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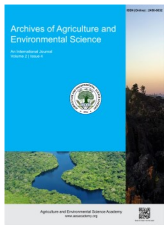

ORIGINAL RESEARCH ARTICLE

Growth and yield performance of hybrid rice varieties under varying zinc levels

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ABSTRACT

Zinc deficiency in soil is currently a widespread problem in Bangladesh that significantly reduces the yield of a variety of crops, including rice. Despite the fact that many farmers started applying zinc fertilizer, many are unaware of the right amount and application technique. For this reason, to determine the impact of variety and zinc treatment on the performance of hybrid rice, a field experiment was carried out between November 2019 and May 2020 at the Sher-e-Bangla Agricultural University's experimental field in Sher-e-Bangla Nagar, Dhaka-1207. The experiment consisted of two factors as variety (3 types) *viz.*, V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5 and, Zinc management (4 levels) *viz.*, Zn_0 – 0 kg ha^{-1} (control), Zn_1 – 2 kg ha^{-1}, Zn_2 – 4 kg ha^{-1} and Zn_3 – 6 kg ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (Factorial) with three replications. Data on different growth and yield parameter of rice were recorded and significant variation was found for different treatments. Regarding varietal performance, the maximum panicle number hill^{-1} (17.10), panicle length (28.03 cm), grain number panicle^{-1} (109.45), 1000-grain weight (26.50 g), grain yield ha^{-1} (6.94 t), straw yield ha^{-1} (8.58 t), biological yield ha^{-1}(15.51 t) and harvest index (44.62%) were found from the variety BRRI hybrid dhan5. Considering Zn effect, the maximum panicle number hill^{-1} (16.33), panicle length (27.14 cm), grain number panicle^{-1} (108.11), 1000-grain weight (25.38 g), grain yield ha^{-1} (6.81 t), straw yield ha^{-1} (8.34 t), biological yield ha^{-1}(15.15 t) and harvest index (44.88%) were found from 6 kg Zn ha^{-1}. In the case of treatment combination of variety and zinc, the maximum panicle number hill^{-1} (20.17), panicle length (29.45 cm), number of grains panicle^{-1} (117.74), 1000-seed weight (27.43 g), grain yield (7.80 t ha^{-1}), straw yield (9.20 t ha^{-1}), biological yield (17.00 t ha^{-1}) and harvest index (45.78%) were found from BRRI hybrid dhan5 along with 6 kg Zn ha^{-1}. Therefore, the hybrid rice variety BRRI hybrid dhan5 with a Zn application of 6 kg ha^{-1} yielded considerably more grain than the other treatment combinations under evaluation.

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INTRODUCTION

Rice (*Oryza sativa* L.) is widely grown in tropical and subtropical regions. It is the staple food of more than three billion people in the world (Aktar *et al.*, 2022; Laila *et al.* 2022). In South-East Asia, rice makes up 76% of all caloric intake and 21% of world calorific consumption (Zhao *et al.* 2020; Mohidem *et al.* 2022). Rice grain has influenced the culture and economy of billions of people worldwide (Paul *et al.*, 2021). Bangladesh ranks 4th in both area and production and 6th in per-hectare production of rice (Sarkar *et al.*, 2016). Rice alone constitutes 97% of the food grain production in Bangladesh (Jahan *et al.*, 2017).

Rice occupied an area of 28,213 thousand acres in 2018-2019, with a yield of 36,603 thousand metric tons (BBS, 2020). Bangladesh's average rice output is roughly 3.21 t ha^{-1} (BBS, 2020), which is quite low when compared to other rice-growing nations such as China (7.056 t ha^{-1}), Japan (6.82 t ha^{-1}), and Korea (6.87 t ha^{-1}) (FAO, 2021).

In Bangladesh, three distinct classes of rice, based on the season of cultivation namely *Aus*, *Aman* and *Boro* are cultivated during the period April to July, August to December and January to May, respectively. Among three growing seasons *Boro* rice occupies the highest area coverage (41% of rice cropping area) (BBS, 2022). In Bangladesh population growth is contributing to an ever-increasing demand for rice. Additionally, in recent years, the depletion of soil organic matter, the mining of nutrients, and the loss of soil aggregates all contributed to a decline in efficiency of soil (Sheel *et al.* 2015; Mahamud *et al.* 2022; Sabil *et al.* 2023). To counter this problem Bangladesh Rice Research Institute has developed several high yielding rice varieties among them BRRI hybrid dhan2, BRRI hybrid dhan3 and BRRI hybrid dhan5 are cultivated in *Boro* season in Bangladesh. There are 2189 thousand acres of land were under hybrid rice cultivation in Bangladesh and produced 4127 metric ton rice (BBS, 2020).

In recent years, there has been a surge in customer desire for meals that contain additional elements, particularly micronutrients, which are beneficial to health and wellbeing in addition to the typical nutrition. One-third of the world's population suffers from zinc. Zinc is essential for all humans, animals, and plants (Zou *et al.*, 2012). It is essential for the appropriate functioning of the immune system as well as for children's healthy growth, and physical and mental development. Cereal crops serve a significant part in meeting daily calorie consumption in underdeveloped nations; however, they are intrinsically quite low in Zn concentrations in grain (Mahamud *et al.*, 2015). The reliance on cereal-based diets may induce Zn deficiency-related health problems in humans, such as impairments in physical development, immune system, and brain function hidden hunger, or malnutrition (Praharaj *et al.* 2021). Furthermore, there is a big gap between daily requirements and daily intake to fulfill the gap our food grains should contain Zn (Wei *et al.*, 2012). Zinc is one of the most important micronutrients essential for plant growth especially for rice grown under submerged conditions. Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country (Afrin *et al.*, 2022). It is the most prevalent micronutrient problem in lowland rice, and in the majority of instances, using Zn fertilizer combined with N fertilizer significantly improves the grain yield (Yamuangmorn *et al.* 2020).

Therefore, it is crucial to understand the proper zinc dosage for the growth, development, and yield of hybrid rice varieties. But, research findings on the zinc application approach are meagre especially under Bangladesh conditions. The present research work was therefore undertaken to evaluate the effect of different doses of Zn growth and yield of hybrid *Boro* rice, and to find out the most suitable level of Zn for higher productivity and profitability of hybrid *Boro* rice.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted at the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh from November, 2019 to May 2020 to study the combined effect of the application of zinc fertilizer on the performance of hybrid rice during the *Boro* Season. The site is at 23°74/N latitude and 90°35/E longitude, and it is 8.2 meters above sea level. The experimental field's soil was from "The Madhapur Tract," AEZ-28 (FAO, 2014). The topsoil was Silty Clay in texture, olive-grey with common fine to medium distinct dark yellowish-brown mottles and the site is under a subtropical monsoon type of climate. Again, the soil having a texture of sandy loam organic matter of 1.15% and is composed of 26% sand, 43% silt and 31% clay.

Experimental treatment, design and layout

The experiment comprised three varieties *viz.* BRRI hybrid dhan2, BRRI hybrid dhan3 and BRRI hybrid dhan5, and four level of Zn management *viz.* Zn_0 = 0 kg ha^{-1} (control), Zn_1=2 kg ha^{-1}, Zn_2=4 kg ha^{-1}, Zn_3=6 kg ha^{-1}. The two factors (3×4) experiment was laid out in Randomized Block Design (Factorial) with three replications. An area of 450.00 m^2 (25.00 × 18.50 m) was divided into 3 blocks. The whole experimental area was divided into three equal blocks, each representing a replication. The size of each unit plot was 2.00 m × 1.50 m.

Crop husbandry

The seeds of three hybrid varieties of rice were obtained from the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. A piece of highland was selected for raising seedlings. Proper care was taken to raise the seedlings in the nursery bed. The final land was prepared thoroughly by tilling once with a power tiller and subsequently ploughing three times with country plough followed by laddering. The fertilizers N, P, K, S and B in the form of Urea, TSP, MoP, Gypsum and borax, respectively. Urea, TSP, MoP, Gypsum and Borax were applied @ 100, 60, 40, 12 and 10 kg ha^{-1} (BRRI, 2016). The doses of zinc were applied as per treatment through $ZnSO_4.H_2O$ (monohydrate). The entire amount of vermicompost, TSP, MP, gypsum and borax were applied during final land preparation. Urea was top dressed in three equal splits at 10, 25 and 40 days after transplanting. Seedlings were carefully uprooted from the nursery bed and transplanted on 26th December, 2019 in well puddled plot with spacing of 20 × 15 cm. All management practices were done as and when necessary.

Data collection

Plant height and number of tillers $hill^{-1}$, were recorded at 30, 60, 90 DAT and at harvest stage for all entries on ten randomly selected plants from the middle rows. Then leaf area index was measured by using leaf area meter (Model: LI-3100, Li-COR, Lincoln, NE, USA) at 30, 60 and 90 DAT. CGR represents the increase of plant material per unit time per unit land area. It was measured by the following formula (Watson, 1956).

$$CGR\ g\ m^{-1}day^{-1} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, W_1 = total dry matter (g) at time T_1 (day), W_2 = Total dry matter (g) at time T_2 (day) and T_2 – T_1 = time interval (days) between first and second harvests. At maturity, five hills (excluding border hills) from each unit plot were taken randomly to record yield contributing attributes and the whole plots were harvested to obtain grain and straw yields. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The harvested crops were threshed manually and the grain was cleaned and dried to a moisture content of 14 %. Straws were sun-dried properly. Final grain and straw yields plot^{-1} were recorded and converted to t ha^{-1}. The harvest index was calculated as follows:

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield}$$

$$\text{Harvest Index (HI)} = \frac{\text{Grain yeild (t ha}^{-1})}{\text{Biological yield (t ha}^{-1})} \times 100$$

Statistical analysis

The data obtained for different characters were statistically analysed to observe the significant difference among different treatments. The analysis of variance (ANOVA) of all the recorded parameters performed using MSTAT-C software. The difference of the means value was separated by least significance difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

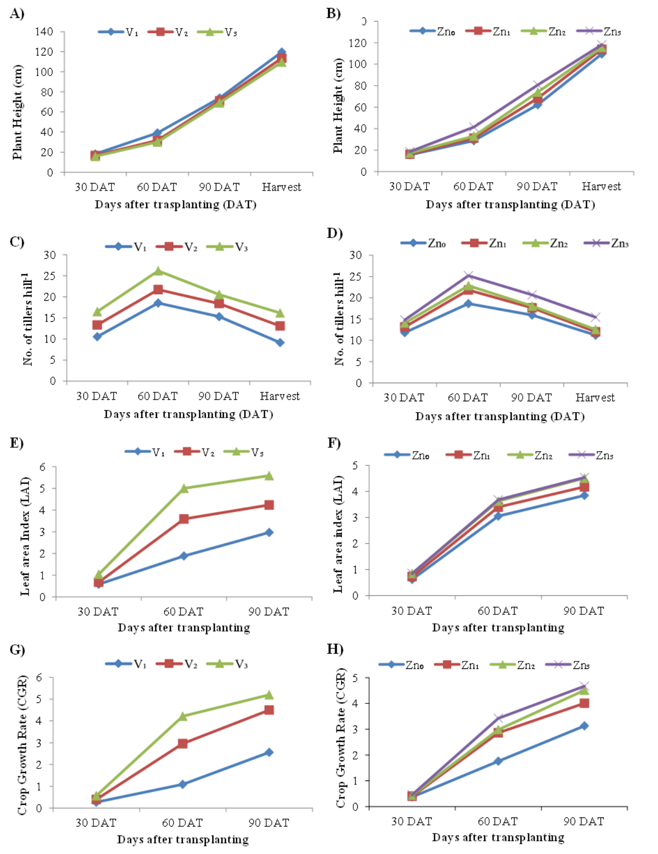

Figure 1. *Effect of variety and zinc levels on plant height (cm) (1A & 1B), no. of tillers hill*$^{-1}$ *(1C & 1D), leaf area index (1E & 1F) and crop growth rate (g m*$^{-1}$ *day*$^{-1}$*) (1G & 1H) in hybrid rice at different days after transplanting. Note:* V_1 *– BRRI hybrid dhan2,* V_2 *– BRRI hybrid dhan3 and* V_3 *– BRRI hybrid dhan5;* Zn_0 *- 0 kg Zn ha*$^{-1}$ *(control),* Zn_1 *– 2 kg Zn ha*$^{-1}$*,* Zn_2 *– 4 kg Zn ha*$^{-1}$ *and* Zn_3 *– 6 kg Zn ha*$^{-1}$*.*

RESULTS AND DISCUSSION

Plant height

Different varieties, Zn level and their interaction showed a significant effect on the plant height of hybrid rice (Figures 1A, 1B and Table 1). Varieties also showed an increasing trend in plant height with advances of age of the plant after transplanting and the highest increase was found at the harvesting stage. Among the varieties BRRI hybrid dhan5 showed the shortest and BRRI hybrid dhan2 showed the tallest plant for all sampling dates. However, the tallest plant at 30, 60, 90 DAT and harvest (18.22, 39.11, 73.89 and 119.82 cm), respectively was reported from BRRI hybrid dhan2 treatment while, the shortest plant (15.83, 30.09, 69.14 and 109.70 cm) respectively, was observed in BRRI hybrid dhan5 treatment (Figure 1A). The genotype of a plant plays a significant role in determining its characteristics, including plant height. This result agreed with Singh *et al.* (2019) and Mahmood *et al.* (2019) who described that plant height varies significantly among varieties. The figure indicated that irrespective of zinc doses height of the plant showed a gradually increasing trend with the advances of growth stages. The rate of increase in plant height was much higher up to harvesting time and then the rate was slower than earlier stage of growth whereas, the tallest plant at 30, 60, 90 DAT and harvest (18.54, 41.48, 80.74 and 118.13 cm, respectively) was recorded from 6 kg Zn ha^{-1} treatment. In comparison, the shortest plant at 30, 60, 90 DAT and harvest (15.59, 28.81, 62.29 and 109.62 cm) respectively was obtained from the control treatment (Figure 1B). Similar findings were made by Farzana *et al.* (2021), who concluded that Zn, in the right concentrations, speeds up the metabolism of auxin and the activity of plant enzymes. Considering the interaction effect at 30, 60, 90 and harvest, the tallest plant (22.67, 49.56, 88.22 and 124.10 cm) respectively was recorded from BRRI hybrid dhan2 along with 6 kg Zn ha^{-1} treatment combination. On the other hand, the shortest plant at 30, 60, 90 DAT and harvest (16.00, 28.82, 62.22 and 103.10 cm) respectively was observed in BRRI hybrid dhan5 along with no zinc application treatment combination (Table 1). This finding supported the claims made by Islam *et al.* (2021) that there are considerable variations in plant height among cultivars and different doses of Zn.

Number of tillers hill^{-1}

The number of total tillers hill^{-1} was significantly influenced by variety, Zn level and their interaction at all stages of crop growth (Figures 1C, 1D and Table 1). At 30, 60, 90 DAT and harvest, BRRI hybrid dhan5 was achieved maximum (16.48, 26.15, 20.55 and 16.16 respectively) tiller then with advancement to age it declined up to maturity and BRRI hybrid dhan2 minimum (10.53, 18.51, 15.32 and 9.14 respectively) tiller production was observed also then with advancement to age it declined up to maturity (Figure 1C). This showed that the rate of tiller mortality was higher than the rate of tiller formation during the reproductive and ripening periods. Variable effect of variety on number of total tillers hill^{-1} was also reported by Rahman *et al.*

Table 1. Interaction effect of variety and zinc on the plant height (cm), no. of tillers hill^{-1}, leaf area index and crop growth rate (g m^{-1} day^{-1}) in hybrid rice.

Variety × Zn level	Plant height (cm)				No. of tillers hill^{-1}				Leaf area index (LAI)			Crop growth rate (g m^{-1} day^{-1})		
	30 DAT	60 DAT	90 DAT	Harvest	30 DAT	60 DAT	90 DAT	Harvest	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
V_1Zn_0	17.33d	33.11e	64.33h	116.36c	9.29f	15.65g	13.55f	7.56d	0.38g	1.55h	2.58h	0.23e	0.69h	1.95g
V_1Zn_1	17.44cd	37.22d	69.00f	119.80b	10.28f	18.25f	14.95ef	8.58d	0.45f	1.73gh	2.81h	0.24e	1.12g	2.51f
V_1Zn_2	19.44b	40.56c	78.00c	123.00a	10.99ef	19.11f	15.30e	8.98d	0.54e	1.91g	3.04g	0.27e	1.17g	2.82f
V_1Zn_3	22.67a	49.56a	88.22a	124.10a	11.54e	21.04e	17.47cd	11.44c	0.54e	1.93g	3.04g	0.28e	1.34g	2.93f
V_2Zn_0	16.44e	27.44i	63.33h	112.40e	11.74e	18.31f	16.19de	11.53c	0.45f	3.04f	3.73f	0.35de	1.88f	3.43e
V_2Zn_1	17.89cd	29.71gh	67.11g	114.30d	13.02d	21.41de	17.92c	12.13c	0.54e	3.40e	4.05e	0.38d	3.06d	4.41d
V_2Zn_2	18.11c	30.00g	74.89d	114.60d	13.95cd	22.44d	18.35c	12.67c	0.65d	3.74d	4.38d	0.42cd	3.18d	4.96c
V_2Zn_3	18.18c	44.00b	83.00b	116.90c	14.66c	24.75cd	21.02b	16.04b	0.65d	3.79d	4.39d	0.44c	3.66c	5.16c
V_3Zn_0	16.00e	28.89h	62.22i	103.10h	14.47c	21.96d	18.08c	14.57b	0.74c	4.27c	4.95c	0.49c	2.68e	3.97d
V_3Zn_1	16.33e	30.00g	72.11e	110.90f	16.08b	25.76bc	20.04b	15.31b	0.89b	4.77b	5.37b	0.54bc	4.37b	5.09c
V_3Zn_2	17.22de	31.56f	72.22e	112.40e	17.24a	27.02b	20.53b	15.98b	1.07a	5.24a	5.81a	0.59ab	4.55b	5.73b
V_3Zn_3	17.78cd	33.89e	74.00d	116.40c	18.13a	29.85a	23.55a	18.78a	1.07a	5.32a	5.89a	0.62a	5.23a	5.96a
LSD	0.78	0.90	1.11	1.65	1.12	1.58	1.41	1.52	0.06	0.28	0.31	0.07	0.29	0.49
CV (%)	4.38	6.38	8.68	9.18	8.75	9.34	6.98	8.27	6.82	9.24	11.37	16.78	14.82	13.27

In a column, means having a similar letter (s) are statistically similar and those having a dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability. Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5, Zn_0 - 0 kg Zn ha^{-1} (control), Zn_1 – 2 kg Zn ha^{-1}, Zn_2 – 4 kg Zn ha^{-1} and Zn_3 – 6 kg Zn ha^{-1}.

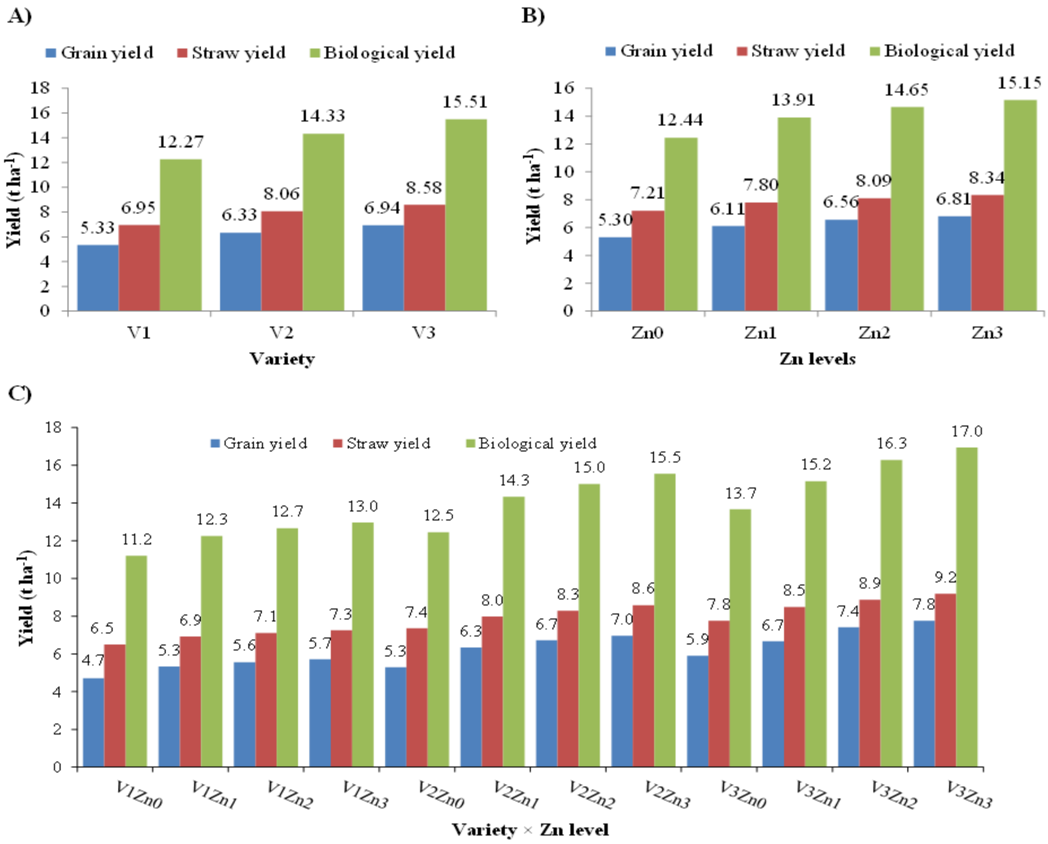

Figure 2. *Effect of variety, zinc levels and their interaction on yield (t ha^{-1}) in hybrid rice at different days after transplanting (2A-2C). Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5, Zn_0 - 0 kg Zn ha^{-1} (control), Zn_1 – 2 kg Zn ha^{-1}, Zn_2 – 4 kg Zn ha^{-1} and Zn_3 – 6 kg Zn ha^{-1}.*

(2022), Chowhan *et al.* (2019) who noticed that number of total tillers hill^{-1} differed among the varieties. Again, at 30 DAT, the maximum (14.78 tillers hill^{-1}) was found from 6 kg Zn ha^{-1} which was statistically similar 14.06 tillers hill^{-1} to 4 kg Zn ha^{-1} treatment, while the minimum (11.83 tillers hill^{-1} was recorded from 0 kg Zn ha^{-1}. At 60, 90 DAT and harvest stage, the maximum (25.21, 20.68 and 15.42 tillers hill^{-1}, respectively) was found from 6 kg Zn ha^{-1} and the minimum (18.64, 15.94 and 11.22 tillers hill^{-1}, respectively) was recorded from 0 kg Zn ha^{-1} (Figure 1D). Kumar *et al.* (2017) observed that the number of tillers hill^{-1} showed positive correlation with the increase in $ZnSO_4$ levels. The interaction effect of variety and zinc levels revelled that at 30, 60, 90 DAT, and at harvest, the maximum tiller number hill^{-1} (18.13, 29.85, 23.55, and 18.78, respectively) was achieved by BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} treatment combination. At 30, 60, 90 DAT and at harvest, the minimum number of tillers hill^{-1} (9.29, 15.65, 13.55, and 7.56, respectively) was found with BRRI hybrid dhan2 along with 0 kg Zn ha^{-1} (Table 1).

The significant variation in effective tiller of rice with different varieties and level zinc was also reported by Islam *et al.* (2021).

Leaf area index (LAI)

Leaf area index (LAI) or the surface area of green leaves produced by rice plants in unit area^{-1} of land was taken as an index of leaf area development. LAI was significantly influenced by variety, Zn level and their interaction at different growth stages (Figures 1E, 1F and Table 1). BRRI hybrid dhan5 variety, maintained the superior LAI as compared to other treatments at all the growth stages of observations. The highest LAI (1.04, 5.00 and 5.59, respectively) was found at 30, 60 and 90 DAT due to the effect of BRRI hybrid dhan5 whereas, the lowest LAI (0.58, 1.88 and 2.97, respectively) was found at 30, 60 and 90 DAT due to the effect of BRRI hybrid dhan2 (Figure 1E). Different genotypes may differ in their overall canopy structure, leaf size, shape, and architecture, all of which can have an impact on the LAI. While considering Zn levels, it was observed that the highest LAI (0.85, 3.68 and 4.54 at 30, 60 and 90 DAT, respectively) was obtained from the treatment 6 kg Zn ha^{-1} which was statistically similar with 4 kg Zn ha^{-1} (0.85, 3.63 and 4.51 at 30, 60, 90 DAT, respectively) whereas, the lowest LAI (0.62, 3.05 and 3.85) at 30, 60, 90 DAT respectively, was found from the treatment control treatment (Figure 1F). Similar result also reported by Haque and Biswash (2014) also concluded that application of Zn as foliar spraying in rice is highly attractive and produced higher LAI than control treatment. Additionally, incise of N doses, similar result also found by Ferdush *et al.* (2020). The interaction effect of variety and zinc rate showed that, at 30, 60, 90 DAT, the highest LAI (1.07, 5.32 and 5.89, respectively) was observed with BRRI hybrid dhan5 and 6 kg Zn ha^{-1}. On the other hand, at 30, 60, 90 DAT, the lowest LAI (0.38, 1.55 and 2.58, respectively) was found by BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}) (Table 1).

Crop growth rate (CGR)

Crop growth rate (CGR) was significantly influenced by different varieties at different growth stages (Figure 1G). Critical appraisal of the data showed that the maximum crop growth rate was recorded in the variety BRRI hybrid dhan5 at 30, 60 and 90 DAT. The maximum CGR (0.57, 4.22 and 5.20 g m^{-1} day^{-1}, respectively) was recorded with BRRI hybrid dhan5 whereas, the minimum CGR (0.27, 1.09 and 2.56 g m^{-1} day^{-1}, respectively) was found at 30, 60 and 90 DAT due to the effect of BRRI hybrid dhan2. A similar result was reported by Mahmood *et al.* (2019) who found significant variation on CGR due to varietal differences. Furthermore, at 30 DAT, there was no significant difference in CGR at different levels of Zn. It was observed that the maximum CGR (3.42 and 4.67 g m^{-1} day^{-1} at 60 and 90 DAT, respectively) was obtained from the treatment 6 kg Zn ha^{-1} whereas, the minimum CGR (1.76 and 3.13 g m^{-1} day^{-1}, respectively) at 60 and 90 DAT was found from the treatment 0 kg Zn ha^{-1} (Figure 1H) Similar results also reported by Boonchuay *et al.* (2013); Muthukumararaja and Sriramachandrasekharan (2012). The interaction effect of different varieties and different levels of zinc application showed a significant influence on the crop growth rate (CGR) of the hybrid *Boro* rice (Table 1). At 30 DAT, the maximum CGR (0.62 g m^{-1} day^{-1}) was observed with BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} which was statistically similar with 0.59 g m^{-1} day^{-1} whereas, the minimum CGR (0.23 g m^{-1} day^{-1}) was observed with BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}. At 60 and 90 DAT, the maximum CGR (5.23 and 5.96 g m^{-1} day^{-1}, respectively) was found by BRRI hybrid dhan5 along with 6 kg Zn ha^{-1}) whereas, the minimum CGR (0.69 and 1.95 g m^{-1} day^{-1}, respectively) was found by BRRI hybrid dhan2 with 0 kg Zn ha^{-1} treatment combination.

Number of panicles hill^{-1}

Number of panicles hill^{-1} of hybrid rice showed statistically significant differences due to different rice variety, Zn levels and their interaction (Tables 2-4). The highest number of panicles hill^{-1} (17.10) was found from BRRI hybrid dhan5 treatment, while the lowest number (10.09) was recorded from BRRI hybrid dhan2 treatment which followed (14.41) by BRRI hybrid dhan3 treatment. A similar kind of result was recorded by Yin *et al.* (2016) and Kumar *et al.* (2017). The number of panicles that are generated per hill might differ based on the genotype of the rice as well as elements like tillering capacity, plant structure, and reproductive development. Therefore, the highest panicle number hill^{-1} (16.33) was found from 6 kg Zn ha^{-1} treatment, while the lowest number (12.00) was recorded from 0 kg Zn ha^{-1} treatment. These may be due to contribution of zinc in reproductive development of rice plant. The similar kind of result was recorded by Yin *et al.* (2016). Furthermore, Interaction effect of variety and zinc levels was found significant on panicle number hill^{-1} of hybrid rice. The highest panicle number hill^{-1} (20.17) was found from the combination of BRRI hybrid dhan5 along with 6 kg Zn ha^{-1}. On the other hand, the lowest panicle number hill^{-1} (8.00) was found in BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}.

Panicle length

The panicle length varied significantly due to variety, Zn levels and their interaction effects shown in Tables 2-4. It was observed that BRRI hybrid dhan5 produced significantly longer (28.03 cm) panicle. The second longer panicle length (25.90 cm) was measured from BRRI hybrid dhan3 and the shortest panicle length (24.36 cm) was measured from BRRI hybrid dhan2. This supports the findings of Aktar *et al.* (2022), who demonstrated that panicle length varied depending on variety and concluded that this variation was likely caused by the genetics of the cultivars. Among the rate of Zn application, the longest panicle (27.14 cm) was recorded in 6 kg Zn ha^{-1} and the shortest panicle (24.78 cm) obtained from 0 kg Zn ha^{-1} treatment. A similar kind of result was also reported by Farzana *et al.* (2021) in which the adequate supply of zinc results in the greater panicle length. The interaction effect of different rate of variety and zinc in hybrid rice, the longest panicle (29.45 cm) was recorded in BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} treatment combination. On the other hand, the shortest panicle length (23.52 cm) was obtained from BRRI hybrid dhan2 along with no zinc application treatment combination.

Number of grains panicle^{-1}

Number of grains panicle^{-1} was significantly influenced by variety, Zn levels (Tables 2-4). The highest number of grains panicle^{-1} (109.45) was found from BRRI hybrid dhan5. The lowest grains panicle^{-1} (90.45) was obtained from BRRI hybrid dhan2. BRRI hybrid dhan5 produced 27.86% higher number of grains panicle^{-1} than BRRI hybrid dhan2. These results agreed with Sarker *et al.* (2021) who reported that the percent filled grain was the highest in Binadhan 15 while comparing with other varieties. Different level of Zn application in hybrid rice showed that the highest value of grains panicle^{-1} (108.11) was recorded in 6 kg Zn ha^{-1} treatment which was statistically identical with (104.30) whereas, the lowest (91.01) was recorded in 0 kg Zn ha^{-1} treatment. This might be due to higher zinc supply from $ZnSO_4$ which is evidenced by higher total Zn uptake. These results are in conformity with the findings of Kumar *et al.* (2017) and Hanifuzzaman *et al.* (2022). The interaction of variety and zinc rate resulted that the maximum number of grain panicle^{-1} (117.74) was recorded from BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} treatment combination. On the other hand, the minimum number of grain panicle^{-1} (82.22) was observed in BRRI hybrid dhan2 along with 0 kg Zn ha^{-1} treatment combination.

Weight of 1000 grains

Weight of 1000 grains showed significant variation among the different varieties, levels of Zn and their interaction (Tables 2-4). BRRI hybrid dhan5 produced highest 1000 grain weight (26.50 g). On the other hand, the lowest 1000 grain weight (22.33 g) was obtained from BRRI hybrid dhan2. Similar findings were reported by Rahman *et al.* (2022) and Mia (2018) who observed significant variation on 1000 seed weight due to varietal difference. Again, the maximum weight of 1000-grains (25.38 g) were recorded from 6 kg Zn ha^{-1} which was statistically similar with 4 kg Zn ha^{-1} (24.60 g) and 2 kg Zn ha^{-1} (24.51 g) and the lowest weight (23.60 g) was recorded to control treatment. This

Table 2. Effect of variety on the yield components in hybrid rice.

Variety	Number of panicles hill^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)
V_1	10.09 c	24.36 c	90.45 c	22.33 c
V_2	14.41 b	25.90 b	102.20 b	24.75 b
V_3	17.10 a	28.03 a	109.45 a	26.50 a
LSD	1.57	0.77	4.25	1.55
CV (%)	6.82	9.92	4.54	7.36

In a column, means having a similar letter (s) are statistically similar and those having a dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability. Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5.

Table 3. Effect of zinc levels on the yield components in hybrid rice.

Zinc level	Number of panicles hill^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)
Zn_0	12.00 c	24.78 d	91.01 c	23.60 b
Zn_1	13.28 b	25.87 c	99.37 b	24.51 ab
Zn_2	13.87 b	26.61 b	104.30 a	24.60 ab
Zn_3	16.33 a	27.14 a	108.11 a	25.38 a
LSD	1.21	0.47	5.85	1.55
CV (%)	6.82	9.92	4.54	7.36

In a column, means having a similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability. Note: Zn_0 - 0 kg Zn ha^{-1} (control), Zn_1 – 2 kg Zn ha^{-1}, Zn_2 – 4 kg Zn ha^{-1} and Zn_3 – 6 kg Zn ha^{-1}.

Table 4. Interaction effect of variety and zinc on the yield components in hybrid rice.

Variety × Zn level	Number of panicles hill^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)
V_1Zn_0	8.00g	23.52j	82.22h	21.49f
V_1Zn_1	9.97f	24.18i	89.39g	22.25ef
V_1Zn_2	10.37f	24.72h	93.32ef	22.46d-f
V_1Zn_3	12.04e	25.04g	96.87e	23.11d-f
V_2Zn_0	13.00de	24.52h	92.35f	23.81de
V_2Zn_1	13.62d	25.75f	100.84d	24.66cd
V_2Zn_2	14.23d	26.40e	105.88c	24.90cd
V_2Zn_3	17.78bc	26.93d	109.71c	25.61bc
V_3Zn_0	15.00c	26.30e	98.45de	25.50bc
V_3Zn_1	16.24bc	27.67c	107.88c	26.41ab
V_3Zn_2	17.00b	28.70b	113.71b	26.66ab
V_3Zn_3	20.17a	29.45a	117.74a	27.43a
LSD	1.21	0.47	3.85	1.40
CV (%)	6.82	9.92	4.54	7.36

In a column, means having a similar letter (s) are statistically similar and those having a dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability. Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5 Zn_0 - 0 kg Zn ha^{-1} (control), Zn_1 – 2 kg Zn ha^{-1}, Zn_2 – 4 kg Zn ha^{-1} and Zn_3 – 6 kg Zn ha^{-1}.

increase in grain weight upon zinc fertilization could be attributed to enhanced zinc uptake and translocation of sugars and higher carbohydrate accumulation in seed. Similar results have been reported by Kumar *et al.* (2017) and Farzana *et al.* (2021). The interaction effect indicated that the maximum 1000-seed weight (27.43 g) was with interaction of BRRI hybrid dhan5 with 6 kg Zn ha^{-1}. On the other hand, the minimum (21.49 g) result was obtained from BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}. Proper Zn application rates and appropriate variety increase grain weight by allowing Zn to participate more efficiently in the various metabolic processes engaged in good seed production Islam *et al.* (2021).

Grain yield

Grain yield varied significantly for different varieties, levels of Zn and their interaction shown in Figures 2A, 2B and 2C. The highest grain yield (6.94 t ha^{-1}) was recorded by BRRI hybrid dhan5. The lowest grain yield (5.33 t ha^{-1}) was recorded from BRRI hybrid dhan2. This result was similar with Rahman *et al.* (2022), Rahman *et al.* (2020), Chowhan *et al.* (2019) and Mia (2018) who found yield variation among different hybrid and/or modern rice varieties. Among Zn levels of treatments, the highest grain yield (6.81 t ha^{-1}) was obtained with 6 kg Zn ha^{-1} which was significantly higher than all remaining treatments. However, the grain yields of 6.56 t ha^{-1} and 6.11 t ha^{-1}was obtained with 4 kg Zn ha^{-1} and 2 kg Zn ha^{-1}, respectively which was significantly higher control (5.30 t ha^{-1}). Hanifuzzaman *et al.* (2022) observed that grain yield showed a positive correlation with the increase in $ZnSO_4$ levels while applied as both basal and foliar spray. According to Farzana *et al.* (2021), the higher yield brought on by Zn fertilization is due to its involvement in a number of metallic enzyme processes, regulatory activities, and auxin formation, as well as better carbohydrate synthesis and delivery to the grain-growing region. The interaction effect of different varieties and different rates of zinc application applied that, the combination of BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} produced the highest grain yield (7.8 t ha^{-1}). On the other hand, the lowest grain yield (4.70 t ha^{-1}) was found with the combination of BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}. Application of BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} produced 48.13% higher grain yield over control treatment. The finding of the study was also in line with the findings of Islam *et al.* (2021) and Zinzala and Narwade (2019).

Straw yield

In this study, significant variation was observed in straw yield due to varietal variation, levels of Zn and their interaction (Figures 2A, 2B and 2C). BRRI hybrid dhan5 recorded the maximum straw yield (8.58 t ha^{-1}) and BRRI hybrid dhan2 recorded the minimum straw yield (6.95 t ha^{-1}). Similar findings were also reported Singh *et al.* (2019) and Mia (2018). Furthermore, the maximum straw yield (8.34 t ha^{-1}) was achieved at the highest rate of zinc application 6 kg Zn ha^{-1} which was statistically identical to 4 kg Zn ha^{-1} (8.09 t ha^{-1}) whereas, the minimum (7.21 t ha^{-1}) was found with the control treatment (0 kg Zn ha^{-1}). Imran *et al.* (2015) and Wang *et al.* (2014) both showed an

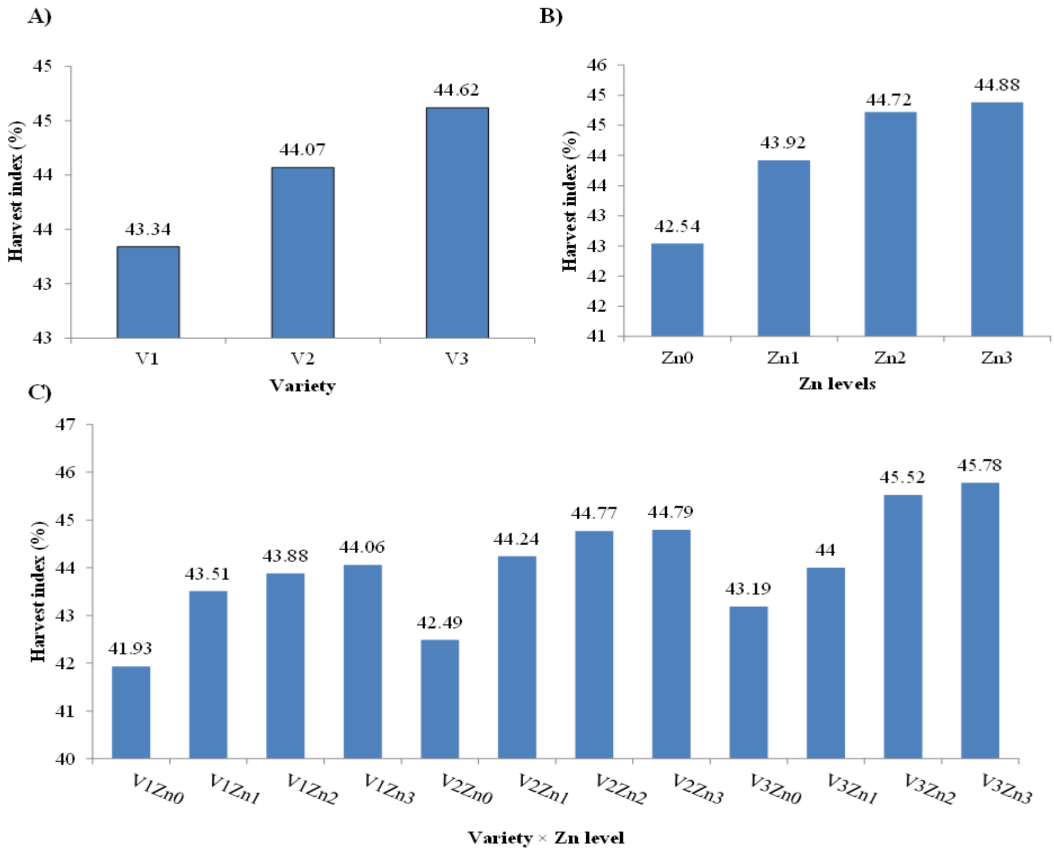

Figure 3. *Effect of variety, zinc levels and their interaction on harvest index in hybrid rice at different days after transplanting (3A-3C). Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5, Zn_0 - 0 kg Zn ha^{-1} (control), Zn_1 – 2 kg Zn ha^{-1}, Zn_2 – 4 kg Zn ha^{-1} and Zn_3 – 6 kg Zn ha^{-1}.*

increase in straw yield when Zn was applied. Further validating the results of the present study, Amanullah *et al.* (2020a) observed that greater Zn concentrations (10 and 15 kg Zn ha^{-1}) boosted yield and Zn content in both rice grains and straw. For the interaction effect of different varieties and zinc application in hybrid rice, the maximum straw yield (9.20 t ha^{-1}) was achieved at the combination treatment of BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} that was significantly differed to other treatment combinations followed by BRRI hybrid Dhan5 along with 4 kg Zn ha^{-1} whereas, the minimum (6.51 t ha^{-1}) was found with the combination treatment of BRRI hybrid dhan2 along with 0 kg Zn ha^{-1}. While considering the interaction between varieties and Zn level, the study's findings concurred with those of Islam *et al.* (2021) and Zinzala and Narwade (2019).

Biological yield

The biological yield (t ha^{-1}) varied significantly due to varieties, levels of Zn and their interaction shown in Figures 2A, 2B and 2C. It was observed that BRRI hybrid dhan5 produced significantly the highest biological yield (15.51 t ha^{-1}) and the lowest biological yield (12.27 t ha^{-1}) was recorded from BRRI hybrid dhan2. Similar results were also observed by Singh *et al.* (2019), Chowhan *et al.* (2019) and Mahmood *et al.* (2019). Therefore, significantly the maximum biological yield (15.15 t ha^{-1}) was found with (6 kg Zn ha^{-1}) which was higher than the rest of the treatments. However, the value of 4 kg Zn ha^{-1} was found statistically at par with all treatments except the control (12.44 t ha^{-1}). Khan *et al.* (2007) reported that the increasing levels of Zn significantly influenced the yield of rice. The interaction effect of variety and zinc application exerted that, BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} produced the maximum biological yield (17.00 t ha^{-1}). On the other hand, the minimum biological yield (11.21 t ha^{-1}) was found with the combination of BRRI hybrid dhan2 and 0 kg Zn ha^{-1}.

Harvest index

Varieties, levels of Zn and their interaction showed significant variation in harvest index (Figures 3A, 3B and 3C). BRRI hybrid dhan5 showed the highest harvest index (44.62%) whereas the lowest harvest index (43.34%) in BRRI hybrid dhan2. Similar results were also observed by Chowhan *et al.* (2019) and Mahmood *et al.* (2019). Furthermore, the higher value of harvest index (44.88%) was reported with 6 kg Zn ha^{-1} whereas, the lowest value of harvest index (42.54%) was with control treatment. Other research (Farzana *et al.*, 2021; Amanullah *et al.*, 2020b) also supported this finding, showing that greater Zn rates (10 and 15 kg/ha) affect yield components, grain yield, dry matter buildup, and rice HI. Additionally, Moniruzzaman *et al.* (2022) observed that different sources of N significantly influenced HI in wheat. Again, due to the interaction of variety and different levels of zinc application in *Boro* rice, the maximum (45.78%) harvest index was found from the combination of BRRI hybrid Dhan5 along with 6 kg Zn ha^{-1} which was statistically identical (45.52%) with BRRI hybrid Dhan5 along with 4 kg Zn ha^{-1}. On the other hand, the minimum harvest index (41.93%) was found from the combination of BRRI hybrid Dhan2 along with the control (no zinc application) treatment combination. Similar findings were found in research of Zinzala and Narwade (2019).

Conclusion

From the above results and discussion, the hybrid rice variety BRRI hybrid dhan5 produced a higher grain yield compared to the variety BRRI hybrid dhan3 and BRRI hybrid dhan2. Regarding the effect of Zn levels, the maximum rice yield was recorded from 6 kg Zn ha^{-1} compared to other Zn doses. Therefore, it can be concluded that, for getting higher growth and yield, BRRI hybrid dhan5 along with 6 kg Zn ha^{-1} can be cultivated in *Boro* season. Furthermore, Similar studies should be conducted under zinc-deficient soil for further validation.

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