**Screening of potato cultivars with Zn biofortification**

**Abstract**

**Aims:** The present investigation was carried out during November, 2018 to February, 2019 at the Horticulture farm of the Department of Horticulture, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. The aim of this study was to screen the potato cultivars upon Zn uptake status of the potato tubers through Zn application in soil. Texturally, the soil is silty-loam and falls under Sonatala series and as per FAO Soil Unit is *Chromic-Eutric Gleysols,* while Aeric Haplaqueptin the USDA Soil Taxonomy system.

**Study design:** 46 varieties of potato were tested with two treatments: control (no Zn fertilization) and Zn; the Zn rate being 8 kg ha-1 added as ZnSO4.7H2O (23% Zn). The experiment was laid-out in a randomized complete block design with three replications. There were three blocks representing the three replications. Each block accommodated 46 potato cultivars for with and without Zn treatments.

**Methodology:** The size of each unit plot was 30 m x 2.5 m. The plots were surrounded by 30 cm wide and 10 cm high earthen bunds. One-meter wide irrigation channel was made in-between two blocks. Row to row distance was 60 cm and plant to plant was 25 cm. Each variety had 10 plants placed in a single line and therefore a total of 46 lines for control(no zinc fertilization) and 46 lines for Zn (8 kg Zn ha-1) were accommodated in each block. Four plants from each line were tagged for recording data.

**Results:** The Zn concentrations in tuber markedly varied with varieties showing a remarkable ability of some potato varieties to uptake and accumulate relatively more Zn in tubers. Application of Zn fertilizer had an additive effect on the tuber Zn concentration with an increase of 8.5 µg g-1 Zn over the varieties. Potato varieties having Zn content ≥ 4 µg g-1 over control were considered responsive varieties to applied Zn. The genetically Zn-enriched varieties having above 24 µg g-1 tuber-Zn identified were BARI (Bangladesh Agricultural Research Institute) Alu-7 (Diamant), BARI Alu-13 (Granola), BARI Alu-21, BARI Alu-25 (Asterix), BARI Alu-53 and BARI Alu-73 among 46. These varieties can be regarded as Zn-efficient potato varieties, which would serve as breeding materials for developing potential high-yield varieties with higher tuber Zn content. 9-19% tuber yield and 10-117%tuber Zn concentration increased over control under study.

**Conclusion:** The ranges of micronutrient concentrations reported indicate ample genetic diversity that might be exploited in breeding programs seeking to increase Zn levels in human diets.

**Keywords:** screening, BARI, Alu(potato), genetic diversity, biofortification;

**1. Introduction**

Potato (*Solanum tuberosum* L.) ranks just behind the cereals rice and wheat and achieved 3rd position among the food crops worldwide (Birch et al*.*, 2012). It is the staple food of more than 40 countries worldwide. More than a billion people in the world eat potatoes regularly (Kromann et al., 2017); hence, one of the main sources of Zn to humans (Mengist et al.*,* 2018). Micronutrient deficiency is a global health concern (Gold et al. 2022) and needs immediate attention. Over two billion people across the world suffer from micronutrient malnutrition (Praharaj et al*.* 2021). Around one third of the world population lives in countries with a high prevalence of zinc deficiency. 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). 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 mgperson-1 day-1). Zinc (Zn) deficiency is one of the emerging threats of the world population and the situation is more severe in Bangladesh. An estimated 44.6% of preschool-age children are at risk of Zn deficiency, while 57% of non-pregnant and non-lactating women is deficient in Zn (Rahman *et al*., 2016). It is estimated that about one-fifth to one-third of the world's population is zinc (Zn) deficient (Muthayya et al*.*, 2013).

About 25% of the world’s population is considered to be zinc (Zn)-deficient (Allai et al. 2022). 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 (Rahman et al*.*, 2016). In humans, Zn deficiency can cause reduced immune and reproductive function (Younas et al. 2023), impaired brain function (Hambidge, 2000), physical retardation (Prasad 2015), and stunted growth (Khan et al. 2022), which is now a major health problem 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.

Zinc concentration in fruits, seeds, grains, and tubers is severely limited (White and Broadley, 2011). Therefore, the traditional and efficient strategy of agronomic biofortification, such as Zn fertilization, is a safe and rapid solution for improving Zn concentration in potato tubers to address the ongoing human Zn deficiency. Potato tubers are inherently low in Zn concentration and bioavailability, particularly when grown on Zn-deficient soils. In the present study, Zn fertilization in soil significantly increased tuber yield and tuber Zn concentration over control (no Zn fertilization).Tuber Zn concentration can be increased by Zn-fertilization in soil (Kromann et al., 2017).Agronomic biofortification can be an economically sustainable and practically acceptable solution to solve Zn deficiency in potatoes (Mahmud et al., 2021; Sarkar et al., 2018). 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 in different areas of the world.

**2. Materials and Methods**

#### The experiment was conducted during November 2018 to February 2019at the Horticulture Farm, Bangladesh Agricultural University (BAU), Mymemsingh, Bangladesh.

2.1 Potato varieties and field trial with Zn application in soil

The seed tubers were collected from Bangladesh Agricultural Research Institute (BARI), Debigonj, Panchagor, Bangladesh and Bangladesh Agricultural Development Corporation (BADC), Jamalpur, Bangladesh. The seed tubers (grade A, i.e., 28-41 mm in diameter) were kept under diffused light conditions for sprouting. Well-sprouted seed tubers were planted in the experimental field. The seed tubers were treated with Autostin (soaked in @ 2 g L-1 fresh water). The cuttings were exposed to the sunlight for a few minutes. The cut tubers were planted in the field just after removing the surface moisture. The experiment involved 46 potato varieties that were tested for screening Zn enriched potato cultivars with high yielding potentials are listed in Table 1. The two factors experiment consists of i) without Zn application (control) and ii) with Zn application @ 8 kg Zn ha-1 in soil.

2.2 Experimental Design

The field trial investigating the role of soil application of Zn fertilizer on the concentration of Zn in edible parts of potato was conducted during November 2018 to February 2019 under study. In order to find out the effect of zinc on 46 potato genotypes at BAU condition, an experiment was laid out in the Randomized Complete Block Design (RCBD) with 3 replications. There were 3 blocks representing 3 replications. Each block had two unit plots accommodating 46 potato cultivars with and without Zn treatments. The size of each unit plot was 30 m x 2.5 m. The plots were surrounded by 30 cm wide and 10 cm high earthen bunds. One-meter wide irrigation channel was made in-between two blocks.

Table 1. List of 46 potato varieties used in the experiment during 2018-2019

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Varietal code in the experiment** | **Name of variety** | **Varietal code in the experiment** | **Name of variety** | **Varietal code in the experiment** | **Name of variety** |
| V1 | BARI Alu-74 | V17 | ARI Alu-54 | V33 | BARI Alu-13 |
| V2 | BARI Alu-71 | V18 | BARI Alu-55 | V34 | BARI Alu-64 |
| V3 | BARI Alu-44 | V19 | BARI Alu-37 | V35 | BARI Alu-51 |
| V4 | BARI Alu-22 | V20 | BARI Alu-26 | V36 | BARI Alu-23 |
| V5 | BARI Alu-35 | V21 | BARI Alu-8 | V37 | BARI Alu-77 |
| V6 | BARI Alu-32 | V22 | BARI Alu-70 | V38 | BARI Alu-36 |
| V7 | BARI Alu-25 | V23 | BARI Alu-46 | V39 | BARI Alu-40 |
| V8 | BARI Alu-7 | V24 | BARI Alu-78 | V40 | BARI Alu-17 |
| V9 | BARI Alu-66 | V25 | BARI Alu-76 | V41 | BARI Alu-31 |
| V10 | BARI Alu-72 | V26 | BARI Alu-5 | V42 | BARI Alu-63 |
| V11 | BARI Alu-53 | V27 | BARI Alu-4 | V43 | BARI Alu-21 |
| V12 | BARI Alu-28 | V28 | BARI Alu-79 | V44 | BARI Alu-6 |
| V13 | BARI Alu-41 | V29 | BARI Alu-75 | V45 | BARI Alu-62 |
| V14 | BARI Alu-73 | V30 | BARI Alu-27 | V46 | BARI Alu-12 |
| V15 | BARI Alu-61 | V31 | BARI Alu-56 |  |  |
| V16 | BARI Alu-29 | V32 | BARI Alu-52 |  |  |

Row to row distance was 60 cm and plant to plant was 25 cm. Each variety had 10 plants placed in a single line and therefore a total of 46 lines for control (no Zn fertilization) and 46 lines for Zn (@ 8 kg Zn ha-1) were accommodated in each block. Five plants from each line were tagged for recording data collection.

2.3 Determination of dry matter and mineral concentration

Potato tubers (peeled) were washed in running water followed by distilled water, prepared, oven-dried at 700 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); the current standard method used by Agri varsity Humboldt Soil Testing Laboratory for Management of Soils and Water, Department of Soil Science, BAU, Mymemsingh, Bangladesh. Finally, the acid-digested plant samples were analyzed in the Atomic Absorption Spectrophotometer (AAS) for Zn content (µg g-1) in Soil Resources Development Institute (SRDI)’s Laboratory for Management of Soils and Water in Dhaka, Bangladesh.

2.4 Statistical Analysis

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). When significant differences were found in ANOVA, means were compared using Tukey's test at P ≤ 0.05. Multiple treatment comparisons were made using orthogonal contrasts. The analysis of variance (General Linear Model procedure) and Tukey’s pair wise comparison test by Duncan’s Multiple Range Test (DMRT) at a 5% level of probability, according to Gomez and Gomez (1984). Atypical data were treated as missing values in the statistical analysis.

**3. Results and Discussions**

Biofortification is a biological process by which the nutritional quality of food crops is improved through conventional plant breeding, modern biotechnology or agronomic management practices. The aim of this research was to screen the potato cultivars upon Zn uptake status of the potato tubers through Zn application in soil with increasing or without affecting crop yield by using 46 varieties.

This study showed that simple fertilizer practices enhancing Zn supply to potato plants can increase the Zn concentration of potato tuber flesh. The experiment showed a statistically significant effect of Zn fertilization in soil on tuber Zn concentration. The Zn rate tested in the field experiment resulted in increases of tuber Zn without affecting tuber yield negatively. The results reveal that potato varieties can be agronomically Zn-biofortified with Zn fertilizers.

The field trial with Zn fertilizer exhibited a significant effect of the Zn fertilizer treatment on tuber Zn concentrations (Table 4). Soil chemical factors such as low pH in the BAU soils, and potato genotypic factors, may be some of the reasons for the good effectiveness of the soil Zn treatment in this experiment. The experiment conducted at the Horticulture Farm, BAU, Mymensingh, resulted in a 1.69-fold (average value) tuber Zn increase over control from soil Zn applications @ 8 kg Zn ha-1 (Table 4).

3.1 Genotype effect

The yield of potato tuber varied with varieties which can be attributed to differences in genetic make-up. Genotypes had a significant effect on tuber yield of potato. The tuber yield of potato varied between 19.18 and 35.21 t ha-1 (Table 2) which illustrates a significant varietal effect. In Bangladesh potato cannot be planted year-round; but in winter (November to February), when the average temperature remains 18-220 C at the experimental field area. Experiments were intensively managed with irrigation. The potato genotypes that showed high tuber Zn concentrations in the absence of Zn fertilization also showed in Table 2 even higher tuber Zn concentrations following Zn fertilization (Table 4).

The Zn concentration of potato tuber varied with the varieties to a small to large extent. As recorded in the present experiment, the tuber Zn concentration of potato tubers ranged from 8.43–24.98 µg g-1 (Table 2). Statistical analysis of data showed that different varieties had significant effect on Zn content of potato tubers. Considering all the varieties, BARI Alu-53 had the highest Zn content (24.98 µg g-1) whereas BARI Alu-74 had the lowest Zn content (8.43 µg g-1), being average 16.49 µg g-1 Zn. When the tuber Zn concentrations of two treatments are pooled, it reveals that the mean Zn concentration lies between 8.43 and 24.98 µg g-1, the mean being 16.49 µg g-1 which is 4.25 µg g-1 higher than the control value (Tables 2 and Table 4). Again, Zn uptake by tubers of potato varied to a great extent among the varieties, BARI Alu-53 had the highest Zn uptake value (180.73 g ha-1) whereas BARI Alu-74 had the lowest Zn uptake (48.82 g ha-1), being average 84.55 g ha-1 Zn (Table 2).

3.2 Agronomic Zn-biofortification of potato tubers with Zn application in soil

The individual ANOVAs of the effect of Zn fertilizer rate on tuber yield revealed a significant effect on Zn application in soil. The Turkey’s ranking (*P* < 0.05) indicated a significant increase of the tuber yield between the control and the Zn treatment of 36 varieties among 46 (Table 4). Combined ANOVAs also revealed a significant effect on tuber yield. Interestingly, no negative effects on tuber yields of the Zn application were seen with the edaphic conditions and fertilizer types of this study. A highly significant effect of Zn fertilizer treatment on yield of potato tubers was recorded in the experiment. The tuber yield of the present trial positively responded to Zn fertilization applied in soil over the forty-six varieties of potato and the increment of tuber yields due to added Zn @ 8 kg ha-1 was found highest in BARI Alu-77 (38.22 t ha-1) followed by variety BARI Alu-53 (37.63 t ha-1) (Table 4). However, the Turkey’s ranking (*p=0.000*) reveals a significant difference in tuber yield of potato that had received Zn fertilizer (Table 4). At about 9-22% yield was increased over control due to added Zn @ 8 kg ha-1in the present study.

Table 2. Effect of variety on tuber yield (t ha-1), tuber Zn conc. (µg g-1) of potato and Zn uptake (g ha-1) by tubers of potato of varietal screening experiment during 2018-19.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variety (BARI released)** | **Yield (t ha-1)** | **Zn concentration (µg g-1)****G G g-1)** | **Zn uptake (g ha-1)** |
| V1 (BARI Alu-74) | 29.16±0.77g-i | 8.43 ± 0.56 l  | 48.82±4.83l |
| V2 (BARI Alu-71) | 23.72±0.66s-v | 16.67 ± 1.04 b-i | 77.57±5.96d-l |
| V3 (BARI Alu-44) (Elgar) | 19.18±0.43 | 14.61 ± 2.26 c-k | 50.84±8.09kl |
| V4 (BARI Alu-22) | 26.1±0.79m-q | 19.63 ± 0.80 a-d | 109.01±7.54b-f |
| V5 (BARI Alu-35) | 23.09±0.81t-v | 19.53 ± 1.67 a-d | 95.85±10.4c-i |
| V6 (BARI Alu-32) (Quincy) | 28.94±0.92g-i | 18.09 ± 1.97 b-e | 98.02±12.4b-i |
| V7 (BARI Alu-25) (Asterix) | 32.72±1.05bc | 20.94 ± 3.28 ab | 136.44±27b |
| V8 (BARI Alu-7) (Diamant) | 28.83±1.12h-j | 20.47 ± 4.02 a-c | 115.35±24.5b-d |
| V9 (BARI Alu-66) (Pamela) | 29.25±0.89f-i | 17.41 ± 1.01 b-g | 94.92±9.39c-j |
| V10 (BARI Alu-72) | 21.69±0.74v | 16.23 ± 1.60 b-j | 75.86±11d-l |
| V11 (BARI Alu-53) | 34.4±1.49ab | 24.98 ± 4.26 a | 180.73±38.6a |
| V12 (BARI Alu-28) (Lady Rosetta) | 25.88±0.78n-r | 17.45 ± 0.96 b-g | 95.06±13.2c-j |
| V13 (BARI Alu-41) | 26.43±1.08k-p | 19.09 ± 1.28 a-e | 96.72±7.92 c-i |
| V14 (BARI Alu-73) | 31.89±1.21c-e | 20.92 ± 3.49 ab | 127.85±27.8bc |
| V15 (BARI Alu-61) (Bhalumia) | 27.67±0.8i-n | 18.79 ± 1.62 b-e | 91.91±11.6c-k |
| V16 (BARI Alu-29) (Courage) | 26.82±0.79j-o | 16.43 ± 1.22 b-j | 92.24±10.9c-k |
| V17 (BARI Alu-54) (Musica) | 28.3±1h-k | 12.13 ± 2.11 g-l | 52.98±8.02j-l |
| V18 (BARI Alu-55) (Red Fantacy) | 30.93±0.87c-g | 12.15 ± 1.19 g-l | 68.23±8.97g-l |
| V19 (BARI Alu-37) | 31.56±0.92c-e | 10.65 ± 1.57 j-l | 71.02±11.9f-l |
| V20 (BARI Alu-26) (Falcina) | 24±0.83r-v | 19.24 ± 0.82 a-d | 82.18±5.94d-l |
| V21 (BARI Alu-8) (Cardinal) | 31.23±0.96c-f | 17.59 ± 0.61 b-g | 113.74±8.22b-d |
| V22 (BARI Alu-70) (Destiny) | 21.55±1.24 | 19.20 ± 2.11 a-d | 68.53±9.74g-l |
| V23 (BARI Alu-46) | 28.19±0.92h-l | 17.03 ± 2.57 b-h | 98.74±18.7b-i |
| V24 (BARI Alu-78) | 25.13±1.14o-t | 12.26 ± 2.15 f-l | 62.90±14h-l |
| V25 (BARI Alu-76) | 24.39±0.64p-u | 18.95 ± 1.86 b-e | 86.44±11.7d-l |
| V26 (BARI Alu-5) (Patronis) | 24.28±0.6q-u | 18.07 ± 1.26 b-f | 97.11±8.17b-i |
| V27 (BARI Alu-4) (Aylsa) | 23.08±0.54uv | 17.49 ± 1.52 b-g  | 70.76±7.15f-l |
| V28 (BARI Alu-79) | 24.78±0.77o-u | 17.26 ± 2.62 b-g | 79.97±14.4d-l |
| V29 (BARI Alu-75) | 24.55±0.74p-u | 14.46 ± 1.22 d-k | 64.89±5.12g-l |
| V30 (BARI Alu-27) (Spirit) | 29.57±0.7e-i | 17.18 ± 1.29 b-g | 77.96±9.74d-l |
| V31 (BARI Alu-56) | 31.34±0.98c-e | 9.87 ± 2.30 kl | 62.48±16.7i-l |
| V32 (BARI Alu-52) (Labadia) | 23.75±0.58s-v | 18.08 ± 1.94 b-f | 79.02±12.2d-l |
| V33 (BARI Alu-13) (Granola) | 26.15±0.64l-q | 21.30 ± 4.55 ab | 102.12±23b-h |
| V34 (BARI Alu-64) (Folva) | 28.08±0.93i-m | 10.79 ± 2.84 i-l  | 56.16±16i-l |
| V35 (BARI Alu-51) (Belarosa) | 25.54±1.15o-s | 12.49 ± 4.05 f-l  | 60.49±20.8i-l |
| V36 (BARI Alu-23) (Ultra) | 24.2±0.78q-v | 11.24 ± 3.59 h-l | 48.95±16.5l |
| V37 (BARI Alu-77) (Serpomira) | 35.21±1.39a | 15.66 ± 2.44 b-k | 110.91±22.1b-e |
| V38 (BARI Alu-36) | 28.87±1.28hi | 11.90 ± 3.13 g-l | 71.44±21.5e-l |
| V39 (BARI Alu-40) | 28.39±1.11h-k | 14.10 ± 3.53 d-l | 72.85±20.8e-l |
| V40 (BARI Alu-17) (Raja) | 23.13±0.51t-v | 13.24 ± 3.48 e-l | 61.80±17i-l |
| V41 (BARI Alu-31) (Sagita) | 23.91±0.87r-v | 19.57 ± 1.24 a-d | 93.65±10.2c-j |
| V42 (BARI Alu-63) | 29.25±0.93f-i | 15.62 ± 1.41 b-k | 82.92±9.57d-l |
| V43 (BARI Alu-21) (Provento) | 22.19±0.79uv | 17.54 ± 3.62 b-g | 62.01±12.7i-l |
| V44 (BARI Alu-6) (Multa) | 21.52±1.06 | 17.28 ± 2.29 b-g | 87.30±15.6d-l |
| V45 (BARI Alu-62)  | 30.2±1d-h | 16.98 ± 2.89 b-h | 99.33±18.5b-i |
| V46 (BARI Alu-12) (Dhira) | 26.22±1.24l-q | 19.46 ± 0.64 a-d | 107.00±13b-g |
| LSD0.05 | 1.00 \*\* | 3.10 \* | 19.37 \* |
| LSD0.01 | 1.32 \*\* | 4.11 \*\* | 25.53 \*\* |
| Level of significance | \*\* | \*\* | \*\* |
| **Max** | **35.21** | **24.98** | **180.73** |
| **Min** | **19.18** | **8.43** | **48.82** |
| **Mean** | **26.85** | **16.49** | **84.55** |

Means within a column followed by the same letter are not significantly different (p<0.05); \*\* = Significant at 1% level of probability and \*=significant at 5% level of probability; LSD for combined effect.

The present results agree with Banerjee et al. (2016) who conducted a field experiment at Kakdwip, South 24-Parganas, West Bengal, India during 2013-14 and 2014-15 to assess the Zn requirements of potatoes on a new alluvial soil (Entisol). They found an increase in tuber yield with increasing Zn dose up to 4.5 kg ha-1 in soil. Sarkar *et al.* (2018) observed that Zn fertilization produced higher tuber yield of potatoes and higher tuber Zn concentration. Brahmachari et al. (2010) also recorded a 9.2% yield increment for using Zn-fortified seeds. Mahmud et al*.* (2021) reported that soil application of Zn resulted in a significant increase in tuber yield with an increase in Zn concentration in potatoes. The same result applies to a study where the potato tuber seeds collected from the Zn-treated plots, gave better results regarding tuber yield and tuber Zn concentration. It is particularly important for Zn-deficient soil (Cakmak, 2010).

Dwivedi and Dwivedi (1992) showed that 10 kg ZnSO4 ha-1 was adequate to increase potato tuber yield and starch content. They concluded that starch content in potato tuber was affected not only by Zn-rate but also by the method of Zn application. In their study, starch content of tuber was significantly affected by soil application (10 kg ZnSO4 ha-1) as well as seed soaking with Zn (R2=0.602). 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 increase in tuber yield due to Zn fertilization might be because Zn played a vital role in the biosynthesis of the IAA (Indole-3 Acetic Acid) and initiation of primordia for reproductive parts a result of the favorable effect of zinc on the metabolic reactions within the plants. However, such an investigation was not done in the present study. 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.,* 2010). 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).

There was a positive significant effect of Zn fertilization on tuber Zn concentration of potato, although the magnitude varied with varieties (Table 4). A highly significant effect of Zn fertilizer treatment on tuber Zn concentration of peeled potato tubers was detected in the experiment. The data revealed that a significant increase in Zn concentration was found in tubers. The increment of tuber Zn concentration due to added Zn @ 8 kg ha-1 in soil was found highest in BARI Alu-53 (34.37 µg g-1) (Table 4). However, the Turkey’s ranking reveals a significant difference in tuber Zn concentrations that had received Zn fertilizer (Table 4). A highly significant effect of Zn fertilizer treatment was found Zn concentration under study. Individual varietal response in Zn concentration increase of potato tubers have also been shown in Table 5 with Zn application. The highest % (376.67) of Zn concentration increased over control was obtained in BARI Alu-51 and the lowest (11.81%) was obtained in BARI Alu-12 (Table 4). On an average, the tuber Zn concentration was increased to an extent of 12.24 - 20.74 µg g-1 across the genotypes under study. Practically, Zn fertilization had an effect on tuber Zn concentration of potato. 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 soil applied Zn fertilizers; zinc rates @ 8 kg ha-1 applied in soil reached a 1.91-fold tuber Zn increase in the field trials. The results conform to those of Phattarakul et al. (2012) reported that soil Zn application is effective in Zn biofortification of food crops.

Murmu et al*.*(2014) also reported from their study that Zn loading in potato through soil-applied Zn, increases Zn concentration in potato tuber up to 3-4 times (30-40 mg Zn kg-1 of dry matter) which is quite higher than most of the commonly known fruit crops. These findings agree with Mahmud et al. (2021) who reported from their study that soil application of Zn resulted in a significant increase of tuber yield with an increase of Zn concentration in potato tuber.

Table 3. Effects of Zn application on tuber yield (t ha-1) of different genotypes of potato in varietal screening experiment at Horticulture farm, BAU, during 2018-19

|  |  |  |  |
| --- | --- | --- | --- |
| **Variety** | **Control****(no Zn fertilization)** | **Zn application** **@ 8 kg ha-1** | **% increase in yield** |
|  V1 (BARI Alu-74) | 27.54± 0.50 o-t | 30.78±0.33 e-n | 11.76 |
|  V2 (BARI Alu-71) | 22.39±0.31 | 25.04±0.58 | 11.84 |
| V3 BARI Alu-44) | 18.35±0.48 | 20.01±0.01 | 9.05 |
| V4 BARI Alu-22) | 24.43±0.34 | 27.78±0.42 n-t | 13.71 |
| V5 (BARI Alu-35) | 21.54±0.61 | 24.63±0.73 | 14.35 |
| V6 (BARI Alu-32) | 27.06±0.40 p-t | 30.88±0.70 e-n | 14.12 |
| V7 (BARI Alu-25) | 30.41±0.36 e-o | 35.03±0.14 bc | 15.19 |
|  V8 (BARI Alu-7) | 26.42±0.49 q-t | 31.24±0.40 e-k | 18.24 |
| V9 (BARI Alu-66) | 27.31±0.33 o-t | 31.19±0.33 e-l | 14.21 |
| V10(BARI Alu-72) | 20.21±0.45 | 23.16±0.60 | 14.60 |
| V11 (BARI Alu-53) | 31.16±0.58 e-m | 37.63±0.56 ab | 20.76 |
| V12 (BARI Alu-28) | 24.21±0.34 | 27.54±0.42 o-t | 13.75 |
| V13 (BARI Alu-41) | 24.12±0.43 | 28.75±0.55 j-t | 19.20 |
| V14 (BARI Alu-73) | 29.33±0.58 h-q | 34.46±0.63 cd | 17.49 |
| V15 (BARI Alu-61) | 26.04±0.32 t | 29.31±0.61 hq | 12.56 |
| V16 (BARI Alu-29) | 25.12±0.37 | 28.52±0.28 j-t | 13.54 |
| V17 (BARI Alu-54) | 26.18±0.25 r-t | 30.43±0.61 e-o | 16.23 |
| V18 (BARI Alu-55) | 29.09±0.59 i-t | 32.77±0.33 c-g | 12.65 |
| V19 (BARI Alu-37) | 29.78±0.79 g-p | 33.34±0.65 c-e | 11.95 |
| V20 (BARI Alu-26) | 22.23±0.50 | 25.77±0.27 vw | 15.92 |
|  V21 (BARI Alu-8) | 29.29±0.61 h-r | 33.16±0.71 c-f | 13.21 |
| V22 (BARI Alu-70) | 19.44±0.44 | 23.66±1.75 | 21.71 |
| V23 (BARI Alu-46) | 26.25±0.27 q-t | 30.12±063 f-p | 14.74 |
| V24 (BARI Alu-78) | 22.68±0.55 | 27.57±0.49 n-t | 21.56 |
| V25 (BARI Alu-76) | 23.06±0.46 | 25.73±0.18 vw | 11.58 |
|  V26 (BARI Alu-5) | 23.13±0.36 | 25.44±0.57 w | 9.99 |
|  V27 (BARI Alu-4) | 22.06±0.64 | 24.09±0.02 | 9.20 |
| V28 (BARI Alu-79) | 23.14±0.34 | 26.42±0.36 q-t | 14.17 |
| V29 (BARI Alu-75) | 23.03±0.15 | 26.07±0.61 st | 13.20 |
| V30 (BARI Alu-27) | 28.14±0.39 k-t | 30.99±0.54 e-m | 10.13 |
| V31 (BARI Alu-56) | 29.19±0.16 h-s | 33.49±0.44 c-e | 14.73 |
| V32 (BARI Alu-52) | 22.68±0.66 | 24.83±0.30 | 9.48 |
| V33 (BARI Alu-13) | 24.85±0.53 | 27.45±0.32 o-t | 10.46 |
| V34 (BARI Alu-64) | 26.03±0.08 t | 30.13±0.33 f-p | 15.75 |
| V35 (BARI Alu-51) | 23.03±0.08 | 28.05±0.54 m-t | 21.80 |
| V36 (BARI Alu-23) | 22.61±0.64 | 25.79±0.26 u-w | 14.06 |
| V37 (BARI Alu-77) | 32.19±0.09 c-i | 38.22±0.70 a | 18.73 |
| V38 (BARI Alu-36) | 26.10±0.40 st | 31.63±0.66 d-j | 21.19 |
| V39 (BARI Alu-40) | 26.05±0.75 t | 30.72±0.36 e-n | 17.93 |
| V40 (BARI Alu-17) | 22.09±0.32 | 24.17±0.36 | 9.42 |
| V41 (BARI Alu-31) | 22.15±0.39 p-t | 25.68±0.70 vw | 15.94 |
| V42 (BARI Alu-63) | 27.17±1.00 p-t | 31.32±0.08 e-j | 15.27 |
| V43 (BARI Alu-21) | 20.54±0.38 | 23.85±0.47 | 16.11 |
|  V44 (BARI Alu-6) | 19.37±0.70 | 23.67±0.71 | 22.20 |
| V45 (BARI Alu-62) | 28.09±0.28 l-t | 32.31±0.65 c-h | 15.02 |
| V46 (BARI Alu-12) | 23.57±0.32 | 28.87±0.72 j-t | 22.49 |
| **Max** | **32.19** | **38.22** | **22.49** |
| **Min** | **18.35** | **20.01** | **9.05** |
| **mean** | **24.98** | **28.73** | **-** |
| LSD0.05 | - | 1.42\* | - |
| LSD0.01 | - | 1.87\*\* | - |

Values in the same column followed by same letter are not significantly different according to Tukey’s test (*p<0.05)*; \*\* indicates 1% level of probability and \* indicates 5% level of probability; LSD for combined effect.

Soil-applied Zn is, however, limited depending on soil properties and inherent Zn status in the upper soil layer (Sawickaet al., 2016). The efficacy of soil-applied fertilizer largely depends on the soil environment (pH, moisture content, soil organic matter, presence of antagonistic nutrients etc.) and ability of plant to successfully absorb the nutrients. The potato varieties that showed high tuber Zn concentrations in the absence of Zn fertilization (Table 2) also showed correspondingly higher tuber Zn concentration following soil applied Zn (Table 4). 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). Zinc sulphate has been widely used to biofortify crops with Zn (White and Broadley, 2011; Velu et al. 2014). The various forms of Zn fertilizer and ways of applying to the potato crop may influence the efficiency of uptake and translocation to tubers differently. In our experiment we used zinc sulphate fertilizer because it is commonly used and readily available in Bangladesh, with the objective to study fertilizer effects more likely to be taken up and translocated to tubers. For practical recommendations on agronomic biofortification of potato with Zn additional studies are needed to define economic optimal compounds, application methods and rates.

Considering the low soil Zn level in Bangladesh soils that appear to be a major factor causing low human Zn intake, agronomic Zn biofortification of potato may prove to be an important approach to improve the critical human Zn status in Bangladesh. 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 soil Zn supplied when sufficient Zn was available to the plants. This suggests a proper combination of N and Zn applications.

The tuber Zn concentrations of commonly used potato varieties need to be improved to fulfill the Zn requirement for the people in Bangladesh as well as other zinc deficient population in the world. Zinc concentration in potato tubers can be enriched by: i) biofortification with Zn fertilizers (Kromann et al*.,* 2017), ii) efficient germplasm screening for higher bioavailable Zn (Haynes et al*.*, 2012). All these methods depend on fertilizer or the soil or both as the source of Zn to produce Zn enriched tubers. Soil-supplied Zn is, however, limited depending on soil properties and inherent Zn status in the upper soil layer (Sawicka et al., 2016). A strategy of combined approaches supporting the synergy between genetic and agronomic biofortification could ensure a wider value of both approaches. Future research should aim at determining economic optimum Zn rates. Zn fertilizer types and application methods, e.g. in combination with fungicide sprays to reduce the cost of application, considering significant residual effects from soil applications and the potential high synergy between Zn accumulating varieties and Zn application. Systematic survey and mapping of plant available soil Zn concentrations across the potato growing countries and other areas with apparent low soil Zn levels would aid the identification of areas with high potential for impact from Zn biofortification.

A highly significant effect of Zn fertilizer treatment was found Zn uptake by tubers in the field trial (Table 2). The Zn uptake by tubers of potato genotypes ranged from 13.72–101.28 g ha-1 in control plots and 56.69–264.55 g ha-1 in Zn treated plots (Table 4). The highest Zn uptake (264.55 g ha-1) was obtained in BARI Alu-53 and the lowest in (56.69 g ha-1) obtained in BARI Alu-74 under Zn treated condition. The average Zn uptake by tubers over the 46 genotypes was noted as 113.26 g ha-1 when Zn was applied to soil; on the other hand, the Zn uptake by tubers was 58.33 g ha-1 in unfertilized control plots. The highest percentage of Zn uptake increase in Zn treated condition over control (513.56%) was obtained in BARI Alu-23, while the lowest (22.62%) was found in BARI Alu-4 (Table 4).

Table 4. Individual varietal responses in Zn concentration (µg g-1)and Zn uptake(g ha-1) increase of potato tubers with Zn application in varietal screening experiment

|  |  |  |
| --- | --- | --- |
| **Variety** | **Zn concentration (µg g-1)** | **Zn uptake (g ha-1)** |
| **with Zn application** | **without Zn application** | **% increase over control** | **with Zn** | **without Zn** | **% increase over control** |
| V1 (BARI Alu-74) | 9.38±0.43 t-u | 7.48±0.71 w | 25.40 | 56.69±6.04 n-v | 40.94±4.25 q-v | 38.47 |
| V2 (BARI Alu-71) | 18.59±1.27 f-s | 14.74±0.37 g-u | 26.12 | 86.81±6.03 g-v | 68.18±7.48 j-v | 27.32 |
| V3 (BARI Alu-44) | 18.64±2.89 f-s | 10.58±1 q-u | 76.18 | 66.21±6.57 j-v | 35.47±6.90 t-v | 86.66 |
| V4 (BARI Alu-22) | 20.95±1.1 c-m | 18.32±0.5 f-t | 14.36 | 122.26±7.26 d-k | 95.76±7.49 f-t | 27.67 |
| V5 (BARI Alu-35) | 22.2±1.26 c-j | 17.1±2.54 f-t | 29.82 | 117.55±6.66 d-m | 74.14±5.19 i-v | 58.55 |
| V6 (BARI Alu-32) | 21.74±0.7 c-j | 14.44±2.37 g-u | 50.55 | 114.83±8.27 d-p | 81.22±20.3 g-v | 41.38 |
| V7 (BARI Alu-25) | 28.07±0.82 a-e | 13.81±1.52 h-u | 103.26 | 195.65±9.40 b | 77.22±7.87 h-v | 153.37 |
| V8 (BARI Alu-7) | 29.41±0.57 a-c | 11.54±0.76 n-u | 154.85 | 170.03±2.80 b-d | 60.67±1.96 l-v | 180.25 |
| V9 (BARI Alu-66) | 19.58±0.21d-q | 15.24±0.57 g-u | 28.48 | 113.86±5.72 d-p | 75.98±7.05 h-v | 49.86 |
| V10 (BARI Alu-72) | 19.08±1.88 e-r | 13.39±1.11 i-u | 42.49 | 94.56±14.90 f-u | 57.15±6.01 m-v | 65.46 |
| V11 (BARI Alu-53) | 34.37±0.96 a | 15.58±1.26 g-u | 120.60 | 264.55±19.6 a | 96.91±6.16 f-s | 172.99 |
| V12 (BARI Alu-28) | 19.08±1.07 e-r | 15.83±0.88 g-u | 20.53 | 115.67±20.0 d-o | 74.46±7.32 h-v | 55.35 |
| V13 (BARI Alu-41) | 21.51±1.01 c-l | 16.67±1.13 f-u | 29.03 | 112.81±4.81 d-p | 80.63±5.61 g-v | 39.91 |
| V14 (BARI Alu-73) | 28.36±1.97 a-d | 13.49±1.36 i-u | 110.23 | 182.98±25.7 bc | 72.71±12.8 j-v | 151.66 |
| V15 (BARI Alu-61) | 21.68±1.21 c-j | 15.9±1.83 g-u | 36.35 | 114.82±6.55 d-p | 68.99±9.97 j-v | 66.43 |
| V16 (BARI Alu-29) | 18.67±0.93 f-s | 14.19±1.25 g-u | 31.57 | 122.44±12.8 d-p | 72.03±4.82 j-v | 69.98 |
| V17 (BARI Alu-54) | 16.27±2.11 f-u | 7.99±0.88 u | 103.63 | 68.95±7.72 j-v | 37.01±2.57 s-v | 86.30 |
| V18 (BARI Alu-55) | 14.58±1.05 g-u | 9.72±0.16 s-u | 50.00 | 86.76±6.11 g-v | 49.69±4.61 q-v | 74.60 |
| V19 (BARI Alu-37) | 13.64±0.96 i-u | 7.65±1.55 vw | 78.30 | 94.14±2.54 f-u | 47.91±11.1 q-v | 96.49 |
| V20 (BARI Alu-26) | 20.54±0.8 c-n | 17.94±0.99 f-t | 14.49 | 92.49±2.56 j-v | 71.87±2.56 j-v | 28.69 |
| V21 (BARI Alu-8) | 18.71±0.53 f-s | 16.48±0.59 f-u | 13.53 | 126.19±13.0 c-j | 101.28±3.52 e-r | 24.60 |
| V22(BARIAlu-70) | 23.42±1.22 b-g | 14.98±1.7 g-u | 56.34 | 88.28±7.45 g-v | 48.77±5.35 q-v | 81.01 |
| V23 (BARI Alu-46) | 22.67±0.86 b-h | 11.39±0.77 o-u | 99.03 | 139.13±10.21 b-g | 58.35±4.59 m-v | 138.44 |
| V24 (BARI Alu-78) | 16.72±1.68 f-u | 7.80±0.57 vw | 114.36 | 93.54±5.66 f-u | 32.26±2.62 uv | 189.96 |
| V25 (BARI Alu-76) | 22.2±2.61 c-i | 15.71±0.03 g-u | 41.31 | 105.95±17.3 e-q | 66.92±0.45 j-v | 58.32 |
| V26 (BARI Alu-5) | 20.35±0.93 d-o | 15.79±1.36 g-u | 28.88 | 107.75±7.06 e-q | 86.47±13.1 g-v | 24.61 |
| V27 (BARI Alu-4) | 20.47±0.56 c-n | 14.51±1.54 g-u | 41.08 | 77.95±12.4 h-v | 63.57±7.014 k-v | 22.62 |
| V28 (BARI Alu-79) | 22.28±2.88 c-i | 12.23±0.85m-u | 82.17 | 104.14±20.5 e-q | 55.79±5.81 o-v | 86.66 |
| V29 (BARI Alu-75) | 16.35±0.88 f-u | 12.57±1.78 l-u | 30.07 | 74.12±1.12 i-v | 55.66±6.70 o-v | 33.17 |
| V30 (BARI Alu-27) | 19.76±1.15 d-r | 14.59±0.58 g-u | 35.44 | 91.83±14.1 g-v | 64.09±9.17 k-v | 43.28 |
| V31 (BARI Alu-56) | 14.44±1.77 g-u | 5.30±1.58 | 172.45 | 95.97±14.6 f-s | 28.99±8.15 | 231.05 |
| V32 (BARI Alu-52) | 21.51±2.44 c-l | 14.7±1.21 g-u | 46.33 | 95.23±16.3 f-u | 62.81±14.9 k-v | 51.62 |
| V33 (BARI Alu-13) | 31.41±0.99 ab | 11.2±0.69 p-u | 180.45 | 152.95±6.29 b-f | 51.29±3.53 q-v | 198.21 |
| V34 (BARI Alu-64) | 16.85±1.67 f-u | 4.72±0.96 | 256.99 | 90.87±6.16 g-v | 21.44±5.6 | 323.83 |
| V35 (BARI Alu-51) | 20.64±3.67c-m | 4.33±1.45 | 376.67 | 102.76±18.1 e-q | 18.22±6.25 | 464.00 |
| V36 (BARI Alu-23) | 18.99±2.1 f-r | 5.30±1.58 | 258.30 | 84.18±11.0 g-v | 13.72±0.4 | 513.56 |
| V37 (BARI Alu-77) | 20.97±1.05c-m | 10.35±0.65 r-u | 102.61 | 159.25±7.47 b-e | 62.9±7.60 k-v | 153.18 |
| V38 (BARI Alu-36) | 18.39±2.21 f-s | 5.42±1.39 | 239.30 | 116.31±15.7 d-m | 26.56±6.48 | 337.91 |
| V39 (BARI Alu-40) | 21.57±2.07 c-l | 6.62±1.46 | 225.83 | 115.96±16.0 d-o | 29.74±7.19 | 289.91 |
| V40 (BARI Alu-17) | 20.98±0.71c-m | 5.50±0.09 | 281.45 | 99.32±5.42 e-r | 24.29±0.78 | 308.89 |
| V41 (BARI Alu-31) | 21.61±1.1 c-k | 17.53±1.53 f-t | 23.27 | 113.66±3.89 d-p | 73.65±10.2 j-v | 54.32 |
| V42 (BARI Alu-63) | 18.24±1.14 f-t | 12.99±1.33 j-u | 40.42 | 102.42±2.64 e-q | 63.43±8.42 k-v | 61.47 |
| V43 (BARI Alu-21) | 25±2.33 b-f | 10.08±2.1 r-u | 148.02 | 88.78±4.58 g-v | 35.25±8.11 t-v | 151.86 |
| V44 (BARI Alu-6) | 21.92±2 c-j | 12.64±0.91 k-u | 73.42 | 119.57±12.7 d-l | 55.03±2.90 p-v | 117.28 |
| V45 (BARI Alu-62) | 21.84±4.14 c-j | 12.12±1.01m-u | 80.20 | 134.66±20.30 c-h | 64.01±6.71 k-v | 110.37 |
| V46 (BARI Alu-12) | 20.55±0.31c-m | 18.38±0.87 f-t | 11.81 | 134.91±3.13 c-i | 79.84±10.1 g-v | 68.98 |
| **Max** | **34.37** | **18.38** | **376.67** | **264.55** | **101.28** | **513.56** |
| **Min** | **9.38** | **4.33** | **11.81** | **56.69** | **13.72** | **22.62** |
| **Mean** | **20.74** | **12.24** | **-** | **113.26** | **58.33** | **-** |
| LSD0.05 (combined effect) | 4.38\* | - | - | 27.24\* | - | - |
| LSD0.01 (combined effect) | 5.81\*\* | - | - | 36.11\*\* | - | - |

Mean values with the same letters are not significantly different based on ANOVA followed by a Tukey’s test at *p< 0.05*. \*\* indicates significant at 1% level of probability and \* indicates 5% level of probability.

Soil applied Zn significantly increased Zn uptake by tubers of 46 potato varieties (Table 4). The table also shows that on an average, Zn uptake by tubers increased 1.94-fold over control (no Zn fertilizer) due to soil Zn rate @ 8 kg ha-1. 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 applied in soil.

The tuber Zn concentration status in control plots and Zn treated plots of the varietal screening experiment are graphically presented in Figure 1.

Figure 1 Variation in tuber Zn concentration (µg g-1) of different genotypes of potato as influenced by added Zn in varietal screening experiment; LSD0.05=4.08\* and LSD0.01=5.38\*\* (\*\* indicates significant at 1% level of probability) [vertical bars represent ±SE (standard errors)]; LSD for combined effect

A comparison of the mean Zn concentrations with the mean tuber yields in the field experiment with Zn fertilizer reveal that the micronutrient concentrations in tubers have a positive correlation with tuber yield (Figure 2).

Figure 2 Relationship between tuber yield and tuber Zn concentration (µg g-1) for Zn added effects over control treatment in different varieties of potato.

Again, a comparison of the mean Zn uptake by tubers with the mean tuber yields in the field experiment with Zn fertilizer reveal that the micronutrient uptake by tubers of 46 genotypes of potato has a strong positive correlation with tuber yield (Figure 3).

Figure 3 Relationship between tuber yield and Zn uptake (g ha-1) by tubers for Zn added effects over control treatment in different varieties of potato.

**5. Conclusion**

The experiment was conducted to screen the potato cultivars upon Zn uptake status of the tubers. The genetically Zn-enriched varieties having above 24 µg g-1 tuber-Zn identified were BARI Alu-7 (Diamant), BARI Alu-13 (Granola), BARI Alu-21, BARI Alu-25 (Asterix), BARI Alu-53 and BARI Alu-73 among 46. On an average, the tuber Zn concentration of the experiment was increased to an extent of 12.24 - 20.74 µg g-1 across the genotypes. Since zinc deficiency is highly prevalent in Bangladesh and principally related to inadequate quality of diet, micronutrient management (especially Zn) has received greater attention in potato cultivation practice to combat widespread Zn deficiency. To speed up the breeding efforts in developing genotypes with higher tuber-Zn concentration and to establish an efficient strategy of Zn fertilization in soil for agronomic biofortification, it is important to understand the physiological basis of differences in tuber Zn concentration between potato genotypes. Zn concentrations increased 9 - 22% yield and 10 - 117% tuber over control under study. Zn biofortification with potato tubers will be necessary in the future to fully understand the number of nutrients in the soil plant ecosystem and holds great effects for malnutrition problems in human health, and it can be a potential option for mitigating widespread Zn-driven malnutrition for the world population.

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