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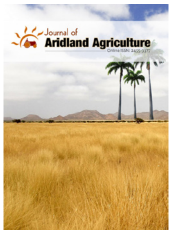
Research Article



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Zinc supplementation boosts the yield performance of aromatic *Boro* rice (cv. BRRI dhan50)

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ABSTRACT

Zinc (Zn) is an essential micronutrient that plays a vital role in various physiological and biochemical processes in rice. Its deficiency is a common nutritional disorder in rice growing regions, often leading to impaired growth and reduced yields. To address this issue an experiment was executed to assess of zinc application on the yield ability of aromatic *Boro* rice cv. BRRI dhan50. The study comprised ten zinc treatment regimes, including a control (0 kg Zn/ha) of various combinations of basal, soil (SA) and foliar applications (FA) with zinc rates ranging from 1.0 to 6.0 kg Zn/ha. Results revealed a significant response of rice yield components to zinc application. The treatment involving 2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf) produced the highest values for total tillers/hill (15.36), panicle length (23.04 cm), 1000-grain weight (20.64 g), grain (5.38 t/ha) and straw (6.56 t/ha) yields while control treatment exhibited the lowest values. The results indicate that the most effective zinc application strategy for maximizing grain yield in BRRI dhan50 is the application of 2.0 kg Zn/ha as basal, followed by 1.0 kg Zn/ha at the seedling stage (SA) and 1.0 kg Zn/ha at the flowering stage (FA), in combination with the recommended NPK fertilizers.

KEYWORDS: Fine rice, Zinc fertilization, Agronomic traits, Productivity

INTRODUCTION

Rice (*Oryza sativa* L) is the second most consumed cereal grain globally and holds a crucial role in human diets, second only to wheat (Rajamoorthy *et al.*, 2015). It serves as a vital source of nutrition for over half of the world's population, particularly in low and middle income nations where it contributes significantly to daily caloric intake, accounting for as much as 20% of their total calories (Verma & Srivastav, 2017). Bangladesh ranks the fourth largest producer of rice globally (IRRI, 2020), with rice cultivated on more than 11.7 million hectares and a yearly output of 37.60 million tons (BBS, 2022). The *Boro* variety is particularly important, being the largest in production volume (Kabiraj *et al.*, 2020; Rahman *et al.*, 2023). There has been a significant increase in demand for fragrant rice both domestically and internationally. This type of rice, valued for its quality attributes such as fineness, aroma, taste and protein content, commands higher prices abroad compared to non-aromatic varieties (Paul *et al.*, 2020; Roy *et al.*, 2020; Salim *et al.*, 2024). Bangladesh's potential for exporting high quality rice offers substantial opportunities for foreign exchange earnings (Sarkar *et al.*, 2014; Khatun *et al.*, 2023; Mushtaree *et al.*, 2023; Roy *et al.*, 2024).

Micronutrients are crucial components that significantly contribute to the health and growth of plants, like primary nutrients and secondary nutrients. Though they are needed in smaller amounts, their effect on productivity is significant (Dey *et al.*, 2023; Islam *et al.*, 2024). In rice producing countries, deficiencies in micronutrients are major contributors to poor yields. Zinc deficiency, a prevalent global issue impacting human health, animals and crops is particularly problematic (Kumar & Dash, 2010; Praharaj *et al.*, 2021). To address zinc deficiency, staple crops require additional zinc supplementation. Zinc is a vital trace element for plants, as it is essential for a wide range of cellular functions. These include key metabolic and physiological processes, activating enzymes, and maintaining a stable balance of ions within the cells (Yang *et al.*, 2020). Insufficient zinc or unfavorable soil conditions can hinder zinc uptake and impede plant growth. Supplementing crops with zinc can be achieved through high concentration fertilizers (a method known as agronomic biofortification) or by enhancing plant uptake through genetic modifications (Praharaj *et al.*, 2021). Zinc applications have been found to enhance rice's dry matter accumulation, grain yield, and zinc concentration within the plant (Fageria *et al.*, 2011). In Bangladesh, zinc deficiency remains a longstanding challenge, affecting more than 70% of cultivated land since its initial identification in the late 1970s (Jahiruddin *et al.*, 2000). As a critical micronutrient, zinc significantly influences plant development, with zinc enriched seeds demonstrating improved germination, seedling vigor, and overall growth performance (Cakmak, 2008). Furthermore, the basal application of zinc sulfate ($ZnSO_4$) has proven effective in boosting rice productivity (Kumar *et al.*, 2017). Addressing critical micronutrient deficiencies, particularly zinc, through targeted agronomic strategies is essential to improving rice yield, quality, and nutritional value, thereby enhancing both national food supply and economic returns.

METHODS AND MATERIALS

Study Area

The experiment took place at 24°07' N latitude and 90°50' E longitude between November 2022 and May 2023. It is located within the AEZ-9, known for its non-calcarious dark grey floodplain soils (UNDP & FAO, 1988). The soil is classified as silty loam having pH of 6.8. The experimental site experiences a subtropical climate. The environmental data during the study period are presented in Figure 1.

Description of Experimentation

The study included ten different zinc treatments, namely: 0 kg Zn/ha (control) (T_0); 2.0 kg Zn/ha (basal) (T_1); 4.0 kg Zn/ha (basal) (T_2); 6.0 kg Zn/ha (basal) (T_3); 1.0 kg Zn/ha (basal) combined with 1.0 kg Zn/ha (SA at 30 DAT) (T_4); 2.0 kg Zn/ha (basal) combined with 2.0 kg Zn/ha (SA at 30 DAT) (T_5); 3.0 kg Zn/ha (basal) combined with 3.0 kg Zn/ha (SA at 30 DAT) (T_6); 1.0 kg Zn/ha (basal) combined with 0.5 kg Zn/ha (SA at 30 DAT) and 0.5 kg Zn/ha (FA at the flag leaf) (T_7); 2.0 kg Zn/ha (basal) combined with 1.0 kg Zn/ha (SA at 30 DAT) and 1.0 kg Zn/ha (FA at the flag leaf) (T_8); and 3.0 kg Zn/ha (basal) combined with 1.5 kg Zn/ha (SA at 30 DAT) and 1.5 kg Zn/ha (FA at the flag leaf) (T_9). The experiment was conducted using the RCBD method with three replications. Area of unit plot was 5 m² (2.5 m × 2.0 m) and parted by a 0.5 m gap between plots and a 1.0 m gap between blocks.

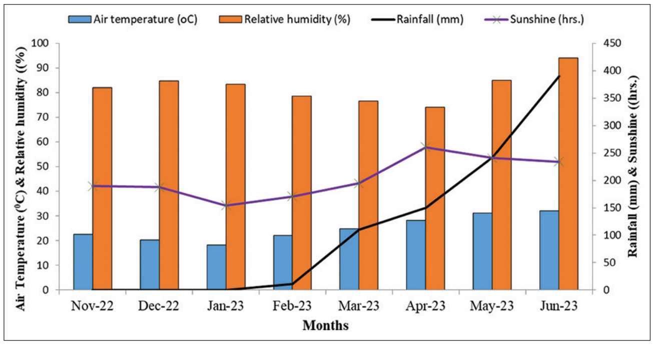

Figure 1: Distribution of monthly temperature, relative humidity, sunshine hour and rainfall of the experimental site during the crop growth period

Crop Management

The seeds were selected following standard procedures and submerged in water for a full day. Then, the seeds were drained and covered with gunny bags. They began sprouting within 48 hours and were ready for seeding after 72 hours. Nursery beds measuring 1.0 m by 1.0 m were prepared through puddling and multiple ploughing sessions. The seeds were sown, covered, and lightly irrigated. The land was prepared using a tractor-pulled cultivator, followed by cross harrowing to loosen the soil. All weeds and crop residues were removed after ploughing and laddering. Fertilizers were applied to the experimental plots: urea, TSP and MOP, applied at 200 kg, 115 kg and 125 kg per hectare. Application of urea was done thrice at 20, 30, and 45 DAT while the other fertilizers were implemented before the last stage of land preparation. 35 day old seedling was transplanted to the field.

Data Collection

The crop was harvested when approximately 80% of the seeds had changed to a golden yellow color. From each plot, we randomly selected and uprooted five hills (not including those on the borders) to collect data. We gathered the harvested crops into bundles, labeled them, and transported them to the threshing area. We used a pedal thresher to thresh the crops, then sun dried and cleaned the grains and straws.

Statistical Analysis

The data was analyzed to identify significant differences among the treatments. An ANOVA was conducted using Statistix 10 software, and the treatment mean was compared using DMRT, following the method described by Gomez and Gomez (1984).

RESULTS

The experimental results showed considerable differences because of the different concentrations of zinc used. The highest plant (86.34 cm), the maximum total tillers/hill (15.36) and the longest panicle (23.04 cm) were recorded under T_8 whereas the lowest result (79.96 cm), (9.73) and (21.51 cm) were achieved from T_0 (Table 1). There was no notable difference in non-effective tillers/hill, but the sterile spikelet's/panicle in rice was expressively affected by different levels of zinc. It was observed that control treatment recorded the minimum non-effective tillers/hill (0.80) whereas T_8 resulted the utmost non-effective tillers/hill (1.71). The least sterile spikelets/panicle (17.18) calculated from T_8 while the highest result (25.65) was calculated T_0 (Table 1). The application of different levels of zinc had a significant effect on the yield and contributing traits of rice. The top 1000-grain weight (20.64 g), grain (5.38 t/ha), straw (6.56 t/ha) and biological (11.95 t/ha) yields were calculated with T_8. Whereas the least grain yield (3.80 t/ha) and 1000-grain weight (17.35) were achieved from T_0. The minimum straw (4.38 t/ha) and biological (8.28 t/ha) yields were achieved from T_1 (Table 1, Figure 2 & 3). The supreme effective tillers/hill (13.00) and grains/panicle (114.65)

Table 1: Effect of Zn management on crop characters and yield contributing characters of *Boro* rice (BRRI dhan50)

Treatments	Plant height (cm)	Total tillers/hill (no.)	Non effective tillers/hill (no.)	Panicle length (cm)	Sterile spikelets (no.)	1000-grain weight (g)	Biological yield (t/ha)	Harvest index (%)
T_0	79.96^{c}	9.73^{g}	0.80	21.51^{b}	25.65^{a}	17.35^{c}	8.77^{de}	43.51^{bc}
T_1	81.51^{bc}	10.52^{fg}	1.21	21.91^{ab}	23.29^{ab}	18.70^{bc}	8.28^{e}	47.14^{a}
T_2	81.67^{bc}	11.90^{de}	1.29	22.07^{ab}	20.11^{cd}	18.76^{bc}	9.30^{d}	43.01^{bcd}
T_3	82.80^{abc}	13.92^{bc}	1.41	22.23^{ab}	19.05^{de}	19.68^{ab}	9.30^{d}	42.27^{cde}
T_4	84.33^{ab}	11.29ef	1.54	22.27^{ab}	22.35^{bc}	18.67^{bc}	10.09^{c}	40.90^{cde}
T_5	82.03^{bc}	12.92^{cd}	1.40	22.18^{ab}	19.98^{cd}	19.35^{ab}	10.00^{c}	41.11^{cde}
T_6	84.00^{abc}	$14.00b_{c}$	1.55	22.63^{ab}	18.11^{de}	20.02^{ab}	10.30^{bc}	39.87^{e}
T_7	82.36^{abc}	14.75_{ab}	1.34	22.23^{ab}	18.59^{de}	20.27^{ab}	10.90^{b}	41.64^{cde}
T_8	86.34^{a}	15.36^{a}	1.71	23.04^{a}	17.18^{e}	20.64^{a}	11.95^{a}	45.06^{ab}
T_9	84.66^{ab}	13.80^{bc}	1.01	22.24^{ab}	17.91^{de}	20.31^{ab}	10.25^{c}	40.48^{de}
Sig. level	**	**	NS	*	**	**	**	**
CV%	2.90	5.76	8.31	3.23	7.54	4.97	3.74	3.62

Means with the same letters or without letters within the same column do not differ significantly. ** = Significant at 1% level of probability, NS=Not significant. Here, T_0=0 kg/ha (control), T_1=2.0 kg Zn/ha (basal), T_2=4.0 kg Zn/ha (basal), T_3=6.0 kg Zn/ha (basal), T_4=1.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT), T_5=2.0 kg Zn/ha (basal) + 2.0 kg Zn/ha (SA at 30 DAT), T_6=3.0 kg Zn/ha (basal) + 3.0 kg Zn/ha (SA at 30 DAT), T_7=1.0 kg Zn/ha (basal) + 0.5 kg Zn/ha (SA at 30 DAT) + 0.5 kg Zn/ha (FA at flag leaf stage), T_8=2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf stage), $T_{9=}$3.0 kg Zn/ha (basal) + 1.5 kg Zn/ha (SA at 30 DAT) + 1.5 kg Zn/ha (FA at flag leaf stage).

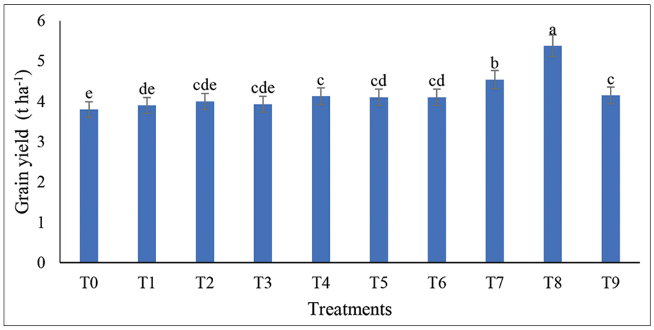

Figure 2: Effect of zinc management on the grain yield of BRRI dhan50 Here, T_0 = 0 kg/ha (control), T_1 = 2.0 kg Zn/ha (basal), T_2 = 4.0 kg Zn/ha (basal), T_3 = 6.0 kg Zn/ha (basal), T_4 = 1.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT), T_5 = 2.0 kg Zn/ha (basal) + 2.0 kg Zn/ha (SA at 30 DAT), T_6 = 3.0 kg Zn/ha (basal) + 3.0 kg Zn/ha (SA at 30 DAT), T_7 = 1.0 kg Zn/ha (basal) + 0.5 kg Zn/ha (SA at 30 DAT) + 0.5 kg Zn/ha (FA at flag leaf stage), T_8 = 2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf stage), T_9 = 3.0 kg Zn/ha (basal) + 1.5 kg Zn/ha (SA at 30 DAT) + 1.5 kg Zn/ha (FA at flag leaf stage)

resulted with T_5 while the lowest results (9.60) and (86.31) were achieved with T_0 (Figure 4 & 5). The top harvest index (47.14%) was found in T_1 where the minimum one (39.87%) was achieved from T_6 (Table 1).

DISCUSSION

Effective zinc management plays a pivotal role in enhancing crop yields, particularly in rice cultivation. The findings from this study demonstrate that different levels of zinc application significantly influence several yield contributing traits. Notably, treatment T_8 yielded the highest values for critical growth metrics, including height of the plant, tillers number, length of the panicle and both the grain and straw yields. This underscores the importance of zinc as an essential nutrient for rice, reinforcing the findings of prior studies. In contrast, the control treatment, which lacked additional zinc, exhibited the lowest performance across various parameters (Table 1, Figures 2 & 3). This aligns with previous research, such as that by Ullah *et al.* (2001), who depicted a rise in plant height with the use of zinc to the soil. Cheema *et al.* (2006) noted similarities between increasing zinc levels and improved plant height, supporting the notion that adequate zinc is vital for optimal rice growth. According to Islam *et al.* (2024), supplementing crops with zinc significantly improves both the characteristics that contribute to yield and the overall yield itself. Their findings indicate that zinc not only promotes key growth factors but also enhances the overall productivity of crops, suggesting its potential as an essential nutrient for increasing crop output.

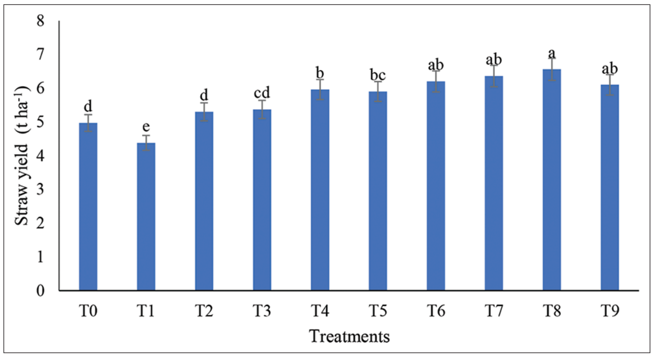

Figure 3: Effect of zinc management on the straw yield of BRRI dhan50 Here, T_0 = 0 kg/ha (control), T_1 = 2.0 kg Zn/ha (basal), T_2 = 4.0 kg Zn/ha (basal), T_3 = 6.0 kg Zn/ha (basal), T_4 = 1.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT), T_5 = 2.0 kg Zn/ha (basal) + 2.0 kg Zn/ha (SA at 30 DAT), T_6 = 3.0 kg Zn/ha (basal) + 3.0 kg Zn/ha (SA at 30 DAT), T_7 = 1.0 kg Zn/ha (basal) + 0.5 kg Zn/ha (SA at 30 DAT) + 0.5 kg Zn/ha (FA at flag leaf stage), T_8 = 2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf stage), T_9 = 3.0 kg Zn/ha (basal) + 1.5 kg Zn/ha (SA at 30 DAT) + 1.5 kg Zn/ha (FA at flag leaf stage)

The analysis showed that treatment T_5 resulted in maximum effective tillers and grains highlighting that specific zinc levels can significantly impact reproductive success. Conversely, T_0 demonstrated the lowest numbers, indicating that insufficient zinc adversely affects these critical metrics (Figures 4 & 5). This suggests that certain treatments may improve the efficiency of biomass conversion into yield, an important factor for

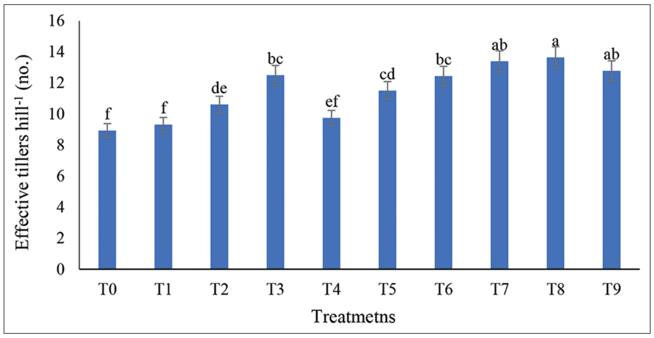

Figure 4: Effect of zinc management on the effective tillers hill^{-1} of BRRI dhan50
Here, T_0 = 0 kg/ha (control), T_1 = 2.0 kg Zn/ha (basal), T_2 = 4.0 kg Zn/ha (basal), T_3 = 6.0 kg Zn/ha (basal), T_4 = 1.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT), T_5 = 2.0 kg Zn/ha (basal) + 2.0 kg Zn/ha (SA at 30 DAT), T_6 = 3.0 kg Zn/ha (basal) + 3.0 kg Zn/ha (SA at 30 DAT), T_7 = 1.0 kg Zn/ha (basal) + 0.5 kg Zn/ha (SA at 30 DAT) + 0.5 kg Zn/ha (FA at flag leaf stage), T_8 = 2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf stage), T_9 = 3.0 kg Zn/ha (basal) + 1.5 kg Zn/ha (SA at 30 DAT) + 1.5 kg Zn/ha (FA at flag leaf stage)

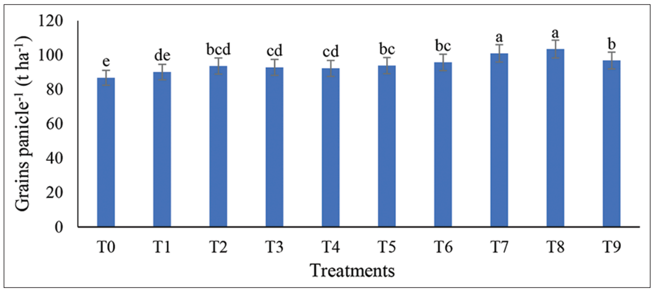

Figure 5: Effect of zinc management on the grains panicle^{-1} of BRRI dhan50
Here, T_0 = 0 kg/ha (control), T_1 = 2.0 kg Zn/ha (basal), T_2 = 4.0 kg Zn/ha (basal), T_3 = 6.0 kg Zn/ha (basal), T_4 = 1.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT), T_5 = 2.0 kg Zn/ha (basal) + 2.0 kg Zn/ha (SA at 30 DAT), T_6 = 3.0 kg Zn/ha (basal) + 3.0 kg Zn/ha (SA at 30 DAT), T_7 = 1.0 kg Zn/ha (basal) + 0.5 kg Zn/ha (SA at 30 DAT) + 0.5 kg Zn/ha (FA at flag leaf stage), T_8 = 2.0 kg Zn/ha (basal) + 1.0 kg Zn/ha (SA at 30 DAT) + 1.0 kg Zn/ha (FA at flag leaf stage), T_9 = 3.0 kg Zn/ha (basal) + 1.5 kg Zn/ha (SA at 30 DAT) + 1.5 kg Zn/ha (FA at flag leaf stage)

maximizing production. The positive correlations found in this study are consistent with the literature. For instance, Khan *et al.* (2007) and Oahiduzzaman *et al.* (2016) corroborated the notion that sufficient zinc availability leads to better tillering and increased panicle length, further validating the need for targeted nutrient applications. Moreover, the study highlighted that zinc fertilizer application increases yield while also boosting zinc absorption by the plants. Shivay *et al.* (2015) demonstrated that a combination of soil and foliar zinc applications could yield the highest straw yields, indicating that multifaceted approaches to zinc fertilization can optimize outcomes. Additionally, the maximum harvest index was recorded for T_1, while the minimum result was observed in T_6 (Table 1). Zinc supplementation can positively influence the harvest index of fine aromatic rice by promoting better plant growth and development, which in turn can enhance the allocation of resources towards grain production rather than vegetative parts. Overall, this research reinforces the necessity of appropriate zinc management in rice cultivation. Treatment T_8 was identified as the most effective, enhancing multiple growth and yield parameters, while the control and T_1 treatments illustrated the detrimental effects of inadequate zinc supply.

CONCLUSION

The application of different zinc concentrations to BRRI dhan50 resulted in significant differences across most agronomic parameters. Among the treatments, 2.0 kg Zn ha^{-1} (basal) + 1.0 kg Zn ha^{-1} (SA at 30 DAT) + 1.0 kg Zn ha^{-1} (FA at flag leaf) demonstrated the most pronounced improvement in yield related traits and overall grain yield, indicating its superior effectiveness in enhancing the crop's performance relative to other zinc treatments.

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