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Impact of foliar zinc and boron application on wheat yield, quality and post-harvest soil properties

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Abstract

Wheat (*Triticum aestivum* L.) is a vital global crop, essential for human nutrition. However, wheat yields often suffer from nutrient deficiencies, particularly in micronutrients like zinc (Zn) and boron (B). This study, conducted at Sher-e-Bangla Agricultural University, Dhaka, during the 2023-2024 Rabi season, evaluated the effects of foliar Zn and B applications on wheat yield, grain quality, and soil properties. Using a Randomized Complete Block Design with three replications including seven treatments, the results showed that foliar application at tillering and booting stages (T_4) significantly improved grain yield (4.25 t ha^{-1}), 1000-grain weight (54.84 g), straw yield (4.96 t ha^{-1}), harvest index (46.15 %) and grain quality, including protein (12.53%), Zn (36.34 ppm), and B content (15.05 ppm). Post-harvest soil analysis indicated minimal changes in soil pH, organic carbon, and organic matter across treatments. However, total nitrogen, available phosphorus, and sulfur levels showed significant improvements with foliar applications, particularly in treatments T_4 and T_6. The study concludes that foliar Zn and B applications at key growth stages enhance wheat yield, quality, and soil health, offering valuable strategies for sustainable agriculture.

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Introduction

Wheat (*Triticum aestivum* L.), a globally cultivated cereal crop, plays a pivotal role in human nutrition, serving as a staple in diets across the world. It significantly contributes to daily protein and calorie intake, with an average yield of 3.693 t ha^{-1} in 2023, reflecting a 7.07% increase from the previous year (BBS, 2023). As an annual, self-pollinated allohexaploid (Khan *et al.*, 2023) from the Poaceae (Saleem *et al.*, 2023) family, wheat is renowned for its high protein (8-15%), carbohydrate (60-68%), (Meena *et al.*, 2013) and fiber content (Kumar *et al.*, 2022), often referred to as the "king of cereals" (Khan *et al.*, 2023). It provides approximately 20% of daily protein and caloric needs and is the second most important global crop after rice (EL Habbasha *et al.*, 2015; Majeed *et al.*, 2023).

Despite its significance, wheat yields are frequently hindered by several factors, including improper fertilizer application, such as untimely nitrogen use, inadequate micronutrient supplementation with elements like boron and zinc, late sowing, water shortages, and increased weed infestations (Nadim *et al.*, 2011). These challenges are compounded by both biotic and abiotic stresses, exacerbated by climate conditions and insufficient awareness of optimal nutrient management. Such stresses adversely affect enzymatic, physiological, and biochemical processes, reducing yields and compromising grain quality (Alotaibi *et al.*, 2023).

Sustainable wheat production requires a balanced application of macro- and micronutrients. However, the overuse of macronutrients has led to widespread deficiencies in micronutrients, particularly zinc, in cultivable soils. This imbalance exacerbates nutrient depletion and stagnates productivity (Jalal *et al.*, 2020; Dhanda *et al.*, 2022). Zinc is a crucial micronutrient for plant growth and survival, uptake by plant roots as a divalent cation and involved in critical metabolic activities, including carbonic anhydrase and hydrogenase functions, cytochrome synthesis, auxin metabolism, ribosomal stabilization, pollen function and fertilization (Das *et al.*, 2020).

Boron, another vital micronutrient, is crucial for the normal growth and reproduction of various crops, including cereals, fruits, and vegetables. It is integral to carbohydrate metabolism, translocation, and several key physiological processes such as pollen tube growth, cell division, leaf expansion, cell wall formation, cell elongation, membrane integrity, water regulation, and ionic absorption. A boron deficiency can disrupt these essential functions (Soomro *et al.*, 2011; Gupta and Solanki, 2013).

Foliar application of micronutrients has emerged as an effective strategy to mitigate edaphic factors that decrease soil bioavailability. Research indicates that foliar application of micronutrients can enhance wheat yield by facilitating rapid absorption and minimizing losses due to leaching and fixation. Specifically, foliar application of zinc has been shown to significantly improve wheat grain yield, its components, and overall grain quality (Bameri *et al.*, 2012). Moreover, combining soil and foliar applications of micronutrients may be equally or more effective than sole soil applications (Firdous *et al.*, 2016).

This study aims to assess the impact of foliar application of zinc and boron on wheat yield, grain quality, and post-harvest soil properties. By elucidating these effects, the research seeks to provide valuable insights into optimizing nutrient management practices to enhance wheat production and sustainability.

Materials and methods

Study sites

The research was conducted at Sher-e-Bangla Agricultural University (SAU) in Dhaka, from November 2023 to March 2024. The experimental site, located at 23°41′N latitude and 90°22′E longitude, lies 8.4 meters above sea level within the Madhupur Tract (AEZ-28). During the 2023 Rabi season, the study used the characteristic wheat-growing soil of the area, which is classified as "Deep Red Brown Terrace Soil" of the Tejgaon Series.

Planting material

The experiment utilized the wheat variety BARI Gom-32, which was developed by the Bangladesh Agricultural Research Institute (BARI) and released in 2017. This variety, suitable for planting until mid-December, is resistant to leaf rust and *Bipolaris* leaf blight, and typically produces 3-4 tillers per plant. The seeds for this variety were sourced from the Bangladesh Agricultural Research Institute (BARI) in Gazipur.

Treatments of the experiment

The study consisted of the following treatments:

T_0= Control (No chemical fertilizers)

T_1= = N_{140} P_{25} K_{110} S_{16} kg ha^{-1} (Recommended fertilizer dose)

T_2= T_1+ soil application @ Zn 2.5 kg ha^{-1}, B 1.5 kg ha^{-1}

T_3= T_1 + foliar application @ Zn 2.5 kg ha^{-1}, B 1.5 kg ha^{-1} at booting stages

T_4= T_1+ foliar application @ Zn 2.5 kg ha^{-1}, B 1.5 kg ha^{-1} at tillering and booting stages

T_5= T_1+ foliar application @ Zn 1.5 kg ha^{-1}, B 1 kg ha^{-1} at booting stages

T_6= T_1+ foliar application @ Zn 1.5 kg ha^{-1}, B 1 kg ha^{-1} at tillering and booting stages

Chemical properties of the initial soil sample are given below (Table 1).

Table 1. Chemical properties of the initial soil sample

Characteristics	Value
pH	6.3
Organic carbon (%)	0.68
Organic matter (%)	1.17
Total N (%)	0.063
Available P (ppm)	28
Exchangeable K (meq/100g soil)	0.118
Available S (ppm)	22

Experimental design and layout

The experiment was designed using a Randomized Complete Block Design, with each treatment replicated three times. The plots were 3 meters by 2 meters in size, with a 1-meter gap between blocks and a 0.5-meter gap between rows.

Fertilizer application and seed sowing

Fertilizers were applied following the BARC Fertilizer Recommendation Guide-2018, using Urea, TSP, MoP, and Gypsum as sources of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S), respectively. All phosphorus, potassium, sulfur, and half of the nitrogen were applied during the final land preparation, with the remaining nitrogen applied before the booting stage. On November 20, 2023, seeds were hand-sewn at a rate of 120 kg per hectare. The seeds were sown in rows and covered with soil, with a line-to-line distance of 20 cm and a plant-to-plant spacing of 4-5 cm.

Methods of data collection

The harvest took place on March 12, 2024. During the harvest, ten plants were randomly selected from each plot. All plants in each plot were carefully cut at the soil surface level. Data included yield parameters [1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), harvest index (%)], grain quality parameters [protein content (%), Zn content (ppm), B content (ppm)] and post-harvest soil properties parameters [soil pH, organic carbon (%), organic matter (%), total N (%), available P (ppm), exchangeable K (meq/100g soil), available S (ppm)].

Statistical analysis

The collected data were analyzed using analysis of variance (ANOVA). The statistical analysis was performed using the Statistics 10 computer program to evaluate the data from various experimental parameters. Mean values for each parameter were calculated, followed by an analysis of variance. To determine the significance of differences among treatment means, the Duncan Multiple Range Test was applied at a 5% probability level.

Results and discussion

Yield and yield components

1000-grain weight (g)

The 1000-grain weight varied significantly across treatments, with the T_4 treatment (54.84 g) producing the highest value, significantly superior to the control (T_0) which recorded the lowest weight (48.43 g) (Table 2). Treatment, T_6 (52.96 g) also produced a significantly higher 1000-grain weight compared to the control, followed by T_5 (51.13 g) and T_3 (50.92 g).

Studies have shown that higher concentrations of foliar-applied iron (Fe) and zinc (Zn) increase the 1000-grain weight of wheat (Akhtar *et al.*, 2022). Gunnes *et al.* (2003) and Khan *et al.* (2006) stated that boron application, particularly at 1 kg B ha^{-1}, also significantly enhances 1000-grain weight when applied at the proper growth stage. Additionally, the foliar application of a micronutrient mix, 'Shelter,' containing Fe, Mn, Zn, Cu, and B, further improves 1000-grain weight (Khan *et al.*, 2010).

Table 2. Effect of foliar application of Zn and B on 1000-grain weight (g), grain yield (t ha-1), straw yield (t ha-1) and harvest index (%) of wheat

Treatment	1000-grain wt (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_0	48.43 d	2.72 f	3.99 c	40.53 d
T_1	49.61 cd	2.91 e	4.11 c	41.45 cd
T_2	50.30 cd	2.98 de	4.18 c	41.60 cd
T_3	50. 92 bcd	3.45 c	4.64 ab	42.70 bc
T_4	54.84 a	4.25 a	4.96 a	46.15 a
T_5	51.13 bc	3.13 d	4.33 bc	41.97 cd
T_6	52.96 ab	3.68 b	4.75 ab	43.75 b
$LSD_{0.05}$	2.64	0.18	0.42	1.55
CV (%)	2.91	3.17	5.37	2.05

Grain yield (t ha^{-1})

The highest grain yield was observed in the T_4 (4.25 t ha^{-1}) treatment, which involved the foliar application of Zn and B at both the tillering and booting stages (Table 2). This yield was significantly higher than all other treatments. Treatment T_6, which also included Zn and B applications at both stages but at a lower dose, produced the second-highest grain yield (3.68 t ha^{-1}), followed by T_3 (3.45 t ha^{-1}) which had Zn and B applied at the booting stage only. The control treatment (T_0) resulted in the lowest grain yield (2.72 t ha^{-1}), followed by T_1 (2.91 t ha^{-1}).

Chaudhry *et al.* (2007) reported that applying micronutrients such as zinc (Zn), iron (Fe), and boron (B), either individually or in combination, significantly increased wheat yield compared to the control. Similarly, Moghadam *et al.* (2012) found that the application of B and Zn as foliar had positively affected wheat yield and its components.

Straw yield (t ha^{-1})

Straw yield was highest in the treatment of T_4 (4.96 t ha^{-1}), significantly greater than all other treatments (Table 2). T_6 and T_3 also produced high straw yields of 4.75 t ha^{-1} and 4.64 t ha^{-1}, respectively. The control treatment (T_0) had the lowest straw yield (3.99 t ha^{-1}), similar to T_1 (4.11 t ha^{-1}) and T_2 (4.18 t ha^{-1}), which did not include foliar applications of micronutrients.

Keram *et al.* (2013) observed that the application of zinc significantly increased the straw yield of wheat. Similarly, foliar spraying of boron at the booting stage enhanced the straw yield of wheat (Fakir *et al.* 2016).

Harvest index (%)

The harvest index was highest in the T_4 (46.15%) treatment, indicating a more efficient conversion of biomass into grain (Table 2). T_6 also had a relatively high harvest index (43.75%), followed by T_3 (42.70%). The control treatment (T_0) had the lowest harvest index (40.53%), reflecting a lower grain yield relative to total biomass production.

Zinc is thought to influence carbohydrate metabolism by affecting photosynthesis and sugar conversion processes. Improved photosynthate partitioning and starch utilization lead to larger, well-developed grains, which may account for the observed increases in test weight and harvest index. The results follow the findings of Niyigaba *et al.* (2019), Sultana *et al.* (2016), and Hassan *et al.* (2019).

Table 3. Effect of foliar application of Zn and B on protein content (%), Zn content (ppm) and B content (ppm) of wheat grain

Treatment	Protein content (%)	Zn content (ppm)	B content (ppm)
T_0	10.15 g	29.67 f	11.08 g
T_1	10.52 f	30.91 e	11.86 f
T_2	10.83 e	32.18 d	12.54 e
T_3	11.44 c	34.97 b	13.93 c
T_4	12.53 a	36.34 a	15.05 a
T_5	11.07 d	34.40 c	13.04 d
T_6	11.94 b	35.80 a	14.64 b
$LSD_{0.05}$	0.12	0.53	0.21
CV (%)	0.63	0.89	0.90

Grain quality

Protein content

The highest protein content was found in treatment T_4 (12.53%), where Zn and B were applied at both the tillering and booting stages (Table 3). This was significantly higher than all other treatments, including the control (T_0), which had the lowest protein content (10.15%). Treatment T_6, which involved Zn and B foliar application at both stages but at lower doses, also resulted in a high protein content (11.94%), followed by T_3 (11.44%) where Zn and B were applied only at the booting stage.

The protein content increase in wheat grains can be attributed to the enhanced availability of zinc in the soil due to its application. This boost in zinc availability improves nitrogen uptake, which in turn enhances protein content. Zinc plays a crucial role in protein synthesis, IAA production, chlorophyll formation, and auxin metabolism, all of which add to the higher protein content found in wheat grains. The same findings were also reported by Singh *et al.* (2015). Ali *et al.* (2009) researched the application of boron and concluded from their results that foliar application of boron effectively increased the protein content in wheat grains.

Zinc content (ppm)

Zinc content in the grains was highest in T_4 (36.34 ppm) and T_6 (35.80 ppm) treatments, both of which involved foliar applications of Zn at critical growth stages (Table 3). These values were significantly higher than the control (T_0) treatment (29.67 ppm) and T_1 (30.91 ppm) treatment, which did not include micronutrient supplements. Treatments with soil application of Zn (T_2) also revealed a significant increase in grain Zn content (32.18 ppm) compared to the control, though lower than the foliar application treatments.

Zhang *et al.* (2010) demonstrated that foliar application of zinc enhances seed zinc content by allowing zinc absorbed through the leaf epidermis to be transported to other plant parts via veins and vascular networks during the grain development stage. Lan *et al.* (2021) and Lu *et al.* (2012) also reported that significant increase in zinc concentration in wheat grains through zinc utilization and fertilization techniques. Similarly, Phattarakul *et al.* (2011) found that foliar application of zinc at panicle initiation effectively doubled the whole-grain zinc content.

Boron content (ppm)

Boron content was similarly highest in the treatment T_4 (15.05 ppm) and T_6 (14.64 ppm), indicating that foliar application at both tillering and booting stages is highly effective in increasing B concentration in grains (Table 3). The control treatment (T_0) had the lowest B content (11.08 ppm), followed by T_1 (11.86 ppm), demonstrating the importance of B supplementation in meeting crop B requirements. T_3 and T_5, which involved foliar applications at the booting stage only, resulted in moderate B content levels (13.93 ppm and 13.04 ppm, respectively), indicating that application timing and dosage are key factors influencing B accumulation in grains.

The increased amount of boron content in wheat grains may be attributed to the enhanced availability of boron to the plant through both soil and foliar applications. Results conform to those already reported by Ariraman *et al.* (2020) and Khan *et al.* (2006).

Post-harvest soil analysis

Soil pH, organic carbon (%), and organic matter (%)

The soil pH remained relatively stable across all treatments, with no significant differences observed (Table 4). Values ranged from 6.19 to 6.23, indicating that the fertilizer treatments did not significantly affect soil acidity or alkalinity. Similarly, organic carbon content and organic matter percentages were consistent across treatments, with no significant changes observed. Organic carbon ranged from 0.64% to 0.66%, while organic matter varied between 1.11% and 1.14% (Table 4). This stability indicates that the treatments had no significant effect on soil organic content during the study period. Arunkumar *et al.* (2017) also reported that different nutrient combinations did not significantly affect soil pH after the maize harvest. A similar impact of B on organic carbon content was observed by Agarwal *et al.* (2007), and a comparable effect of Zn application was noted by Keram *et al.* (2012).

Table 4. Effect of foliar application of Zn and B on soil pH, organic carbon (%), organic matter (%), total N (%), available P (ppm), exchangeable K (meq/100g soil) and available S (ppm) of the post-harvest soil

Treatment	Soil pH	Organic carbon (%)	Organic matter (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)
T_0	6.21	0.64	1.11	0.060 d	36.36	0.125	22.75 c
T_1	6.22	0.66	1.14	0.061 d	36.21	0.125	26.01 ab
T_2	6.22	0.65	1.13	0.070 ab	35.93	0.140	25.64 abc
T_3	6.19	0.64	1.11	0.072 a	37.94	0.131	27.33 a
T_4	6.23	0.65	1.13	0.069 bc	39.85	0.125	24.54 abc
T_5	6.20	0.65	1.13	0.067 c	37.85	0.127	26.86 a
T_6	6.19	0.66	1.14	0.063 d	38.64	0.135	23.68 bc
$LSD_{0.05}$	NS	NS	NS	2.93	NS	NS	3.00
CV %	0.91	1.93	1.93	2.50	9.98	5.62	6.69

Total nitrogen (%)

Total nitrogen content in the soil showed significant variation among treatments. Treatment T_3, which involved foliar application of Zn and B at the booting stage, had the highest total nitrogen content (0.072%), followed closely by T_2 (0.070%) with soil application of Zn and B, and T_4 (0.069%) with foliar application at both tillering and booting stages (Table 4). The control treatment (T_0) and T_1 (recommended fertilizer dose without micronutrient application) recorded the lowest total nitrogen content (0.060% and 0.061%, respectively). An examination of the data showed that the available nitrogen content in the soil increased from its initial level following the harvest of the wheat crop when N fertilizer was applied. Conversely, it decreased in the absence of N application. This increase in mineralizable nitrogen with incremental N levels has been reported by several researchers, including Kumar (2008).

Available Phosphorus (ppm)

Available phosphorus levels were highest in the treatment T_4 (39.85 ppm) and T_6 (38.64 ppm), indicating that aerial application of Zn and B at tillering and booting stages can enhance phosphorus availability (Table 4). The control treatment (T_0) had lower available phosphorus levels (36.36 ppm), comparable to T_1 (36.21 ppm) and T_2 (35.93 ppm). This could be due to the decrease in inorganic phosphorus in the soil with zinc application (Ghoneim, 2016), as zinc and phosphorus have an antagonistic relationship that affects their uptake and distribution in the plant (Mousavi, 2011), therefore it influences the same.

Exchangeable potassium (meq/100g soil)

Exchangeable potassium levels did not show significant variation across treatments, with values ranging from 0.125 to 0.140 meq/100g soil (Table 4). This suggests that the different fertilizer treatments had a minimal impact on soil potassium levels within the scope of the study. The increase in potassium (K) might be attributed to the positive interaction between K and zinc (Zn) (Keram *et al.,* 2012; Alloway, 2004).

Available sulfur (ppm)

Available sulfur content was highest in T_3 (27.33 ppm) and T_5 (26.86 ppm), indicating that foliar applications at the booting stage are effective in increasing sulfur availability in the soil (Table 4). The control treatment (T_0) had the lowest sulfur content (22.75 ppm), highlighting the importance of supplemental micronutrient applications in maintaining adequate sulfur levels.

Conclusion

The study on the impact of foliar zinc and boron application on wheat revealed significant improvements in both yield and quality parameters. The foliar treatments enhanced grain yield, 1000-grain weight, straw yield, harvest index, and overall nutritional quality (protein content, Zn content, B content) of the wheat. Specifically, using the recommended fertilizer dose + foliar application @ Zn 2.5 kg ha^{-1}, B 1.5 kg ha^{-1} at tillering and booting stages showed potential for boosting wheat production Additionally, these treatments positively influenced the post-harvest soil properties, leading to better soil fertility through increased micronutrient content. The findings suggest that the foliar application of zinc and boron is an effective strategy to optimize wheat production and maintain soil health, offering a sustainable approach to enhancing agricultural productivity.

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