200:150:150 kg/ha; Means followed by a different letter are significantly different at $p \leq 0.05$ by Duncan's multiple range tests (Source: Banerjee *et al.,* 2015).

Table 3. Response of potato to Zn fertilizer in different soils of India.

	Number of experiments		Response (t ha^{-1})	
Soil group	Total	Response (> 10 q ha^{-1})	Range	Mean
Alluvial soils	15	9	1.1-6.5	3.1
Hill soils	11	7	1.0-7.9	3.4
Black soils	8	6	1.0-4.5	2.6
Red and laterite soils	7	5	1.1-3.4	2.4

Source: Grewal and Trehan (1990)

(IAA) level.

Reproduction: Flowering and seed production are known to be severely depressed by Zn deficiency in beans, peas, and other plants (Hu and Sparks, 1990). Lower seed production under Zn deficiency can be attributed to (i) enhanced formation of abscisic acid in the plant, causing premature abscission of leaves and flower buds; (ii) disruption of the development and physiology of anthers and pollen grains.

Defence mechanisms: Zn plays an important function to prevent disease pest incidence in higher plants by improving their defence mechanism (Graham, 1983). Dipping of tuber in 0.05 % $ZnSO_4$ + 1.0 % acetic acid reduces the indices of black-scurf of potato from 97 to 12% (Somani, 1986).

Deficiency symptoms of Zn in potato plants: With the increase of cropping intensity, growing of HYVs and minimum or no use of organic manures lead to deficiency of micronutrients especially Zn in different potato growing soil of India. Now, it has got the primary importance to supplement the micronutrient directly through soil application or spraying on plants or seed treatment methods in order to overcome its deficiency.

Deficiency symptoms of Zn in potato have been listed below.

- Retards photosynthesis and nitrogen metabolism
- Deficient plant show severe stunting and bronzing or yellowing of the foliage, usually around the leaf margins, starting from the tips.
- Youngest leaves are cupped upward and rolled to such an extent that terminal growth resembles that fern (Fern leaf symptom).
- Leaves of affected plants are smaller and their upper internodes are shorter (little leaf symptom).

Table 4. Zn uptake and Zn-use efficiency by potato cv. Kufri Jyoti as affected by different Zn levels (values are pooled data of 2013-14 and 2014-15).

Treatments	Zn uptake in tuber (kg ha^{-1})	Zn uptake in haulm (kg ha^{-1})	Total Zn uptake (kg ha^{-1})
RDF + Zn_0	31.65^e	102.69^e	134.34^e
RDF + $Zn_{1.5}$	34.07^d	126.01^d	160.08^d
RDF + $Zn_{3.0}$	37.10^c	140.64^c	177.73^c
RDF + $Zn_{4.5}$	41.03^b	154.00^b	195.03^b
RDF + $Zn_{6.0}$	43.20^a	163.68^a	206.88^a

RDF/recommended dose of fertilizer, 200:150:150 kg ha^{-1}, Means followed by a different letter are significantly different at p≤0.05 (otherwise statistically at par); NS, Non-significant (Source: Banerjee *et al.,* 2016)

Table 5. Quality parameters of potato (cv. Kufri Jyoti) as influenced by different Zn levels.

Zinc levels (kg ha^{-1})	TSS (ºBrix)	Total Acidity (%)	Ascorbic Acid (mg 100 g^{-1})	Total starch (mg 100 g^{-1})
RDF + Zn_0	5.90^a	8.25^a	19.75^a	56.76^c
RDF + $Zn_{1.5}$	5.90^a	8.25^a	20.25^a	56.6^c
RDF + $Zn_{3.0}$	5.92^a	8.37^a	19.25^a	57.4^b
RDF + $Zn_{4.5}$	6.10^a	8.12^a	19.50^a	57.73^{ab}
RDF + $Zn_{6.0}$	6.42^a	8.97^a	19.25^a	58.05^a

RDF of NPK i.e. 200:150:150 kg ha^{-1}; Means followed by a different letter are significantly different at p≤0.05 by Duncan's multiple range tests (Source: Banerjee *et al.,* 2017).

- Delayed maturity as a result of prolonged growth periods, ultimately resulting into low yield and poor quality of tuber.

Strategies for increasing Zn content in crops: The Zn content in crops can be improved by two ways, either by breeding new cultivars that absorb and transmit more Zn to grains (Bio-fortification) or by fertilizing crops with Zn (Ferti-fortification).

There are a number of programmes for bio-fortification, such as *Harvest-Plus* Consortium of the CGIAR Challenge Programme, The Global Rice Project, African fortified Sorghum Project, Bio-Cassava Plus and Bio-fortification of Banana with a goal of developing nutrient-rich crop varieties (Prasad *et al.,* 2012). The ability of a plant to grow and yield under Zn stress in soil is known as high Zn efficiency. This could be achieved by a crop due to possession of either one or all of the following characters- a better root system, higher synthesis and release of iron and Zn mobilizing phyto-siderophores by the roots, affinity of the root uptake system, translocation in plants and capacity to utilize absorbed Zn. Moreover, micro-nutrient uptake by plants is also influenced by physical, chemical and biological properties of soil (Prasad, 2012).

Ferti-fortification: The term 'Ferti-fortification' was coined by Prasad (2012) which refers fertilizing crops with micronutrients. It gives immediate results and in general, goes well along with an increase in yield. The Zn deficiency is found in 49% of Indian soils, wherein response of most crops to Zn fertilization has been reported (Shukla and Behera, 2012); however, the attention on Zn concentration in grains did not receive much attention until the bio-fortification of grains and fruits became popular.

Potato: As potential option for Zn ferti-fortification: Zinc plays a very important role in increasing the production as well as quality. Results of IZA-MOA joint project revealed that the application of $ZnSO_4$, H_2O @ 15 kg ha^{-1} in potato resulted highest percent of yield increase (upto 25%) compared to other fruit and vegetable crops. Potato is one of the highest Zn accumulator compared to the rice where rice can accumulate upto 18.6 to 28.1 mg Zn kg^{-1} of dry matter where most of the Zn has removed during processing (milling, polishing and cooking) (Hazra *et al.,* 2015). In contradictory to rice, Zn accumulation in potato taken places in the tuber (vegetative portion) which was not removed during possessing. People need up to 15 mg of zinc per day, as recommended by World Health Organization (WHO). Most of the Zn ferti-fortification programme carried out through the world, showed that Zn loading in potato through foliar as well as soil-applied Zn, increases Zn concentration in potato tuber upto 3-4 times (30-40 mg Zn kg^{-1} of dry matter) which is quite higher than most of the commonly known fruit crops (White *et al.,* 2012; Murmu *et al.,* 2014). Understanding these findings, Zn-fortified potato can be a potential option to reduce Zn driven malnutrition among the developing countries.

Critical values of Zn in soil and potato plants: Critical levels of Zn in potato growing soils of West Bengal (India) for soil as well as potato shoot and tuber were estimated by Dhar (2011) in a green house experiment where potato was grown at four levels of Zn (0, 5, 10 and 20 kg ha^{-1}). For this purpose, 21 soil samples were collected from various locations of the different districts like Coochbehar, Jalpaiguri, Murshidabad, Nadia, Hooghly and Midnapore of West Bengal (India). For available Zn status, soils were extracted with DTPA. Critical limits of Zn in soils, potato shoot and potato tuber were determined through the graphical method proposed by Cate and Nelson (1971). In this graphical method, for determination of critical limit of Zn in soils, potato shoot and potato tuber, Bray's percent yield (BPY) was calculated using the following formula:

$$BYP = \frac{\text{Yield without nutrient}}{\text{Yield with optimum nutrient}} \times 100 \qquad \text{Eq.1}$$

Results showed that critical level of Zn in soils for potato plant (shoot + tuber) is approximately 0.59 mg kg^{-1}. In this respect, we can say that Zn concentration below 0.59 mg kg^{-1} will respond readily to its application. Zn concentration above it may reduce the growth of potato plant and may be toxic for that particular plant. Results also showed that the critical limits of Zn in potato shoot and tuber was 45 and 10 mg kg^{-1}, respectively.

Management options for zinc: To meet the demand of potato crop and ameliorate the Zn deficiency in soils, the application of Zn-fertilizer is highly profitable. Moreover, the choice of an appropriate Zn-fertilizer with proper dose and application method is very much important (Das, 2011).

Fertilizer sources: Different sources of zinc fertilizers are inorganic compounds, synthetic chelates and natural organic complexes; they vary considerably with respect to zinc content, effectiveness for crops on different types of soils and price (Table 1). However, sulphate salt is the common source of Zn. Zinc sulphate monohydrate and zinc sulphate heptahydrate are the most widely marketed used Zn fertilizer in India.

- Zinc sulphate, zinc oxide, zinc carbonate, zinc nitrate, and zinc chloride are some of the inorganic sources of Zn. Worldwide the most commonly used zinc fertilizer source is zinc sulphate, both crystalline monohydrate and heptahydrate forms.
- Synthetic chelates, a form of complex micronutrients, are prepared by mixing a chelating agent such as Ethylene Diamine Tetra-acetic Acid (EDTA) with a metal ion. The most commonly used chelated source of zinc is disodium salt of Zn-EDTA (Na_2Zn-EDTA). Synthetic chelates, with their high stability, are highly suitable for mixing with concentrated fertilizer solutions for soil, fertigation and hydroponic applications. They are also suitable for foliar feeding, but repeated applications may be required under moderate to severe zinc deficient conditions because of their relatively low zinc content.
- Natural organic complexes are manufactured by reacting zinc salts with citrates or with organic by-products from paper pulp manufacture such as lignosulphonates, phenols and polyflavonoids. Generally, they are cheaper than synthetic chelates.

Application method: Under filed conditions, several methods of Zn application have been evaluated to overcome Zn-deficiency. Usually three methods are followed for Zn fertilization in potato.

Soil application: The deficiency of Zn may be corrected by soil application of inorganic fertilizer like zinc sulphate @ 25 kg ha^{-1}. Soil application through broadcasting followed by mixing, drilling, band placement and top dressing have been found to be effective (Das, 2011). The application of Zn in soils not only increased the yield of crops, but also decreased the concentration of cadmium (Cd) in soils, thereby decreased the content and uptake of Cd by the plants.

Foliar application: Foliar sprays with 0.02% zinc solution (200 g 100 $litres^{-1}$ of water) on the standing crop at 40 and 60 DAP in the plains, and 60 and 80 DAP in hills have been found effective. Foliar spray should be avoided between 11.00 am to 3.00 pm to prevent scorching of leaves (Sharma, 2002).

Seed treatment: In this method, seed tubers are soaked in 0.05% zinc sulphate solution (50 g per 100 litres of water) for 3 hours. The soaked tubers are dried in shade for 24 hours and then planted in the field (Mondal *et al.,* 2015).

A number of studies have been conducted to compare the effectiveness of different methods and it has been found that all the three methods are equally effective for increasing the tuber yield of potato (Mondal *et al.,* 2015). Further, the application of Zn either as soil application or foliar spray triggers several metabolic pathways in the plants like translocation of Zn within the plant, enzyme activities etc. which finally influences growth and yield of crops (Das, 2011).

Zn fertilization effects on potato

Growth of potato as affected by Zn fertilization: Growth of potato plant is greatly influenced by micronutrient application like zinc. Kumar *et al.* (2008a) recorded significant influence by the zinc on the growth characters of potato and obtained higher values of plant height, LAI and dry matter with tuber dipping in 0.05% $ZnSO_4$ solution for 3 hrs one day prior to sowing. The reason is zinc plays a key role in plant metabolism, particularly in auxin synthesis which is an essentially required for growth and development of a crop. However, in an earlier study, Banerjee *et al.* (2015) did not find any significant effect of Zn fertilization on plant height, number of compound of compound $plant^{-1}$ as well as the number of haulms $plant^{-1}$ at Kalyani region of West Bengal. This result corroborates to that of Bari *et al.* (2001) and Islam *et al.* (1982) who demonstrated non-significant of Zn fertilization on plant growth of potato. Banerjee *et al.* (2016) also reported that Zn fertilization increased leaf area index of potato during early stage of growth only which might be due to higher vegetative growth, as resulted from higher rate of nitrogen metabolism and photosynthetic activity with Zn fertilization (Paygozar *et al.,* 2009). Ravi *et* *al.* (2010) also supported the increase of LAI by Zn fertilization in potato and thereby increase in amount of dry matter accumulation and economic yield. The omission of Zn causes significant reduction in dry matter (12.2%) of potato cv. Kufri Bahar (Singh *et al.*, 2014). Al-Jobori and Al-Hadithy (2014) found higher dry matter content in potato plant with chelated-Zn fertilization. Moreover, increased tuber dry matter percent with Zn fertilization was obtained as a result of greater tuber size and higher starch accumulation.

Yield of potato as affected by Zn fertilization: The positive influences of Zn fertilization in augmenting quantitative (yield) and qualitative parameters of potato crop were earlier indicated by several investigators (Mousavi *et al.,* 2007). Zinc fertilization in potato resulted significant increase in tuber number, tuber weight, tuber yield, other qualitative traits and post–harvest indices. The increased tuber yield of potato might be attributed to the beneficial effect on tuberization as a result of Zn application (Mondal *et al.,* 2015) and Zn content in tubers (Singh *et al.,* 2009; Singh *et al.,* 2010). Banerjee *et al.* (2016) recorded highest potato yield 7.51% along with total tuber number, net return and B:C ratio with RDF + 4.5 kg Zn ha^{-1}, respectively over potato fertilized with RDF only (Table 2).

In an earlier study, Kumar *et al.* (2008a) meticulously documented the beneficial effect of $ZnSO_4$ on crop growth, greater synthesis as well as translocation of food material to developing tuber. Their subsequent study proved that Zn application also helped in increasing the average weight of individual tuber from small to medium and medium to large size (Kumar *et al.,* 2008b). Al-Jobori and Al-Hadithy (2014) who demonstrated foliar spray of Zn recorded 10.67 % higher yield over control. Brahmachari *et al.* (2010) also recorded 9.2 % yield increment with tuber soaking in 0.5 % $ZnSO_4$ solution. All India coordinated study on potato to micronutrient response showed that yield response of potato to applied Zn fertilizer varies with the soil type, variety, quantity of other major nutrients applied to the soil and finally method of application (Mondal *et al.,* 2015). The extents of response of potato to applied Zn fertilizer in different soils are stated in Table 3. Zinc application through soil (20 kg $ZnSO_4$ ha^{-1}), foliar spray (0.02 % zinc sulphate solution at 40 and 60 days after planting) and soaking of tuber (0.05 % zinc sulphate solution for three hours) significantly increased the tuber yield of potato (Sharma and Grewal, 1988).

Zn uptake by potato: It was found that the concentration of Zn in tubers increased with increasing Zn fertilization upto a certain extent, however, Zn concentrations in tubers were far below to that of shoot Zn concentrations (Table 4). The relationship between Zn application and tuber Zn concentration exhibited a saturation curve, depicting a maximum value of 30 mg kg^{-1} DM (White *et al.,* 2012). Poor tuber Zn concentrations might be accorded to restricted entry of Zn into leaf cells, or restricted loading of Zn into the phloem in the shoot. Below this maximum value, tuber Zn concentrations were greater in crops that had received multiple smaller applications than a single large foliar application of Zn-fertilizer to the plot. Hazra *et al.* (2012) obtained a result from Hooghly (West Bengal) while studying the effect of Zn on yield of two popular cultivars i.e. Kufri Jyoti and Kufri Chandramukhi of West Bengal, that Zn uptake of potato tubers increased with Zn fertilization in both cultivars of potato and magnitude of increase was higher in case of Kufri Chandramukhi than Kufri Jyoti. In Iran, Mousavi *et al.* (2007) demonstrated that foliar application of Zn @ 2, 4 and 8 ppt caused considerable increase in tuber Zn concentration, accounting 8, 22 and 23% more than control, respectively.

Quality of potato as influenced by Zn fertilization: Zn fertilization has a great impact on the quality parameters of potato. Banerjee *et al.* (2015) reported that 4.5 kg ha^{-1} Zn fertilization has positive impact on tuber specific gravity as well as dry matter accumulation (Fig. 3). Mousavi *et al.* (2007) also found 1.9 % increment in potato tuber specific weight with 8 ppm $ZnSO_4$ foliar application. Zn fertilization may have positive impact on tuber ascorbic acid content as Mondy *et al.* (1993) find that higher ascorbic acid content in tuber with a high dose of $ZnSO_4$ (112 kg ha^{-1}), but Banerjee *et al.* (2015) did not find any significant effect with Zn on tuber ascorbic acid content (Table 5). In the same experiment, Banerjee *et al.* (2017) found that Zn fertilization has a little impact on tuber total sugar content but higher amount of starch content which is very important for chipping quality (Table 4). Earlier studies of Dwivedi and Dwivedi (1992) also showed that 10 kg $ZnSO_4$ ha^{-1} was adequate to increase the potato tuber yield and starch content. They concluded that starch content in potato tuber was affected not only by Zn-rates but also by the method of Zn application. In their study, starch content of tuber was significantly affected by soil application (10 kg $ZnSO_4$ ha^{-1}) as well as seed soaking with Zn (R^2 = 0.602). Kumar *et al.,* (2008a) opined that greater accumulation of starch depends on the higher rate of photosynthesis, better translocation of photosynthates from leaves to tubers and subsequent conversion to starch. Therefore, increased starch accumulation in tubers might be due to higher rate of photosynthesis with zinc application. However, Murmu *et al.* (2014) reported non-significant effect of $ZnSO_4$ application on total sugar content of potato (cv. Kufri Jyoti) upto 10 kg ha^{-1}. Mondal *et al.* (2015) had an opinion that omission of Zn reduced the protein yield when compared with balanced fertilization plus Zn owing to reduction in tuber yield.

Zinc fertilization interestingly improves the chip colour of potato. This may be due to less production of phenol substances in tuber influenced by Zn^{++} ion thus few chances of enzymatic discolouration of potato chips during frying. Mondy and Chandra (1981) found that Zn fertilization significantly reduce the total phenol content of tuber thus improves chip colour while frying. Kumar et al. (2008a) also found similar results with 'Kufri Chipsona–1' cultivar where three times 0.2% foliar sprays with $ZnSO_4$ significantly improved chip colour over control.

Conclusion

Since most of the Indian soils are deficient in Zn (50 % soils of India and 34 % of West Bengal), micronutrient management (especially Zn) has received greater attention in potato production system to combat wide spared Zn deficiency. Potato responds well to the applied Zn fertilizer (3-10 kg Zn ha^{-1}). Zn plays an important role for growth, productivity and post-harvest quality of potato. Zn-fortified potato can be a potential option for mitigating wide spread Zn-driven malnutrition in Indian subcontinent.

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