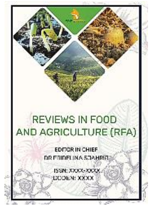
ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2735-0312 (Online)
CODEN: RFAEAW

Reviews In Food And Agriculture (RFNA)

DOI: http://doi.org/10.26480/rfna.01.2024.61.68



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RESEARCH ARTICLE

YIELD ENHANCEMENT OF HYBRID *BORO* RICE THROUGH ZINC BORON AND TRIACONTANOL APPLICATION

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ARTICLE DETAILS

Article History:

Received 23 November 2024
Revised 18 December 2024
Accepted 11 December 2024
Available online 10 January 2025

ABSTRACT

Despite the high potentiality, the yield of hybrid rice varieties is not satisfactory in Bangladesh. Among others, micronutrients like zinc and boron deficiency in soil is one of the major reasons behind the low productivity of hybrid rice. Apart from micronutrient fertilizers application, growth promoters like triacontanol (TRIA), can play a vital role in ensuring the potential yield of hybrid rice. Thus, a field experiment was performed at the Agronomy Field Laboratory at Bangladesh Agricultural University during the period from November 2021 to May 2022 to evaluate the effect of zinc, boron and triacontanol alone or in different combinations on the yield of hybrid *boro* rice. From the present study, it is evident that the hybrid *boro* rice variety Tej gold performed better than Heera-19. Findings confirm that the application of triacontanol and zinc resulted in yield enhancement of hybrid rice, but the application of boron did not influence hybrid rice yield. Therefore, soil application of Zn @ 10 kg ha^{-1} at 10 days after transplanting and foliar spraying with triacontanol @ 15 ml 10 L^{-1} at 30, 50 and 70 days after transplanting may be recommended for the higher yield of *boro* rice.

KEYWORDS

Boron, Growth promoter, Hybrid rice, Triacontanol, Zinc

1. INTRODUCTION

The most important cereal crop in the world is rice (*Oryza sativa*). The world continues to consume the most rice per person each year (Salam et al., 2019). Bangladesh is a major producer and consumer of rice worldwide, among other rice-producing nations. The rice-based agricultural system has a tremendous influence on the agrarian economy of this country and earns approximately 13.47 % of its gross domestic product (GDP) from agriculture (BBS, 2021). For Bangladesh's food and nutrition security, a robust rice system is a strategic goal (Timsina et al., 2018). The nation has achieved self-sufficiency in rice production in recent years and has also progressively joined the export regime (BER, 2015). Nowadays, 11.70 million hectares of land in Bangladesh are used to produce over 37.61 million metric tons (MT) of rice (BBS, 2021).

In Bangladesh, rice cultivation occurs across three separate growing seasons: '*aus*' from March to July, '*aman*' from July to December, and '*boro*' from December to May. The distribution of the total cropped area is approximately 11.15% for *aus* rice, 47.93% for *aman* rice, and 40.91% for *boro* rice (BBS, 2021). *Boro* rice stands out as the most significant and largest crop in Bangladesh in terms of production volume. It occupies an area of 4.79 million hectares, yielding a total production of 19.89 million metric tons (BBS, 2021).

Hybrid rice cultivation technology has been extensively implemented in China, yielding significant benefits in the fight against hunger and poverty. This type of rice can produce between 6.0 and 7.0 tons per hectare. In Bangladesh, while the potential for hybrid rice is promising, there has been minimal research focused on the development of hybrid varieties. Hybrid rice represents a viable option for surpassing the yield limitations of both the best modern varieties and conventional semi-dwarf rice. Given the continuous increase in Bangladesh's population, the horizontal expansion of rice cultivation is constrained by limited land resources and high population density. Therefore, the primary strategy to enhance rice production lies in the adoption of hybrid rice (Pan et al., 2013).

Micronutrients are crucial for the growth and development of crop plants. In Bangladesh, the decline in soil fertility over time has led to a deficiency of micronutrients in the soil. Among these, zinc (Zn) is recognized as the most deficient micronutrient worldwide, and more than 30% of soils in the world have low Zn availability (Cakmak, 2002; Shivay et al., 2008; Rana and Kashit, 2014). Zinc is essential for various metabolic processes in plants. Although classified as a micronutrient, zinc deficiency ranks as the third most significant nutritional limitation, following nitrogen and phosphorus.

This deficiency is prevalent in the soils of the Gangetic alluvium. Zinc was identified as a crucial micronutrient over 70 years ago (Sommer and Lipman, 1926). Numerous studies conducted since that time have demonstrated that zinc deficiency poses a significant nutritional challenge for upland crops. This deficiency adversely affects tillering, increases spikelet sterility, and prolongs the maturation process of the crops. (IRRI, 2000). Zinc deficiency in agricultural crops leads to decreased yields and contributes to zinc malnutrition in humans, particularly in regions where rice is a primary staple food.

Boron (B) deficiency issues affecting crop production have recently been recognized in Bangladesh. The concentration of available B in the predominant soil types across the country varies from 0.1 to 1.9 mg kg^{-1} of soil. It is estimated that around 1 million hectares of arable land may

Quick Response Code	Access this article online	
	Website: www.rfna.com.my	**DOI:** 10.26480/rfna.01.2024.61.68

Cite The Article: Faiza Tanjim, Md. Parvez Anwar, Sabina Yeasmin, Amdadul Hoque Amran, Joairia Hossain Faria, Nazmun Nahar Priya, Mahirul Islam Biswas, Afroza Sultana (2024). Yield Enhancement Of Hybrid *Boro* Rice Through Zinc Boron And Triacontanol Application. *Reviews In Food And Agriculture, 4(1): 61-68.*

experience B deficiency challenges. Field trials conducted in B-deficient regions of northern Bangladesh have demonstrated yield increases of 10-92% in wheat and 14-52% in various vegetables due to B fertilization (Zhang et al., 2017). Boron is a vital mineral nutrient that promotes various physiological functions in vascular plants. It plays a crucial role in carbohydrate metabolism, the translocation of nutrients, and the formation of cell walls, as well as in RNA metabolism (Herrera-Rodriguez et al., 2010).

It has been established that boron significantly influences multiple stages of rice development, including the germination of pollen, the growth of pollen tubes, the setting of seeds, and the formation of grains in diverse rice varieties. Moreover, B is vital for the stimulation of the plasma membrane, the development of anthers, the fertility of florets, and the overall process of seed development (Wang et al., 2003). Insufficient B results in diminished leaf photosynthetic rates, reduced total dry matter production, lower plant height, and fewer reproductive structures during the squaring and fruiting stages (Zhao and Oosterhuis, 2003). In light-textured soils, the use of boron fertilization results in a 46.1% increase in the seed yield of rapeseed (Yang et al., 2009). According to a study, there was a notable increase in the grain yield of rice varieties, which was linked to a reduction in panicle sterility following the application of indicated that the cumulative application of Zn and B led to significantly greater grain yields in rice than those achieved through direct and residual applications (Rashid et al., 2004; Hussain, 2006).

Plant growth regulators (PGRs) are organic compounds that modify the physiological processes of plants, distinct from traditional nutrients. These compounds, often labeled as bio-stimulants or bio-inhibitors, act within plant cells to either activate or inhibit certain enzymes or enzyme systems, thereby regulating the overall metabolism of the plant (Rahman et al., 2017). In the context of rice cultivation in Bangladesh, the application of PGRs is notably low. Identifying effective PGRs is vital for achieving maximum rice yields with superior quality (Aziz and Miah, 2009). Research indicates that PGRs can lead to a 14.3% increase in the number of rice panicles (Banful and Attivor, 2017).

The discovery of triacontanol (TRIA) as a plant growth regulator was made by in alfalfa (*Medicago sativa* L.) (Ries et al., 1977). Mandava characterized TRIA as a secondary plant growth substance, which does not fall under the category of phytohormones (Mandava, 1979). Such growth regulators are known to enhance the physiological efficiency of plant cells, thereby allowing for a more extensive utilization of the plant's genetic capabilities. Triacontanol is a naturally occurring growth regulator present in epicuticular waxes and is employed to improve crop yields over millions of hectares, particularly in Asia. A significant number of researchers have reported that TRIA facilitates improvements in growth, yield, photosynthesis, protein synthesis, water and nutrient absorption, nitrogen fixation, enzyme activity, and the concentrations of free amino acids, reducing sugars, soluble proteins, and essential oil components in various crops.

Specifically, TRIA has been observed to increase the levels of free amino acids, reducing sugars, and soluble proteins in rice (*Oryza sativa* L.) and maize (*Zea mays* L.) within just five minutes (Ekamber and Kumar, 2007). Therefore, this study was undertaken to evaluate the single and combined effect of Zn, B, and triacontanol on the growth and yield of hybrid rice and to find out the best micronutrient and triacontanol combination for maximizing hybrid rice yield in *boro* season.

2. Materials And Methods

2.1 Experimental Site

The study was carried out at the Agronomy Field Laboratory within the Department of Agronomy at Bangladesh Agricultural University, Mymensingh, during the *boro* season from November 2021 to May 2022. The experimental site is located at a latitude of 24.75°N and a longitude of 90.50°E, at an elevation of 18 meters above sea level, and is classified under the 'Old Brahmaputra Floodplain, Agro-Ecological Zone (AEZ)-9. The soil characteristics of the experimental field indicated a neutral pH of 6.8, a low organic matter content of 1.37%, and generally low fertility levels, with total nitrogen at 1.1%, available phosphorus at 25 ppm, exchangeable potassium at 0.16 me%, available sulfur at 22.2 ppm, and zinc at 0.43 ppm.

2.2 Description of the Materials Used

2.2.1 Tej gold

Bayer Crop Science developed this hybrid variety and was released in 2014. The variety is popular due to its high yield, clean medium rice, long slender grain having good cooking quality, 75% milling rate and suitable for both *boro* and *aman* season. It is resistant to Bacterial Leaf Blight (BLB) and performs well in moisture stress conditions. This variety attains a height of 95-105 cm and it takes 140-145 days in the *boro* season and 120-125 days in the *aman* season to mature. Tej gold requires 2-3 less irrigations than other *boro* rice varieties. The seeds were collected from the local seed dealer.

2.2.2 Heera-19

Supreme Seed Company Limited developed this hybrid variety and was released in 2008. The variety is popular due to its high yield potential, medium coarse grain, no lodging, lower spikelet strility, 75% milling rate and suitable for growing all over Bangladesh. Heera-19 also performs well in moisture-stress conditions. This variety attains a height of 108 cm and it takes 140-145 days to mature in *boro* season. The seeds were collected from the local seed dealer.

2.2.3 Sico Green L Super

It is marketed by Haychem (Bangladesh) Limited. The active ingredient of Sico Green is Triacontanol (TRIA). TRIA is a saturated long-chain alcohol recognized for its ability to promote growth when applied externally to various plant species.

2.3 Experimental Treatments and Design

The experiment comprised two factors namely, *boro* rice variety and Micronutrient and Triacontanol combination. Two *boro* rice varieties included were (i) Tej gold and (ii) Heer-19. While eight Micronutrient and Triacontanol combinations were (i) No micronutrient or Triacontanol (control) (ii) Triacontanol @ 15 ml 10 L^{-1} water (iii) Zinc (Zn) @ 10 kg ha^{-1} (iv) Boron (B) @ 1 kg ha^{-1},(v) Triacontanol + Zn (vi) Triacontanol + B (vii) Zn + B and viii) Triacontanol + Zn +B. The study was structured using a randomized complete block design (RCBD), consisting of three replications, each serving as a distinct block. Within each block, there were 16-unit plots, into which 16 treatment combinations were randomly assigned. The total number of unit plots in the experiment was (2 x 8 x 3) 48, each of size 5 m^2 (2.5 m x 2.0 m).

2.4 Land Preparation and Fertilizer Application

The land was ploughed with the help of a power tiller. Subsequently, the land was sufficiently irrigated and puddled properly with a power tiller. Prior to the final land preparation, well-decomposed compost was applied at a rate of 5 tons per hectare. The fertilization of the field included 200 kg, 120 kg, 100 kg, and 70 kg per hectare of urea, triple super phosphate (TSP), muriate of potash (MoP), and gypsum, respectively. The full quantities of TSP, MoP, and gypsum were applied before the transplanting took place. Urea was subsequently top-dressed in three equal applications at 15, 35, and 55 days after transplanting (DAT). Zinc in the form of ZnSO4 (21% Zn) and boron in the form of Boric acid (17% B) were applied as per treatment at 10 DAT. Sico Green L Super was foliar sprayed @ 15 ml 10 L^{-1} water (spray volume: 300 L ha^{-1}) thrice at 30, 50, and 70 DAT.

2.5 Crop Husbandry

Different intercultural operations were done to maintain the normal growth and development of the crop. Weeding was done thrice manually at 15, 35, and 55 days after transplanting. Irrigation was given as necessary.

2.6 Data Collection

Data collection encompassed a range of parameters, including plant height, total tillers $hill^{-1}$, effective tillers $hill^{-1}$, non-effective tillers $hill^{-1}$, grains $panicle^{-1}$, sterility percentage, 1000-grain weight, grain yield, straw yield, and harvest index. Individual plant parameters were assessed from randomly chosen sample hills within each plot, while data concerning 1000-grain weight, grain yield, straw yield, biological yield, and harvest index were collected from the entire plot at the time of harvest.

2.7 Data Analysis

The analysis of the recorded data was conducted utilizing the MSTAT-C computer software. Duncan's Multiple Range Test (DMRT) was employed to determine the significance of the mean differences.

3. Results

3.1 Effect of micronutrient and triacontanol application on growth parameters of hybrid rice

Plant height of rice was significant for varietal effect at 60 days after transplanting (DAT) but not at 40, 80 DAT, and at harvest (Table 1). At 40 and 80 DAT, Tej gold produced taller plants than Heera-19. But at 60 DAT

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and at the time of harvest Heera-19 produced relatively taller plants than Tej gold (Table 1).

Effect of different micronutrient and triacontanol applications on plant height of rice was significant at 40, 60, and 80 DAT and at harvest (Table 2). The highest plant height (27.71, 56.07, 93.55 and 100.22 cm at 40, 60, 80 DAT and at harvest, respectively) were observed when triacontanol + Zn + B were applied together. At all the recorded dates and at harvest, minimum plant height was obtained from control (Table 2).

Table 1: Effect of variety on plant height at different days after transplanting of boro hybrid rice

Variety	Plant height (cm) at different days after transplanting (DAT)			
	40	60	**80**	**At harvest**
Tej gold	24.98	52.14 b	88.12	96.01
Heera-19	23.61	54.08 a	85.45	97.39
$S\bar{x}$	0.71	0.97	1.60	1.69
Level of significance	NS	*	NS	NS
CV (%)	**10.14**	**6.30**	**6.40**	**6.05**

Table 2: Effect of micronutrient and triacontanol application on plant height at different days after transplanting of *boro* hybrid rice

Treatments	Plant height (cm) at different days after transplanting (DAT)			
	40	**60**	**80**	**At harvest**
No micronutrient and triacontanol	22.18b	50.79c	82.77 b	93.01 b
Triacontanol	24.41b	53.22abc	86.93 b	97.63ab
Zinc	23.58b	52.09bc	84.41 b	95.37ab
Boron	23.02b	51.34c	84.68 b	94.86ab
Triacontanol + Zn	24.95ab	53.29abc	88.24ab	98.96ab
Triacontanol + B	24.66b	55.60ab	87.73ab	97.28ab
Zn + B	23.84b	52.45abc	85.91 b	96.27ab
Triacontanol + Zn + B	27.71a	56.07a	93.55a	100.22a
Sx -	1.42	1.93	3.20	3.38
Level of significance	*	**	**	**
CV (%)	10.14	6.30	6.40	6.05

** =Significant at 1% level of probability, * =Significant at 5% level of probability

The interaction of variety, micronutrient and triacontanol application did not significantly affect the plant height of rice at harvest but significantly affected the plant height at 40, 60 and 80 DAT (Table 3). The maximum plant height (27.93, 57.60 and 93.94 cm at 40, 60 and 80 DAT, respectively) was recorded when Heera-19 was treated with soil application of triacontanol + Zn + B. The minimum plant height at Tej gold (49.81 cm at 60 DAT) and at Heera-19 (22.46 and 84.22 cm at 60 and 80 DAT) were recorded when no micronutrient and triacontanol were applied (Table 3).

Table 3: Interaction effects of variety, micronutrient and triacontanol on plant height at different days after transplanting of *boro* hybrid rice

Variety x treatments		Plant height (cm) at different days after transplanting (DAT)			
		40	**60**	**80**	**At harvest**
Tej Gold	No micronutrient and triacontanol	22.46c	49.81 c	84.22bc	92.67
	Triacontanol	25.55abc	52.67abc	88.35abc	96.91
	Zinc	24.66abc	51.69bc	86.69abc	94.96
	Boron	23.65bc	50.00c	86.25abc	93.67
	Triacontanol + Zn	25.80abc	52.06abc	90.38abc	97.55
	Triacontanol + B	25.11abc	54.51abc	88.69abc	96.43
	Zn + B	24.66abc	51.80bc	86.37abc	95.59
	Triacontanol + Zn + B	27.50a	54.55abc	93.16ab	100.10
Heera-19	No micronutrient and triacontanol	21.90c	51.78bc	81.33c	93.35
	Triacontanol	23.26c	53.78abc	85.51abc	98.34
	Zinc	22.50c	52.49abc	82.13c	95.79
	Boron	22.39c	52.69abc	83.11c	96.06
	Triacontanol + Zn	24.11abc	54.52abc	86.11abc	100.38
	Triacontanol + B	24.22abc	56.70ab	86.78abc	98.13
	Zn + B	23.02c	53.11abc	85.45abc	96.94
	Triacontanol + Zn + B	27.93ab	57.60a	93.94a	100.33
	Sx -	2.01	2.73	4.53	4.78
	Level of significance	**	**	**	NS
	CV (%)	**10.14**	**6.30**	**6.40**	**6.05**

** =Significant at 1% level of probability, NS = Non-significant

Number of tillers hill^{-1} was not significant for variety at any growth stage (Table 4). At all the growth stages, Tej gold produced numerically more tiller than Heera-19 (Table 4).

Effect of different micronutrient and triacontanol applications on the number of tillers hill^{-1} was significant at 40, 60 and 80 DAT but not significant at harvest (Table 5). At 40, 60 and 80 DAT, micronutrient and triacontanol application significantly increased number of tillers hill^{-1} over control. Maximum tiller number hill^{-1} (5.25, 13.28 and 13.51 at 40, 60 and 80 DAT, respectively) were obtained with triacontanol + Zn + B application. Minimum tiller number hill^{-1} (4.27, 11.96 and 12.20 at 40, 60 and 80 DAT, respectively) were obtained from control (Table 5). Although the effect of micronutrient and triacontanol application approaches on tiller number hill^{-1} was not significant at harvest, but micronutrient application numerically resulted in more tiller than control (Table 5)

Table 4: Effect of variety on number of tillers hill-1 at different days after transplanting of boro hybrid rice

Variety	**Number of tillers hill-1 at different days after transplanting (DAT)**			
Tej gold Heera-19	**40**	**60**	**80**	**At harvest**
	4.97 4.80	12.74 12.52	12.84 12.54	11.02 10.76
Sx - Level of significance CV (%)	0.15 NS 10.49	0.29 NS 7.99	0.27 NS 7.29	0.43 NS 13.80

NS = Non-significant

** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS = Non-significant

The interaction of variety and micronutrient and triacontanol application showed significant effect at 40, 60 and 80 DAT and did not significantly affect the number of tillers hill^{-1} at harvest (Table 6). The maximum number of tillers hill^{-1} (5.27, 13.49 and 13.70 at 30, 60 and 80 DAT, respectively) were recorded when Heera-19 was treated with soil application of triacontanol + Zn + B and the minimum number of tillers hill^{-1} (4.26, 11.80 and 12.00 at 30, 60 and 80 DAT, respectively) were recorded when Heera-19 was treated with no micronutrient and triacontanol (Table 6).

Table 5: Effect of micronutrient and triacontanol on number of tillers hill-1 at different days after transplanting of boro hybrid rice

Treatments	**Number of tillers hill-1 at different days after transplanting (DAT)**			
	40	**60**	**80**	**At harvest**
No micronutrient and triacontanol	4.27c	11.96b	12.20b	10.62
Triacontanol	5.00ab	12.67ab	12.63ab	11.02
Zinc	4.80abc	12.27ab	12.45ab	10.37
Boron	4.44 bc	12.41ab	12.46ab	10.72
Triacontanol + Zn	5.15a	12.86ab	13.03ab	11.02
Triacontanol + B	5.14a	13.08ab	12.76ab	11.04
Zn + B	4.99ab	12.49ab	12.44ab	10.46
Triacontanol + Zn + B	5.25a	13.28a	13.51a	11.85
Sx - Level of significance CV (%)	0.30 * **10.49**	0.58 ** **7.99**	0.53 ** **7.29**	0.87 NS **13.80**

Table 6: Combined effects of variety, micronutrient and triacontanol on number of tillers hill^{-1} at different days after transplanting of *boro* hybrid rice.

Variety x treatments		**Number of tillers hill^{-1} at different days after transplanting (DAT)**			
		40	**60**	**80**	**At harvest**
Tej Gold	Triacontanol Zinc Boron Triacontanol + Zn Triacontanol + B Zn + B Triacontanol + Zn + B	4.29cd 5.33a 4.96abcd 4.44 bcd 5.11abcd 5.22ab 5.14abc 5.22ab	12.12ab 12.69ab 12.46ab 12.55ab 12.83ab 13.33ab 12.44ab 13.07a	12.40ab 12.71ab 12.67ab 12.69ab 13.13ab 13.06ab 12.72ab 13.32ab	10.67 11.10 10.40 11.00 11.37 11.23 10.77 11.59
Heera-19	No micronutrient and triacontanol Triacontanol Zinc Boron Triacontanol + Zn Triacontanol + B Zn + B Triacontanol + Zn + B	4.26 d 4.66abcd 4.63abcd 4.44 bcd 5.19ab 5.06abcd 4.84abcd 5.27a	11.80 b 12.66ab 12.09ab 12.27ab 12.89ab 12.83ab 12.54ab 13.49a	12.00 b 12.56ab 12.22ab 12.24ab 12.93ab 12.45ab 12.15 b 13.70a	10.57 10.94 10.33 10.44 10.68 10.84 10.15 12.10
Sx Level of significance CV (%)		**0.42** ** **10.49**	**0.82** ** **7.99**	**0.76** ** **7.29**	**1.23** **NS** **13.80**

** =Significant at 1% level of probability, NS = Non-significant

3.2 Effect of micronutrient and triacontanol application on yield contributing parameters and yield of hybrid rice

Variety did not show any significant effect on all the yield contributing parameters and yield of hybrid rice except 1000 grain weight (Table 7).

Numerically, the highest number of grains panicle^{-1} (143.97), 1000 grain weight (25.42 g), grain and straw yields (6.76 and 7.66 t ha^{-1}, respectively) were found from Heera-19

but the number of non-effective tillers hill^{-1} (1.40) and sterility percentage (10.89) was also higher in this variety compared to Tej gold. On the other hand, numerically, the maximum

number of effective tillers hill^{-1} (9.72) and the highest harvest index (46.88 %) was found from Tej gold (Table 7).

Table 7: Effect of variety on yield contributing characters and yield of *boro* hybrid rice

Variety	No. of effective tillers hill^{-1}	No. of non-effective tillers hill-1	No of grains panicle^{-1}	Sterility %	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Tej gold	9.72	1.30	141.79	10.81	24.76b	6.67	7.54	46.88
Sx - Level of significance CV (%)	**0.41**	**0.12**	**3.12**	**0.35**	**0.21**	**0.07**	**0.10**	**0.92**

** =Significant at 1% level of probability, NS = Non-significant

Micronutrient and triacontanol application approaches significantly affected all the yield contributing parameters and yield of hybrid rice except the number of grains panicle^{-1} and harvest index (Table 8). The highest number of effective tillers hill^{-1} (10.75) and 1000-grain weight (25.51 g) and the lowest number of non-effective tillers hill^{-1} (1.09) were recorded when triacontanol + Zn + B was applied as soil application. Application of triacontanol in any form numerically reduced sterility percentage in hybrid rice. The highest grain and straw yields (7.13 and 7.99 t ha^{-1}) were found when triacontanol + Zn was applied as soil application which was statistically similar to the sole application of triacontanol, triacontanol + B and triacontanol + Zn + B application. No application of micronutrient and triacontanol (Control) produced the lowest number of effective tillers hill^{-1} (9.0), the highest number of non-effective tillers hill^{-1} (1.61), the highest sterility percentage (15.66), and the lowest 1000-grain weight (24.54 g). The lowest grain and straw yields (6.16 and 7.06 t ha^{-1}) were found with the sole application of Zn (Table 8). The interaction effect of variety, micronutrient and triacontanol applications significantly affected all the yield contributing parameters and yield of hybrid rice except the number of effective and non-effective tillers hill^{-1} (Table 9). The highest number of grains panicle^{-1} (151.23) and 1000-grain weight (25.83 g) was recorded when Heera-19 was treated with soil application of triacontanol + Zn + B. The lowest sterility (9.47 %) was found when Tej gold was treated with triacontanol solution (Table 9 and Figure 1). The maximum grain yield (7.33 t ha^{-1}), straw yield (8.13 t ha^{-1}) and harvest index (47.35) were the highest in Tej gold with triacontanol + Zn application. The minimum number of grains panicle^{-1} (132.60) was recorded in Tej gold when treated with triacontanol + Zn + B. The highest sterility (16.10 %) and the minimum 1000-grain weight were found in Tej gold with no micronutrient and triacontanol application. The minimum grain and straw yields (6.00 t ha^{-1} and 7.00 t ha^{-1}) and harvest index (46.15) were recorded in Tej gold with the sole application of Zn (Table 9)

Table 8: Effect of micronutrient and triacontanol on yield contributing characters and yield of *boro* hybrid rice

Treatments	No. of effective tillers hill^{-1}	No. of non-effective tillers hill^{-1}	No. of grains panicle^{-1}	Sterility %	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
No micronutrient and triacontanol	9.00b	1.61b	142.35	15.66a	24.54b	6.28de	7.18cd	46.54
Triacontanol	9.77ab	1.24ab	139.60	9.90b	25.14ab	6.88ab	7.78ab	46.87
Zinc	8.92 b	1.44ab	139.37	10.38b	24.81ab	6.16e	7.06 d	46.56
Boron	9.22ab	1.50ab	144.37	10.51b	24.87ab	6.58cd	7.54bc	46.60
Triacontanol + Zn	9.78ab	1.23ab	144.65	9.92b	25.23ab	7.13a	7.99a	47.11
Triacontanol + B	9.78ab	1.25ab	142.30	9.98b	25.34ab	6.91ab	7.77ab	47.04
Zn + B	9.04 b	1.41ab	141.49	10.47b	25.25ab	6.70 bc	7.56bc	46.96
Triacontanol + Zn + B	10.75a	1.09a	148.92	9.94b	25.51a	7.01a	7.87ab	47.09
Sx –	0.81	0.23	6.23	0.69	0.42	0.15	0.21	0.28
Level of significance	**	**	NS	**	**	**	**	NS
CV (%)	**14.75**	**30.13**	**7.56**	**11.08**	**2.88**	**3.80**	**4.73**	**1.04**

** =Significant at 1% level of probability, NS = Non-significant.

Table 9: Combined effects of variety, micronutrient and triacontanol on yield contributing characters and yield of boro hybrid rice.

Variety x treatments		No. of effective tillers hill^{-1}	No. of non-effective tillers hill^{-1}	No. of grains panicle^{-1}	Sterility %	1000-grain weight (g)	Straw yield (t ha^{-1})	Harvest index (%)
Tej Gold	**No micronutrient and triacontanol**	9.11	1.56	2.16ab	16.10a	24.24c	7.30d-g	46.22b

Table 9 (Cons): Combined effects of variety, micronutrient and triacontanol on yield contributing characters and yield of boro hybrid rice.

	Triacontanol	8.95	1.45	138.63ab	10.14b	24.31bc	7.00	46.15 b
	Zinc	9.58	1.42	145.46ab	10.39b	24.37bc	7.73a-d	46.54ab
	Boron	10.18	1.19	144.00ab	9.86b	24.99abc	8.13a	47.35a
	Triacontanol + Zn	10.06	1.18	143.31ab	10.08b	25.08abc	7.72a-e	47.24a
	Triacontanol + B	9.43	1.34	148.57ab	10.36b	25.03abc	7.65a-f	47.22a
	Zn + B	10.51	1.08	132.60 b	10.08b	25.20abc	7.79abcd	47.24a
	Triacontanol + Zn + B	8.89	1.68	142.53ab	15.23a	24.84abc	7.07fg	46.64ab
	No micronutrient and triacontanol	9.63	1.32	139.61ab	10.33b	25.43abc	7.64a-f	47.18a
	Triacontanol **Zinc**	8.89	1.45	140.10ab	10.62b	25.32abc	7.13efg	46.96ab
Heera-19	Boron	8.87	1.58	143.28ab	10.64b	25.36abc	7.34c-g	46.85ab
	Triacontanol + Zn	9.40	1.28	145.30ab	9.98b	25.47ab	7.86a-d	46.87ab
	Triacontanol + B	9.51	1.33	141.28ab	9.89b	25.61a	7.82a-d	46.83ab
	Zn + B	8.66	1.49	148.42ab	10.57b	25.48ab	7.47b-g	46.70ab
	Triacontanol + Zn + B	10.99	1.11	151.23a	9.81b	25.83a	7.95ab	46.93ab
	$S\bar{x}$	1.15	0.33	8.82	0.98	0.59	0.29	0.40
	Level of significance	NS	NS	**	**	**	**	**
	CV %	**14.75**	**30.13**	**7.56**	**11.08**	**2.88**	**4.73**	**1.04**

** =Significant at 1% level of probability, NS = Non-significant

4. Discussion

The height of rice plants is a critical vegetative growth parameter that reflects the impact of fertilizers. Zinc and boron are vital micronutrients necessary for various plant functions, including the production of growth hormones and the elongation of internodes. A deficiency in zinc results in stunted growth, while a lack of boron leads to white discoloration and curling of leaf tips. Conversely, triacontanol acts as a growth regulator, enhancing numerous metabolic processes within the plant and thereby promoting improved growth and development. The findings of this study indicate that all treatments significantly enhanced plant height compared to the control group, likely due to the sufficient availability of zinc, boron, and triacontanol, which facilitated increased enzymatic activity, auxin metabolism, cell wall development, sugar translocation, and reproductive success in rice crop.

Similar findings were reported who noted that the application of $ZnSO_4$ at a rate of 15 kg Zn per hectare in rice cultivation under Faisalabad conditions had a significant positive effect on all yield components (Maqsood et al., 1999). A group researcher indicated that the application of various micronutrients significantly affected growth parameters and yield components at harvest, including plant height, the number of effective tillers hill^{-1}, panicle length, the number of grains panicle^{-1}, and dry matter yield (Ayesha et al., 2016). Tillering represents a crucial developmental phase in plants, with the number of tillers being influenced by both the variety and the growing conditions. The findings of this study demonstrated that the Heera-19 variety exhibited the highest number of tillers hill^{-1} when treated with a combination of triacontanol, zinc, and boron.

This enhancement in tillering capacity may be attributed to the increased availability of essential nutrients compared to other treatment methods. Furthermore, the combination of triacontanol, zinc, and boron also resulted in the highest count of effective tillers hill^{-1}. A group researcher noted that the rise in productive tillers per meter could be linked to an adequate supply of zinc, which improved the plant's metabolic processes and ultimately enhanced crop growth (Khan et al., 2003). Some researcher similarly reported that sufficient zinc availability led to an increase in productive tillers per square meter (Naik and Das, 2010). Rashid mentioned that the application of boron contributed to yield increases by reducing panicle sterility in the lower sections of the ear and promoting a higher number of productive tillers hill^{-1} (Rashid, 2006).

All treatments significantly enhanced the number of grains panicle^{-1} relative to the control, due to the critical roles played by zinc (Zn), boron (B), and triacontanol in enzyme activation, chlorophyll production, pollen tube formation, pollen viability, and starch utilization. The application of Zn and B as soil treatments resulted in the highest grain count panicle^{-1}. These findings are consistent with those of who reported an increase in grains panicle^{-1} following Zn application (Naik and Das, 2010). Additionally, the foliar application of Zn was found to increase the total number of grains panicle^{-1}, as indicated by the studies (Karim et al., 2012; Khan et al., 2008).

This study demonstrated that the weight of 1000 grains was significantly enhanced by both the variety of the crop and the various methods of micronutrient application when compared to the control group. The observed increase in 1000-grain weight associated with the application of zinc, boron, and triacontanol may be attributed to a more effective involvement of nitrogen, potassium, and phosphorus in several metabolic processes. Previous research by also indicated an increase in 1000-grain weight resulting from foliar application of zinc (Khan et al., 2008; Asad and Rafique, 2008). Furthermore, a group researcher found that the application of micronutrients had a significant impact on the 1000-grain weight of rice, with the highest weight recorded in treatments where zinc and copper were applied at a rate of 10 kg ha^{-1} (Nawaz et al., 2015). Additionally, a group researcher reported notable differences in 1000-grain weight due to boron treatments (Khan et al., 2007). In the case of brown rice, noted that triacontanol facilitated improvements in heading and the percentage of ripened grains at harvest, which contributed to the increase in both individual grain weight and 1000-grain weight (Nagoshi and Kawashima, 1996).

Maximizing grain yield is the foremost goal in rice production. The findings of this study indicate that the selection of rice variety and the application of micronutrients led to a significant increase in grain yield. The combination of triacontanol and zinc produced the highest yields of grain and straw, while the application of zinc alone resulted in the lowest yield. The rise in grain yield can be linked to ongoing photosynthesis in the leaves during the critical grain-filling period. It appears that micronutrients have a substantial impact on plant physiology and the improvement of photosynthetic activity. In a related study, a group researcher reported that the simultaneous application of micronutrients has a considerable impact on crop yield (Imtiaz et al., 2010). A group researcher discovered that the maximum straw yield was achieved when micronutrients were used in conjunction with nitrogen, potassium, and phosphorus (Ayesha et al., 2016).

Their research also indicated that the application of micronutrients, particularly zinc and boron, significantly affected the grain and straw yields of rice. A variety of studies have demonstrated that the use of TRIA, whether applied to the roots or leaves, enhances the growth and yield of both vegetables and cereal crops. The increase in yield is attributed to a swift rise in the net assimilation rate, as evidenced in tomatoes after TRIA treatment. A group researcher reported beneficial effects of TRIA on yield and yield parameters, such as the number of pods and seed yield plant^{-1}, in hyacinth bean and coffee senna (Naeem et al., 2009).

The studies conducted by highlighted the considerable influence of TRIA on the yield and yield characteristics of crops such as pea, tomato, green gram, water chestnut, and soybean (Borowski et al., 2000; Kumaravelu et al., 2000; Chaudhary et al., 2006; Sharma et al., 2006; Nogalska et al., 2008). A study found that the combined application of zinc and boron led to the highest yield values, along with improved yield attributes and nutrient uptake (Chaturvedi, 2006). Additionally, a group researcher indicated that the application of boron significantly improved shoot height, leaf area, and grain yield plant^{-1} (Ahmed et al., 2009).

The harvest index serves as a measure of how plant metabolites are distributed among various parts of the plant. It reflects the physiological capacity to transform photosynthates into grain yield. In this research, a notable increase in the harvest index was observed with the simultaneous application of triacontanol and zinc. This enhancement in the harvest index correlates positively with the grain yield in rice. A group researcher noted that the joint application of micronutrients could elevate grain yield, thereby potentially enhancing the harvest index of rice (Hundal et al., 2008). Furthermore, a study reported that the application of micronutrients zinc and boron, either individually or in combination, resulted in a significantly higher harvest index (Sarwar, 2012).

5. Conclusion

From the present study, it is evident that hybrid *boro* rice variety Tej gold performed better than Heera-19. Findings confirm that the application of triacontanol and zinc resulted in yield enhancement of hybrid rice, but application of boron had no influence on hybrid rice yield. Therefore, soil application of Zn @ 10 kg ha^{-1} at 10 days after transplanting and foliar spraying with triacontanol @ 15 ml 10 L^{-1} at 30, 50 and 70 days after transplanting may be recommended for higher yield of *boro* rice.

Declaration

The authors declare that they do not have any conflict of interest.

Acknowledgments

The authors gratefully acknowledge Haychem (Bangladesh) Limited for providing Sico Green L Super for conducting this research.

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