**Biofortification of Potato Tubers with Zinc Through Foliar Application of Zn Fertilizer**

**Abstract**

The aim of this study was to investigate the proof-of-concept that the potato(*Solanum tuberosum* L.) can agronomically be biofortified with zinc (Zn) fertilization as foliar spray. The experiment was set up in a two-way factorial randomized complete block design with three replications. Foliar Zn fertilizer significantly increased tuber Zn concentration with an increase of tuber yield of potato. All Zn rates tested in the field experiments resulted in relatively constant increase of tuber Zn with an increase in Zn fertilizer rate without affecting tuber yield negatively. Agronomic biofortification, such as Zn fertilization as foliar spray, is a safe and rapid solution for improving Zn concentration in potato tubers to address the ongoing human Zn deficiency. Tuber yield 13-14% and tuber Zn concentration 197-231% increased over control as influenced by added Zn as foliar spray @ 4 kg ha-1 applied twice at 45 and 60DAP. High rates of foliar Zn application reached an average of 3.81-fold tuber Zn increase of the varieties. Agronomic biofortification assists with the transport of zinc from leaf tissue to the tubers during their reproductive growth stage. Enrichment of potatoes with high bio-available Zn is suggested as a way to generate significant health benefits for a large number of susceptible people across the world.

**Keywords:** biofortification, foliar application, potential, concentration, BARI Alu (Potato);

**1. Introduction**

Over two billion people across the world suffer from micronutrient malnutrition(Praharaj et al*.* 2021). Micronutrient deficiency is a global health concern (Gold et al. 2022). More than a billion people eat potatoes regularly (Kromann et al., 2017); hence, one of the main sources of Zn to humans (Mengist et al.*,* 2018). Zinc is one of the essential nutrients for animal as well as for plants (Gupta et al. 2020). In recent years, zinc deficiency has been a common issue for plants and animals (Younas et al. 2023). Around 2800-3000 proteins in the human body contain zinc prosthetic groups (Ahsan et al. 2021).Food insecurity, imbalanced diet, consumption of food grains with poor nutritional quality, lack of dietary diversity, etc., negatively affect human health (Gundersen and Ziliak, 2015). Food and nutritional insecurity may further deteriorate diet quality, thus, increasing the danger of under nutrition and obesity (Anon., 2020).In a recent study, it was recommended daily allowance (RDA) of Zn consumption is 17 mg (Anon., 2020). Islam et al*.* (2022) reported in their total diet study of Bangladesh that more that 85% household adults had dietary intake of Zn below RDA (17 mg/person/day).

Nearly 25% of the world’s population is considered to be zinc (Zn)-deficient (Allai et al. 2022, Poudel et al. 2023). In Bangladesh, over 41% children aged below five years are stunted while an estimated 44% children of the same age group are at risk of zinc deficiency (Anon., 2013). In humans, Zn deficiency can cause reduced immune and reproductive function (Khan et al. 2018; Younas et al. 2023), impaired brain function (Hambidge, 2000), physical retardation and stunted growth (Khan et al. 2022), which is now a major health problems in human (Hanife and Süleyman (2021). Kiran et al. (2022) reported that micronutrient malnutrition is a global health challenge affecting almost half of the global population, causing poor physical and mental development of children and a wide range of illnesses.

Nutrient biofortification (e.g. vitamin A, zinc, iron) is a cost-effective intervention to increase the concentration and/or bioavailability of nutrients in the edible part of plants (Praharaj et al., 2021). Golden rice is an example of a genetically biofortified rice variety enriched with Vitamin A (Wu et al*.*, 2021). Biofortification of major cereals (e.g. rice, wheat and maize), tuber crops (e.g. potato, cassava), edible oil (soybean) and fruits (banana, watermelon) can supply the required amount of dietary zinc (Bhardwaj et al*.*, 2022). Staple food grains like wheat, rice, maize, potato etc. are consumed by a large number of people across the globe; when they are biofortified with Zn, it could have a great impact in reducing hidden hunger (Sheoran et al*.*, 2022).The food's micronutrient level needs to rise for improved human and animal health. Preliminary studies indicate that Zn enrichment of potato tubers is possible through Zn fertilization, and the magnitude depends on the crops and varieties (Mengist et al., 2021; Haynes et al., 2012). Kromann et al.(2017) state that dietary Zn deficiency is a major nutritional disorder of the poor people of a country who heavily subsist on potatoes. It is quite applicable to Bangladesh, where the people commonly eat potatoes daily, amounting to about 64 g of potato(Anon., 2016). Enrichment of potatoes with high bio-available Zn is suggested as a way to generate significant health benefit for a good number of susceptible people especially in Bangladesh as well as Zn deficient areas in the world. Agronomic biofortification can be an economically sustainable and practically acceptable solution to solve Zn deficiency in potatoes (Mahmud et al., 2021; Bhatt et al., 2020). Conventional breeding, genetic engineering, and agronomic management are important agricultural tools to improve potato tuber Zn concentration (Kromann et al., 2017). Application of zinc as foliar offers a quick solution to increase Zn concentration in cultivated plants (Tabesh et al*.*, 2020). Potato tubers are inherently low in Zn concentration and bioavailability, particularly when grown on Zn-deficient soils. Tuber Zn concentration can be increased by Zn-fertilization as foliar spray (Kromann et al., 2017).

#### 2. Materials and Methods

#### The experiment was conducted during November to March 2019-20 and 2020-21 at the Horticulture Farm, Bangladesh Agricultural University (BAU), Mymemsingh, Bangladesh.

#### *2.1. Biophysical characteristics of the study location*

Table 1:- Biophysical and chemical characteristics of the study experimental fields

|  |  |
| --- | --- |
| Biophysical attributes | Description |
| Location, Division | Horticulture Farm, BAU, Mymensingh |
| Latitude and longitude | 240 42ꞌ 56.04ꞌꞌ N and 900 25ꞌ 31.01ꞌꞌ E |
| Altitude | 14.00 m/ 45.93 ft |
| Average. temperature (0 C) (crop growing period) | 19.38 |
| Agro-ecological Zone | Old Brahmaputra Floodplain (AEZ 9) |
| General Soil Type | Non-Calcareous Dark Grey Floodplain soil |
| Topography | Fairly level |
| Flood level | Above flood level |
| Soil physical characteristics before planting |  |
| Soil texture | Silt loam |
| Sand | 22.89% |
| Silt | 73.23% |
| Clay | 3.65% |
| Agricultural Practices |  |
| Cropping pattern | Sesbania – Potato – summer vegetables |
| Planting date | 26 November 2019 / 26 November 2020 |
| Harvest date | 10 March 2020 / 9 March 2021 |
| Soil chemical composition |  |
| Total N (%) | 0.11 |
| Available phosphorus (mg kg-1) (Olseen method) | 9.52 |
| Exchangeable potassium (meq/100 g soil) | 0.11 |
| Available Sulphur (mg kg-1) | 6.87 |
| Total nitrogen (mg kg-1) | 54.36 |
| Available zinc (mg kg-1) (Olsen Extract) | 0.81 |
| Organic matter (%) | 1.39 |
| pH | 6.37 |

#### *Agronomic Zn-biofortification of potato with foliar Zn application*

In 2019-20, a field experiment with Zn fertilizer was replicated at the Horticulture Farm of BAU. The experiment comprises Zn application as foliar spray with six potato varieties and eight different doses. Next year, in 2020-21, the experiment was repeated in the same field to validate the results. The experiment involved six varieties: BARI Alu-7, BARI Alu-13, BARI Alu-25, BARI Alu-53, BARI Alu-73, and BARI Alu-77. Among the varieties, BARI Alu-53 and BARI Alu-77 have late maturity, dense foliar cover with high yield potential, and dense root system, and BARI Alu-53 has the densest foliar cover among the varieties. The other four are the comparatively somewhat early maturing varieties with medium yield potential and moderate foliar cover.

#### *2.3. Experimental design and treatments*

The experiment was designed to evaluate foliar applications of Zn on the concentration of Zn in harvested tubers. It was set up in a two-way factorial Randomized Complete Block Design with three replications to evaluate the foliar Zn application for Zn biofortification in potato tubers. The two factors were potato cultivars and fertilizer treatments. There were three blocks representing three replications. Each block contained 48-unit plots to accommodate treatment combinations (6 varieties x 8 treatments). Therefore, a total of 144 (48 x 3) unit plots were maintained in the experiments. The size of each unit plot was 1.5 x 2.4 m2 (3.6 m2).

Eight fertilizer treatments were: ZnF0 =control (no Zn fertilizer); ZnF1 =4 kg Zn ha-1(full dose) applied once at 30 days after planting (DAP); ZnF2=2 kg Zn ha-1 (half dose) applied once at 45 DAP; ZnF3=half dose applied twice at 45 and 60 DAP; ZnF4=half dose applied three times at 30, 45 and 60 DAP; ZnF5=full dose applied twice at 45 and 60 DAP; ZnF6=full dose applied once at 45 DAP; ZnF7=full dose applied once at 60 DAP as foliar spray as zinc sulphate (ZnSO4, 7H2O).

#### *Determination of dry matter*

Potato tubers were washed in running water followed by distilled water, andoven-dried at 70o C, dry weight (dw) determined, ground to powder and analytical samples taken of 0.5 g with 5.0 ml Trace Element Grade (TEG) concentrated nitric acid (HNO3) for pre-digestion overnight and digested with 3.0 ml of 30% (v/v) hydrogen peroxide (H2O2) at 1400 C following an adaptation of the methods described by Subramanian et al. (2011). Plant parameters (yield and yield components) and tuber Zn concentration data were subjected to statistical analysis through the statistical program Minitab 17 (Minitab Inc., State College, PA, USA) following the basic principles as outlined by Gomez and Gomez (1984).

1. **Results and Discussions**

The experiments showed a statistically significant effect of foliar applied Zn fertilization on tuber Zn concentration. All Zn rates tested in the field experiments resulted in relatively constant increases of tuber Zn with an increase in Zn fertilizer rate without affecting tuber yield negatively.

*3.1. Genotypic effects*

The tuber yield of potato greatly varied with varieties which can be attributed to differences in genetic make-up.

Genotypes had significant effect on tuber yield of potato. The tuber yield of trial average varied between 24.90 and 32.02t ha-1(Table 2) which illustrates a significant varietal effect. In Bangladesh potato cannot be planted year-round; but in winter (November to March) when average temperature remains 18-220 C at the experimental field area. Experiments were intensively managed with irrigation.

Table2**:-**Varietal effects on marketable yield (t ha-1) of potato tubers of Zn application as foliar spray of trial 1, trial 2and trial average.

|  |  |  |  |
| --- | --- | --- | --- |
| Variety | Yield (t ha-1) | | |
| Trial 1 (2019-20) | Trial 2 (2020-21) | Trial average |
| V1 (BARI Alu-7) | 26.36±0.37d | 26.80±0.29d | 26.58±0.25d |
| V2 (BARI Alu-13) | 24.45±0.38e | 25.35±0.30e | 24.90±0.24e |
| V3 (BARI Alu-25) | 28.78±0.35c | 28.43±0.38c | 28.60±0.29c |
| V4 (BARI Alu-53) | 31.72±0.42 a | 32.31±0.35 a | 32.02±0.33 a |
| V5 (BARI Alu-73) | 30.14±0.44 b | 30.36±0.31b | 30.25±0.30b |
| V6 (BARI Alu-77) | 31.90±0.42 a | 31.81±0.38a | 31.86±0.34a |
| Max | 31.90 | 32.31 | 32.02 |
| Min | 24.45 | 25.35 | 24.90 |
| Mean | 28.89 | 29.18 | 29.04 |
| LSD0.05 | 0.69 \*\* | 0.69 \*\* | 0.46 \*\* |
| LSD0.01 | 0.92 \*\* | 0.92 \*\* | 0.61 \*\* |
| Level of significance | \*\* | \*\* | \*\* |
| *p-value* | *<0.01* | *<0.01* | *<0.01* |

\*\*p<0.01(Significant at 1% level of probability);Values in the same column followed by same letter are not significantly different according to Tukey’s test (p*<0.05)*.

The tuber Zn concentrations of potato varied with varieties which can be attributed to differences in genetic make-up. Genotypes had significant effect on tuber Zn concentrations of potato. The tuber Zn concentrations of trial average varied between 20.71 and 30.84µg g-1 (Table 3) which illustrates a significant varietal effect. Experiments were intensively managed with irrigation.

Table 3**:-**Varietal effect on tuber Zn concentrations (µg g-1) of potato of Zn application as foliar spray in trial 1, trial 2and trial average

|  |  |  |  |
| --- | --- | --- | --- |
| Variety | Zn concentration (µg g-1) | | |
| Trial 1 (2019-20) | Trial 2(2020-21) | Trial average |
| V1 (BARI Alu-7) | 27.08±1.80b | 26.41±1.72c | 26.75±1.72c |
| V2 (BARI Alu-13) | 20.97±1.53c | 20.45±1.46 d | 20.71±1.47d |
| V3 (BARI Alu-25) | 26.59±1.91b | 27.03±1.74bc | 26.81±1.81 c |
| V4 (BARI Alu-53) | 30.44±2.25a | 31.24±2.26a | 30.84±2.24a |
| V5 (BARI Alu-73) | 26.20±2.10b | 26.61±1.96c | 26.41±2.02c |
| V6 (BARI Alu-77) | 28.97±2.23a | 28.56±2.05 b | 28.76±2.12 b |
| Max | 30.44 | 31.24 | 30.84 |
| Min | 20.97 | 20.45 | 20.71 |
| Mean | 26.71 | 26.72 | 26.71 |
| LSD0.05 | 1.01 \*\* | 1.30 \*\* | 1.02 \*\* |
| LSD0.01 | 1.21 \*\* | 1.72 \*\* | 1.36 \*\* |
| Level of significance | \*\* | \*\* | \*\* |
| *p-value* | *0.01* | *0.01* | *0.01* |

*3.2. Agronomic Zn-biofortification of potato tubers with foliar application of Zn fertilizer*

In individual ANOVAs, the effect of Zn fertilizer rates on tuber yield revealed a significant effect in foliar Zn application (p*<*0.01). The Tukey ranking (p < 0.05) indicated a significant increase of the tuber yield between the control and the lowest Zn rate of foliar Zn treatments of 3 varieties among 6 (Table 4). Combined ANOVAs revealed no significant effect on tuber yield (p =1.000). Interestingly, no negative effects on yield of the high Zn applications were seen with the edaphic conditions and fertilizer types of this study.

Table 4:-Interaction effects of Zn treatments as foliar spray on marketable yield (t ha-1) of tubers of six varieties of potato (results are the average of two trials: 2019-20 and 2020-21).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variety | Treatment | | | | | | | |
| ZnF0 | ZnF1 | ZnF2 | ZnF3 | ZnF4 | ZnF5 | ZnF6 | ZnF7 |
| V1 (BARI Alu-7) | 25.02 p-r | 26.01 n-r | 25.14 p-r | 26.93 l-q | 27.53 j-p | 28.64 h-o | 26.71 l-q | 26.64 n-q |
| V2 (BARI Alu-13) | 23.66 r | 24.41qr | 23.76 r | 25.01 p-r | 25.82 o-r | 26.77 l-q | 24.93 p-r | 24.84 p-r |
| V3 (BARI Alu-25) | 26.59m-q | 28.01 i-o | 27.38k-p | 28.67 h-n | 29.79 e-k | 31.00 b-h | 28.54 h-o | 28.86 g-h |
| V4 (BARI Alu-53) | 30.11 d-k | 31.25 b-h | 30.40 c-i | 32.14 a-e | 33.49 ab | 34.56 a | 32.10 a-e | 32.11 a-e |
| V5 (BARI Alu-73) | 28.81 g-n | 29.52 e-l | 28.92 f-m | 30.31 c-j | 31.62 b-g | 32.85 a-d | 30.02 e-k | 29.94 e-k |
| V6 (BARI Alu-77) | 30.36 c-i | 31.21 b-h | 30.57 c-i | 31.71 b-f | 32.95 a-c | 34.69 a | 31.69 b-f | 31.68 b-f |
| **Max** | **30.36** | **31.25** | **30.57** | **32.14** | **33.49** | **34.69** | **32.10** | **32.11** |
| **Min** | **23.66** | **24.41** | **23.76** | **25.01** | **25.82** | **26.77** | **24.93** | **24.84** |
| **Mean** | **27.56** | **28.40** | **27.56** | **29.13** | **30.20** | **31.42** | **29.00** | **29.01** |

Values in the same column followed by same letter are not significantly different according to Tukey’s test (*p<0.05)*.

The tuber yield of the trial average results of Zn treated plots positively responded that the increment of tuber yields due to added Zn @ 4 kg ha-1 as foliar spray applied twice at 45 and 60 DAP was found highest in BARI Alu-77 (34.69 t ha-1) followed by variety BARI Alu-53 (34.56 t ha-1) (Table 4). 13-14% tuber yield was increased over control due to added Zn @ 4 kg ha-1applied twice at 45 and 60 DAP as foliar spray under study.

The present results agree with Sarkar et al. (2018) who observed that Zn fertilization produced higher tuber yield of potatoes and higher tuber Zn concentration.

Kumar et al. (2008) 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.

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). The reason is zinc plays a key role in plant metabolism, particularly in auxin synthesis which is essentially required for growth and development of a crop (Sarkar et al., 2018).

A highly significant effect of Zn fertilizer treatments on tuber Zn concentration of peeled potato tubers was detected in the trial average results (Table 5) when Zn fertilizer was applied on plant body as foliar spray. The trial average data revealed that a significant increase in Zn concentration was found in tubers fed with Zn (ZnSO4,7H2O) in different doses as foliar spray with different durations. The increment of tuber Zn concentration due to added Zn @ 4 kg ha-1 applied twice at 45 and 60 DAP as foliar spray was found highest in BARI Alu-53 (51.12 µg g-1) (Table 5). However, the Tukey’s ranking (p=0.000) reveals a significant difference in tuber Zn concentrations among treatments that had received Zn fertilizer.

A highly significant effect of Zn fertilizer rate was seen on tuber Zn concentration in both trials (ANOVA, p value <0.005 for all comparisons). The highest foliar Zn rate increased the Zn concentration in tuber flesh 3.42, 2.79, 2.70, 3.31, 3.50, 3.84-foldover unfertilized control in BARI Alu-7, BARI Alu-13, BARI Alu-25, BARI Alu-53, BARI Alu-73, BARI Alu-77 respectively(Table 5). A maximum Zn application level for increasing tuber Zn concentration was not done under study.

Table 5:- Interaction effects of Zn treatments as foliar spray on Zn concentration (µg g-1) of tubers of six genotypes of potato (results are the average of two trials: 2019-20 and 2020-21).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variety | Treatment | | | | | | | |
| ZnF0 | ZnF1 | ZnF2 | ZnF3 | ZnF4 | ZnF5 | ZnF6 | ZnF7 |
| V1 (BARI Alu-7) | 11.48 u | 24.86 m-o | 19.66 p-r | 28.64 i-m | 36.50 e-g | 39.23 c-e | 26.84 k-n | 26.81 k-n |
| V2 (BARI Alu-13) | 12.19 u | 15.45r-t | 14.05 t | 22.56 n-q | 28.37 j-m | 34.07 f-h | 20.05 p-r | 18.96 p-s |
| V3 (BARI Alu-25) | 14.93st | 23.38 n-p | 15.39 r-t | 30.94 h-k | 36.84ef | 40.25 c-e | 26.73 k-n | 26.05 l-n |
| V4 (BARI Alu-53) | 15.43 r-t | 26.47 k-n | 20.34 o-q | 33.23 f-i | 41.89 cd | 51.12 a | 29.28 i-m | 28.93 i-m |
| V5 (BARI Alu-73) | 12.45 u | 23.48 n-p | 14.45st | 29.95 h-l | 35.74 e-g | 43.61bc | 25.99 l-n | 25.58 l-n |
| V6 (BARI Alu-77) | 12.20 u | 25.59 l-n | 18.11 q-t | 31.92 g-j | 37.87 d-f | 46.84 ab | 28.93 i-m | 28.66 i-m |
| Max | 15.43 | 26.47 | 20.34 | 33.23 | 41.89 | 51.12 | 29.28 | 28.93 |
| Min | 11.48 | 15.45 | 14.05 | 22.56 | 28.37 | 34.07 | 20.05 | 18.96 |
| Mean | 13.11 | 23.21 | 17.00 | 29.54 | 36.20 | 42.52 | 26.30 | 25.83 |

Mean values with the same letters are not significantly different based on ANOVA followed by a Tukey’s test at p< 0.05.

The field trials with Zn fertilizers as foliar spray showed a significant effect of the Zn fertilizer treatments on tuber Zn concentrations (Table 5). The finding that potato can be Zn-biofortified with soil applied Zn stands apart from previous publications that have indicated that Zn biofortification of potato tubers may best be achieved with foliar Zn applications because of low phloem mobility of Zn and low functional xylem continuity to potato tubers from roots (Waters and Sankaran, 2011). To elucidate the efficacy and validation of foliar applied Zn rates a repetition of field experiments were done. These experiments, conducted at the same location of previous field experiments, resulted in a 3.26-fold(average value) tuber Zn increase over unfertilized control due to added Zn as foliar applications (Table 5).

The present results are comparable to many works in the past. Kromann et al. (2017) conducted a study to evaluate a fertilizer approach's potential role in increasing Zn concentrations in Andean potato cultivars through a series of investigations in Ecuador. The results confirmed that Andean potato cultivars could be agronomically Zn-biofortified with foliar Zn fertilizers. High rates of foliar Zn application reached a 2.51-fold tuber Zn increase over control in the field trials. The results also conform with those of Phattarakul et al.(2012) reported that foliar Zn application is effective in Zn biofortification of food crops.

The potato varieties that showed high tuber Zn concentrations in the absence of Zn fertilization (Table 3) also showed correspondingly higher tuber Zn concentration following foliar applied Zn (Table 5). Nevertheless, Zn soil uptake and translocation to haulms and tubers may vary significantly among varieties. Many andigenum type cultivars have different root system architecture compared to tuberosum type cultivars (Wishart et al., 2013).

A comparison of the mean Zn concentrations and mean of Zn uptake by tubers with the mean tuber yields in the field trials with Zn fertilizer as foliar application reveal that the micronutrient concentrations in tubers have a positive correlation with tuber yield (Figure 1 and Figure 2).

Figure 1:-Relationship between tuber yield and tuber Zn concentrations (µg g-1) due to Zn application as foliar spray @ 4 kg ha-1applied twice at 45 and 60 DAP of 6 varieties of potato

Figure2:-Relationship between tuber yield and Zn uptake (g ha-1) by tubers due to Zn application as foliar spray @ 4 kg ha-1applied twice at 45 and 60 DAP of 6 varieties of potato.

A highly significant effect of Zn fertilizer treatments was found Zn uptake by tubers in both trials (ANOVA, *p* value <0.005 for all comparisons).Foliar application of Zn fertilizer significantly increased Zn uptake(by tubers) of 6 potato varieties (Table 6). The highest foliar Zn rate increased the Zn uptake by tubers flesh 3.90, 3.11, 3.08, 4.49, 4.13, 4.69-fold over control in BARI Alu-7, BARI Alu-13, BARI Alu-25, BARI Alu-53, BARI Alu-73, BARI Alu-77 respectively (Table 6).

Table 6:-Interaction effects of Zn treatments as foliar spray on Zn uptake (g ha-1) by tubers of six genotypes of potato (results are the average of two trials: 2019--20 and 2020--21).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variety | Treatment | | | | | | | |
| ZnF0 | ZnF1 | ZnF2 | ZnF3 | ZnF4 | ZnF5 | ZnF6 | ZnF7 |
| V1 (BARI Alu-7) | 60.31r-t | 126.93n-p | 84.99q-t | 147.46k-n | 201.67e-h | 235.16de | 137.81m-o | 137.99m-o |
| V2 (BARI Alu-13) | 57.68r-t | 70.37q-t | 66.77r-t | 105.46o-q | 141.69m-o | 179.44g-l | 88.39q-s | 83.83q-t |
| V3 (BARI Alu-25) | 81.76q-t | 126.39n-p | 85.94q-t | 163.76i-m | 208.25e-g | 252.05d | 144.79l-n | 144.30l-n |
| V4 (BARI Alu-53) | 92.92p-r | 163.89i-m | 106.62o-q | 214.23e-g | 292.75c | 417.29a | 185.16f-j | 191.01f-j |
| V5 (BARI Alu-73) | 71.74q-t | 137.15m-o | 78.31q-t | 170.85h-m | 218.28d-f | 296.12c | 158.93j-n | 154.97j-n |
| V6 (BARI Alu-77) | 80.95 q-t | 158.37j-n | 94.06p-r | 198.61e-i | 254.17d | 379.26b | 181.86f-k | 179.49g-l |
| Max | 80.29 | 163.89 | 106.62 | 214.23 | 292.75 | 417.29 | 185.16 | 191.01 |
| Min | 50.26 | 70.37 | 55.91 | 105.46 | 141.69 | 179.44 | 88.39 | 83.83 |
| Mean | 64.63 | 130.52 | 81.79 | 166.73 | 219.47 | 293.22 | 149.49 | 148.60 |

Mean values with the same letters are not significantly different based on ANOVA followed by a Tukey’s test at p< 0.05.

Zinc activates glutamic dehydrogenase enzyme, synthesis of RNA and DNA enhancing gliadin and glutenin contents which are the main protein components of gluten accumulated in the later stage of tuber forming. The present study hints that the scope exists to enhance tuber Zn concentration by applying Zn fertilizer. Lone et al. (2017) reported enhanced tuber Zn concentration due to increasing foliar Zn was applied when sufficient Zn was available to the plants. This suggests a proper combination of N and Zn applications.

Foliar applied Zn significantly increased Zn uptake by tubers of 6 potato varieties (Table 6). Foliar Zn spray resulted in a 3.9-fold (average value) Zn uptake(by tubers) increase over control under study. Similar findings were described by Banerjee et al. (2016) that zinc uptake by tubers, haulm and whole plant significantly increased with the progressive increase in Zn application levels from 0 to 6 kg ha-1 Zn application.

**4. Conclusions**

The application of foliar zinc fertilizers to a potato crop can be used to increase Zn concentrations in tubers. To speed up the breeding efforts in developing genotypes with higher tuber-Zn concentration and to establish an efficient strategy of Zn fertilization as foliar spray for agronomic biofortification, it is important to understand the physiological basis of differences in tuber Zn concentration between potato genotypes. Remobilization of Zn from leaves was one of the sources of Zn translocated to the tubers.

**5. Acknowledgments**

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**6. Conflict of Interest**

The authors declare that they have no conflict of interest.

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