

Zinc Biofortification of Mungbean Cultivars through Root and Foliar Zinc Fertilization

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Abstract Zinc (Zn) deficiency in soil limits proper crop growth and yield, and bio-available zinc content in produced food stuffs as required to human nutrition for thoroughgoing physiological functioning and development. So, Zn bio-availability is to be enhanced in food crops through suitable methods where agronomic approach could give a short-term solution. A field investigation was conducted with eight mungbean cultivars with four treatments viz. no Zn (control), soil Zn with 5 kg Zn ha⁻¹, foliar Zn with spraying of 1% aqueous Zn solution on crop foliage at 35 and 50 days after seed sowing, and soil Zn + foliar Zn applications. Plant growth, yield traits and grain yield, and grain Zn contents of all eight cultivars of mungbean were significantly enhanced by Zn treatments. Application of root (soil) Zn was responsible for higher grain yield, while foliage Zn application was beneficial for Zn enrichment in mungbean grain. Irrespective of the mungbean cultivars, the root Zn, foliar Zn, and root Zn plus foliar Zn applications were responsible for about 16, 12 and 25% higher grain yield, 14, 27 and 37% higher grain Zn enrichment, 31, 22 and 47% higher net economic return, and 12, 8 and 16% higher benefit cost ratio, respectively than that at control. A combine Zn application both in root and foliage played a complementary role for ensuring higher grain yield and net economic return on one hand and the greater Zn content in the grains on the other.

Keywords: Agronomic approach, Benefit cost ratio, Grain yield, Micronutrient, Pulse, Zinc enrichment

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1. Introduction

The zinc (Zn) element is indispensable for most physiological functions and resistance activities for sound health, and proper growth and development of plants and animals including people wellbeing [1,2]. Shortfall of Zn results stunted growth of children, illness, immune system dysfunctions, poor reproductive development, adverse pregnancy outcomes, losses of hair, skin and memory, premature deaths, neuro-behavioral disorders, and recently with the failure to recover from COVID-19, and so on [3,4,5]. Pollination and fertilization events in flowers and subsequent reproductive development, and seed germination are regulated by Zn concentration [6]. Its shortfall leads to disease inception and limits plant development, and lowers crop yield and produced goods with inferior quality [5]. Zn reigns over firmness of cell film alignment and thus defense to germ attacks that responsible for ailment in plants [7,8].

Mungbean (*Vigna radiata* L. Wilczek) is a foremost orthodox legume which distinguished by far up protein content (21-31%) as compared to the grains produced from other pulse crops like soybean (18-22% protein) and double the protein content than cereal seed maize (7-10%) [9,10]. Additionally, mungbean protein is highly and

easily digestible than other grain legumes because it has less sulphur containing amino acid like cysteine and methionine [11]. Thus, it is an excellent source of low-price protein and a large population section especially vegetarians and vegans rely on it [12]. Due to its quick growing and short-life span habit, mungbean is easily incorporated in the existing cropping patterns. It has tolerant ability to salinity, drought and as well as excessive soil moisture. Residues of mungbean plant are additionally used as feed and fodder for animals. Due to a leguminous plant, mungbean has ability to fix atmospheric nitrogen to soil through root nodules and add organic matter through subsuming plant residue [13,14]. However, it lacks in adequate Zn content [15] that is a critical dubiety for maintaining hale and hearty human and so necessary effort is crucial if we would like to provide better nutrition through mungbean.

The main barrier to boost mungbean grain with Zn is the low zinc content in soil. Zn deficiency in soil-crop systems is widespread globally [16]. Cereal-based diet and intensive production of such crops with no or otherwise insufficient addition of Zn in soil have led to fall down the zinc content to its critical limit for crop growth. Long-run Zn scantiness in soil lowers vegetative growth, shortens internodes, induces epinasty and reduces leaf size, impairs sexual development, and brings down grain yield and grain Zn concentration [17].

Therefore, mungbean cultivation with proper Zn fertilization not only facilitates production through enhanced crop growth and development but also reinforces the mungbean grain with higher content of Zn. Plants regularly require Zn in a little quantity, although it is yet a pressing concern for their growth and development [18]. Foliar applications of Zn may fix the problem for the plant shortly but they have can't resolve the drawback due to the dearth of Zn in the soil. Thus, application of Zn through both root and foliage use may facilitate the mungbean grain yield with higher concentration of Zn in the seed [19,20,21]. But Haider *et al.* [19,20,21]'s investigations have limited scope to recommend their findings to the widespread application in the field as they mostly used a single cultivar grown in limited number of pots under wire house condition. Thus, an inclusive endorsement from natural field's condition research using a suitable number of mungbean cultivars is required. For doing so, an investigation was carried out to address the hypothesis 'mungbean cultivars have different zinc biofortification potential to root and foliar fertilization of zinc'.

2. Materials and Methods

2.1. Experimental Site

The study was conducted in the Crop Botany Field Laboratory, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh 2202 (24°71'N latitude and 90°42'E longitude at the elevation of 18 meter above the sea level), during the spring and pre-monsoon seasons of 2023 and 2024 to investigate the effect of Zn fertilization through root and foliar application on the growth, yield and grain zinc biofortification, and net economic return of eight cultivars of mungbean (*Vigna radiata* L. Wilczek). The experimental site belongs to the monsoon climatic zone as per the Köppen classification with plenty of rains and moist weather during the months from June to October while minimum rain with dry weather that prevails during rest of the time of the year. The experimental field belongs to the Sonatala Soil Series of gray flood plain soil under the Agro-Ecological Zone 9. The experimental soil having 20.2, 68.4 and 11.4% sand, silt and clay contents, respectively mostly called the silt-loam in texture with below par to poorly-drained permeability. The pH of experimental soil was 6.32 having 1.36, 0.08 and 0.07% organic matter, total nitrogen and exchangeable potassium, respectively. The experimental soil contained 12, 18, 1, 0.17 and 0.15 ppm available P, S, Zn, B and Mo, respectively, prior to conduct the investigation.

2.2. Experimental Design and Treatments

In each year, the experiment having 16 treatment combinations (4 mungbean cultivars × 4 Zn treatments) and three replications with 48 plots in total was laid out in a Factorial Randomized Block Design. The four Zn treatments were (i) zero Zn or no Zn (i.e. control), (ii) root Zn, (iii) foliar Zn, and (iv) root Zn + foliar Zn. The source

of Zn treatments was White Vitriol or Zinc Sulphate Heptahydrate ($ZnSO_4 \cdot 7H_2O$). The root Zn application indicates the spraying of aqueous solution of Zn @ 5.0 kg Zn per ha on the finally prepared plot's soil and then top soil was properly mixed each other. The foliar Zn application means 1% aqueous Zn solution that sprayed on crop foliage so that all leaves become uniformly and fully wet on 35 and 50 days after sowing (DAS). In both cases, spraying was done with a manual sprayer. The root Zn + foliar Zn treatment denotes the combination of root Zn application plus foliar Zn application.

2.3. Land and Plot Preparation

The land was ploughed and cross ploughed several times with a tractor until a good tilth condition is achieved. All debris and weeds were removed from the field as much as possible from the field. Finally, the land was leveled with a ladder. Well decomposed cowdung ($10 t ha^{-1}$) was applied to the field as manure during land preparation. N, P, K, S and B @ 15, 16, 21, 10 and 1 kg ha^{-1} were applied as basic nutrients requirement of mungbean crop [22]. One-third amount of total N and full amount of other nutrients were mixed in soil respectively in the form of urea, triple super phosphate, muriate of potash, gypsum and boric acid powder during final land preparation. Remaining amount of N was applied in two equal installments at 3 and 5 weeks after sowing. Total experimental area was demarcated first and divided into 3 blocks with 1 m apart where each block represents a replication. Plot to plot in a block was far apart with a distance of 50 cm. The size of unit plot was 3m × 2m. The height of plot was 10 cm to avoid water congestion from rainfall.

2.4. Crop Husbandry

Seeds of four mungbean cultivars viz. BARI Mug-5, BARI Mug-6, BARI Mug-7 and BARI Mug-8 were sown on 20 Feb 2023 in line 40 cm apart following north to south (N-S) row orientation with 10 cm inter plant distance. Similarly, seeds of another four mungbean cultivars like BARI Mug-2, BARI Mug-3, BARI Mug-4 and BINA Mug-8 were sown on 20 February 2024. The mean values of major climatic parameters during experimental periods were very close in 2023 and 2024 years (Table 1). Little variation in rainfall was minimized through minor irrigation management as needed. So it is assumed that year's effect on crop growth for the mungbean cultivars studied was negligible. Seeds of BINA Mug-8 and seven aforesaid BARI Mug cultivars were collected respectively from Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, and Pulses Research Centre & RARS, Bangladesh Agricultural Research Institute (BARI), Ishurdi, Pabna. Before sowing, the seeds were treated with fungicide solution of Provax-200 WP for 10 minutes. The seeds were then dried shortly to remove excess water. Initially, three healthy seeds were sown in a sowing point. However, one healthy seedling was kept after emergence. Weeding, irrigation, measures against insect pests and diseases etc. were performed as and when required to optimize the growth and development of crops.

Table 1. Major climatic parameters^a measured onsite during the experimental periods in 2023 and 2024 years

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm) ^b		Sunshine hour (day ⁻¹)		Daily evaporation (mm)	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
February	21.2	22.1	76.4	78.6	17.3	11	5.93	6.10	3.40	3.17
March	24.3	24.9	76.3	76.7	72.0	110.2	6.95	6.29	3.50	3.17
April	30.0	28.4	76.5	74.2	0.2	15.5	7.19	8.69	4.30	4.43
May	29.4	28.7	77.3	75.9	285.9	242.1	6.40	7.77	4.17	4.51
February-May	26.3	26.1	76.6	76.3	375.4	378.8	6.62	7.23	3.85	3.83

^a and ^b represent daily mean and daily total, respectively. Source: Bangladesh Meteorological Department, Ministry of Defense.

2.5. Data Collection

During peak blooming, data on plant height and number of primary branches per plant were recorded from 10 plants selected randomly. A graduated linear meter scale was placed at ground level to measure plant height up to the tip or apex of the plant. Primary branch represents the branch which directly developed from the main stem of plant having at least a district trifoliate leaf. Due to indeterminate types of flowering habit pods were harvested several times as and when matured. Entire plants were harvested when 80 percent pods become ripen that defined as physiological maturity of crops. Harvested plants threshed manually after sun-drying and the seeds were adjusted to 10 percent moisture content to obtain data on grain yield. Ten plants selected randomly from each plot to record the data on number of pods per plant while 50 pods taken randomly from a plot to count the pod length and number of grains per pod. Five individual thousand grains from a plot were separated and weighed to record the 1000-seed weight. Raw data obtained from plot were duly averaged that represents a plot or replication datum.

2.6. Analysis of Grain Zn Concentration

The Zn content of experimented mungbean seeds were estimated after digestion with a perchloric and nitric di-acid mixture (HClO₄ + HNO₃; 1:2 ratio) solution. The 500 mg seed samples were digested in the said acid mixture at 360°C for 1-2 hours until the digest became transparent and unclouded. After digestion, it was diluted to 50 ml with distilled water. After proper dilution of the extract, the Zn concentration of extract was estimated by an Atomic Absorption Spectrophotometer (Perkin Elmer, CA, USA).

2.7. Economic and Statistical Analysis

Economic analysis of the investigation was performed on the basis of prevailing market price of the items. Gross returns from every treatment represent the income obtained from the grain and stover yield. Total cost of production was subtracted from the gross return to find the net economic return. Benefit cost ratio (BCR) was calculated as the gross return to the total cost of production.

Analysis for determining variances of traits was

executed for each mungbean cultivar and fertilization treatments with 3 repeated measurements (i.e., $n = 3$ replicates) and comparisons with $P < 0.01$ (if applicable) or at least $P < 0.05$ level was considered for significance difference. Significance test between the interactions was conducted with Least Significance Difference (LSD) and Duncan's Multiple Range Test (DMRT).

3. Results

3.1. Plant Growth and Yield Traits

Taller plants with greater number of main stem branches and pods per plant and grains per pod, bigger pod and heavier grain (i.e. larger 1000-grain weight) were produced by all the mungbean varieties when the crops fertilized with Zn through soil plus foliar applications followed by the crops fertilized with Zn through soil or foliar application alone (Table 2 and Table 3). Mean over the Zn treatments, the variety BARI Mug-7 exhibited the higher values for most growth and yield traits except the number of main stem branches and pods per plant, while BARI Mug-3 and BARI Mug-2 respectively produced the greater number of primary branches and pods per plant. The variety BARI Mug-3 produced the smaller pods while BARI Mug-2 variety not only produced lesser number of grains per pod but also produced the smaller sized grains.

3.2. Grain Yield

The mungbean crops grown with no Zn application exhibited minimum grain yield while maximum grain yield was obtained from the crop grown with combine of soil Zn plus foliar Zn applications (Table 2 and Table 3). Grain yield obtained from the crops grown with soil Zn and foliar Zn applications ranked second and third position, respectively. The grain yields obtained from the crops fertilized with the soil Zn, foliar Zn, and soil Zn + foliar Zn applications were respectively about 17, 14 and 23% higher for the mungbean cultivars those grown during 2023 year, and 15, 11 and 27% higher for the cultivars grown during 2024 than that at control i.e. no Zn application. Mean over the Zn application treatments, the cultivars BARI Mug-7 and BINA Mug-8 produced higher grain yield while the BARI Mug-2 and BARI Mug-3 cultivars were found as low grain yielders.

Table 2. Growth and yield traits, grain yield, grain Zn content, net economic return and benefit cost ratio of BARI Mug-5, BARI Mug-6, BARI Mug-7 and BARI Mug-8 cultivars of mungbean as affected by Zn fertilization treatments

Mungbean variety × Zn fertilization interaction	Plant height (cm)	No. of primary branches/plant	No. of pods/plants	Pod length (cm)	No. of grains/pod	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Grain Zn conc. (μg g ⁻¹)	Net economic return (BDT ha ⁻¹)	Benefit cost ratio (BCR)
BARI Mug-5×										
Control (No Zn)	36.4 b	3.51	17.0 d	6.39 d	9.9 d	39.0 b	1.29 d	35.5 d	85,390 d	1.70 d
Soil Zn	38.8 a	3.56	18.4 b	6.76 b	10.9 b	40.8 a	1.53 c	40.5 c	118,144 b	1.94 b
Foliar Zn	38.4 a	3.53	18.1 c	6.71 c	10.8 c	40.6 ab	1.51 b	43.2 b	114,411 c	1.90 c
Soil Zn + Foliar Zn	39.0 a	3.60	18.7 a	6.82 a	11.1 a	41.1 a	1.64 a	45.5 a	131,299 a	2.00 a
α (n = 12)	0.01	NS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BARI Mug-6×										
Control (No Zn)	40.1 c	3.88 d	19.0 d	7.33 d	9.6 d	42.3 d	1.49 d	35.3 d	117,273 d	1.97 c
Soil Zn	42.8 b	4.01 b	20.5 b	7.89 b	10.7 b	44.4 b	1.76 c	39.2 c	156,377 b	2.25 a
Foliar Zn	42.5 b	3.95 c	20.3 c	7.82 c	10.5 c	43.4 c	1.71 b	45.1 b	146,128 c	2.15 b
Soil Zn + Foliar Zn	43.3 a	4.06 a	21.1 a	7.97 a	11.2 a	45.1 a	1.84 a	48.4 a	163,082 a	2.25 a
α (n = 12)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BARI Mug-7×										
Control (No Zn)	47.1 d	3.86 d	15.2 c	8.31 d	10.9 d	46.3 c	1.78 d	33.7 d	163,173 d	2.34 d
Soil Zn	49.8 b	3.99 b	16.2 b	8.66 b	11.4 b	47.2 b	2.03 c	38.5 c	199,077 b	2.58 b
Foliar Zn	48.5 c	3.95 c	16.0 b	8.62 c	11.2 c	47.1 b	1.99 b	42.4 b	190,978 c	2.50 c
Soil Zn + Foliar Zn	50.8 a	4.03 a	17.1 a	8.84 a	11.8 a	48.0 a	2.12 a	45.6 a	208,765 a	2.59 a
α (n = 12)	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BARI Mug-8×										
Control (No Zn)	43.6 d	3.70 c	18.4 d	5.78 d	9.8 d	27.7 d	1.28 d	32.3 d	82,623 d	1.68 d
Soil Zn	45.6 b	3.92 b	20.1 b	6.00 b	10.4 b	28.4 b	1.52 c	36.1 c	117,944 b	1.94 b
Foliar Zn	45.0 c	3.88 b	19.4 c	5.85 c	10.2 c	28.0 c	1.47 b	38.7 b	108,911 c	1.86 c
Soil Zn + Foliar Zn	46.5 a	3.99 a	21.2 a	6.07 a	10.9 a	29.1 a	1.61 a	43.3 a	125,932 a	1.96 a
α (n = 12)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LSD for all interactions (n = 48)	0.236	0.003	0.147	0.005	0.010	0.214	0.001	0.300	3,492	0.002

For a mungbean variety, the figures followed by a similar smaller letter do not differ significantly at 1% or 5% level of probability as per Duncan's Multiple Range Test (DMRT); NS = Not significant at $P < 0.05$; α = Level of significance; LSD = Least Significant Difference at $P < 0.01$; n = number of observation; BDT = Bangladesh Taka.

Table 3. Growth and yield traits, grain yield, grain Zn content, net economic return and benefit cost ratio of BARI Mug-2, BARI Mug-3, BARI Mug-4 and BINA Mug-8 cultivars of mungbean as affected by Zn fertilization treatments

Mungbean variety × Zn fertilization interaction	Plant height (cm)	No. of primary branches/plant	No. of pods/plants	Pod length (cm)	No. of grains/pod	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Grain Zn conc. (μg g ⁻¹)	Net economic return (BDT ha ⁻¹)	Benefit cost ratio (BCR)
BARI Mug-2×										
Control (No Zn)	43.7 d	3.49 d	19.9 d	5.91 d	9.7 d	24.0 c	1.11 d	33.8 d	55,473 d	1.46 d
Soil Zn	46.3 b	3.65 b	21.6 b	6.21 b	10.2 b	24.3 b	1.30 b	39.1 c	81,810 b	1.65 b
Foliar Zn	45.9 c	3.55 c	20.8 c	6.14 c	10.1 c	24.2 b	1.26 c	45.2 b	74,145 c	1.59 c
Soil Zn + Foliar Zn	47.5 a	3.70 a	22.3 a	6.26 a	10.4 a	25.2 a	1.43 a	49.7 a	97,682 a	1.75 a
α (n = 12)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BARI Mug-3×										
Control (No Zn)	42.2 d	3.98 d	19.5 d	5.35 d	10.6 d	25.8	1.17 d	35.9 d	66,223 d	1.55 d
Soil Zn	44.8 b	4.16 b	21.5 b	5.41 b	10.9 b	26.7	1.35 b	41.8 c	89,744 b	1.71 b
Foliar Zn	44.0 c	4.01 c	20.4 c	5.38 c	10.7 c	26.5	1.30 c	46.3 b	81,645 c	1.64 c
Soil Zn + Foliar Zn	45.7 a	4.19 a	21.9 a	5.45 a	11.0 a	26.9	1.50 a	50.2 a	109,449 a	1.83 a
α (n = 12)	0.01	0.05	0.01	0.05	0.05	NS	0.01	0.01	0.01	0.01
BARI Mug-4×										
Control (No Zn)	40.7 d	3.62 d	16.6 d	5.98 d	10.7 d	31.6	1.25 d	31.0 d	78,656 d	1.65 d
Soil Zn	43.6 b	3.85 b	17.5 b	6.15 b	11.4 b	32.2	1.40 b	35.8 c	98,844 b	1.78 b
Foliar Zn	42.5 c	3.75 c	17.1 c	6.10 c	11.2 c	31.9	1.36 c	39.5 b	91,361 c	1.72 c
Soil Zn + Foliar Zn	45.3 a	3.94 a	18.2 a	6.21 a	11.9 a	32.6	1.57 a	43.1 a	120,082 a	1.92 a
α (n = 12)	0.01	0.01	0.01	0.01	0.01	NS	0.01	0.01	0.01	0.01
BINA Mug-8×										
Control (No Zn)	38.4 d	3.95 d	15.7 d	8.17 d	10.7 c	42.6	1.71 d	31.8 d	152,706 d	2.26 d
Soil Zn	41.2 b	4.05 b	16.6 b	8.40 b	11.4 b	43.1	1.98 b	36.4 c	191,594 b	2.52 b
Foliar Zn	40.4 c	3.99 c	16.1 c	8.29 c	11.1 c	42.8	1.86 c	40.4 b	171,245 c	2.35 c

Soil Zn + Foliar Zn α ($n = 12$)	42.8 a	4.11 a	17.1 a	8.50 a	11.7 a	43.6	2.19 a	43.5 a	218,682 a	2.67 a
LSD for all interactions ($n = 48$)	0.01	0.01	0.01	0.01	0.01	NS	0.01	0.01	0.01	0.01
LSD for interactions considering all 8 cultivars ^y ($n = 96$)	0.241	0.003	0.127	0.003	0.026	0.288	0.001	0.847	1,499	0.001
LSD for interactions considering all 8 cultivars ^y ($n = 96$)	0.282	0.003	0.135	0.004	0.019	0.242	0.001	0.712	2,566	0.002

For a mungbean variety, the figures followed by a similar smaller letter do not differ significantly at 1% or 5% level of probability as per Duncan's Multiple Range Test (DMRT); NS = Not significant at $P < 0.05$; α = Level of significance; LSD = Least Significant Difference at $P < 0.01$; n = Number of observation; BDT = Bangladesh Taka; ^yConsidered the data in Table 2 and Table 3.

3.3. Grain Zinc and Zn Enrichment

Irrespective of the cultivars, minimum 33.7 ± 1.8 ppm Zn was found in mungbean grain when no Zn was applied or fertilized at all. Foliar Zn application enriched higher Zn content in mungbean grain than that by the Zn application in soil (Table 2 and Table 3). Among the Zn treatments notably, combine Zn application (i.e. soil Zn + foliar Zn) showed additional zinc enrichment in mungbean grain. Mean across the cultivars, Zn application in soil, foliage, and both in soil and foliage enriched respectively about 13, 24 and 34% higher grain Zn content in mungbean cultivars those grown during 2023 year, and 16, 30 and 41% higher grain zinc content in the cultivars those grown during 2024 than that at control. In contrast mean across the Zn treatments, the BARI Mug-3 cultivar exhibited higher amount of grain Zn content followed by the cultivar BARI Mug-2 or BARI Mug-6 while lower amount of grain Zn content was observed in BARI Mug-4 cultivar followed by the BARI Mug-8.

3.4. Net Economic Return and Benefit Cost Ratio (BCR)

Both root and foliage Zn fertilized mungbean crops earned more net economic return followed by the crops grown with Zn put into practice through root before seed sowing while crops grown with no Zn application earned minimum net economic return (Table 2 and Table 3). Among the mungbean cultivars grown with root plus foliarly feeding Zn, higher net return was obtained from the BINA Mug-8 followed by the BARI Mug-7 cultivar while BARI Mug-2 exhibited as the minimum net returner. Mean across the cultivars, root, foliar and root plus foliar feeding Zn treatments respectively ensured about 31, 22 and 47% higher net economic returns and 12, 8 and 16% higher benefit cost ratios (BCRs) than that over control. Irrespective of the cultivars and Zn treatments, higher benefit cost ratios (BCRs) were associated with higher net economic returns.

4. Discussion

The nutrient element like the Zn is utilized with fertilizer prior to sowing or seeding in soil as basal or root application and during plant growth and development as foliar use in a part of agronomic approach of biofortification. Zinc element is immensely phloem-mobile, who's transfer inner the vessel of phloem tissue takes place through the media of root, shoot's base or stems, and leaf tissues and eventually to progressing seeds

or grains. Haider et al. [19] also noticed higher uptake of Zn and grain Zn content in mungbean because of Zn supply in soil. The zinc that is applied in soil before seed sowing warrants ample zinc for absorption by roots since seedling emergence which not only contributes the entire plant growth and development, and yield but also enhances Zn content in the produced seeds [21,23]. Similar yield and grain zinc enhancements were obtained in the present piece of research.

In case of foliar application, zinc is reinstated from vacuoles (a small cavity or space in tissue) and plastids like chloroplasts of leaf tissues and charged into phloem vessel for deliver to seeds or grains by the way of stems' inside. The foliage-sprayed Zn shortly intensifies zinc concentration in the leaves phloem and transferred towards the grains throughout the progenitive development. Since its journey starts from middle stage of plant development that's why it leads to more Zn enrichment in grains as compared to that from the root application. Besides the grain Zn enrichment [24], foliar application was also reported to enhance the mungbean yield due to the positive effect of Zn on the yield formation traits like numbers of pod/plant and seeds/pod, 1000-grain weight etc., and the findings of present study commensurate those [20]. Thus, foliar Zn application is manifested as an exemplary and band-aid solution for conquering zinc inadequacy in the recent times. Root plus foliar Zn feeding treatment substantially contributes to improved grain yield with higher enrichment of Zn in seeds. The higher net economic returns and BCRs as obtained from the combine Zn treatment were due to significantly higher value of grain and stover yield as compared to cost of cultivation. The results were supported by the findings of mungbean published by Mubeen et al [25] and Soni and Kushwaha [26].

As mungbean is an excellent origin of plant protein to impoverished people, boosting zinc concentration in its grain likely be worthwhile to take the edge off undernourishment in wellbeing's. Many crops like rice, wheat etc. have been biofortified by adjoining the targeted trace nutrient elements in the course of development phase since seeding of crop plants to obtain the maximum nutrients [27,28]. Hence the present study based on the root and foliar fertilization techniques may be a holistic endeavor for coming researchers and growers for augmenting grain yield and grain Zn contents of mungbean cultivars. The root application of Zn in crops can be performed with basal use as it's easily adding to other fertilizers before seeding while Zn can foliarly be applied in combination with pesticide spraying, so that labour cost for the said purposes is minimized.

Taking the consideration, biofortification with agronomic line of action as investigated through the

present piece of research is an affordable, cost-efficient, socially acceptable and sustainable exercise to enhance the concentration of Zn nutrient element and its bioavailability in produced crops. As an important outcome, consumers don't have to pay additional cost for desired zinc during purchasing the foods. Zn-biofortified mungbean grains, if regularly consumed, lead to effectuate appraisable refinements in nutrition and human well-being. The approach is a viable option to reach rural people who have narrower passage for getting diversified foodstuffs or some other nutrition-related interventions.

5. Conclusion

Zinc fertilization treatments remarkably improved the plant growth, yield traits and grain yield, and Zn grain content in mungbean cultivars. However, application of Zn in soil was responsible for higher grain yield, and Zn application in foliage was beneficial for Zn increment in mungbean grain. A combine zinc application both in soil and foliage played a complementary role for ensuring higher grain yield and net economic return on one hand and the greater Zn content in produced grains on the other. Mean across the Zn treatments, the cultivars BARI Mug-7 and BINA Mug-8 exhibited as higher grain yielders, while BARI Mug-2, BARI Mug-3 and BARI Mug-6 showed the cultivars as higher zinc accumulators in their grains.

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Conflict of Interest

The authors declared that there is no conflict of interest.

Authors Contributions

SK, JJK reviewed and wrote the MS. PCD carried out the experiments. MAA visualized, supervised and edited the MS.

References

- [1] Hussain A, Jiang W, Wang X, Shahid S, Saba N, Ahmad M, Dar A, Masood SU, Imran M, Mustafa A. Mechanistic impact of zinc deficiency in human development. *Front. Nutr.* 2022; 9: 717064.
- [2] Chen B, Yu P, Chan WN, Xie F, Zhang Y, Liang L, Leung KT, Lo KW, Yu J, Tse GMK, Kang W, To KF. Cellular zinc metabolism and zinc signaling: from biological functions to diseases and therapeutic targets. *Sig. Trans. Target Ther.* 2024; 9(1): 6.
- [3] Khan ST, Malik A, Alwarthan A, Shaik MR. The enormity of the zinc deficiency problem and available solutions; an overview. *Arabian J. Chem.* 2022; 15(3): 103668.
- [4] Maxfield L, Shukla S, Crane JS. Zinc Deficiency. NCBI Bookshelf. A service of the National Library of Medicine, National Institutes of Health. Bookshelf ID: NBK493231, StatPearls Publishing LLC, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK493231/>; accessed on 14 May 2024.
- [5] Ozturk H, Niazi P, Mansoor M, Monib AW, Alikhail M, Azizi A. The function of zinc in animal, plant, and human nutrition. *J. Res. App. Sci. Biotechnol.* 2023; 2(2): 35-43.
- [6] Souza JA, Moraes LAC, Moreira A. Zinc and amino acids on wheat-soybean intercropping under no-till management. *J. Plant Nutr.* 2019; 42(16): 1992-2002.
- [7] Zaheer IE, Ali S, Saleem MH, Ali M, Riaz M, Javed S, Sehar A, Abbas Z, Rizwan M, El-Sheikh A, Alyemini MN. Interactive role of zinc and iron lysine on *Spinacia oleracea* L. growth, photosynthesis and antioxidant capacity irrigated with tannery wastewater. *Physiol. Mol. Biol. Plants.* 2020; 26(12): 2435-2452.
- [8] Kareem HA, Hassan MU, Zain M, Irshad A, Shakoor N, Saleem S, Niu J, Skalicky M, Chen Z, Guo Z, Wang Q. Nanosized zinc oxide (n-ZnO) particles pretreatment to alfalfa seedlings alleviate heat-induced morpho-physiological and ultrastructural damages. *Environ. Pollut.* 2022; 303: 119069.
- [9] Chen MX, Zheng SX, Yang YN, Xu C, Liu JS, Yang WD, Chye ML, Li HY. Strong seed-specific protein expression from the *Vigna radiata* storage protein 8SG alpha promoter in transgenic *Arabidopsis* seeds. *J. Biotechnol.* 2014; 49-56.
- [10] Xu XP, Liu H, Tian LH, Dong XB, Shen SH, Qu LQ. Integrated and comparative proteomics of high-oil and high-protein soybean seeds. *Food Chem.* 2015; 172: 105-116.
- [11] Zhu YS, Shuai S, FitzGerald R. Mung bean proteins and peptides: nutritional, functional and bioactive properties. *Food Nutr. Res.* 2018; 62: 1290.
- [12] Majeed A, Minhas WA, Mehboob N, Farooq S, Hussain M, Alam S, Rizwan MS. Iron application improves yield, economic returns and grain-Fe concentration of mungbean. *PLoS One.* 2020; 15(3): e0230720.
- [13] Favero VO, de Carvalho RH, Leite ABC, de Freitas KM, Zilli JÉ, Xavier GR, Rumjanek NG, Urquiaga S. Characterization and nodulation capacity of native bacteria isolated from mung bean nodules used as a trap plant in Brazilian tropical soils. *App. Soil Ecol.* 2021; 167: 104041.
- [14] Sadiq M, Rahim N, Iqbal MA, Alqahtani MD, Tahir NM, Majeed A, Ahmed R. Rhizobia inoculation supplemented with nitrogen fertilization enhances root nodulation, productivity, and nitrogen dynamics in soil and black gram (*Vigna mungo* (L.) Hepper). *Land.* 2023; 12(7): 1434.
- [15] Awal MA, Hossain MA, Iqbal MA, Soufan W, Erman M, Ammar H, Elsabagh A. Zinc biofortification of mungbean (*Vigna radiata* L.) cultivars through zinc chemo-priming. *Pak. J. Bot.* 2024; 56(5): 1781-1791.
- [16] Noulas C, Tziouvalekas M, Karyotis T. Zinc in soils, water and food crops. *J. Trace Elem. Med. Biol.* 2018; 49: 252-260.
- [17] Natasha N, Shahid M, Bibi I, Iqbal J, Khalid S, Murtaza B, Bakhat HF, Farooq ABU, Amjad M, Hammad HM, Niazi NK, Arshad M. Zinc in soil-plant-human system: A data-analysis review. *Sci. Total Environ.* 2022; 808: 152024.
- [18] Sturikova H, Krystofova O, Huska D, Adam V. Zinc, zinc nanoparticles and plants. *J. Hazard Mat.* 2018; 349: 101-110.

- [19] Haider MU, Hussain M, Farooq M, Nawaz A. Soil application of zinc improves the growth, yield and grain zinc biofortification of mungbean. *Soil Environ.* 2018a; 37(2): 123-128.
- [20] Haider MU, Farooq M, Nawaz A, Hussain M. Foliage applied zinc ensures better growth, yield and grain biofortification of mungbean. *Int. J. Agric. Biol.* 2018b; 20: 2817-2822.
- [21] Haider MU, Hussain M, Farooq M, Nawaz A. Zinc nutrition for improving the productivity and grain biofortification of mungbean. *J. Soil Sci. Plant Nutr.* 2020; 20: 1321-1335.
- [22] BARC. Fertilizer Recommendation Guide-2018. Bangladesh Agricultural Research Council. New Airport Road, Farmgate, Dhaka-1215. URL: www.barc.gov.bd.
- [23] Haider MU, Hussain M, Farooq M, Ul-Allah S, Ansari MJ, Alwahibi MS, Farooq S. Zinc biofortification potential of diverse mungbean [*Vigna radiata* (L.) Wilczek] genotypes under field conditions. *PLoS ONE* 16(6): e0253085.
- [24] Dhaliwal SS, Sharma V, Shukla AK, Kaur M, Kaur J, Verma V, Singh P, Berek V, Gaber A, Hossain A. Biofortification of mungbean (*Vigna radiata* L. (Wilczek)) with boron, zinc and iron alters its grain yield and nutrition. *Sci. Rep.* 2023; 13: 3506.
- [25] Mubeen A, Saeed MT, Saleem MF, Wahid MA. Zinc and Boron Application Improves Yield, Yield Components and Gross Returns of Mungbean (*Vigna radiata* L.). *J. Arable Crops Market.* 2020; 2(2): 79-87.
- [26] Soni J, Kushwaha HS. Effect of foliar spray of zinc and iron on productivity of mungbean [*Vigna radiata* (L.) Wilczek]. *J. Pharmacog. Phytochem.* 2020; 9(1): 108-111.
- [27] Awal MA, Islam T, Rahman MH. Zinc biofortification of wheat grain through agronomic approaches in Bangladesh. *Discovery.* 2022; 58(324): 1415-1428.
- [28] Farooq M, Ullah A, Rehman A, Nawaz A, Nadeem A, Wakeel A, Nadeem F, Siddique KHM. Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. *Field Crop Res.* 2018; 216: 53-62.



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