EFFECT OF VARIETY AND ZINC FERTILIZATION ON GROWTH AND YIELD OF HYBRID RICE

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*This is to certify that the thesis entitled, "**EFFECT OF VARIETY AND ZINC FERTILIZATION ON GROWTH AND YIELD OF HYBRID RICE**" was submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRICULTURAL BOTANY** embodies the result of a piece of bona-fide research work carried out by **MD. RAKIB HASAN**, Registration no. **19-10382** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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By

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ABSTRACT

The field experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to May, 2020 in *Boro* season to find out the effect of variety and zinc application on the performance of hybrid rice. 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 of 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 V_3. 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 Zn_3 (6 kg Zn ha^{-1}). In case of treatment combination of variety and zinc, the maximum panicle number $hill^{-1}$ (20.17), panicle length (29.17 cm), number of grains $panicle^{-1}$ (179.74), 1000-seed weight (27.43 g), grain yield (7.76 t ha^{-1}), straw yield (9.19 t ha^{-1}), biological yield (16.95 t ha^{-1}) and harvest index (45.78%) were found from V_3Zn_3. 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.

LIST OF CONTENTS

CHAPTER		TITLE	PAGE
		ACKNOWLEDGEMENT	**i**
		ABSTRACT	**ii**
		LIST OF CONTENTS	**iii-iv**
		LIST OF TABLES	**V**
		LIST OF FIGURES	**Vi**
		LIST OF APPENDICES	**Vii**
		LIST OF ABBREVIATION	**Viii**
I		**INTRODUCTION**	**1-3**
II		**REVIEW OF LITERATURE**	**4-24**
	2.1	Varietal performance of rice	**4-11**
	2.2	Effects of zinc on growth, yields attribute and yield of rice	**11-24**
III		**MATERIALS AND METHODS**	**25-31**
3.1		Description of the experimental site	25
	3.1.1	Experimental period	25
	3.1.2	Experimental location	25
	3.1.3	Climatic condition	25
	3.1.4	Soil characteristics	26
3.2		Experimental details	26
	3.2.1	Planting material	26
	3.2.2	Treatment of the experiment	26
	3.2.3	Experimental design and layout	26
3.3		Growing of crops	27
	3.3.1	Seed collection and sprouting	27
	3.3.2	Raising of seedlings	27
	3.3.3	Land preparation	27
	3.3.4	Fertilizers and manure application	27
	3.3.5	Transplanting of seedling	28

LIST OF CONTENTS

CHAPTER	TITLE	PAGE
3.4	Intercultural operations	28
3.4.1	Irrigation and drainage	28
3.4.2	Weeding	28
3.4.3	Insect and pest control	28
3.5	Harvesting, threshing and cleaning	28
3.6	Recording of data	29
3.7	Experimental measurements	29
3.8	Statistical Analysis	31
IV	**RESULTS AND DISCUSSION**	**32-54**
4.1	Plant height	32
4.2	Tiller number hill^{-1}	34
4.3	Leaf Area Index (LAI)	38
4.4	Crop Growth Rate (CGR)	40
4.5	Panicle number hill^{-1}	43
4.6	Panicle length	45
4.7	Number of grains panicle^{-1}	46
4.8	Weight of 1000 grains	47
4.9	Grain yield	48
4.10	Straw yield	50
4.11	Biological yield	51
4.12	Harvest Index	52
V	**SUMMARY AND CONCLUSION**	**55-58**
	REFERENCES	**59-70**
	APPENDICES	**71-75**

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1	Interaction effect of variety and zinc on the plant height (cm) in hybrid rice	34
2	Interaction effect of variety and zinc on the number of tillers hill^{-1} in hybrid rice	37
3	Interaction effect of variety and zinc on the leaf area index (LAI) in hybrid rice	40
4	Interaction effect of variety and zinc on the crop growth rate (CGR) in hybrid rice	43
5	Effect of variety on the yield components in hybrid rice	44
6	Effect of zinc levels on the yield components in hybrid rice	44
7	Interaction effect of variety and zinc on the yield components in hybrid rice	45
8	Interaction effect of variety and zinc on the grain yield, stover yield and biological yield in hybrid rice	50

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1	Effect of variety on the plant height in hybrid rice at different days after transplanting	32
2	Effect of zinc levels on the plant height in hybrid rice at different days after transplanting	33
3	Effect of variety on the number of tillers hill^{-1} in hybrid rice at different days after transplanting	35
4	Effect of zinc levels on the number of tillers hill^{-1} in hybrid rice at different days after transplanting	36
5	Effect of variety on the leaf area index (LAI) in hybrid rice at different days after transplanting	38
6	Effect of zinc levels on the leaf area index (LAI) in hybrid rice at different days after transplanting	39
7	Effect of variety on the crop growth rate (CGR) in hybrid rice at different days after transplanting	41
8	Effect of zinc levels on the crop growth rate (CGR) in hybrid rice at different days after transplanting	42
9	Effect of variety on the yield in hybrid rice	48
10	Effect of zinc levels on yield in hybrid rice	49
11	Effect of variety on the harvest index (%) in hybrid rice	52
12	Effect of zinc levels on the harvest index (%) in hybrid rice	53
13.	Combined effect of variety and zinc levels on the harvest index (%) in hybrid rice	54

LIST OF APPENDICES

APPENDIX NO.	TITLE	PAGE
I (A)	Map showing the experimental sites under study	71
I (B)	Map showing the general soil sites under study	72
II	Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka	73
III	Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2019 to May 2020	73
IV	Analysis of variance (mean square) of plant height at different DAT	74
V	Analysis of variance (mean square) of tillers hill^{-1} at different DAT	74
VI	Analysis of variance (mean square) of Leaf area index at different DAT	74
VII	Analysis of variance (mean square) of Crop growth rate at different DAT	74
VIII	Analysis of variance (mean square) of yield components	75
IX	Analysis of variance (mean square) of yield and harvest index	75

LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAT	Days After Transplanting
eds.	editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
L.	Linnaeus
LSD	Least Significant Difference
i.e.	id est (that is)
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	variety
viz.	namely

CHAPTER I

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 (Amanullah *et al.*, 2020). Rice alone constitutes 97% of the food grain production in Bangladesh (Jahan *et al.*, 2017). In 2014-15, 474.86 million metric tons were generated from 159.64 million hectares of land (USDA, 2015). Rice accounts for 21% of global calorific consumption and 76% of total calorific intake in the South-East Asian area. Rice grain has influenced the culture and economy of billions of people worldwide (Farooq *et al.*, 2009).

Bangladesh ranks 4th in both area and production and 6th in per hectare production of rice (Sarkar *et al*., 2016). 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).

Bangladesh is a state which population is congested. Rice accounts for 77% of total planted land, 70-80% of total grain output, and continues to play an important role in the national food and livelihood security system (Haque *et al.*, 2018). About two million people are added each year, totalling 30 million over the next 20 years; hence, Bangladesh needs 37.26 million tons of rice in 2020 to fulfil the food supply for this growing population (BRRI, 2011). Bangladesh's population expansion necessitates a steady rise in rice output, and this has been given top priority (Bhuiyan, 2004). World food security become challenged for increasing food demand and estimated that about 114 million tonnes of additional rice will be needed by 2035, equivalent to the overall increase of 26% for the next 25 years (Kumar and Ladha, 2011). Rice output must be boosted by at least 60% by 2020 to fulfil the growing population's food needs (Masum, 2009). Thus, the population will gradually increase to 223 million by 2030, necessitating an extra 48 million tons of food grains (Julfiquar *et al*., 2008).

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. According to BBS (2020) *Aus, Aman* and *Boro* produced 2756, 14204 and 19646 metric tons of rice from 2706, 13740 and 11767 thousand acres of land, respectively. Among three growing seasons *Boro* rice occupies the highest area coverage (45% of gross cropping area). 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 an increase in consumer preference for meals that include not just traditional nutrients but also additional substances, notably micronutrients, that are helpful to health and well-being. One-third of the world's population suffers from zinc deficiency (Zhang *et al.*, 2012). 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 (Cakmak, 2008 and Cakmak *et al.*, 2010), particularly when grown on Zn-deficient soils. 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. In Bangladesh, 26% population is suffering from zinc deficiency (Bouis and Welch, 2010). Zn is the 5th leading cause of illness in low-income countries. For effective zinc nutrition, one person requires 15 mg Zn day^{-1} but our food grains contain only 15–35 mg Zn kg^{-1} (Cakmak, 2012), and out of which only 13–35% are bio-available. So, there is a big gap between daily requirements and daily intake to fulfill the gap our food grains should contain 40-60 mg Zn kg^{-1} (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 (Muthukumararaja and Sriramachandrasekharan, 2012). Zn deficiency is the most widespread micronutrient disorder in lowland rice and application of Zn along with NPK fertilizer increases the grain yield dramatically in most cases (Fageria *et al*., 2011; Singh *et al*., 2011).

Fertilization of food crops with Zn represents a short term and complementary strategy, which is necessary to build the Zn pool for uptake or translocation (Cakmak, 2008). Plants take up zinc in the form of Zn^{2+} ions. Diffusion is believed to be the dominant mechanism for Zn^{2+} transport to plant roots (Rashid, 2001). The critical index of effective zinc in the soil suitable for rice growth is 1.5 mg kg^{-1} (Yan, 2003. Average up take of zinc is 0.05 kg t^{-1} of grain, of which 60% remains in the straw at maturity (IRRI, 2000). As a result, it is essential to assess the optimum dose of zinc fertilizer for hybrid rice varieties in Bangladesh. Under the aforementioned conditions, the current experiment was carried out with the following goals in mind:

1. To evaluate the effect of variety on the growth and yield of hybrid rice in *Boro* season;
2. To find out the optimum zinc level for higher yield and yield components of hybrid rice.

CHAPTER II

REVIEW OF LITERATURE

Yield and yield contributing characters of rice considerably depend on basic ingredients of agriculture. The basic ingredients include variety, environment and agronomic practices (planting density, fertilizer, irrigation, seedling types etc.). The recommended doses of zinc are also necessary for potential rice yield. The available relevant reviews of literature on the related works done in the recent past have been presented and discussed in this chapter.

2.1 Varietal performance of rice

Rahman *et al.* (2022) carried out an investigation to evaluate growth, morphology and yield performance of five hybrid and two inbred salt tolerant rice varieties. Growth study revealed that all the rice varieties produced the highest number of leaves and tiller at 78 and 64 DAT (Days after Transplanting), respectively. Based on the morphological performance, hybrid rice namely Hira-2 followed by Tejgold and HYV rice namely Binadhan-10 produced the highest grain yield due to increased seed width, 1000 seed weight and total dry matter production. In addition, the seed width showed strong positive correlations with the grain yield and 1000-grain weight indicated an important trait for higher grain yield production in rice.

Rahman *et al.* (2020) conducted an experiment to study the effects of crop establishment methods on the growth and yield of *Boro* rice. The experiment comprised methods of crop establishment *viz.*, dry direct seeding, unpuddle transplanting, alternate wetting and drying (AWD) and puddle transplanting with rice cultivars *viz.*, BRRI dhan28, BRRI dhan58, BRRI dhan74 and BRRI hybrid dhan3. Among the varieties the highest grain yield was obtain in BRRI hybrid dhan3 due to highest number of grains panicle^{-1} and 1000-grain weight. The highest grain yield (6.21 t ha^{-1}) was found in puddle transplanting with BRRI dhan28, while the lowest grain yield (2.80 t ha^{-1}) was produced in dry direct seeding with BRRI dhan28. Therefore, puddle transplanting with BRRI dhan28 might be recommended due to best physiological performance and obtaining highest grain yield of *Boro* rice.

Khatun, (2020) carried out a field experiment with six rice varieties to determine their growth and yield performance. The results revealed that in all rice varieties maximum growth performance observed at 58-68 Days after transplanting and maximum dry matter production was observed at 68 days after transplanting. Maximum number of filled spikelet observed in Binadhan-17 (164.89 panicle^{-1}) and that was significantly different from other varieties. Percent of sterile spikelet was highest in BRRI dhan39 (12.9%) and that was statistically similar with Binadhan-16 (11.96%) and BRRI dhan33 (12.36%). Maximum 1000-seed weight was observed in Binadhan-17 (27.25 g). Highest grain yield was obtained from Binadhan-17 (6.13 t ha^{-1}) that was significantly different from other varieties. Lowest grain yield observed in BRRI dhan39 (4.49 t ha^{-1}) that was statistically similar to BRRI dhan33 (4.57 t ha^{-1}) and Binadhan-7 (4.86 t ha^{-1}).

Singh *et al*. (2019) conducted a field experiment to find the performance of 40 hybrids. The experiment finding revealed that the variety T38 (KR 38) has performed significantly better than all other hybrids *viz*; Germination (96%), plant height (115.14 cm), number of tillers per m^2 (381.00), panicle length (30.70 cm), number of filled grains plant^{-1} (307.66), number of un-filled grains plant^{-1} (22.56), test weight (29.89 g), grain yield plant^{-1} (0.041 kg), grain yield (13.96 t ha^{-1}), straw yield (19.98 t ha^{-1}), biological yield (33.94 t ha^{-1}). However, variety T35 (KR 35), T25 (KR 25), T36 (KR 36) and T16 (KR 16) were statistically at par with treatment T38 (KR 38) respectively.

Mahmood *et al*. (2019) conducted an experiment to evaluate the performance of hybrid *Boro* rice (genotypes) in coastal area of Bangladesh. The experiment consisted of five rice varieties as treatment such as Arize Tej, Tea Sakti, Shathi and BRRI Dhan 28. Among the five varieties the Arize Tej gave the highest performance. From the above investigated results, it was observed that the Arize Tej was the most efficient for better growth and higher yield of hybrid *Boro* rice genotypes grown in coastal area of Bangladesh.

Salam *et al*. (2019) conducted an experiment in *Boro* season with the objective of testing agronomic status and adaptability of four modern rice varieties in comparison with the popular mega variety BRRI dhan28. The varieties were BRRI dhan67, BRRI dhan81, BRRI dhan84 and BRRI dhan86. BRRI dhan28 was chosen as a control due to its wide acceptability among the farmers. It was observed that germination rate, plant height, effective tiller number were significantly higher in BRRI dhan67 than the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for both fields. All the yield components spikelets per panicle, filled grain and 1000-grain weight were also significantly higher in BRRI dhan67 in compared to the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for both fields as well. The highest grain yield was observed in BRRI dhan67 in both plots (7.89 and 7.29 t ha^{-1}) and showed significant differences among all other varieties ($p \leq 0.05$). Harvest Index of BRRI dhan67 (51.02±4.2, 57.84±8.6) % indicated that this variety is the best yielder among the varieties.

Chowhan *et al*. (2019) conducted an experiment to determine the number of seedling(s) during transplanting for *Boro* rice varieties or higher growth and yield. The experiment tested three seedling numbers; S_1 (Single), S_2 (double), S_3 (triple) and four varieties V_1 (BRRI dhan-28), V_2 (Binadhan-14), V_3 (Heera-1), V_4 (Shakti-2) in a factorial RCB design with three replications. Results revealed that significantly highest plant height was obtained with treatment $S_1 \times V_3$ (110.30 cm) and (109.4 cm) $S_3 \times V_4$ while the maximum number of tillers $hill^{-1}$ from $S_3 \times V_1$ (16.93) and (16.07) $S_2 \times V_1$. In terms of production, treatment combination $S_3 \times V_4$ gave the highest grain, straw and biological yield. Harvest index was the highest in treatment $S_1 \times V_4$ (59.48).

Mia (2018) carried out a field experiment consisted of three rice varieties *viz*. (i) V_1 = BRRI dhan45, (ii) V_2 = BRRI dhan63 and (iii) V_3= BRRI hybrid dhan3 with four Zn application methods *viz*. (i) F_0= No zinc application, (ii) F_1= Zn application through root soaking, (iii) F_2= Zn application through foliar spray and (iv) F_3 = Zn application through soil application. The result revealed that BRRI hybrid dhan3 produced the highest yield (8.47 t ha^{-1}) because of its higher panicle length (23.48 cm), grains $panicle^{-1}$ (100.33), weight of 1000-seeds (29.33g), straw yield (9.10 t ha^{-1}) and the lowest unfilled grains $panicle^{-1}$ (6.84).

Mahmood (2017) carried out an experiment to evaluate the Performance of hybrid *Boro* rice (genotypes) in coastal area of Bangladesh. The experiment consisted of five rice varieties as treatment such as Arize Tej, Tea Sakti, Shathi and BRRI Dhan28. Data were collected on morphological characters such as plant height, number of leaves $plant^{-1}$ and leaf area $hill^{-1}$, growth characters such as leaf area index (LAI), crop growth rate (CGR) and relative growth rate (RGR), yield and yield components such as number of effective tillers $hill^{-1}$, number of non-effective tillers $hill^{-1}$, panicle length, number of filled grains $panicle^{-1}$, number of unfilled grains $panicle^{-1}$, 1000 grain weight, grain yield, straw yield, biological yield and harvest index (%). Among the five varieties the Arize Tej gave the highest performance. From the above investigated results, it was observed that the Arize Tej was the most efficient for better growth and higher yield of hybrid *Boro* rice genotypes grown in coastal area of Bangladesh.

Sarkar *et al.* (2016) conducted an experiment to check the performance of five hybrid rice varieties namely Shakti 2, Suborna8, Tia, Aloron and BRRI hybrid dhan2 where inbred BRRI dhan33 was used as check variety. The highest TDM hill^{-1} (84.0 g), maximum leaf area hill^{-1} (1787cm^{2}), average highest CGR and RGR (40.63 g m^{-2} d^{-1} and 17.9 mg g^{-1} d^{-1}) were observed Tia and lowest TDM hill^{-1} (70.10 g), minimum leaf area hill^{-1} (1198 cm^{2}), average lowest CGR and RGR (27.26 g m^{-2} d^{-1} and 13.35 mg g^{-1} d^{-1}) were observed in BRRI dhan33. These hybrid varieties also showed higher yield attributes *viz.* effective tillers hill^{-1}, 1000-grain weight, biological yield and harvest index (HI) over the inbred. The highest grain yield was achieved from Tia (7.82 t ha^{-1}), which was closely followed by Shakti 2 (7.65 t ha^{-1}). These two hybrid varieties produced 24.0% higher yield over the inbred BRRI dhan33. Effective tillers hill^{-1} and higher filled grains panicle^{-1} mainly contributed to the higher grain yield of hybrid varieties.

Haque *et al.* (2015) evaluated the two popular indica hybrids (BRRI hybrid dhan2 and Heera2) and one elite inbred (BRRI dhan45) rice varieties. Both hybrid varieties out yielded the inbred. However, the hybrids and inbred varieties exhibited statistically identical yield in late planting. Filled grain (%) declined significantly at delayed planting in the hybrids compared to elite inbred due to increased temperature impaired- inefficient transport of assimilates. Results suggest that greater remobilization of shoot reserves to the grain rendered higher yield of hybrid rice varieties.

Chamely *et al*. (2015) carried out an experiment with three varieties *viz*., BRRI dhan28 (V_1), BRRI dhan29 (V_2) and BRRI dhan45 (V_3); and five rates of nitrogen *viz*., control (N_0), 50 kg (N_1), 100 kg (N_2), 150 kg (N_3) and 200 kg (N_4) N ha^{-1} to study the effect of variety and rate of nitrogen on the performance of *Boro* rice. Regarding varietal performance, results indicate that the tallest plant (80.88 cm) and the highest number of total tillers hill^{-1} (13.80) were observed in BRRI dhan29 at 70

DATs and the highest total dry matter (66.41 g m^{-2}) was observed in BRRI dhan45. The shortest plant (78.15 cm) and the lowest number of tillers $hill^{-1}$ (12.41) were recorded from BRRI dhan45 and the lowest dry matter (61.24 g) was observed in BRRI dhan29. The harvest data reveal that variety had significant effect on total tillers $hill^{-1}$, effective tillers $hill^{-1}$, non-effective tillers $hill^{-1}$, panicle length, grain yield, straw yield and harvest index. The highest grain yield (4.84 t ha^{-1}) was recorded from BRRI dhan29.

Hossain *et al.* (2014) evaluated the five rice cultivars (one hybrid: WR96, three modern: BR16, BR26, and BRRI Dhan27 and one local: Pari). Most of the yield-contributing characters examined and showed wide variations among the cultivars whereas modern cultivar BR16 produced the highest panicle length, number of grain $panicle^{-1}$ and grain yield ha^{-1}. At the same time as local cultivar Pari generated the lowest number of tiller $plant^{-1}$, panicle length, grain number $panicle^{-1}$ and grain yield ha^{-1}. Moreover, hybrid cultivar WR96 produced the highest percentage of spotted grain $panicle^{-1}$.

Roy (2014) conducted a field experiment to evaluate the growth and yield performance of local *Boro* rice varieties. Twelve local *Boro* rice varieties were included in this study namely Nayon moni, Tere bale, Bere ratna, Ashan *Boro*, Kajol lata, Koijore, Kali *Boro*, Bapoy, Latai balam, Choite *Boro*, GS one and Sylhety *Boro*. At harvest, the tallest plant (123.80 cm) was recorded in Bapoy and the shortest (81.13 cm) was found in GS one. The maximum number of tillers $hill^{-1}$ (46.00) was observed in Sylhety *Boro* and the minimum (19.80) in Bere ratna. The maximum number of effective tillers $hill^{-1}$ (43.87) was recorded in the variety Sylhety *Boro* and the minimum (17.73) was found in Bere ratna. The highest (110.57) and the lowest (42.13) number of filled grains $panicle^{-1}$ was observed in the variety Koijore and Sylhety *Boro*, respectively. Thousand grain weight was the highest (26.35g) in Kali *Boro* and the lowest (17.83g) in GS one. The highest grain yield (5.01 t ha^{-1}) was found in the variety Koijore and the lowest in GS one (3.17 t ha^{-1}).

Hosain *et al*. (2014) conducted an experiment to observe the effect of transplanting dates on the yield and yield attributes of exotic hybrid rice varieties. The experiment comprised of three rice varieties (two hybrids-Heera2, Aloron and one inbred- BRRI dhan48) and four transplanting dates *viz*. 16^{th} March, 31^{st} March, 15^{th} April and 30^{th}.

BRRI dhan48 produced the highest grain yield (3.51 t ha^{-1}) whereas the hybrid varieties Heera2 (3.03 t ha^{-1}) and Aloron (2.77 t ha^{-1}) achieved lower grain yield due to higher spikelet sterility. BRRI dhan48 produced the highest grain yield (4.91 t ha^{-1}) at 16^{th} March transplanting.

Shiyam *et al.* (2014) conducted an experiment to evaluate the performance of four Chinese hybrid rice varieties where it was showed comparative superiority of FARO 15 to the hybrids in all growth and yield components assessed. FARO 15 was taller (140 cm) with more productive tillers (11.0), higher spikelets $plant^{-1}$ (166.0), higher filled grains $panicle^{-1}$ (156.17), higher filled grains (92.17%), highest 100-grain weight of 2.63 g and the higher paddy yield (5.021 t ha^{-1}) than others. Despite the comparative poor performance of the hybrids, Xudao151 came close to FARO 15 with grain yield of 2.987 t ha^{-1}.

Masum *et al*. (2014) conducted a study to investigate the influence of population density on growth and yield of inbred and hybrid *Boro* rice. The treatments consisted of four varieties *viz*., BRRI Dhan28, BRRI dhan29, BRRI Hybrid Dhan2 and ACI Hybrid Dhan2 and four population density *viz*. 1, 2, 3 and 4 seedlings $hill^{-1}$. The effect of variety, population density $hill^{-1}$ and their interaction showed significant variation in respect of yield contributing parameters and yield. ACI Hybrid Dhan2, 2 seedlings $hill^{-1}$ and their combination increased yield attributing parameters, grain and straw yield for *Boro* season.

Sarker *et al.* (2013) conducted an experiment to study morphological, yield and yield contributing characters of four *Boro* rice varieties of which three were local *viz*., Bashful, Poshursail and Gosi; while another one was a high yielding variety (HYV) BRRI dhan28. The BRRI dhan28 were significantly superior among the cultivars studied. The BRRI dhan28 was shorter in plant height, having more tillering capacity, higher leaf number which in turn showed superior growth character and yielded more than those of the local cultivars. The HYV BRRI dhan28 produced higher number of grains $panicle^{-1}$ and bolder grains resulted in higher grain yield over the local cultivars. Further, BRRI dhan28 had more total dry mass than those of local varieties. The BRRI dhan28 produced higher grain yield (7.41 t ha^{-1}) than Bashful, Poshurshail and Gosi, respectively. Among the local rice cultivars, Gosi showed the higher yielding ability than Bashful and Poshursail.

Haque *et al.* (2013) carried out an experiment to evaluate some physiological traits and yield of three hybrid rice varieties (BRRI hybrid dhan2, Heera2, and Tia) in comparison to BRRI dhan48 in *Aus* season. Compared to BRRI dhan48, hybrid varieties accumulated greater shoot dry matter at anthesis, higher flag leaf chlorophyll at 2, 9, 16 and 23 days after flowering (DAF), flag leaf photosynthetic rate at 2 DAF and longer panicles. Heera2 and BRRI hybrid dhan2 maintained significantly higher chlorophyll a, b ratio over Tia and BRRI dhan48 at 2, 9, 16 and 23 DAF in their flag leaf. Shoot reserve remobilization to grain exhibited higher degree of sensitivity to rising of minimum temperature in the studied hybrids compared to the inbred. Inefficient photosynthetic activities of flag leaf and poor shoot reserve translocation to grain resulted poor grain filling percentage in the test hybrids. Consequently, the studied hybrids showed significantly lower grain yield (36.7%) as compared to inbred BRRI dhan48, irrespective of planting date in *Aus* season.

Oko *et al.* (2012) assessed the agronomic characteristics of 15 selected indigenous and newly introduced hybrid rice varieties. The results showed that plant height ranged between 144.01 cm in "Mass (I)" and 76.00 cm in "Chinyeugo". Cv. "E4197" had the highest value of 38±0.02 cm for panicle length and "Chinyereugo" had the highest value of 6.3g ± 0.03 for panicle weight. Leaf area showed the highest value of 63.8cm^2 ± 0.01 in "Mass (I)". Cv. "Co-operative" had high number of seeds panicle^{-1} (139 ± 0.19). "Chinyereugo" had the highest value of 25.9g ±1.4 for 1000-grains weight. The grain of "E4314" was the longest (8.00 mm ± 0.89) of the varieties studied.

Abou-Khalif (2009) carried out an experiment for physiological evaluation of some hybrid rice varieties in different sowing dates. Four hybrid rice H1, H2, GZ 6522 and GZ 6903 were used. Results indicated that H1 hybrid rice variety surpassed other varieties for number of tillers m^{-2}, chlorophyll content, leaf area index, sink capacity, number of grains panicle^{-1}, panicle length (cm), 1000-grain weight (g), number of panicles m^{-1}, panicle weight (g) and grain yield (ton ha^{-1}).

Islam *et al*. (2009) conducted a pot experiments with Hybrid variety Sonarbangla-1 and inbred modern variety BRRI dhan31 and BRRI hybrid dhan1 to compare the growth and yield behavior of hybrid and inbred rice varieties under controlled condition. BRRI dhan3l had about 10-15% higher plant height, very similar tillers plant^{-1}, 15-25% higher leaf area at all days after transplanting (DAT) compared to Sonarbangla-1. The photosynthetic rate was higher (20 μ mol m^{-2} sec^{-1}) in BRRI dhan3l at 35 DAT (maximum tillering stage) but at 65 DAT, Sonarbangla-l had higher photosynthetic rate of 19.5 μ mol m^{-2} sec^{-1}. BRRI dhan3l had higher panicles plant^{-1} than Sonarbangla-1, but Sonarbangla-1 had higher number of grains panicle^{-1}, 1000-grain weight and grain yield than BRRI dhan31.

Kamal (2007) conducted an experiment to determine the effect of variety and planting method on the yield of *Boro* rice. Four varieties *viz*., BINADHAN-5, BINADHAN-6, BRRI dhan28 and BRRI dhan29, and three planting methods *viz*., transplanting method, drum seeding and line sowing were included as experimental treatments. BINADHAN-5 produced the highest grain yield (4.61 t ha^{-1}) which was the consequence of highest number of effective tillers hill^{-1} and highest number of grains panicle^{-1}. In case of effect of interaction of BINADHAN-5 and transplanting method produced the highest grain (5.20 t ha^{-1}) yield.

Akram *et al.* (2007) studied on fifteen rice hybrids where two hybrids *viz*., MK Hybrid 111 and 27P72 produced more productive tillers than KS 282. All most all the hybrids produced more number of grains panicle^{-1} and higher 1000-grain weight. Yield advantage of the hybrids over the commercially grown rice variety ranges between 4.59-21.33% except RH-257 and GNY-40. These two hybrids were low yielder by 4.20 % and 14.95%, respectively than the check variety.

2.2 Effects of zinc on growth, yields attribute and yield of rice

Hanifuzzaman *et al.* (2022) carried out a field experiment to study the effect of different levels of Zn and B fertilizers on the yield of *Aus* rice (cv. BRRI dhan48). The experiment included four levels of Zn fertilizer management ($ZnSO_4.7H_2O$) (0 kg/ha; control, basal application @ 10 kg/ha, basal application @ 5 kg ha^{-1} + soil application during active tillering stage @ 5 kg ha^{-1}, and foliar application; 0.5% solution of $ZnSO_4.7H_2O$ during flag leaf stage) and three levels of boron fertilizer (boric acid) management (0 kg ha^{-1}; control, 1.5 kg ha^{-1} basal application, and foliar application of 2% solution of H_3BO_3 during flag leaf stage). Zn and B boosted all studied parameters of rice in comparison to their controls, i.e., no fertilization. The highest number of filled grains panicle^{-1} and grain yield was obtained from foliar application of $ZnSO_4.7H_2O$. The results also showed that grain yield of rice increased with increasing levels of Zn up to 4.39 t ha^{-1}.

Farzana *et al.* (2021) carried out a study to figure out how water management and Zn application rates affect the growth and yield of rice. The treatments consisted of two factors, a) water management, like 1) Continuous flooding (CF) and 2) Alternate wetting and drying (AWD) system and b) Zn application like 1) Control (0% Zn), 2) 75% Zn, 3) 100% Zn, 4) 125% Zn, and 5) 150% Zn of the recommended dose. All the plots received an equal amount of NPKS fertilizers. The application of Zn in both AWD and CF systems had a significant effect on a number of grains $panicle^{-1}$, 1000 grain weight and grain yield. The highest value for both yield contributing traits and yield was obtained by the application of 150% Zn in the AWD system. However, the lowest value was found in the control treatment of the CF system for both the yield components and yield. It is also evident that the growth rate of yield components and yield was increased with increased doses of Zn in both AWD and CF systems.

Paul *et al.* (2021) conducted an experiment to study the effect of Zn on growth performance of aromatic *Boro* rice (cv. BRRI dhan50) in response to nitrogen and potassium fertilization. The experiment consisted of four levels of zinc *viz*., 0, 5, 10 and 15 $kgha^{-1}$, and four levels of potassium viz., 0, 30, 60 and 90 $kgha^{-1}$. Application of 10 kg $Znha^{-1}$ produced the tallest plant (82.17 cm), the highest number of $tillershill^{-1}$ (10.08) and chlorophyll content (52.21) at heading stage. In case of interaction, the tallest plant (85.33 cm), the highest number of $tillershill^{-1}$ (10.83) and chlorophyll content (58.28) were obtained from 10 kg Zn ha^{-1} along with 90 kg Kha^{-1} at heading stage.

Singh *et al.* (2020) conducted a study entitled effect of Zinc and silicon on growth and yield of aromatic rice. The ten treatment combinations (*viz*., T_1 Control, T_2- RDF 120:80:40, T_3- RDF 120:80:40 + Two Zinc spray @ 0.5%, T_4- RDF 120:80:40 + Two Si spray @ 0.2%, T_5- RDF 120:80:40 + Two Si spray @ 0.3%, T_6- NPK 150:80:40, T_7- NPK 150:80:40 + Two Zinc spray @ 0.5%, T_8- NPK 150:80:40 + Two Si spray @ 0.2%, T_9- NPK 150:80:40 + Two Si spray @ 0.3%) were tested. The results revealed that the application of zinc and silicon significantly influenced the growth and yield of aromatic rice. Plant height, LAI, dry weight, number of tillers, panicle length, number of grains per panicle and 1000-grain weight were recorded maximum with the application of 120:80:40 kg ha^{-1} NPK + @ 0.5% Zn spray at 30 and 45 DAT. Grain yield and harvest index also influenced significantly with the application of zinc and silicon and maximum grain yield was recorded with the application of 150:80:40 NPK + two Zn spray 0.5% (65.88 q ha^{-1}) followed by treatment 150:80:40 NPK + Two Si spray @ 0.3% (63.46 q ha^{-1}) and lowest in T_1 control (30.12 q ha^{-1}). Harvest index was recorded non-significant.

Mo *et al.* (2019) conducted field experiments in the early season (March–July) and repeated in the late season (July–November) to conform that zinc application and different water regimes at booting stage improved yield and 2-acetyl-1-pyrroline (2AP) formation in fragrant rice. Three Zn levels i.e., 0 kg Zn ha^{-1} (Zn_1), 3kg Zn ha^{-1} (Zn_2), and 6 kg Zn ha^{-1} (Zn_3) and three water levels i.e., W_1 treatment (water layer of 2–4 cm), W_2 treatment (soil water potential 15 ± 5 kPa), and W_3 treatment (soil water potential 25±5 kPa) at booting stage was set up for three rice varieties i.e., Nongxiang 18, Yungengyou 14 and Basmati. The Zn_2 and Zn_3 treatment significantly increased the 2AP contents in brown rice by 9.54% and 11.95%; 8.88% and 32.54% in the early and the late season, respectively; improved grain yield and head milled rice yield. This study also revealed that the 6 kg Zn ha^{-1} coupled with 25±5 kPa water treatment showed the best positive effects on yield and aroma in fragrant rice.

Mia (2018) conducted a field experiment to evaluate the effects of different zinc application methods on growth and yield of *Boro* rice. The experiment was consisted of three rice varieties *viz*. (i) V_1 = BRRI dhan45, (ii) V_2 = BRRI dhan63 and (iii) V_3 = BRRI hybrid dhan3 with four Zn application methods *viz*. (i) F_0 = No zinc application, (ii) F_1 = Zn application through root soaking, (iii) F_2 = Zn application through foliar spray and (iv) F_3 = Zn application through soil application. The result revealed that Zn application through soil application produced the highest grain yield (7.73 t ha^{-1}) and also produced the highest tillers $hill^{-1}$ (14.49), panicle length (23.69 cm), filled grains $panicle^{-1}$ (93.65) weight of 1000-seeds (27.03g), straw yield (8.00 t ha^{-1}) along with the lowest unfilled grains $panicle^{-1}$ (7.32).

Khatun *et al*. (2018) conducted a field experiment to evaluate the growth, yield and yield attributes of aromatic rice (cv. Tulshimala) under the fertilization of cow dung (organic manure) and zinc (micronutrient). The application of different levels of cow dung and zinc fertilizers considerably increased the number of total tillers $hill^{-1}$, number of productive tillers hill^{-1}, panicle length, test weight (g), grain yield hill^{-1} (g), straw yield hill^{-1} (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), and biological yields over control. However, the treatment combination of CD_1Zn_2 i.e. 10 t ha^{-1} cow dung and 12 kg ha^{-1} $ZnSO_4$ along with other recommended doses of inorganic fertilizers produced the highest grain yield (2.79 t ha^{-1}) and straw yield (5.80 t ha^{-1}) over other treatments.

Roy (2018) conducted an experiment to find out the influence of zinc on yield and quality of aromatic rice. The experiment consisted of four levels of zinc (Zn) such As- Zn_1: 2.5 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 3.5 kg Zn ha^{-1}, Zn_4: 4.0 kg Zn ha^{-1}; with four cultivars of aromatic rice such as - V_1: Dulhabhog, V_2: Chinigura, V_3: Khoisanne and V_4: Chiniatab. The result revealed that zinc level had no significant effect on grain yield. Results revealed that supplementation of zinc and/or different varieties had significant effect on most of the yield and quality contributing parameters. Effective tillers, filled grains, weight of milled rice increased with increasing zinc level. But Zn level had no significant effect on 1000-grains weight, grain yield, harvest index among the four aromatic rice varieties.

Podder (2017) conducted a field experiment to find out the response of *Boro* rice to foliar spray of zinc and *Boro*n. BRRI dhan29 was used as testing variety. The treatments were T_1 = Recommended Fertilizer (RF), T_2 = RF + Foliar spray (FS) with water at tiller initiation (TI), T_3 (RF + Foliar spray; (FS) with water at flowering initiation (FI), T_4 = Zn (0.2%) FS at TI + RF, T_5 = Zn (0.5%) FS at TI + RF, T_6 = Zn (0.8%) FS at TI + RF, T_7 = Zn (0.2%) FS at FI + RF, T_8 = Zn (0.5%) FS at FI + RF, T_9 = Zn (0.8%) FS at FI + RF, T_{10} = B (0.5%) FS at TI + RF, T_{11} = B (1.5%) FS at TI + RF, T_{12} = B (2.0%) FS at TI + RF, T_{13} = B (0.5%) FS at FI + RF, T_{14} = B (1.5%) FS at FI + RF, T_{15} = B (2.0%) FS at FI + RF. Among the zinc foliar spray treatments, the maximum leaf area index (LAI) (3.14), number of effective tillers hill^{-1} (13.24), panicle length (24.49 cm), number of filled grains panicle^{-1} (136.73), the highest grain yield of rice (6.33 t ha^{-1}), straw yield (7.09 t ha^{-1}), biological yield (13.42 t ha^{-1}) and harvest index (47.17%) was recorded from T_4 treatment [Zn (0.2%) foliar spray at tiller initiation stage + Recommended Fertilizer]. 1000-grains weight (g) of rice was not varied significantly due to different treatments but numerically the maximum weight of 1000-grains (28.60 g) was recorded from T_5 treatment [Zn (0.5%) FS at TI + RF].

Apoorva (2016) observed that the highest mean values of yield and its components, i.e. number of panicles m^{-2} (446.6), the number of filled grains $panicle^{-1}$ (13.3), the highest grain yield (5355 kg ha^{-1}) and the highest straw yield (6347kg ha^{-1}) were recorded from the treatment receiving RDF + Soil application of bio Zn @ 30 kg ha^{-1}which was at par with RDF + foliar application of 0.2% Zn as $ZnSO_4$ and RDF + foliar application of 1 ml Zn as Nano zinc. Application of bio Zn @ 30 kg ha^{-1} also recorded the highest number of tillers m^{-1} (440.0) followed by foliar application of 0.2% Zn as $ZnSO_4$over control treatment.

Ghoneim (2016) reported that the highest number of panicles m^{-2} was recorded in soil application of Zn followed by foliar application of Zn, while the minimum number of panicles m^{-2} in rice plants was recorded in control. The number of spikelet's $panicle^{-1}$, percentage of filled grain and 1000-grain weight followed the same trend of response i.e. increased with different methods of Zn application compared to control but, no significant differences were found amongst the various methods. The highest grain yield of 9.60 tones ha^{-1} was recorded from soil application of Zn. No significant differences were observed in grain yield with root soaking or foliar. It is also observed that straw yield of rice significantly increased with different methods of Zn application (soil, root soaking or foliar application of Zn) compared with no zinc application, but, no significant difference was observed between Zn application methods.

Kumar *et al*. (2016) found that application of 20 kg $ZnSO_4$ ha^{-1} incubated or blended either with press mud or FYM produced significantly higher number of filled grains $panicle^{-1}$ in rice plants, but it was at par with the application of 40 kg $ZnSO_4$ ha^{-1} alone on sodic soils of U.P.

Ghoneim (2016) observed that different methods of Zn application significantly increased the tiller number over control. The increase in tiller number by soil application of Zn might be attributed due to increase of nutrients availability in soil compared with other treatments.

Islam (2015) carried out an experiment to study the effect of zinc and Boron on the growth and yield of T. *Aman* rice (BRRI dhan34). Two factors were comprised with study viz. factor A: B_0 = 0 kg B ha^{-1}, B_1 = 2 kg B ha^{-1} and B_2 = 4 kg B ha^{-1} and Factor

B: Zn_0 = 0 kg Zn ha^{-1}, Zn_1 = 2 kg Zn ha^{-1} and Zn_2 = 4 kg Zn ha^{-1}. Results indicated that the highest straw weight ha^{-1} (8.07 t) was recorded from B_1Zn_1; the number of total tiller $hill^{-1}$ (19.81) and effective tiller $hill^{-1}$ (14.53) were received from B_1Zn_0. Again, the longest panicle (25.28 cm), filled grain $panicle^{-1}$ (143.60), total grain $panicle^{-1}$ (161.40), grain weight ha^{-1} (5.72 t ha^{-1}) and harvest index (45.77%) were recorded from B_2Zn_2. The tallest plant (132.30 cm), non-effective tiller $hill^{-1}$ (5.55) and un-filled grain $panicle^{-1}$ (56.52) were achieved from the treatment combination of B_1Zn_2, B_0Zn_2 and B_0Zn_0 respectively. The treatment combination B_2Zn_2 performed better for increasing the yield of T. *Aman* rice and improved the nutrient status of post-harvest soil of AEZ 28.

Alam and Kumar (2015) investigated to evaluate the effect of Zinc on growth and yield of rice var. Pusa Basmati-1. The experiment was laid out with four treatments (0 kg ha^{-1} $ZnSO_4$, 5 kg ha^{-1} $ZnSO_4$, 10 kg ha^{-1} $ZnSO_4$ and 20 kg ha^{-1} $ZnSO_4$). The result revealed that the maximum panicle length (23.39 cm), number of effective tillers m^{-2} (317), weight of 1000-grains (24.97 g), grain yield (32.45 q ha^{-1}) and straw yield (69.25 q ha^{-1}) were obtained from 10 kg ha^{-1} $ZnSO_4$ whereas the minimum panicle length (16.57 cm), number of effective tillers m^{-2} (225), weight of 1000-grains (22.25 g), grain yield (24.32 q ha^{-1}) and straw yield (46.37 q ha^{-1}) were obtained from 0 kg ha^{-1} $ZnSO_4$.

Gomaa *et al*. (2015) observed that the highest mean values of yield and its components i.e. panicle weight (2.38 g), number of filled grains $panicle^{-1}$ (112.73), number of panicles m^{-2} (482.2), 1000 grain weight (22.15 g), grain yield (3.8 t $ha^{-1}$and straw yield (5.05 t ha^{-1}) of rice were recorded from treatment (soil + foliar) of Zn in combination with 50% Mineral Nitrogen + 50% organic Nitrogen.

Shivay *et al*. (2015) observed that application of 5 kg Zn ha^{-1} (soil) + 1 kg Zn ha^{-1} (foliar) recorded the highest grain yield (4.52 t ha^{-1}), straw yield (8.12 t ha^{-1}), tillers m^{-1} (342), grains $panicle^{-1}$ (94), 1,000 grain weight (22.7 g) of rice which was significantly more than soil application of ZnS or Zn-coated urea (ZnCu), which in turn was significantly superior to foliar application of ZnS.

Sharmin (2014) conducted an experiment to find out the influence of sulphur and zinc on yield of transplanted (T.) *Aman* rice. BRRI dhan34 was used as the test crop in this experiment. The experiment consisted of two factors. Factor A:3 levels of sulphur (S_0: 0 kg S ha^{-1}, S_1: 8.0 kg S ha^{-1}, S_2: 12.0 kg S ha^{-1}) and Factor B: 4 levels of zinc (Zn_0: 0 kg Zn ha^{-1}, Zn_1: 1.0 kg Zn ha^{-1}, Zn_2: 2.0 kg Zn ha^{-1}, Zn_3: 3.0 kg Zn ha^{-1}). For different levels of zinc, the highest yield and yield contributing characters were observed were recorded from Zn_3, whereas the lowest was recorded from Zn_0. Due to the interaction effect of different levels of sulphur and zinc, the maximum number of total tillers $hill^{-1}$ (20.60), the longest panicle (29.65 cm), the highest grain yield (4.00 t ha^{-1}) and the highest straw yield (5.36 t ha^{-1}) were recorded from S_2Zn_3, whereas the minimum result was recorded from S_0Zn_0.

Oahiduzzaman (2013) conducted an experiment to study the effect of zinc and cow dung on growth, yield and nutrient content of transplanted *Aman* rice. BRRI dhan33 was used as the test crop in this experiment. The experiment consisted of 4 levels of zinc (Zn_0: 0 kg Zn ha^{-1} (control), Zn_1: 2.0 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 4.0 kg Zn ha^{-1}) and 4 levels of cow dung (C_o: 0-ton cow dung ha^{-1} (control). C_1: 4.50-ton cow dung ha^{-1}, C_2: 5.0-ton cow dung ha^{-1} and C_3: 5.5-ton cow dung ha^{-1}). For 4.0 kg Zn ha^{-1} (Zn_3), the tallest plant (25.12, 41.09, 58.90, 75.03 and 88.34 cm) were recorded at 30, 50, 70, 90 days after transplanting (DAT) and at harvest, respectively. On the other hand, the shortest plant (19.95, 33.52, 51.08, 65.25 and 80.50 cm) were found from control treatment (Zn_0) at 30, 50, 70, 90 DAT and at harvest, respectively. The maximum number of effective tillers $hill^{-1}$ (13.30) was observed from Zn_3 and the minimum number (10.18) from Zn_0. The highest grain yield ha^{-1} (5.11 ton) was found from Zn_3 and the lowest grain yield ha^{-1} (3.28 ton) from Zn_0.

Boonchuay *et al*. (2013) observed that foliar application with 0.5% zinc sulfate spray at panicle initiation, booting and 1 week and 2 weeks after flowering showed significantly higher grain weight (20.1 g $plant^{-1}$), straw weight (30.1 g $plant^{-1}$), panicles $plant^{-1}$ (13) and the lowest was seen in control where there was no foliar application. Foliar application with 0.5% zinc sulfate spray at panicle initiation, booting and 1 week and 2 weeks after flowering also showed significantly higher number of tillers $plant^{-1}$ (17) and plant dry matter (50.1 g $plant^{-1}$). The lowest tillers $plant^{-1}$ (10) and plant dry matter (41.1 g $plant^{-1}$) was recorded in control where there was no foliar application of zinc.

Kabeya and Shanker (2013) recorded that the treatment receiving 30 kg $ZnSO_4$ ha^{-1}

showed the highest SPAD (Soil Plant Analysis Development) value (57) in rice. The highest straw dry matter (41 g) and leaf dry matter (28 g) in rice was also obtained from this treatment, the lowest was obtained in control.

Muthukumararaja and Sriramachandrasekharan (2012) reported that maximum amount of dry matter production of rice plant at tillering (2.98 g pot^{-1}) and at panicle initiation stage (40.93 g pot^{-1}) was obtained with application of 5 mg Zn kg^{-1} which was about 44% to 60% greater as compared with the treatment that did not receive zinc.

Ali *et al.* (2012) and Singh *et al.* (2012) from their corresponding study stated that maximum rice yield (7.63 t ha^{-1}) was recorded with combined application of 30 kg sulphur and 6 kg Zinc ha^{-1}. This combined analysis suggested that for better output and for balanced nutrition combined application is advocated.

Dixit *et al*. (2012) observed that application of Zn at 25 kg ha^{-1} in rice significantly increased the panicle length (24.96 cm), grain yield (60.34 q ha^{-1}), straw yield (77.37 q ha^{-1}) with significant difference from that of plant grown without Zinc treatment.

Keram *et al*. (2012) recorded that the highest grain (3.88 t ha^{-1}) and straw (4.76 t ha^{-1}) yield of rice were observed in treatment consisting of NPK + 20 kg Zn ha^{-1} compared with NPK alone.

Singh *et al*. (2012) observed that the maximum amount of dry matter weight (28.25 g $hill^{-1}$) and grain yield (7.5 t ha^{-1}) of rice were recorded with application of Zn @ 6 kg and the minimum dry matter (7.8 g $hill^{-1}$) and grain yield (6.0 t ha^{-1}) were seen in control.

Sriramachandrasekharan and Mathan (2012) and Chaudhary and Sinha (2007) reported that the highest amount of dry matter (28.25 g $hill^{-1}$) and the lowest amount of dry matter (7.28 g $hill^{-1}$) in rice was accumulated in case of Zn_4 (6 kg) and Zn_1 (0 kg) treatment at maturity and tillering, respectively.

Malik *et al*. (2011) observed that the treatment receiving 300 ppm Zn in rice recorded the highest length of shoot + root (117 cm), length of spikelet (10.67 cm), dry matter production of root (3.90 g pot^{-1}) and shoot (14.20 g pot^{-1}) while the lowest height was observed at control.

Abid *et al*. (2011) reported that the growth and rice yield were significantly enhanced by application of Zn, Fe and Mn either alone or in various combinations. The treatment comprising 10 mg each of Mn and Zn added per kg soil along with basal dose of NPK fertilizers proved to be the best combination. It was evident that the highest grain number panicle^{-1} (118.66), 1000 grain weight (23.93 g) and maximum paddy yield (78.73 g) was recorded by treatment (NPK + Mn + Zn) and minimum yield (20.53 g) was recorded in (control). It was probably due to the more balanced nutrient ratio, which improved the yield and yield contributing characteristics of rice.

Reddy *et al*. (2011) and Khan *et al*. (2003) stated that there was no significant impact observed on 1000-grain weight of rice from zinc application methods (basal and foliar spray) on a partially reclaimed sodic soil at Faizabad.

Mustafa *et al*. (2011) conducted a field experiment on Super basmati rice variety and reported that basal application of 25 kg $ZnSO_4$ ha^{-1} showed heavier weight of test grains and it remained at par with foliar application of 0.5% $ZnSO_4$ and root dip treatments with zinc solution. They observed that Zn application had significantly pronounced effect on growth and yield of rice. Maximum productive tillers m^{-2} (249.80) and maximum grain yield (5.21 t ha^{-1}) were noted with basal application at the rate 25 kg ha^{-1}, 21% $ZnSO_4$ and minimum productive tillers (220.28) and minimum grain yield (4.17 t ha^{-1}) was noted in foliar application at 75 DAT @ 0.5% Zn solution. Basal application of 25 kg ha^{-1} of $ZnSO_4$ also recorded a greater number of tillers m^{-2} (258) and it was at par (254) with foliar application of 0.5% $ZnSO_4$ at 15 DAT.

Tahura (2011) conducted a field experiment with the objective of evaluating the effect of S and Zn on the yield performance and nutrient content of T-*Aman* Rice. The experiment composed of four different individual and combined treatment (sixteen) of sulphur *viz.* S_0 (control). S_8 (8 kg ha^{-1}), S_{12} (12 kg ha^{-1}) and S_{16} (16 kg ha^{-1}) and zinc *viz.* Zn_0 (0 kg ha^{-1}), $Zn_{1.0}$ (1.0 kg ha^{-1}), $Zn_{1.5}$ (1.5 kg ha^{-1}) and $Zn_{2.0}$ (2.0 kg ha^{-1}). The tallest plant (124.0 cm), highest grain yield (5.663 t ha^{-1}) and straw yield (8.163 t ha^{-1}) of T-*Aman* Rice was recorded in $S_{12}Zn_{1.5}$ (12 kg S ha^{-1} + 1.5 kg Zn ha^{-1}). Overall results indicate that the treatment combination of $S_{12}Zn_{1.5}$ (12 kg S ha^{-1} and 1.5 kg Zn ha^{-1}) alone or combinedly was more effective to produce higher yield of T-Arran rice supported with recommended doses of N, P and K.

Prasad *et al.* (2010) reported that the highest grain yield (4.35 t ha^{-1}) and straw yield (7.27 t ha^{-1}) were recorded under 100% crop residue level and 10 kg Zn ha^{-1} in rice compared with no zinc application treatment. Perusal of data revealed that minimum rice yield (7.09 t ha^{-1}) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period.

Rahman *et al*. (2008) carried out a field investigation on *Boro* rice with seven treatments *viz*. T_1: S_0Zn_0 (control), T_2: $S_{10}Zn_0$, T_3: $S_{20}Zn_0$, T_4: $S_0Zn_{1.5}$, T_5: S_0Zn_3, T_6: $S_{10}Zn_{1.5}$ and T_7: $S_{20}Zn_3$. The experimental result indicated that, number of tillers in *Boro* rice plant was significantly affected due to application S and Zn. Apparently, the maximum number of tiller (12.1) was observed in $S_{20}Zn_3$, the recommended dose of S and Zn, which was superior to all other treatments. The lowest number of tiller (7.6) was recorded in S_0Zn_0 (control). The highest grain yield (5.76 t ha^{-1}) was observed in $S_{20}Zn_3$. The $S_{10}Zn_{1.5}$ which is the 50% of recommended dose produced the intermediate grain yield (4.95 t ha^{-1}). The lowest grain yield (4.35 t ha^{-1}) was obtained in control. A significant and positive effect of S and Zn on straw yield of *Boro* rice was observed. The highest straw yield (7.32 t ha^{-1}) obtained in $S_{20}Zn_{1.5}$, the second highest in $S_{20}Zn_0$ (7.25 t ha^{-1}) and the lowest (5.47 t ha^{-1}) in S_0Zn_0.

Maqsood *et al*. (2008) conducted this study to evaluate the effect of different methods and timing of zinc application on growth and yield of rice. Experiment was comprised of eight treatments *viz*., control, rice nursery root dipping in 0.5% Zn solution, $ZnSO_4$ application at the rate of 25 kg ha^{-1} as basal dose, foliar application of 0.5% Zn solution at 15, 30, 45, 60 and 75 days after transplanting. Maximum productive tillers m^{-2} (249.80) was noted with basal application at the rate 25 kg ha^{-1} and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5% Zn solution. Zinc application methods and timing had significantly pronounced effect on paddy yield. Maximum rice yield (5.21 t ha^{-1}) was achieved in treatment Zn_1 (Basal application at the rate of 25 kg ha^{-1}) and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn_2 (foliar application at 75 DAT @ 0.5% Zn solution). Zinc application increased the crop growth rate of rice.

Islam *et al.* (2008) conducted a field experiment to find out the effect of zinc levels and transplanting dates on the yield and yield components of aromatic rice cv. Kalizira. The experiment was comprised of four levels of zinc (0, 5, 10 and 15 kg Zn ha^{-1}) and three transplanting dates (10 August, 22 August and 04 September, 2007) along with the basal doses of TSP, MP and gypsum. The maximum plant height (137 cm and 135 cm, respectively) was observed in 15 and 10 kg Zn ha^{-1} and 10 August transplanting date. The maximum number of effective tillers·$hill^{-1}$ (12.2, 9.40 respectively) was also observed with same Zn rate and transplanting date. The highest number of grains $panicle^{-1}$ was obtained (191) in 15 kg Zn ha^{-1} treatment with 10 August transplanting date and the lowest number was obtained (175) in Zn control. Single effect of Zn and transplanting date significantly affected the 1000-grain weight. The highest 1000-grain weight (12.0 g) was obtained in 15 kg Zn ha^{-1} with transplanting date 10 August and the lowest (10.7 g) in 0 kg Zn ha^{-1} with transplanting date 10 August. The highest grain yield (2.63 t ha^{-1}) was observed in 10 kg Zn $ha^{-1}$with 10 August transplanting treatment and straw yield (6.43 tha^{-1}) was found the highest in 15 kg Zn ha^{-1} with same date of transplanting and the lowest grain (1.83 tha^{-1}) and straw yields (5.14 t ha^{-1}) were found in Zn control treatment with transplanting date of 04 September.

Rahman (2007) conducted a field experiment with an objective of evaluating the effect of S and Zn on the yield, yield components and nutrient uptake by T-*Aman* (BRRI dhan31). There were twelve treatments taking various doses of Sulphur and Zinc *Viz*. S_0Zn_0 (control), S_0Zn_1, S_0Zn_2, $S_{12}Zn_0$, $S_{12}Zn_1$, $S_{12}Zn_2$, $S_{16}Zn_0$, $S_{16}Zn_1$, $S_{16}Zn_2$, $S_{20}Zn_0$, $S_{20}Zn_1$ and $S_{20}Zn_2$. The subscripts represent doses in kg ha^{-1}. The application of Sulphur and Zinc had a positive significant effect on tillers $hill^{-1}$, plant height, panicle length and no. of grains $panicle^{-1}$. The highest grain yield (4.20 t ha^{-1}) and straw yield (5.62 t ha^{-1}) of BRRI dhan31 was recorded in $S_{20}Zn_2$ treatment. The S_0Zn_0 treatment (control) had the lowest grain (3.01 t ha^{-1}) and straw yield (4.50 t ha^{-1}). Overall results indicate that the application of Sulphur and Zn at a rate of 20 kg S and 2 kg Zn ha^{-1} along with recommended dose of N, P, and K is necessary for obtaining maximum grain yield as well as straw yield of T-*Aman* rice.

Naik and Das (2007) reported that the soil application of Zn @ 1.0 kg ha^{-1} as Zn-EDTA showed the highest grain yield (5.42 t ha^{-1}) of rice, filled grain percentage

(90.2%), 1000-grains weight (25.41 g), and number of panicles m^{-2} (452) compared to basal application of $ZnSO_4.7H_2O$.

Khan *et al*. (2007) reported that, increasing the levels of Zn in soil significantly influenced yield and yield components of the rice crop. The treatment receiving 10 kg Zn ha^{-1} significantly increased maximum number of tillers $plant^{-1}$ (17.41), maximum number of panicles $plant^{-1}$ (15.88) and spikelet's $panicle^{-1}$ (86.48). The highest grain yield of (101.80 g pot^{-1}) and straw yield (140.40 g pot^{-1}) was recorded in treatment receiving 10kg Zn ha^{-1} which was statistically at par with the treatment receiving 15 kg Zn ha^{-1}. The minimum grain yield (73.90 g pot^{-1}), straw yield (102.28 g pot^{-1}) was recorded in control. The increase in yield parameters might be ascribed to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and there by resulting in the improvement of crop growth in rice.

Sinha (2007) noticed that combined application of 120 kg N together with 25 kg $ZnSO_4$ ha^{-1} resulted in significantly higher effective tillers m^{-2} in rice field on silty-clay soil of Pusa, Bihar.

Sarker (2007) conducted a field experiment to find out the performance of *Aman* rice as influenced by nitrogen and zinc on the yield of BRRI Dhan39. There were 16 treatments combinations comprising of four levels of N (0, 50, 100 and 150 kg N ha^{-1}) and four levels of Zn (0, 5, 10 and 15 kg Zn ha^{-1}). Plant height, total tillers, effective tillers and panicle length increased significantly with increasing Zn application up to 5 kg Zn ha^{-1}, while the number of filled grain $panicle^{-1}$, grain yield and straw yield enhanced with increasing Zn doses up to 10 kg Zn ha^{-1}. However, the application of 15 kg Zn ha^{-1} had a significant negative effect on grain yield but not on straw yield. The T_{11} (N_2Zn_2) treatment combination at the rate of 100 kg N ha^{-1} and 10 kg Zn ha^{-1} perform better than other treatments in this present trial considering rice yield and yield contributing parameters.

Kumar and Singh (2006) conducted a trial on a silty loam soil and reported that foliar application with 0.5% $ZnSO_4$ at three weeks after transplanting recorded higher number of productive tillers m^{-2} in rice field but it was on a par with soil application and root dip treatments.

Islam (2005) conducted a field experiment to evaluate the effect of organic manures (FYM + PM) and zinc fertilizer on yield attributing characters, yield, nutrient contents and their uptake in transplanted *Aman* rice (BRRI dhan30). The experiment was laid-out comprising 3 levels of organic manures (0, FYM 12 t ha^{-1}, PM 3 t ha^{-1}) and 3 levels of zinc fertilizer (0, 12, 15 kg ha^{-1}). Zinc sulphate ($ZnSO_4$) was used as the source of zinc fertilizer. The individual effect of zinc had significant positive impact on the different morphological character, grain and straw yield of rice. The highest number of tillers $hill^{-1}$ (11.13), the highest number of effective tillers $hill^{-1}$ (10.23), the longest panicle (23.96 cm), the maximum grain number $panicle^{-1}$ (111.90), the maximum weight of 1000-grains (20.50g), the highest grain yield (4.67 t ha^{-1}) and straw yield (7.00 t ha^{-1}) was obtained from Z_{12} treatment (12 kg Z ha^{-1}), which is the recommended optimum dose for rice.

Ram *et al*. (2005) observed the maximum number of filled grains $panicle^{-1}$ in rice plants were from the treatment that received combined application of 20 kg $ZnSO_4$ ha^{-1} as basal + three times foliar sprays of 0.5% $ZnSO_4$ solution initiated from 20 DAT at 10 days' interval but it was at a par with separate application of $ZnSO_4$ as soil and foliar spray on partially reclaimed sodic or silty loam soils of Faizabad (U.P.).

Sultana (2005) was conducted a field experiment with an objective of evaluating the effects of S and Zn on the yield, yield components and nutrient uptake of *Boro* rice (cv. BRRI dhan29). There were seven treatments taking various doses of S and Zn viz. S_0Zn_0 (control), $S_{20}Zn_0$, S_0Zn_3, $S_{20}Zn_3$, $S_{10}Zn_0$, $S_oZn_{1.5}$ and $S_{10}Zn_{1.5}$, the subscripts represent doses in kg ha^{-1}. The application of S and Zn had a significant positive effect on the tillers $hill^{-1}$, plant height, panicle length and grains $panicle^{-1}$. The highest grain (5110 kg ha^{-1}) and straw yields (5812 kg ha^{-1}) of rice were recorded in the $S_{20}Zn_3$ treatment (country's recommended dose). The S_0Zn_0 (control) treatment had the lowest grain (2832 kg ha^{-1}) and straw yields (3199 kg ha^{-1}). Overall results indicate that the application of S and Zn at a recommended rate i.e. 20 kg S and 3 kg Zn ha^{-1} along with recommended rate of N, P, and K is necessary for obtaining higher grain yield as well as straw yield of hybrid rice.

Kulandaivel *et al*. (2004) reported that application of 30 kg $ZnSO_4$ ha^{-1} along with 5 kg $FeSO_4$ ha^{-1} produced higher amount of dry matter content in hybrid rice on sandy clay loam soils of New Delhi.

Fageria (2004) reported that lowland rice responded significantly to applications of Zn, Cu, B, Mo, Mn and Fe. The adequate rates of micronutrients for maximum grain yield were Zn 33 mg kg^{-1}, Cu 25 mg kg^{-1}, B 26 mg kg^{-1}, Mo 10 mg kg^{-1}, Mn 250 mg kg^{-1}, and Fe 1269 mg kg^{-1}. In addition to grain yield, straw yield and panicle density, root growth of lowland rice was also improved with the addition of most of these micronutrients.

Ravikiran and Reddy (2004) found that foliar spray of Zn increased the number of productive tillers from control to 0.5% Zn spray followed by soil application but the highest increase was noticed with 0.5% spray only in rice field.

Khan *et al*. (2003) conducted a field experiment where comparative effect of three different methods of zinc application was studied, aimed at alleviating Zn deficiency in transplanted flood rice (cv. IRRI 6) grown in alkaline soil. Three methods were tried i.e. nursery root dipping in 1.0% $ZnSO_4$, 0, 20% $ZnSO_4$ Solution spray after transplanting and 10 g Zn ha^{-1} by field broadcast method. The yield and yield parameters increased significantly from the application of Zn by any method. Among the methods, the effect of Zn was non-significant on yield components like tiller m^{-2}, spikelet's $panicle^{-1}$, % filled grains, 1000-grain weight and straw yield. However, soil application of Zn @ 10 kg ha^{-1} was rated superior because it produced significantly higher paddy yield. The maximum number of tillers m^{-2} (415.67) in rice field was recorded where zinc was applied @ 10 kg ha^{-1} by soil dressing which did not differ significantly from that of foliar spray of 0.20% $ZnSO_4$ and root dipping of 1.0% $ZnSO_4$ on silt loam soils.

Rahman *et al*. (2002) stated that application of N along with Zn increased grain yield and grain-to-straw ratio in rice significantly. Ammonium sulfate used as N source along with Zn gave significantly higher yield as 25% in grain and 14% in straw and the highest grain-to-straw ration compared to all other treatments. It was possibly due to availability of more Zn and a greater number of filled grains under reduced pH. Application of zinc along with N had synergistic effect on N and Zn uptake in rice.

Hossain *et al*. (2001) reported that the application of Zn in combination with B and Mo significantly produced longer panicle length (24.4 cm), higher grain yield (4.7 t ha^{-1}), straw yield (7.07 t ha^{-1}) and 1000-grain weight (23.5 g) in rice and the minimum were recorded in control where no micronutrients were applied.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the effect of application of zinc fertilizer on performance of hybrid rice. This chapter deals with a brief description on experimental site, climate, soil, land preparation, layout, experimental design, intercultural operations, data recording and their analyses. The details of experimental materials and methods are described below:

3.1 Description of the experimental site

3.1.1 Experimental period

This research work was carried out within November, 2019 to May, 2020.

3.1.2 Experimental location

The experiment was carried out in the *Boro* season in the Field laboratory of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The location of the site is 23°74/N latitude and 90°35/E longitude with an elevation of 8.2 meter from sea level. Experimental location presented in Appendix I.

3.1.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February, the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al*., 1979). During the experimental period the maximum temperature (36.8°C), highest relative humidity (87%) and highest rainfall (273 mm) was recorded for the month of May, 2020 whereas, the minimum temperature (14.60°C), minimum relative humidity (64%) and no rainfall was recorded for the month of January, 2020. Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during study period has been presented in Appendix II.

3.1.4 Soil characteristics

The soil of the experimental field belonged to "The Madhapur Tract", AEZ-28 (FAO, 1988). Top soil was Silty Clay in texture, olive-grey with common fine to medium distinct dark yellowish-brown mottles. The soil having a texture of sandy loam organic matter 1.15% and composed of 26% sand, 43% silt and 31% clay. Details morphological, physical and chemical properties of the experimental field soil are presented in Appendix III.

3.2 Experimental details

3.2.1 Planting material

Three hybrid varieties of rice, namely BRRI hybrid dhan2, BRRI hybrid dhan3 and BRRI hybrid dhan5 were used in this study.

3.2.2 Treatment of the experiment

The experiment consisted of two factors:

Factor A: Varieties - 3 varieties as

1. V_1=BRRI hybrid dhan2
2. V_2=BRRI hybrid dhan3
3. V_3=BRRI hybrid dhan5

Factor B: Zinc management - 4 levels of Zn as

1. Zn_0= 0 kg ha^{-1} (control)
2. Zn_1=2 kg ha^{-1}
3. Zn_2=4 kg ha^{-1}
4. Zn_3=6 kg ha^{-1}

There were total 12 (3 × 4) combination as a whole *viz.*, V_1Zn_0, V_1Zn_1, V_1Zn_2, V_1Zn_3, V_2Zn_0, V_2Zn_1, V_2Zn_2, V_2Zn_3, V_3Zn_0, V_3Zn_1, V_3Zn_2 and V_3Zn_3.

3.2.3 Experimental design and layout

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.

3.3 Growing of crops

3.3.1 Seed collection and sprouting

The seeds of three hybrid varieties of rice were obtained from the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. Only 20 days old seedlings are planted in the seed bed. Clean seeds were soaked in water in a pail for 24 hours to produce seedlings. The imbibed seeds were then removed from the water and placed in gunny bags. After 48 hours, the seeds sprouted and were ready for planting in the seed bed in 72 hours.

3.3.2 Raising of seedlings

The nursery bed was prepared by puddling with repeated ploughing followed by laddering. The sprouted seeds were sown on beds as uniformly as possible at 15th November, 2019. Irrigation was gently provided to the bed when needed. No fertilizer was used in the nursery bed.

3.3.3 Land preparation

The plot selected for conducting the experiment was opened on the 12th December, 2019 with a power tiller, and left exposed to the sun for a week. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain good puddle condition. The experimental plot was partitioned into unit plots in accordance with the experimental design at 23th December, 2019.

3.3.4 Fertilizers and manure application

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). Vermicompost were applied @ 75.00 kg ha^{-1} in each plot. 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.

3.3.5 Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 26th December, 2019 in well puddled plot with spacing of 20 × 15 cm. One seedling was transplanted in each hill. After one week of transplanting all plots were checked for any missing hill, which was filled up with extra seedlings of the same source whenever required.

3.4 Intercultural operations

Intercultural operations were done to ensure normal growth of the crop. Plant protection measures were followed as and when necessary. The following intercultural operations were done.

3.4.1 Irrigation and drainage

Irrigation was given to maintain a consistent level of standing water up to 6 cm during the early phases of seedling establishment, and thereafter the quantity of drying and wetting was maintained throughout the whole vegetative period. There was no water stress during the reproductive and ripening phases.

3.4.2 Weeding

Weeding was done to keep the plots weed-free, which resulted in enhanced seedling growth and development. The weeds were mechanically pulled at 20 DAT (days after transplanting) and 40 DAT.

3.4.3 Insect and pest control

Furadan 5G was used in the plot at 25 and 45 DAT. Leaf roller (*Cnaphalocrosis medinalis*) was discovered and treated with Malathion 10 EC @ 1.12 L ha^{-1} through sprayer at 40 and 60 DAT, but no disease infection was recorded in the field.

3.5 Harvesting, threshing and cleaning

Depending on the variety, the crop was harvested after 80-90% of the grains had become straw in colour. The harvested crop was wrapped individually, correctly labelled, and sent to the threshing floor. For each plot, the grains were dried, washed, and weighed. The weight was changed to contain 14% moisture.

3.6 Recording of data

The following data were recorded during the experimentation period:

i. Plant height
ii. Number of tillers $hill^{-1}$,
iii. Leaf Area Index (LAI),
iv. Crop Growth Rate (CGR)
v. Number of panicles $hill^{-1}$,
vi. Panicle length
vii. Number of grains $panicle^{-1}$,
viii. 1000-grain weight
ix. Grain yield
x. Straw yield
xi. Biological yield and
xii. Harvest Index.

3.7 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

3.7.1 Plant height

Plant height was measured in centimeter (cm) at 30, 60, 90, and harvest stages for all entries on ten randomly selected plants from the middle rows. The height was measured from the ground to the tip of the highest panicle.

3.7.2Number of tillers $hill^{-1}$

Tiller number $hill^{-1}$ was recorded at 30, 60, 90 DAT and at harvest stage as the average of randomly selected 5 plants from the inner rows of each plot.

3.7.3 Leaf Area Index (LAI)

Green leaf area (LA) was measured by an automatic leaf area meter (Model: LI-3100, Li-COR, Lincoln, NE, USA) after removal of leaves to avoid rolling and shrinkage and then transformed into leaf area index (LAI) according to Yoshida (1981).

3.7.4 Crop Growth rate (CGR)

CGR represents the increase of plant material per unit time per unit land area. It was measured by the following formula.

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

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.

3.7.5 Number of panicles hill^{-1}

The number of panicles was counted at maturity from randomly selected ten hills of each plot. The average value on this parameter was computed and expressed in terms of average panicle number hill^{-1}.

3.7.6 Panicle length

The panicles of tagged plants from each plot were measured from the neck node to the tip of the panicle using a scale. Finally, the average panicle length in centimetres was calculated.

3.7.7 Number of grains panicle^{-1}

All panicles from the five tagged hills of each plot were threshed. Grain and sterile

spikelets were separated by a seed sorter (Kiya Seisakusho LDT, model 1973, Tokyo, Japan). After separation, the grains were counted by an automatic counter (Nagoga, model DC I-O, Japan) and then number of grains panicle^{-1} was calculated.

3.7.8 1000-grain weight

After threshing and washing, a handful of grains were randomly selected from the total grain yield of each plot. On an electronic balance, 1000 grains from each plot sample were counted and weighted, and their weight was reported in g per 1000 grains.

3.7.9 Grain yield

Crop was harvested according to maturity from each of the plot. After threshing, cleaning and sun drying, the grain weight was recorded and adjusted to 14% moisture content (MC) using the following formula.

$$\text{Grain yield at 14\% MC} = \frac{100-\text{Sample MC (\%)}}{100-14} \times \text{weight of the grains at harvest}$$

3.7.10 Straw yield

Straw obtained from each unit plot were sun-dried and weighed carefully. Dry weight of straw of each plot were taken and converted to ton per hectare (t ha^{-1}).

3.7.11 Biological yield

Grain yield and straw yield together were regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

3.7.12 Harvest Index (HI) (%)

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

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

3.8 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).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out effect of variety and zinc application on performance of hybrid rice. The results obtained from the study are presented, discussed and compared in this chapter through table(s) and figures. The results are presented and discussed with the help of table and graphs and possible interpretations given under the following headings.

4.1 Plant height

4.1.1 Effect of variety

Varieties showed significant effect on plant height of hybrid rice among them (Figure 1 and Appendix IV). Varieties also showed an increasing trend in plant height with advances of age of plant after transplanting and the highest increase was found at harvesting stage. Among the varieties V_3 (BRRI hybrid dhan5) showed the shortest and V_1 (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 179.82 cm, respectively) was reported from V_1 (BRRI hybrid dhan2) treatment while, the shortest plant (15.83, 30.09, 69.14 and 109.70 cm, respectively) was observed in V_3 (BRRI hybrid dhan5) treatment. This result agreed with Singh *et al*., (2019) and Mahmood (2017) who described that plant height varies significantly among varieties.

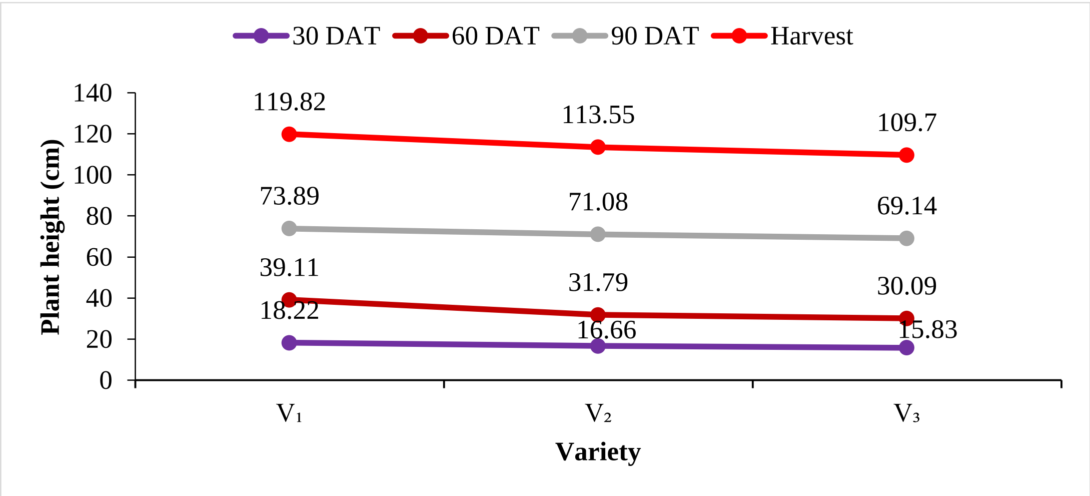

Figure 1. Effect of variety on the plant height (cm) in hybrid rice at different days after transplanting (LSD value = 0.94, 1.67, 1.97 and 2.06 at 30, 60, 90 DAT and harvest, respectively).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.1.2 Effect of zinc application

Plant height of *Boro* rice was significantly influenced by the application of different levels of zinc (Figure 2 and Appendix IV). The figure indicated that irrespective zinc doses height of the plant showed a gradual 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 Zn_3 (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 Zn_0 (no zinc application) treatment.

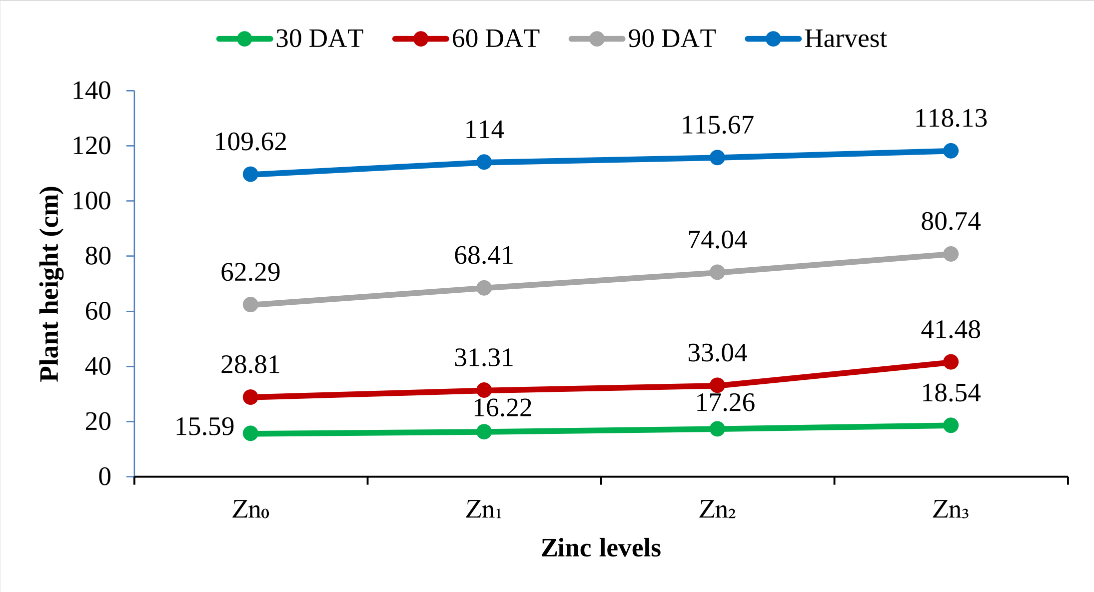

Figure 2. Effect of zinc levels on the plant height (cm) in hybrid rice at different days after transplanting (LSD value = 0.93, 1.38, 1.75 and 2.45 at 30, 60, 90 DAT and harvest, respectively).

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}

4.1.3 Interaction effect of variety and zinc application

Plant height of hybrid rice was significantly influenced by the interaction of different varieties and different levels of zinc doses (Table 1 and Appendix IV). At 30, 60, 90 and harvest, the tallest plant (22.67, 49.56, 88.22 and 124.10 cm, respectively) was recorded from V_1Zn_3 (BRRI hybrid dhan2 with 6 kg Zn ha^{-1}) treatment combination which was statistically identical with V_1Zn_2 (123.00 cm) at harvest. 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 V_3Zn_0 (BRRI hybrid dhan5 with no zinc application) treatment combination which was statistically identical with V_3Zn_1 (16.33 cm) and V_2Zn_0 (16.44 cm) and statistically similar to V_3Zn_2 (17.22 cm) at 30 DAT.

Table 1. Interaction effect of variety and zinc on the plant height (cm) in hybrid rice

Treatment combination	Plant height (cm) at			
	30 DAT	**60 DAT**	**90 DAT**	**Harvest**
V_1Zn_0	17.33 d	33.11 e	64.33 h	116.36 c
V_1Zn_1	17.44 cd	37.22 d	69.00 f	119.80 b
V_1Zn_2	19.44 b	40.56 c	78.00 c	123.00 a
V_1Zn_3	22.67 a	49.56 a	88.22 a	124.10 a
V_2Zn_0	16.44 e	27.44 i	63.33 h	112.40 e
V_2Zn_1	17.89 cd	29.71 gh	67.11 g	114.30 d
V_2Zn_2	18.11 c	30.00 g	74.89 d	114.60 d
V_2Zn_3	18.18 c	44.00 b	83.00 b	116.90 c
V_3Zn_0	16.00 e	28.89 h	62.22 i	103.10 h
V_3Zn_1	16.33 e	30.00 g	72.11 e	110.90 f
V_3Zn_2	17.22 de	31.56 f	72.22 e	112.40 e
V_3Zn_3	17.78 cd	33.89 e	74.00 d	116.40 c
$LSD_{(0.05)}$	0.78	0.90	1.11	1.65
CV (%)	4.38	6.38	8.68	9.18

In a column, means having similar letter (s) are statistically similar and those having 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}

4.2 Number of tillers hill^{-1}

4.2.1 Effect of variety

The number of total tillers hill^{-1} was significantly influenced by variety at all stages of crop growth (Figure 3 and Appendix V). At 30, 60, 90 DAT and harvest, BRRI hybrid dhan5 (V_3) 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 (V_1) 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. This revealed that during the reproductive and ripening phases the rate of tiller mortality exceeded the tiller production rate. Variable effect of variety on number of total tillers hill^{-1} was also reported by Rahman *et al.* (2022), Chowhan *et al*. (2019) and Hussain *et al*. (1989), who noticed that number of total tillers hill^{-1} differed among the varieties.

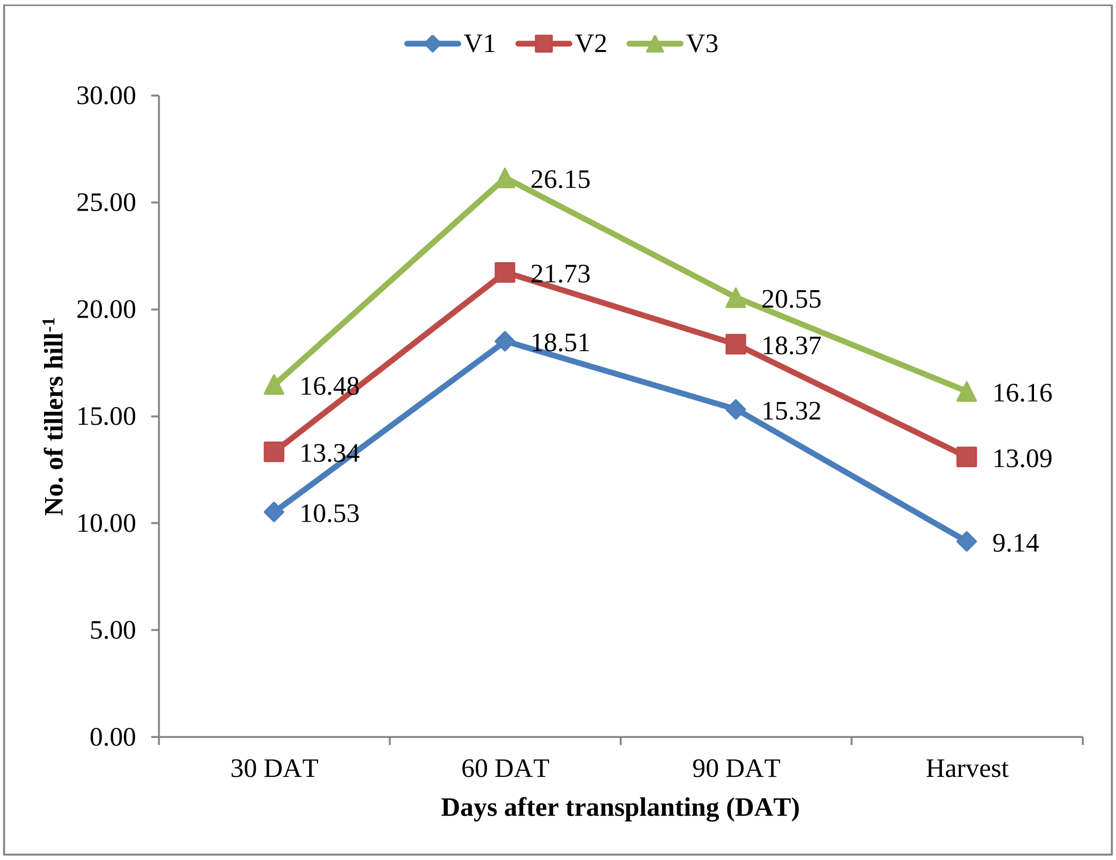

Figure 3. Effect of variety on the number of tillers hill^{-1} in hybrid rice at different days after transplanting (LSD value = 1.45, 2.03, 1.83 and 1.96 at 30, 60, 90 DAT and harvest, respectively).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.2.2 Effect of zinc application

Different rate of zinc varied in terms of number of tillers hill^{-1}of hybrid rice at 30, 60, 90 DAT and harvest (Figure 4 and Appendix V). At 30 DAT, the maximum (14.78 tillers hill^{-1}) was found from 6 kg Zn ha^{-1} (Zn_3) which was statistically similar (14.06 tillers hill^{-1}) to Zn_2 (4 kg Zn ha^{-1}) treatment, while the minimum (11.83 tillers hill^{-1}) was recorded from 0 kg Zn ha^{-1} (Zn_0). At 60, 90 DAT and harvest stage, the maximum (25.21, 20.68 and 14.42 tillers hill^{-1}, respectively) was found from 6 kg Zn ha^{-1} (Zn_3)

and the minimum (18.64, 15.94 and 11.22 tillers hill^{-1}, respectively) was recorded from 0 kg Zn ha^{-1}(Zn_0). Cheema *et al.* (2006) observed that number of tillers hill^{-1} showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

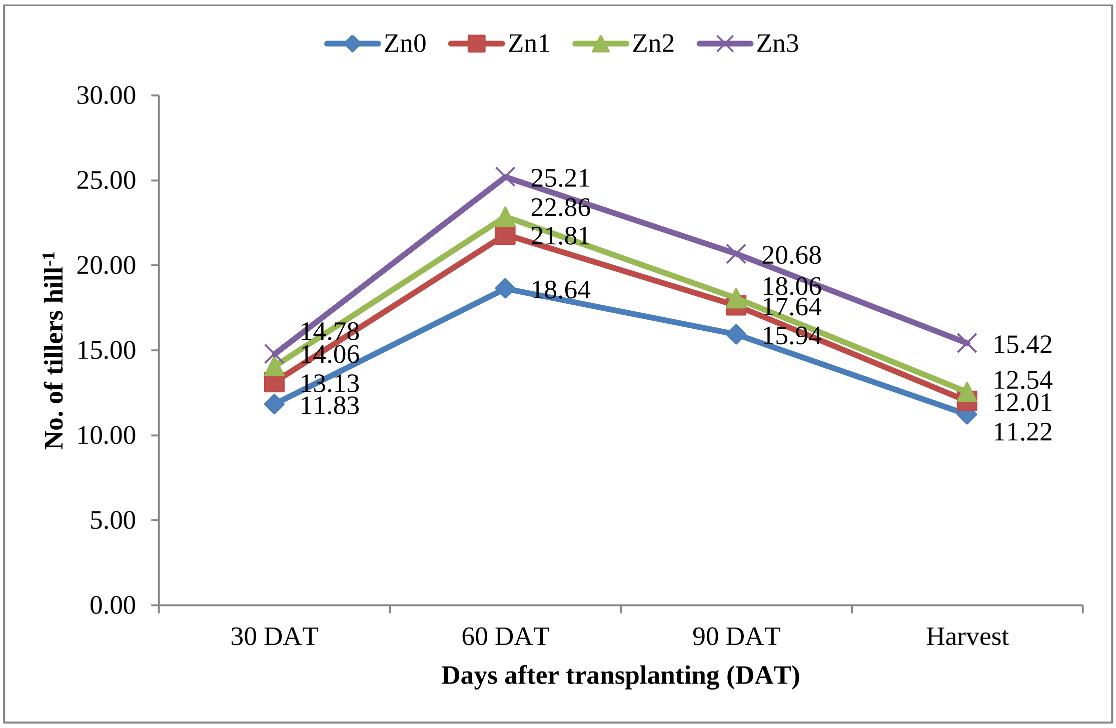

Figure 4. Effect of zinc levels on the number of tillers hill^{-1} in hybrid rice at different days after transplanting (LSD value = 1.12, 1.58, 1.41 and 1.52 at 30, 60, 90 DAT and harvest, respectively).

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}

4.2.3 Interaction effect of variety and zinc application

The interaction effect of variety and zinc levels showed significant influence on the tiller dynamic of the hybrid rice (Table 2 and appendix V). 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 V_3Zn_3 (BRRI hybrid dhan5with6 kg Zn ha^{-1}) treatment combination which was statistically identical to V_3Zn_2 (17.24) at 30 DAT. 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 V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}) which was statistically similar to V_1Zn_1 (10.28) and V_1Zn_2 (10.99) at 30 DAT; V_1Zn_1 (14.95) at 90 DAT and V_1Zn_1 (8.58) and V_1Zn_2 (8.98) at harvest stage.

Table 2. Interaction effect of variety and zinc on the number of tillers hill^{-1} in hybrid rice

Treatment combination	No. of tillers hill^{-1} at			
	30 DAT	60 DAT	90 DAT	Harvest
V_1Zn_0	9.29 f	15.65 g	13.55 f	7.56 d
V_1Zn_1	10.28 f	18.25 f	14.95 ef	8.58 d
V_1Zn_2	10.99 ef	19.11 f	15.30 e	8.98 d
V_1Zn_3	11.54 e	21.04 e	17.47 cd	11.44 c
V_2Zn_0	11.74 e	18.31 f	16.19 de	11.53 c
V_2Zn_1	13.02 d	21.41 de	17.92 c	12.13 c
V_2Zn_2	13.95 cd	22.44 d	18.35 c	12.67 c
V_2Zn_3	14.66 c	24.75 cd	21.02 b	16.04 b
V_3Zn_0	14.47 c	21.96 d	18.08 c	14.57 b
V_3Zn_1	16.08 b	25.76 bc	20.04 b	15.31 b
V_3Zn_2	17.24 a	27.02 b	20.53 b	15.98 b
V_3Zn_3	18.13 a	29.85 a	23.55 a	18.78 a
LSD $_{(0.05)}$	1.12	1.58	1.41	1.52
CV (%)	8.75	9.34	6.98	8.27

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: 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}

4.3 Leaf area index (LAI)

4.3.1 Effect of variety

Leaf area index (LAI) or the surface area of green leaves produced by rice plants unit area^{-1} of land was taken as an index of leaf area development. The leaf area of plant is one of the major determinants of its growth. LAI was significantly influenced by variety to variety at different growth stages (Figure 5 and Appendix VI). 'BRRI hybrid dhan5' variety (V_3), maintained the superior LAI as compared to other treatment 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 (V_3) 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 (V_1).

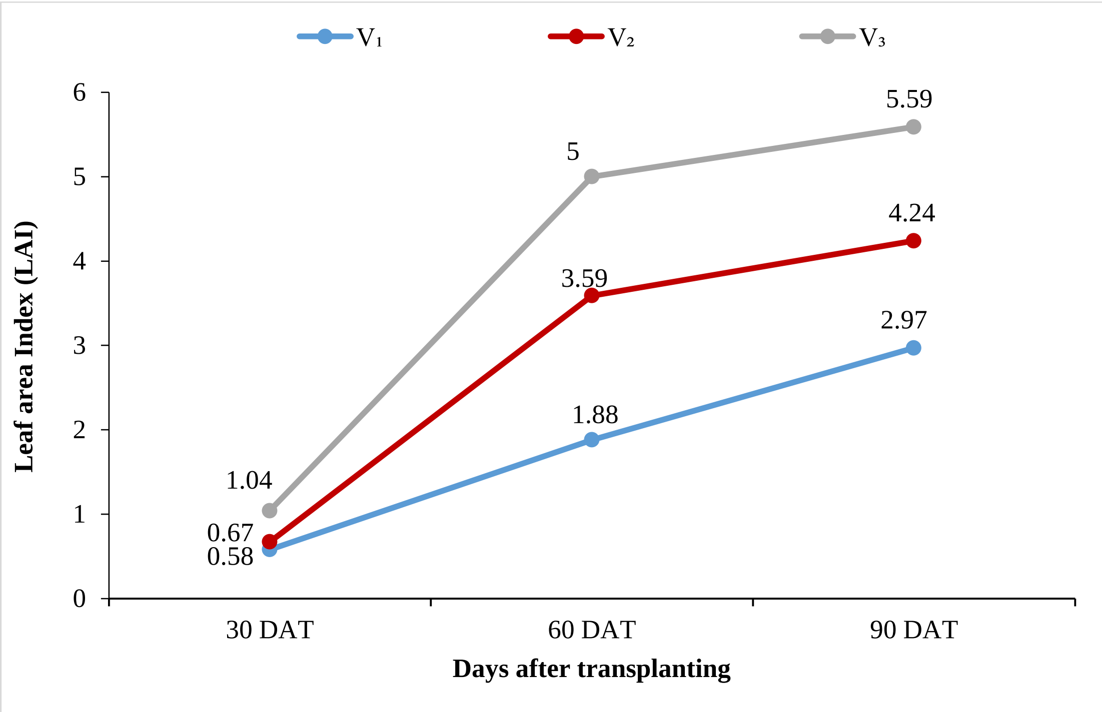

Figure 5. Effect of variety on the leaf area index (LAI) in hybrid rice at different days after transplanting (LSD value = 0.08, 0.22 and 0.24 at 30, 60 and 90 DAT, respectively).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.3.2 Effect of zinc application

Significant variation was observed in terms of leaf area index (LAI) at different growth stages of hybrid rice influenced by different zinc rates (Figure 6 and Appendix VI). It was observed that the highest LAI (0.85, 3.51 and 3.54 at 30, 60 and 90 DAT, respectively) was obtained from the treatment Zn_3 (6 kg Zn ha^{-1}) which was statistically similar with Zn_2 (0.75, 3.63 and 4.41 at 30, 60, 90 DAT, respectively) whereas, the lowest LAI (0.62, 3.05 and 3.85, respectively) at 30, 60, 90 DAT was found from the treatment Zn_0 (0 kg Zn ha^{-1}). Similar result also reported by Hussain and Yasin (2004) also concluded that application of Zn as foliar spraying in rice is highly attractive and produced higher LAI than control treatment.

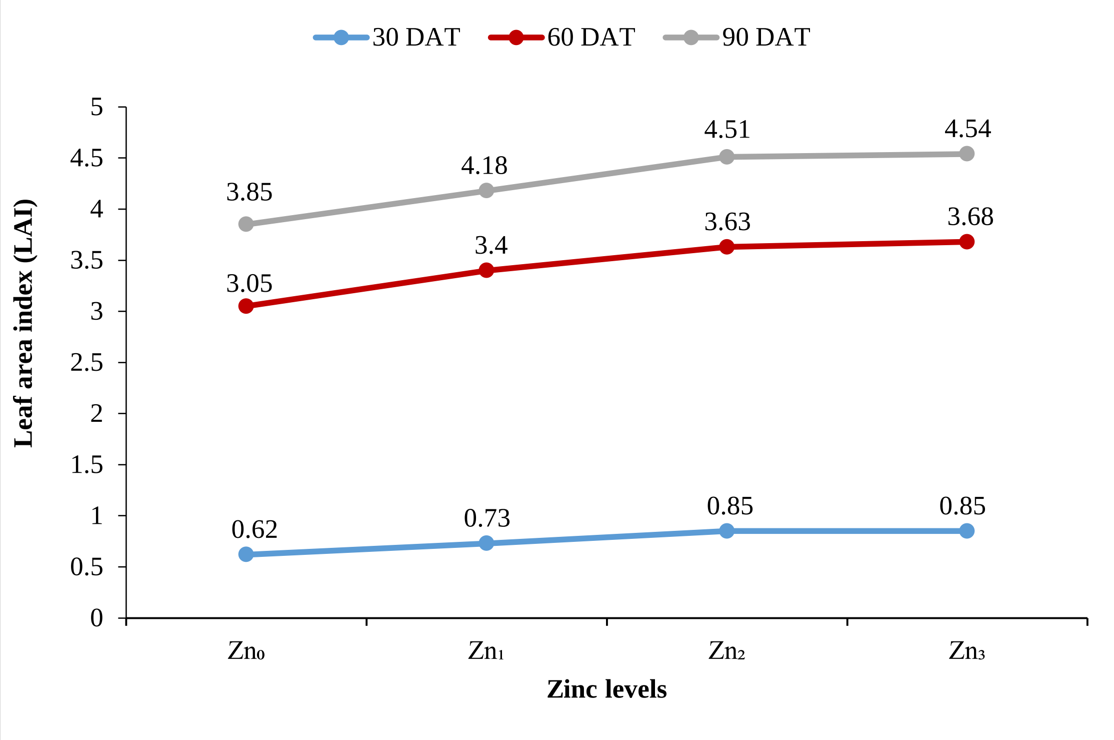

Figure 6. Effect of zinc levels on the leaf area index (LAI) in hybrid rice at different days after transplanting (LSD value = 0.06, 0.28 and 0.31 at 30, 60 and 90 DAT, respectively).

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}

4.3.3 Interaction effect of variety and zinc application

The interaction effect of variety and zinc rate showed significant influence on the leaf area index (LAI) of the hybrid rice (Table 3 and appendix VI). At 30, 60, 90 DAT, the highest LAI (1.07, 5.32 and 5.83, respectively) was observed with V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}) which was statistically identical with V_3Zn_2(1.07, 5.24 and 5.81, respectively). On the other hand, at 30, 60, 90 DAT, the lowest LAI (0.38, 1.55 and 2.58, respectively) was found by V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}) which was statistically similar with V_1Zn_1 (1.73 and 2.81 at 60 and 90 DAT, respectively).

Table 3. Interaction effect of variety and zinc on the leaf area index (LAI) in hybrid rice

Treatment combination	Leaf area index (LAI) at		
	30 DAT	60 DAT	90 DAT
V_1Zn_0	0.38 g	1.55 h	2.58 h
V_1Zn_1	0.45 f	1.73 gh	2.81 h
V_1Zn_2	0.54 e	1.91 g	3.04 g
V_1Zn_3	0.54 e	1.93 g	3.04 g
V_2Zn_0	0.45 f	3.04 f	3.73 f
V_2Zn_1	0.54 e	3.40 e	4.05 e
V_2Zn_2	0.65 d	3.74 d	4.38 d
V_2Zn_3	0.65 d	3.79 d	4.39 d
V_3Zn_0	0.74 c	4.27 c	4.95 c
V_3Zn_1	0.89 b	4.77 b	5.37 b
V_3Zn_2	1.07 a	5.24 a	5.81 a
V_3Zn_3	1.07 a	5.32 a	5.89 a
$LSD_{(0.05)}$	0.06	0.28	0.31
CV (%)	6.82	9.24	11.37

In a column, means having similar letter (s) are statistically similar and those having 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}

4.4 Crop Growth Rate (CGR)

4.4.1 Effect of variety

Crop growth rate (CGR) was significantly influenced by different variety at different growth stages (Figure 7 and Appendix VII). Critical appraised of the data showed that the maximum crop growth rate was recorded the variety ‘BRRI hybrid dhan5’ (V_3) at 30, 60 and 90 DAT. The maximum CGR (0.57, 4.22 and 5.20 g running m^{-1} day^{-1}, respectively) was recorded with BRRI hybrid dhan5 (V_3) whereas, the minimum CGR (0.27, 1.09 and 2.56 g running m^{-1} day^{-1}, respectively) was found at 30, 60 and 90 DAT due to the effect of BRRI hybrid dhan2 (V_1). Similar result was reported by Mahmood (2017) who found significant variation on CGR due to varietal difference.

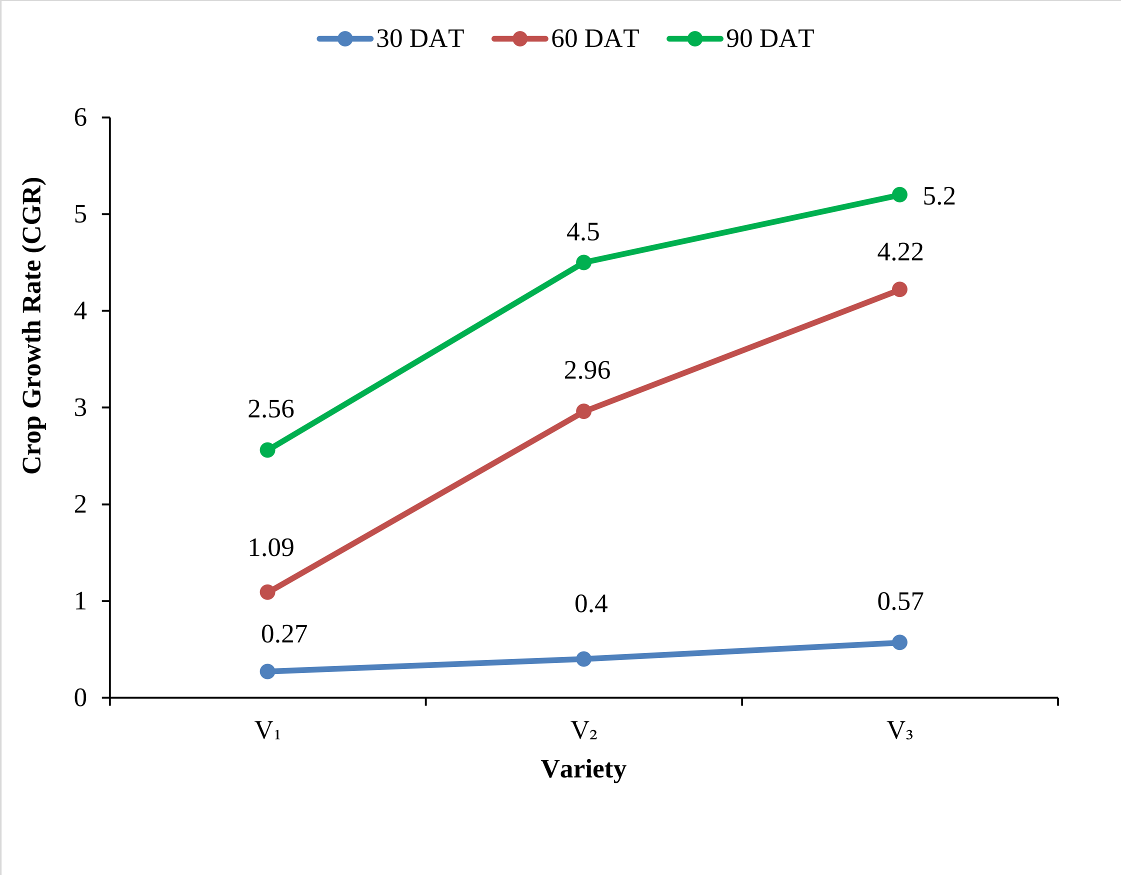

Figure 7. Effect of variety on the crop growth rate (CGR) in hybrid rice at different days after transplanting (LSD value = 0.07. 0.29 and 0.49 at 30, 60 and 90 DAT, respectively).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.4.2 Effect of zinc application

Significant variation was observed in terms of crop growth rate (CGR) at different growth stages of hybrid rice influenced by different zinc rate except 30 DAT (Figure 8 and Appendix VII). At 30 DAT, numerically maximum CGR (0.46 g running m^{-1} day^{-1}) was recorded with Zn_3 (6 kg Zn ha^{-1}) and minimum (0.37 g running m^{-1} day^{-1}) was recorded with Zn_0 (0 kg Zn ha^{-1}). It was observed that the maximum CGR (3.42 and 4.67 g running m^{-1} day^{-1} at 60 and 90 DAT, respectively) was obtained from the treatment Zn_3 (6 kg Zn ha^{-1}) which was statistically identical with Zn_2(4.51 g running m^{-1} day^{-1} at 90 DAT) whereas, the minimum CGR (1.76 and 3.13 g running m^{-1} day^{-1}, respectively) at 60 and 90 DAT was found from the treatment Zn_0 (0 kg Zn ha^{-1}). Similar results also reported by Boonchuay *et al.* (2013); Muthukumararaja and Sriramachandrasekharan (2012).

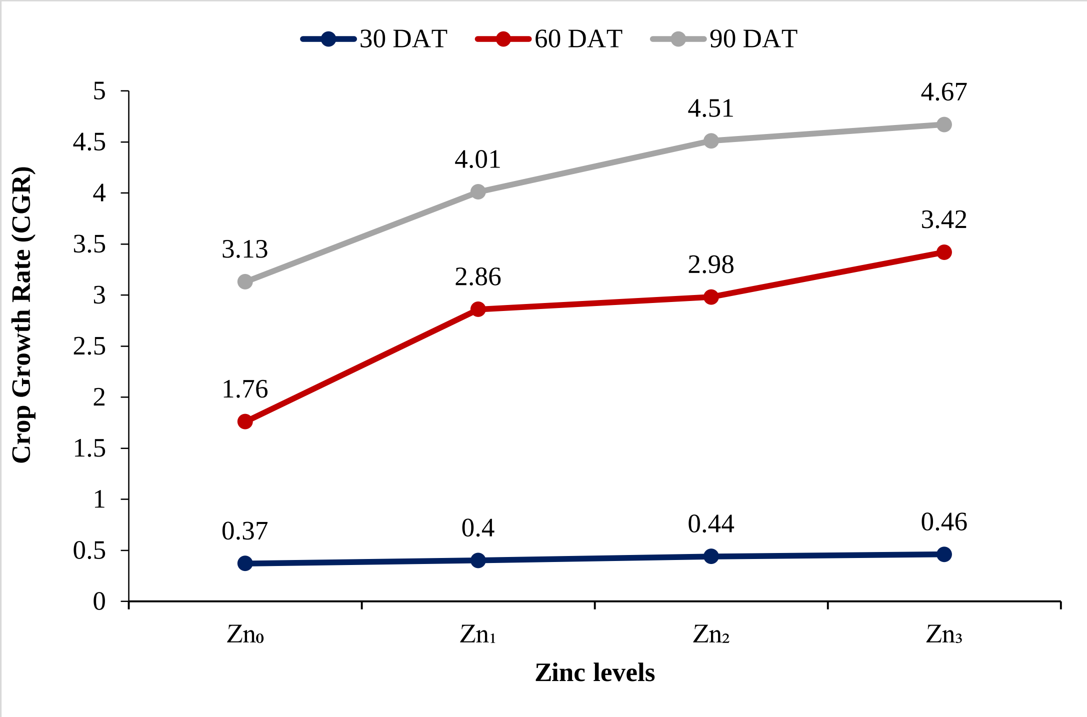

Figure 8. Effect of zinc levels on the crop growth rate (CGR) in hybrid rice at different days after transplanting (LSD value = NS, 0.21 and 0.38 at 30, 60 and 90 DAT, respectively).

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}

4.4.3 Interaction effect of variety and zinc application

The interaction effect of different variety and different levels of zinc application showed significant influence on the crop growth rate (CGR) of the hybrid *Boro* rice (Table 4 and appendix VII). At 30 DAT, the maximum CGR (0.62 g running m^{-1} day^{-1}) was observed with V_3Zn_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) which was statistically similar with V_3Zn_2 (0.59 g running m^{-1} day^{-1}) whereas, the minimum CGR (0.23 g running m^{-1} day^{-1}) was observed with V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}) which was statistically identical with V_1Zn_1 (0.24 g running m^{-1} day^{-1}), V_1Zn_2 (0.27 g running m^{-1} day^{-1}), V_1Zn_3 (0.28 g running m^{-1} day^{-1}) and statistically similar to V_2Zn_0 (0.35 g running m^{-1} day^{-1}) treatment combination. At 60 and 90 DAT, the maximum CGR (5.23 and 5.96 g running m^{-1} day^{-1}, respectively) was found by V_3N_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) whereas, the minimum CGR (0.69 and 1.95 g running m^{-1} day^{-1}, respectively) was found by V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}) treatment combination.

Table 4. Interaction effect of variety and zinc on the crop growth rate (CGR) in hybrid rice

Treatment combination	Crop growth rate (g running m^{-1} day^{-1}) at		
	30 DAT	60 DAT	90 DAT
V_1Zn_0	0.23 e	0.69 h	1.95 g
V_1Zn_1	0.24 e	1.12 g	2.51 f
V_1Zn_2	0.27 e	1.17 g	2.82 f
V_1Zn_3	0.28 e	1.34 g	2.93 f
V_2Zn_0	0.35 de	1.88 f	3.43 e
V_2Zn_1	0.38 d	3.06 d	4.41 d
V_2Zn_2	0.42 cd	3.18 d	4.96 c
V_2Zn_3	0.44 c	3.66 c	5.16 c
V_3Zn_0	0.49 c	2.68 e	3.97 d
V_3Zn_1	0.54 bc	4.37 b	5.09 c
V_3Zn_2	0.59 ab	4.55 b	5.73 b
V_3Zn_3	0.62 a	5.23 a	5.96 a
$LSD_{(0.05)}$	0.07	0.29	0.49
CV (%)	16.78	14.82	13.27

In a column, means having similar letter (s) are statistically similar and those having 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}

4.5 Number of panicles hill^{-1}

4.5.1 Effect of variety

Number of panicles hill^{-1} of hybrid rice showed statistically significant differences due to different rice variety (Table 5 and Appendix VIII). The highest number of panicles hill^{-1} (17.10) was found from V_3 (BRRI hybrid dhan5) treatment, while the lowest number (10.09) was recorded from V_1 (BRRI hybrid dhan2) treatment which Followed (14.41) by V_2 (BRRI hybrid dhan3) treatment. A similar kind of result was recorded by Yin *et al.* (2016).

Table 5. Effect of variety on the yield components in hybrid rice in *Boro* season

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 $_{(0.05)}$	1.57	0.77	4.25	1.55
CV (%)	6.82	9.92	4.54	7.36

In a column, means having similar letter (s) are statistically similar and those having 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

4.5.2 Effect of zinc application

Panicle number hill^{-1} of hybrid rice showed statistically significant differences due to different rate of zinc (Table 6 and Appendix VIII). The highest panicle number hill^{-1} (16.33) was found from Zn_3 (6 kg Zn ha^{-1}) treatment, while the lowest number (12.78) was recorded from Zn_0 (0 kg Zn ha^{-1}) treatment. These may be due to contribution of zinc in plant growth. The similar kind of result was recorded by Yin *et al.* (2016).

Table 6. Effect of zinc levels on the yield components in hybrid rice

Zinc scheduling	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 $_{(0.05)}$	1.21	0.47	5.85	1.55
CV (%)	6.82	9.92	4.54	7.36

In a column, means having 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}

4.5.3 Interaction effect of variety and zinc application

Interaction effect of variety and zinc levels was found significant on panicle number hill^{-1} of hybrid rice (Table 7 and appendix VIII). The highest panicle number hill^{-1} (20.17) was found from the combination of V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}). On the other hand, the lowest panicle number hill^{-1} (9.63) was found in V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}).

Table 7. Interaction effect of variety and zinc on the yield components in hybrid rice

Treatment combination	Number of panicles hill^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)
V_1Zn_0	8.00 g	23.52 j	82.22 h	21.49 f
V_1Zn_1	9.97 f	24.18 i	89.39 g	22.25 ef
V_1Zn_2	10.37 f	24.72 h	93.32 ef	22.46 d-f
V_1Zn_3	12.04 e	25.04 g	96.87 e	23.11 d-f
V_2Zn_0	13.00 de	24.52 h	92.35 f	23.81 de
V_2Zn_1	13.62 d	25.75 f	100.84 d	24.66 cd
V_2Zn_2	14.23 d	26.40 e	105.88 c	24.90 cd
V_2Zn_3	17.78 bc	26.93 d	109.71 c	25.61 bc
V_3Zn_0	15.00 c	26.30 e	98.45 de	25.50 bc
V_3Zn_1	16.24 bc	27.67 c	107.88 c	26.41 ab
V_3Zn_2	17.00 b	28.70 b	113.71 b	26.66 ab
V_3Zn_3	20.17 a	29.45 a	117.74 a	27.43 a
LSD (0.05)	1.21	0.47	3.85	1.40
CV (%)	6.82	9.92	4.54	7.36

In a column, means having similar letter (s) are statistically similar and those having 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}

4.6 Panicle length

4.6.1 Effect of variety

The panicle length varied significantly due to variety shown in Table 5 and Appendix VIII. It was observed that BRRI hybrid dhan5 (V_3) produced significantly longer

(28.03 cm) panicle. The second longer panicle length (25.90 cm) was measured from BRRI hybrid dhan3 (V_2) and the shortest panicle length (24.36 cm) was measured from BRRI hybrid dhan2 (V_1). This confirms the report of Ahmed *et al.* (1997) who showed that panicle length was differed due to variety.

4.6.2 Effect of zinc application

Significant differences were noticed in respect of panicle length in rice due to different rate of Zn application (Table 6 and Appendix VIII). Among the rate of Zn application, the longest panicle (27.14 cm) was recorded in 6 kg Zn ha^{-1} (Zn_3) and the shortest panicle (24.78 cm) obtained from 0 kg Zn ha^{-1} (Zn_0) treatment. A similar kind of result was also reported by Bodruzzaman *et al*. (2007) and Khan *et al.* (2007) in which the adequate supply of zinc results in the greater panicle length.

4.6.3 Interaction effect of variety and zinc application

Panicle length was significantly influenced by the interaction effect of different rate of variety and zinc in hybrid rice (Table 7 and Appendix VIII). The longest panicle (29.45 cm) was recorded in BRRI hybrid dhan5 and 6 kg Zn ha^{-1} (V_3Zn_3) treatment combination. On the other hand, the shortest panicle length (23.52 cm) was obtained from BRRI hybrid dhan2 and no zinc application (V_1Zn_0) treatment combination.

4.7 Number of grains panicle^{-1}

4.7.1 Effect of variety

Number of grains panicle^{-1} was significantly influenced by variety (Table 5 and appendix VIII). The highest number of grains panicle^{-1} (109.45) was found from V_3 (BRRI hybrid dhan5). The lowest grains panicle^{-1} (90.45) was obtained from V_1 (BRRI hybrid dhan2) treatment. BRRI hybrid dhan5 produced 27.86% higher number of grains panicle^{-1} than BRRI hybrid dhan2. These results agreed with Ahmed *et al.,* (1997) who reported that percent filled grain was the highest in Nizersail (a local variety) followed by BR25 and the lowest in BR11 and BR23.

4.7.2 Effect of zinc application

Grain number panicle^{-1} affected significantly due to rate of Zn application in hybrid rice (Table 6 and appendix VIII) which indicated that zinc fertilization by all the three rates increased the grain number panicle^{-1} significantly over no Zn application. The highest value of grains panicle^{-1} (108.11) was recorded in 6 kg Zn ha^{-1} (Zn_3) treatment which was statistically identical with Zn_2 (104.30) whereas, the lowest (91.01) was recorded in 0 kg Zn ha^{-1} (Zn_0) treatment. This might be due to higher zinc supply from $ZnSO_4.H_2O$ which is evidenced from higher total Zn uptake. These results are in conformity with the findings of Chaudary *et al*. (2007) and Reddy *et al*. (2011).

4.7.3 Interaction effect of variety and zinc application

Interaction of variety and zinc rate significantly influenced the grain panicle^{-1}of hybrid rice (Table 7 and Appendix VIII). The maximum number of grain panicle^{-1}(117.74) was recorded from V_3Zn_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) treatment combination. On the other hand, the minimum number of grain panicle^{-1} (82.22) was observed in V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}) treatment combination.

4.8 Weight of 1000 grains

4.8.1 Effect of variety

Weight of 1000 grains showed significant variation among the different varieties (Table 5 and Appendix VIII). BRRI hybrid dhan5 (V_3) 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 (V_1). Similar findings were reported by Rahman *et al.* (2022) and Mia (2018) who observed significant variation on 1000 seed weight due to varietal difference.

4.8.2 Effect of zinc application

Statistically significant variation was recorded for weight of 1000-grains due to different rate of zinc application (Table 6 and Appendix VIII). The maximum weight of 1000-grains (25.38 g) was recorded from Zn_3 (6 kg Zn ha^{-1}) which was statistically similar with Zn_2 (24.60 g) and Zn_1 (24.51 g) and the lowest weight (23.60 g) was recorded to control (0 kg Zn ha^{-1}) treatment. Ullah *et al*. (2001) found the highest 1000-grain weight (28.70 g) from 20 kg zinc sulphate ha^{-1}. This increase in seed 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 Anand *et al.* (2007) and Abid *et al*. (2011).

4.8.3 Interaction effect of variety and zinc application

Interaction effect of different variety and different rate of zinc application significantly influenced on 1000-seed weight (Table 7 and Appendix VIII). Results indicated that the maximum 1000-seed weight (27.43 g) was with interaction of V_3Zn_3(BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) which was statistically similar to V_3Zn_2 (26.66 g) and V_3Zn_1 (26.41 g). On the other hand, the minimum (21.49 g) result was obtained from V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}) which was statistically similar to V_1Zn_1 (22.25 g), V_1Zn_2 (22.46 g) and V_1Zn_3 (23.11 g).

4.9 Grain yield

4.9.1 Effect of variety

Grain yield varied significantly for different varieties shown in Figure 9 and Appendix IX. The highest grain yield (6.94 t ha^{-1}) was recorded by BRRI hybrid dhan5 (V_3). The second highest grain yield (6.33 t ha^{-1}) was recorded from BRRI hybrid dhan3 (V_2). The lowest grain yield (5.33 t ha^{-1}) was recorded from BRRI hybrid dhan2 (V_1). 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.

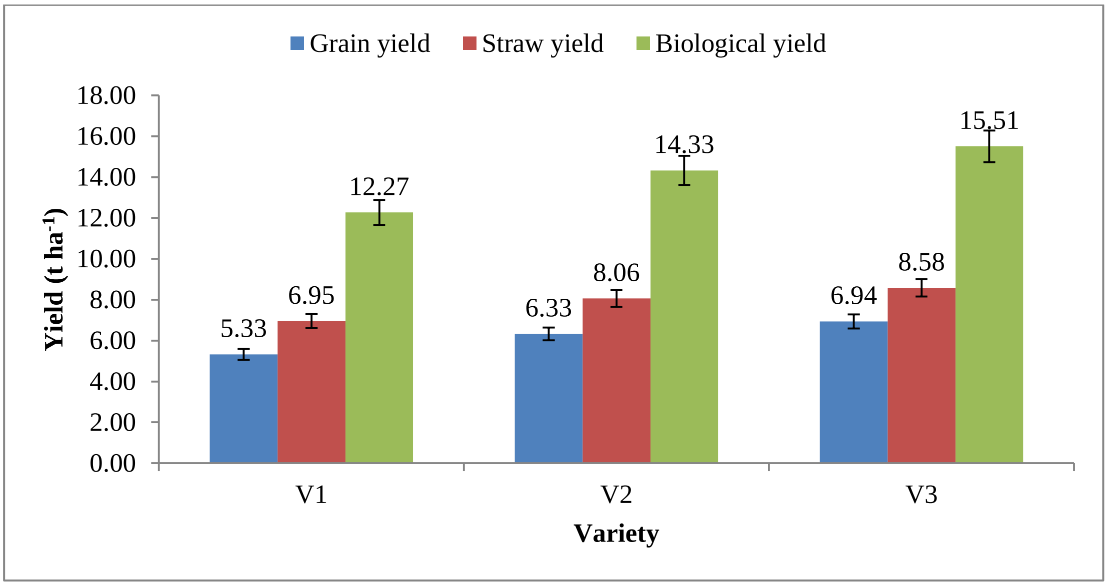

Figure 9. Effect of variety on the yield (t ha^{-1}) in hybrid rice (LSD value = 0.97, 0.67 and 1.72 at grain yield, straw yield and biological yield, respectively).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.9.2 Effect of zinc application

Grain yield was significantly influenced by different rate of zinc in hybrid rice (Appendix IX). Critical appraisal of data (Figure 10) showed that grain yield of crop was influenced by zinc application at different stages. Among treatments, the highest grain yield (6.81 t ha^{-1}) was obtained with Zn_3 (6 kg Zn ha^{-1}), which was significantly higher than all remaining treatments. However, the grain yields of 6.57 t ha^{-1} and 6.11 t $ha^{-1}$was obtained with Zn_2 (4 kg Zn ha^{-1}) and Zn_1 (2 kg Zn ha^{-1}), respectively that was significant higher control (5.30 t ha^{-1}). Cheema *et al*., (2006) observed that paddy yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Zinc deficiency is the most widespread micronutrient disorder in lowland rice and application of zinc along with NPK fertilizer increases the grain yield dramatically in most cases (Chaudhary *et al*., 2007; Muthukumararaja and Sriramachandrasekharan, 2012).

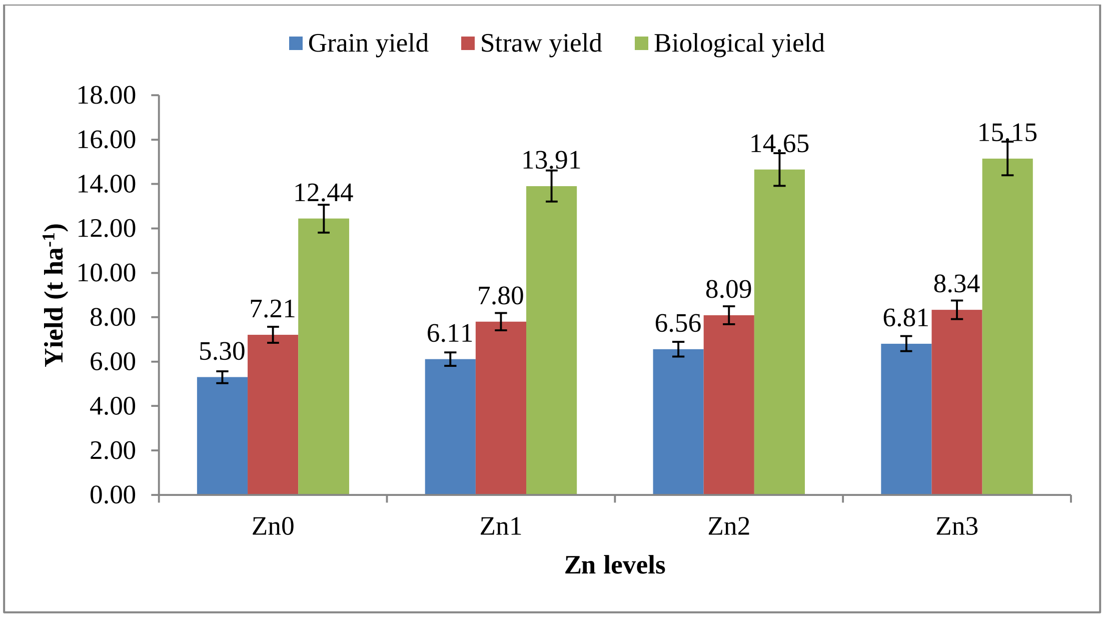

Figure 10. Effect of zinc levels on yield (t ha^{-1}) in hybrid rice (LSD value = 0.45, 0.59 and 1.46 at grain yield, straw yield and biological yield, respectively).

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}

4.9.3 Interaction effect of variety and zinc application

The interaction effect of different variety and different rate of zinc application exerted significant influence on the grain yield of hybrid *Boro* rice (Table 8 and Appendix IX). Combination of V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}) produced the highest grain yield (7.76 t ha^{-1}). On the other hand, the lowest grain yield (4.70 t ha^{-1}) was found with the combination of V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}). Application of V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}) produced 48.13% higher grain yield over control treatment.

Table 8. Interaction effect of variety and zinc on the grain yield, stover yield and biological yield in hybrid rice

Treatment combination	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
V_1Zn_0	4.70 i	6.51 j	11.21 i
V_1Zn_1	5.33 g	6.92 i	12.25 h
V_1Zn_2	5.56 gh	7.11 hi	12.67 gh
V_1Zn_3	5.71 g	7.25 gh	12.96 g
V_2Zn_0	5.29 h	7.36 g	12.45 gh
V_2Zn_1	6.34 e	7.99 e	14.33 e
V_2Zn_2	6.72 d	8.29 d	15.01 d
V_2Zn_3	6.96 c	8.58 c	15.54 c
V_3Zn_0	5.90 f	7.76 f	13.66 f
V_3Zn_1	6.67 d	8.49 cd	15.16 cd
V_3Zn_2	7.41 b	8.87 b	16.28 b
V_3Zn_3	7.76 a	9.19 a	16.95 a
LSD $_{(0.05)}$	0.23	0.21	0.46
CV (%)	6.92	11.42	10.71

In a column, means having similar letter (s) are statistically similar and those having 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}

4.10 Straw yield

4.10.1 Effect of variety

There observed significant variation for straw yield due to varietal variation (Figure 9 and Appendix IX). BRRI hybrid dhan5 (V_3) recorded the maximum straw yield (8.58 t ha^{-1}) and BRRI hybrid dhan2 (V_1) recorded the minimum straw yield (6.95 t ha^{-1}). Similar findings were also reported Singh *et al*. (2019) and Mia (2018).

4.10.2 Effect of zinc application

From Figure 10 and Appendix IX, it was revealed that straw yield was significantly affected due to the different rate of zinc application. The maximum straw yield (8.34 t ha^{-1}) was achieved at highest rate of zinc (Zn_3) application (6 kg Zn ha^{-1}) which was statistically identical with Zn_2 (8.09 t ha^{-1}) whereas, the minimum (7.21 t ha^{-1}) was found with the control (Zn_0) treatment (0 kg Zn ha^{-1}). Cheema *et al*., (2006) observed that straw yield showed positive correlation with the increase in $ZnSO_4.H_2O$ levels from 2.5 to 10 kg ha^{-1}. Cihatak *et al.* (2005) found that that Zinc fertilizer application significantly increased the straw yields, uptake of Zn by plant. Ullah *et al.* (2001) found that soil application of zinc sulphate increased straw yields. Increase in the straw yield with soil application of Zn was reported by many scientists like Kulandaivel *et al*. (2003), Mythili *et al.* (2003) and Singh *et al.* (2006)**.**

4.10.3 Interaction effect of variety and zinc application

From Table 8 and Appendix IX, it was revealed that straw yield was significantly affected due to the interaction effect of different variety and zinc application in hybrid rice. The maximum straw yield (9.19 t ha^{-1}) was achieved at the combination treatment of V_3Zn_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) that was significantly differed to other treatment combinations followed by V_3Zn_2 whereas, the minimum (6.51 t ha^{-1}) was found with the combination treatment of V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}).

4.11 Biological yield

4.11.1 Effect of variety

The biological yield (t ha^{-1}) varied significantly due to variety shown in Figure 9 and Appendix IX. It was observed that BRRI hybrid dhan5 (V_3) 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 dhan5 (V_1). Similar results were also observed by Singh *et al*. (2019), Chowhan *et al*. (2019) and Mahmood (2017).

4.11.2 Effect of zinc application

The biological yield was affected by application of zinc (Figure 10 and Appendix IX). Significantly the maximum biological yield (15.15 t ha^{-1}) was found with Zn_3 (6 kg

Zn ha^{-1}) which was higher than rest of the treatments. However, the value of Zn_2 was found statistically at par with all treatment except control (12.44 t ha^{-1}). Khan *et al*. (2007) reported that the increasing levels of Zn significantly influenced yield of rice.

4.11.3 Interaction effect of variety and zinc application

The interaction effect of variety and zinc application exerted significant influence on the biological yield of hybrid rice (Table 8 and Appendix IX). Combination of V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}) produced the maximum biological yield (16.95 t ha^{-1}). On the other hand, the minimum biological yield (11.21 t ha^{-1}) was found with the combination of V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}).

4.12 Harvest Index

4.12.1 Effect of variety

Variety showed significant variation in harvest index (Figure 11 and Appendix IX). BRRI hybrid dhan2 (V_1) showed the highest harvest index (44.62%) whereas the lowest harvest index (43.34%) in BRRI hybrid dhan5 (V_3) which was different to BRRI hybrid dhan3 (V_2) and BRRI hybrid dhan5 (V_3). Similar results were also observed by Chowhan *et al*. (2019) and Mahmood (2017).

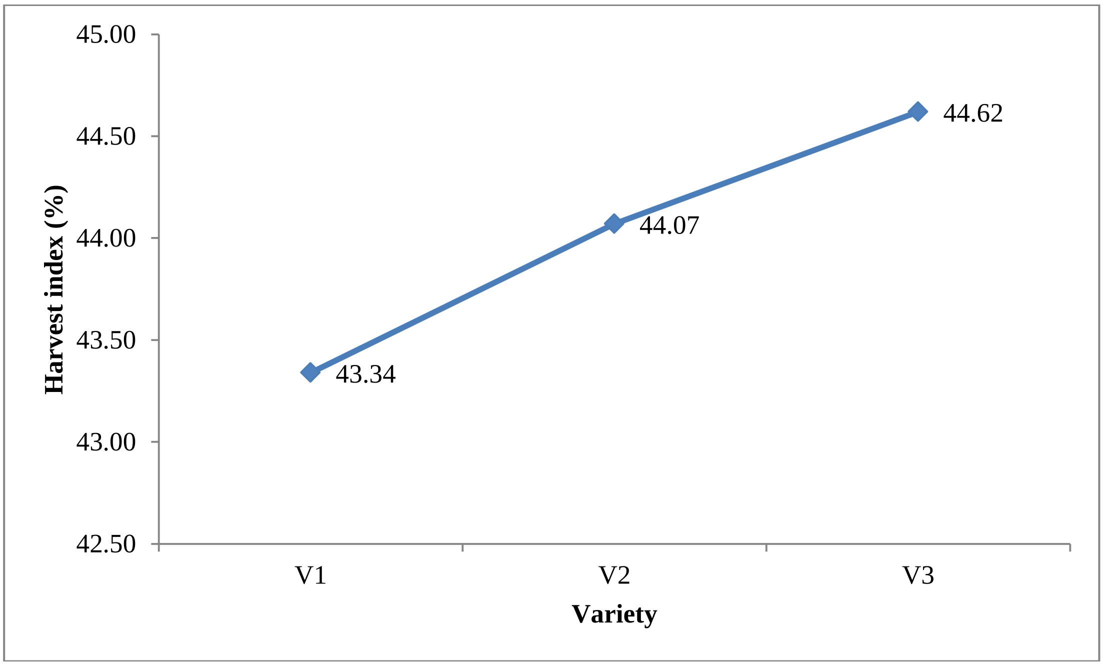

Figure 11. Effect of variety on the harvest index (%) in hybrid rice (LSD value = 1.88).

Note: V_1 – BRRI hybrid dhan2, V_2 – BRRI hybrid dhan3 and V_3 – BRRI hybrid dhan5

4.12.2 Effect of zinc application

Data (Figure 12 and Appendix IX) clearly indicate that there was significant variation in harvest index due to the various zinc application. The higher value of harvest index (44.88%) was reported with Zn_3 (6 kg Zn ha^{-1}) whereas, the lowest value of harvest index (42.54%) with control (Zn_0) treatment. Cheema *et al*. (2006) observed that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Babiker (1986) observed that harvest index was significantly affected by rice cultivars and $ZnS0_4$ rates.

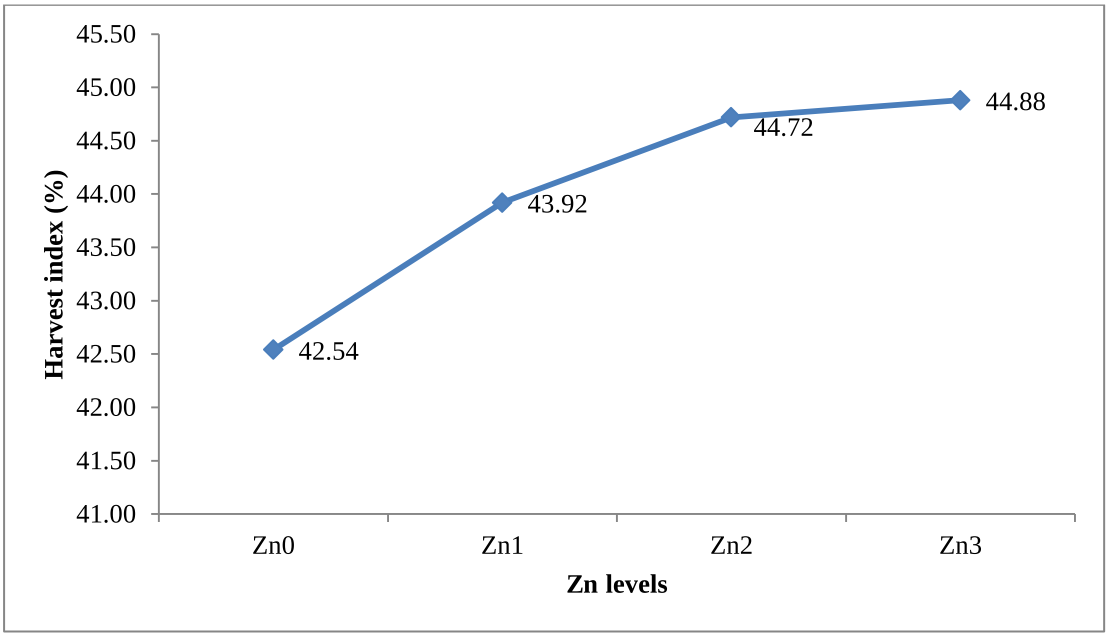

Figure 12. Effect of zinc levels on the harvest index (%) in hybrid rice (LSD value = 1.28).

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}

4.12.3 Interaction effect of variety and zinc application

There was observed significant effect on harvest index due to the interaction of variety and different levels of zinc application in *Boro* rice (Figure 13 and Appendix IX). The maximum (45.78%) harvest index was found from the combination of BRRI hybrid Dhan5 with 6 kg Zn ha^{-1} (V_3Zn_3) which was statistically identical (45.52%) with V_3Zn_2. On the other hand, the minimum harvest index (41.93%) was found from the combination of BRRI hybrid Dhan2 with control (no zinc application) (V_1Zn_0) treatment combination which was statistically similar (42.49%) to the treatment combination of V_3Zn_1.

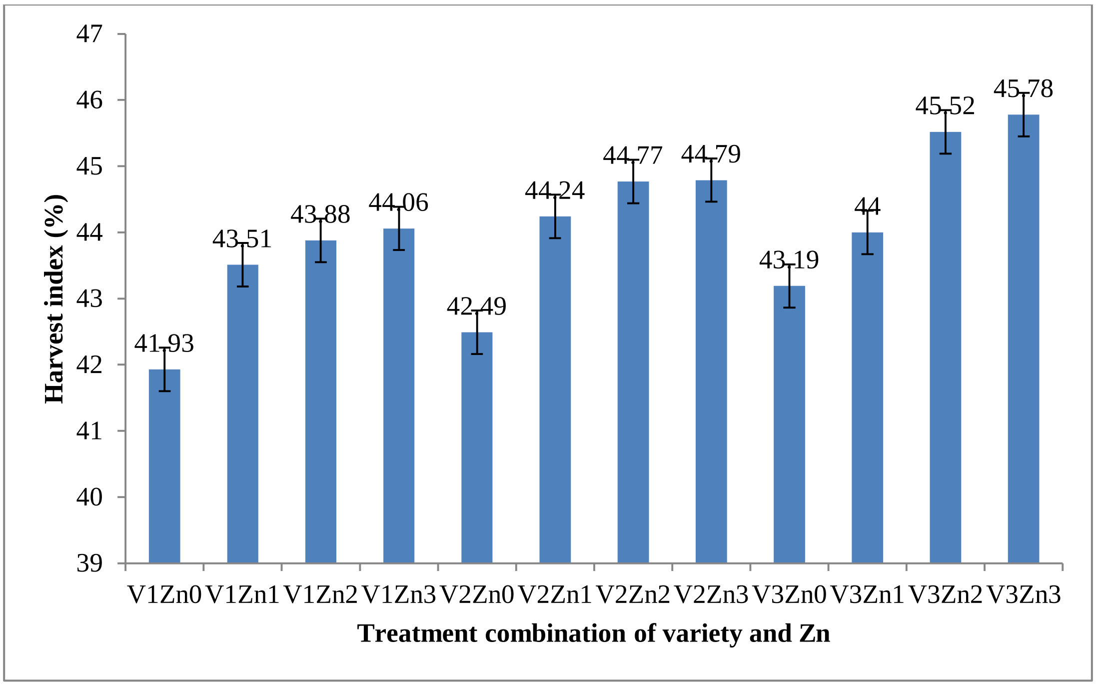

Figure 13. Combined effect of variety and zinc levels on the harvest index (%) in hybrid rice (LSD value = 0.374).

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}

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to May, 2020 in *Boro* season to find out the effect of variety and zinc application on performance of hybrid rice. The experiment consisted of two factors: Factor A Variety (3 types) as i) V_1 – BRRI hybrid dhan2, ii) V_2 – BRRI hybrid dhan3 and iii) V_3 – BRRI hybrid dhan5.Factor B: Zinc management (4 levels) as i) Zn_0 - 0 kg ha^{-1} (control), ii) Zn_1 – 2 kg ha^{-1}, iii) Zn_2 – 4 kg ha^{-1} and iv) Zn_3 – 6 kg ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (Factorial) with three (3) replications. For the experiment, 36 unit-plots with 12 treatments were created. Each plot was the appropriate size. Data on several rice growth and yield parameters were collected, and substantial variance was found for different treatments.

In case of different hybrid rice varieties, the tallest plant at 30, 60, 90 DAT, and harvest (19.22, 40.11, 74.89, and 120.82 cm, respectively) was recorded in the V_1 (BRRI hybrid dhan2) treatment, whereas the shortest plant (16.83, 31.09, 70.14, and 110.70 cm, respectively) was observed in the V3 (BRRI hybrid dhan5) treatment..At 30, 60, 90 DAT and at harvest stage, the maximum number of tillers $hill^{-1}$(16.48, 26.15, 20.55 and 16.16 tillers $hill^{-1}$, respectively) was observed with BRRI hybrid dhan5 (V_3) and the minimum number of tillers $hill^{-1}$ (10.53, 18.51, 15.32 and 9.14 tillers $hill^{-1}$, respectively) with BRRI hybrid dhan2 (V_1) treatment. The highest LAI (0.94, 4.90 and 5.49, respectively) was found at 30, 60, 90 DAT due to the effect of BRRI hybrid dhan5 (V_3) whereas, the lowest LAI (0.48, 1.78 and 2.87, respectively) was found at 30, 60, 90 DAT due to the effect of BRRI hybrid dhan2 (V_1). At 30, 60, 90 DAT, the maximum CGR (0.56, 4.21 and 5.19 g running m^{-1} day^{-1}, respectively) was recorded with BRRI hybrid dhan5 (V_3). On the other hand, the minimum CGR (0.26, 1.08 and 2.55 g running m^{-1} day^{-1}, respectively) was found at 30, 60, 90 DAT due to the effect of BRRI hybrid dhan2 (V_1). The highest panicle number $hill^{-1}$ (17.10), the longest panicle (28.03 cm), the highest grain number $panicle^{-1}$ (109.45), the maximum 1000-grain weight (26.50 g), significantly the highest grain yield (6.94 t ha^{-1}), the maximum straw yield (8.58 t ha^{-1}), significantly the maximum biological yield of 15.51 t ha^{-1} and the highest value of harvest index (44.62%) were found from V_3 (BRRI hybrid dhan5) variety. Whereas, the lowest panicle number $hill^{-1}$ (10.09), the shortest panicle (24.36 cm), the lowest grain number $panicle^{-1}$ (90.45), the minimum 1000-grain weight (22.33 g), the lowest grain yield of 5.33 t ha^{-1}, the minimum straw yield (6.95 t ha^{-1}), the lowest biological yield of 12.27 t ha^{-1} and the lowest value of harvest index (43.34%) were found from V_1 (BRRI hybrid dhan2) variety.

In case of different zinc application rates, the tallest plant at 30, 60, 90 DAT and harvest (19.54, 42.48, 81.74 and 119.13 cm, respectively) was recorded from Zn_3 (6 kg Zn ha^{-1}) treatment and the shortest plant (16.59, 31.81, 63.29 and 110.62 cm, respectively) was obtained from Zn_0 (no zinc application) treatment.At 30, 60, 90 DAT and at harvest, the maximum number of tillers $hill^{-1}$ (14.78, 25.21, 20.68 and 15.42 respectively) were found from 6 kg Zn ha^{-1} (Zn_3) while, the minimum number of tillers $hill^{-1}$ (11.83, 18.64, 15.94 and 11.22 tillers $hill^{-1}$ respectively) was recorded from 0 kg Zn ha^{-1}(Zn_0). The highest LAI (0.75, 3.68 and 4.42 at 30, 60 and 90 DAT, respectively) was obtained from the treatment Zn_3 (6 kg Zn ha^{-1}) whereas, the lowest LAI (0.52, 2.95 and 3.75, respectively) was found from the treatment Zn_0 (0 kg Zn ha^{-1}). At 30, 60 and 90 DAT, numerically the maximum CGR (0.45, 3.41 and 4.68 g running m^{-1} day^{-1}) was recorded with Zn_3 (6 kg Zn ha^{-1}) and the minimum CGR (0.36, 1.75 and 3.12 g running m^{-1} day^{-1} at 30, 60 and 90 DAT, respectively) was recorded with Zn_0 (0 kg Zn ha^{-1}). The highest panicle number $hill^{-1}$ (16.33), the longest panicle (27.14 cm), the highest value of grains $panicle^{-1}$ (108.11), the maximum weight of 1000-grains (25.38 g), the highest grain yield (6.81 t ha^{-1}), the maximum straw yield (8.34 t ha^{-1}), the maximum biological yield (15.15 t ha^{-1}) and the highest value of harvest index (44.88%) were found from Zn_3 (6 kg Zn ha^{-1}) treatment. On the other hand, the lowest panicle number $hill^{-1}$ (12.78), the shortest panicle (25.35 cm), the lowest value of grains $panicle^{-1}$ (91.01), the lowest weight of 1000-grains (23.60 g), the lowest grain yield (5.30 t ha^{-1}), the minimum straw yield (7.21 t ha^{-1}, the minimum biological yield (12.44 t ha^{-1}) and the lowest value of harvest index (42.54%) was recorded from Zn_0 (0 kg Zn ha^{-1}) treatment.

The interaction effect of variety and zinc application showed significant impact on most of the parameters under study. At 30, 60, 90 and harvest, the tallest plant (22.67, 49.56, 88.22 and 124.10 cm, respectively) was recorded from V_1Zn_3 (BRRI hybrid dhan2 with 6 kg Zn ha^{-1}) treatment combination whereas, the shortest plant (16.00, 28.82, 62.22 and 103.10 cm, respectively) was observed in V_3Zn_0 (BRRI hybrid dhan5 with no zinc application) treatment combination.At 30, 60, 90 DAT and at harvest, the maximum number of tillers $hill^{-1}$ (18.13, 29.85, 23.55 and 18.78, respectively) was achieved by V_3Zn_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) treatment combination and the minimum number of tillers $hill^{-1}$ (9.29, 15.65, 13.55 and 7.56, respectively) was found with V_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}). At 30, 60 and 90 DAT, the highest LAI (1.07, 5.32 and 5.83, respectively) was observed with V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}) and the lowest LAI (0.38, 1.55 and 2.58, respectively) was found by $N_0Zn_0V_1Zn_1$ (1.73 and 2.81 at 60 and 90 DAT, respectively). At 30, 60 and 90 DAT, the maximum CGR (0.62,5.23 and 5.96 g running m^{-1} day^{-1}, respectively) was observed with V_3Zn_3 (BRRI hybrid dhan5 with 6 kg Zn ha^{-1}) and the minimum CGR (0.23, 0.69 and 1.95 g running m^{-1} day^{-1}) was observed with V_1Zn_0 (BRRI hybrid dhan2 with 0 kg Zn ha^{-1}). The highest panicle number $hill^{-1}$ (20.17), the longest panicle (29.17 cm), the highest number grains $panicle^{-1}$ (179.74), the maximum 1000-seed weight (27.43 g), the highest grain yield (7.76 t ha^{-1}), the maximum straw yield (9.19 t ha^{-1}), the maximum biological yield (16.95 t ha^{-1}) and the higher value of harvest index (45.78%) were found from the combination treatment of V_3Zn_3 (BRRI hybrid dhan5 and 6 kg Zn ha^{-1}). On the other hand, the lowest panicle number $hill^{-1}$ (9.63), the shortest panicle length (23.52 cm), the lowest grain number $panicle^{-1}$ (82.22), the minimum weight of 1000-seed (21.49 g), the lowest grain yield (4.70 t ha^{-1}), the minimum straw yield (6.51 t ha^{-1}), the minimum biological yield (11.21 t ha^{-1}) and the lowest value of harvest index (41.93%) were found with the combination treatment ofV_1Zn_0 (BRRI hybrid dhan2 and 0 kg Zn ha^{-1}).

Conclusion

From the above results the following conclusion may be drawn:

1. The hybrid rice variety “BRRI hybrid dhan5” produced higher grain yield (6.94 t ha^{-1}) compared to the variety BRRI hybrid dhan2 (5.33 t ha^{-1}) and BRRI hybrid dhan3 (6.33 t ha^{-1}).

2. Regarding the effect of Zn levels, the maximum rice yield (6.81 t ha^{-1}) was recorded from 6 kg Zn ha^{-1} compared to control (5.30 t ha^{-1}) and (6.11 t ha^{-1}) also 2 and 4 kg Zn ha^{-1} doses (6.56 t ha^{-1}).
3. Hybrid rice variety 'BRRI hybrid dhan5' with 6 kg Zn ha^{-1} produced a higher grain yield (7.76 t ha^{-1}) compared to 'BRRI hybrid dhan2' and 'BRRI hybrid dhan3' in combination with different Zn doses.

Recommendation

Considering the results of the present experiment, further studies in the following areas are suggested:

1. For getting higher grain yield, 'BRRI hybrid dhan5' is to be cultivated with 6 kg Zn ha^{-1} in *Boro* season.
2. Similar studies should be conducted in other agro-ecological zones (AEZ) in Bangladesh to assess zonal adaptation and conformation of the findings.

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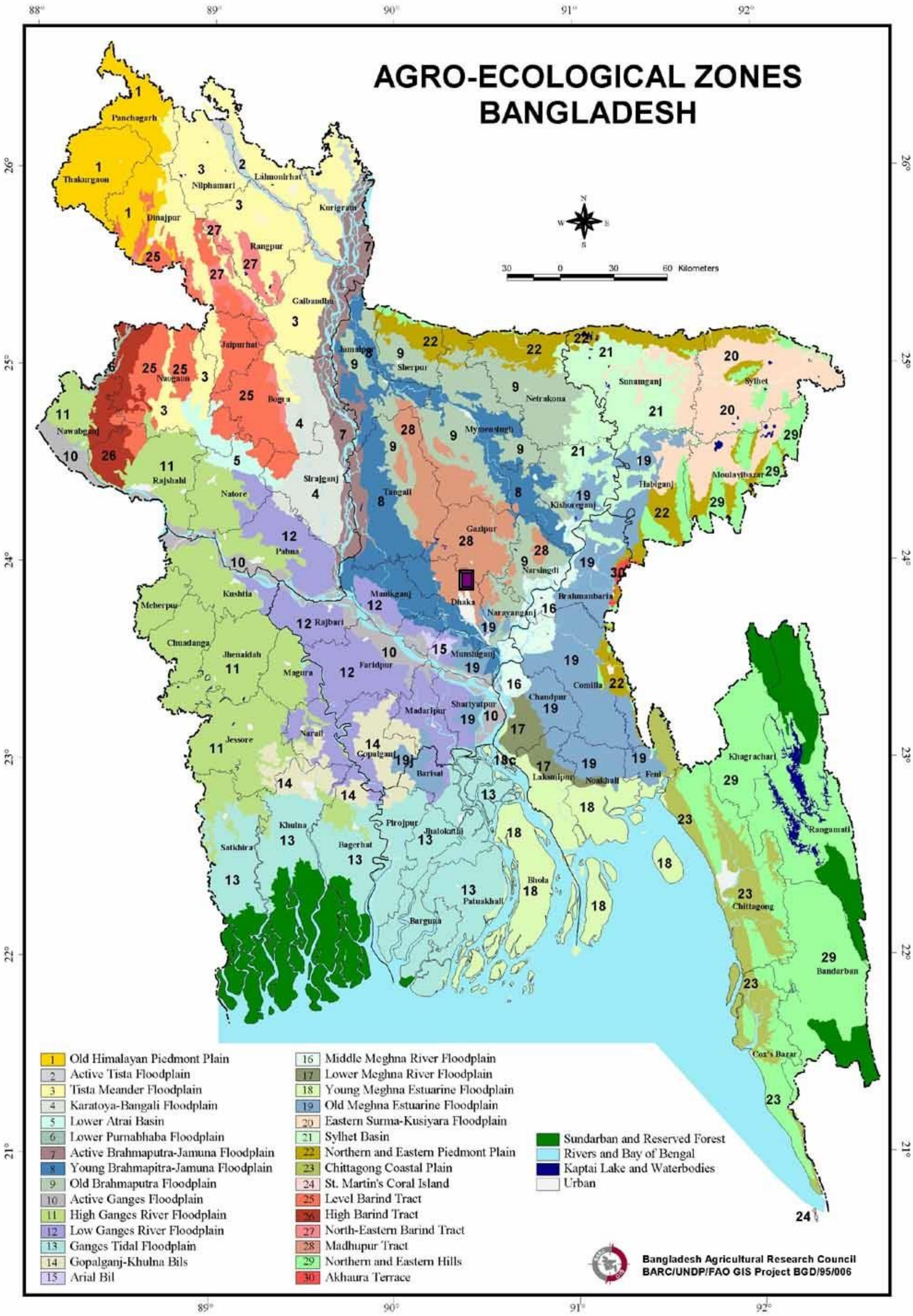
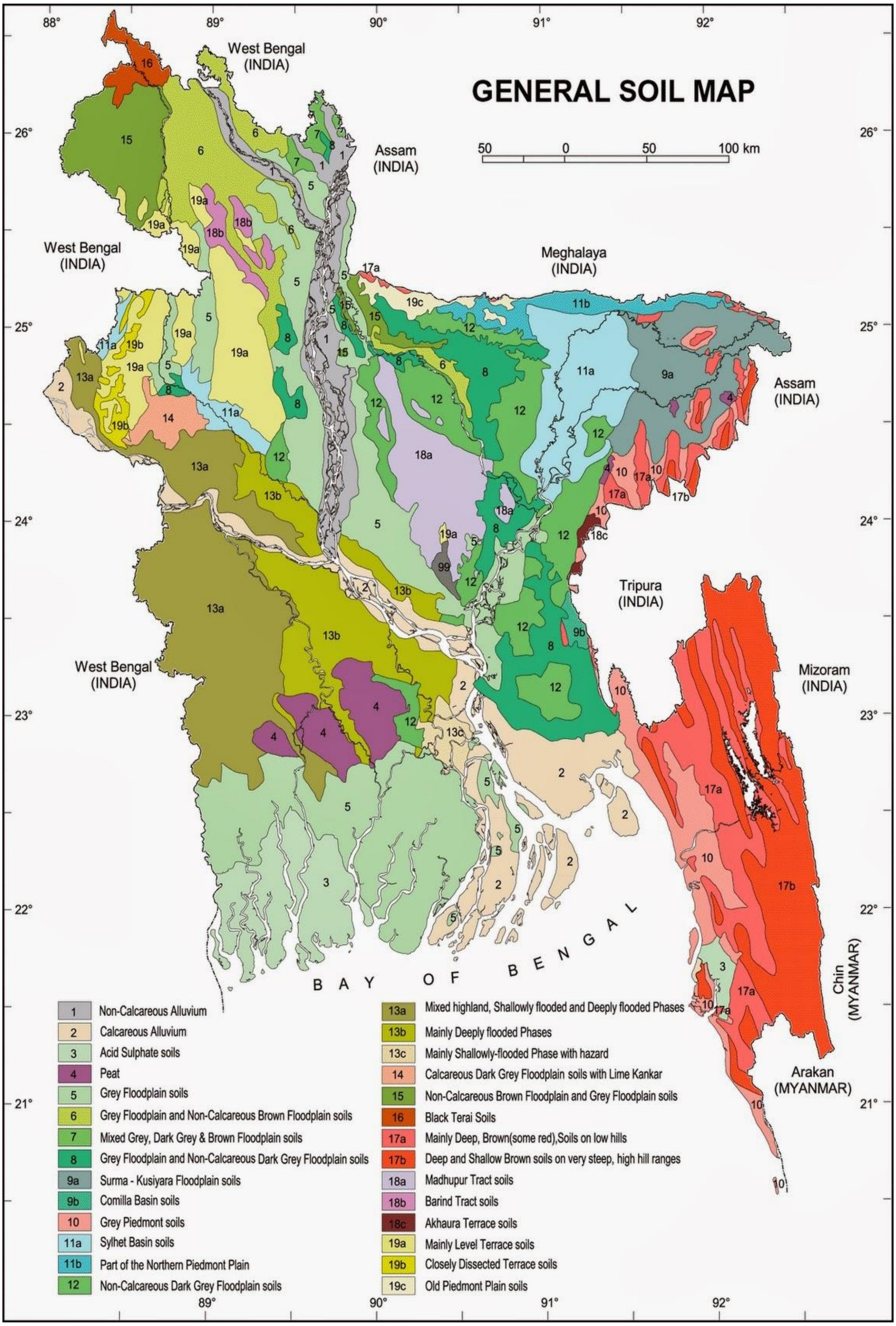
APPENDICES

Appendix I (A): Map showing the experimental sites under study



The experimental site under study

Appendix I(B): Map showing the general soil sites under study



Appendix II: Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping Pattern	*Boro*–Aman–*Boro*

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.5
Organic carbon (%)	0.43
Organic matter (%)	0.75
Total N (%)	0.075
Available P (ppm)	21.00
Exchangeable K (meq/ 100 g soil)	0.11
Available S (ppm)	43

Appendix III: Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2019 to May 2020

Year	Month	Temperature			Relative Humidity (%)	Rainfall (mm)	Sunshine (Hour)
		Max (°C)	Min (°C)	Mean (°C)			
2019	November	32	24	29	65	42.8	349
	December	27	19	24	53	1.4	372
2020	January	27	18	23	50	3.9	364
	February	30	19	26	38	3.1	340
	March	35	24	31	38	19.6	353
	April	38	25	33	54	292.4	315
	May	37	27	33	59	152.5	297

Appendix IV. Analysis of variance (mean square) of plant height at different DAT

Source of variation	Degrees of freedom	Plant height			
		30 DAT	60 DAT	90 DAT	Harvest
Replication	2	5.852	80.983	156.225	6.516
Variety (A)	2	10.897*	49.245*	170.324*	53.933*
Nitrogen(B)	3	6.051*	49.026*	110.420*	3.034*
A×B	6	0.549**	3.452**	9.923**	6.954**
Error	22	1.305	8.520	29.517	0.585

*** and ** indicate significance at 5% and 1% level of probability, respectively.**

Appendix V. Analysis of variance (mean square) of tillers hill^{-1} at different DAT

Source of variation	Degrees of freedom	No. tillers hill^{-1}			
		30 DAT	60 DAT	90 DAT	Harvest
Replication	2	5.852	80.983	156.225	6.516
Nitrogen (A)	2	10.897*	49.245*	170.324*	53.933*
Zinc (B)	3	6.051*	49.026*	110.420*	3.034*
A×B	6	0.549**	3.452**	9.923**	6.954**
Error	22	1.305	8.520	29.517	0.585

*** and ** indicate significant at 5% and 1% level of probability, respectively.**

Appendix VI**. Analysis of variance (mean square) of Leaf area index at different DAT**

Source of variation	Degrees of freedom	Leaf area index		
		25 DAT	55 DAT	85 DAT
Replication	2	0.239	7.238	1.646
Nitrogen (A)	2	13.411*	571.676*	207.136*
Zinc (B)	3	16.141**	546.668**	167.304**
A×B	6	0.396*	8.145**	0.001**
Error	22	0.283	0.825	6.063

*** and ** indicate significant at 5% and 1% level of probability, respectively**

A**ppendix VII. Analysis of variance (mean square) of Crop growth rate at different DAT**

Source of variation	Degrees of freedom	Crop growth rate		
		25 DAT	55 DAT	85 DAT
Replication	2	1.970	41.200	149.040
Nitrogen (A)	2	50.408*	119.856*	205.300^{NS}
Zinc (B)	3	9.672^{NS}	26.023*	79.191*
A×B	6	0.577*	6.475*	3.825*
Error	22	2.327	13.856	25.211

*** and ** indicate significant at 5% and 1% level of probability, respectively**

NS = non-significant

Appendix VIII. Analysis of variance (mean square) of yield components

Source of variation	Degrees of freedom	No. of panicles hill^{-1}	Panicle length	No. of grain panicle^{-1}	1000-grain weight
Replication	2	156.208	80.330	31.342	28.073
Nitrogen (A)	2	62.519*	65.135*	8.090**	46.212*
Zinc (B)	3	3.558**	11.910NS	2.122**	25.339*
A×B	6	3.345**	2.393**	1.673**	2.480*
Error	22	20.387	48.889	20.423	10.007

*** and ** indicate significance at 5% and 1% level of probability, respectively**

NS = non-significant

Appendix IX. Analysis of variance (mean square) of yield and harvest index

Source of variation	Degrees of freedom	Grain yield	Straw yield	Biological yield	Harvest index
Replication	2	2.765	7.313	6.516	10.002
Nitrogen (A)	2	0.633*	145.606*	53.933*	20.601**
Zinc (B)	3	1.753*	12.964**	3.034*	23.761**
A×B	6	0.355*	3.995**	6.954**	11.002**
Error	22	0.365	0.310	0.585	0.002

*** and ** indicate significance at 5% and 1% level of probability, respectively**