EFFECT OF MICRONUTRIENT ZINC ON THE PERFORMANCE OF MODERN RICE VARIETIES

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CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF MICRONUTRIENT ZINC ON THE PERFORMANCE OF MODERN RICE VARIETIES"** submitted to the **DEPARTMENT OF SOIL SCIENCE**, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE (MS)** in **SOIL SCIENCE**, embodies the result of a piece of bonafide research work carried out by **RAZIA SULTANA**, Registration No. **19-10204** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

December, 2021
Dhaka, Bangladesh

Prof. Dr. Alok Kumar Paul
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Dedicated to

My

Beloved Parents

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The Author

EFFECT OF MICRONUTRIENT ZINC ON THE PERFORMANCE OF MODERN RICE VARIETIES

ABSTRACT

The experiment was carried out during the period from December 2020 to May 2021 at the research field of the Bangladesh Rice Research Institute, Regional Station, Sonagazi, Feni, Bangladesh. The experiment consisted of two factors: Factor A: eight Zn levels *viz*. T_1 (Recommended rate: N, P, K, S and Zn (monohydrate) @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 (T_1 – 50% Zn), T_3 (T_1 – 100% Zn; T_1 but without Zn), T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}), T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}), T_6 (T_1 but Zn was applied by spraying), T_7 (Soil test based (STB) nutrient rates N, P, K, S and Zn @ 158, 24, 82, 10 and 2 kg ha^{-1}) and control treatment T_8 (control/native supply of nutrient; no nutrient was applied) and Factor B: three rice varieties *viz*. V_1 (BRRI dhan74), V_2 (BRRI dhan84) and V_3 (BRRI dhan88). The experiment was laid out in Strip Plot Design with three replications. Among different levels of micronutrient zinc (Zn) treatments, the longest plant height (90.4 cm), maximum number of tillers m^{-2} (472), panicles $hill^{-1}$ (11.6), and panicles m^{-2} (385); and highest grain yield (5.28 t ha^{-1}) were recorded in the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$:15.4 kg ha^{-1}) and this treatment also showed highest Zn content in grain (0.136 ppm), however the highest Zn content in straw (0.403 ppm) was acquired from T_6 (T_1 but Zn was applied by spraying). Again, the treatment T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) gave the highest number of grains $hill^{-1}$ (988) and 1000-grain weight (23.4 g). Control treatment T_8 (no nutrient was applied) gave least performance for the respected parameters. Among three rice varieties, the highest number of tillers m^{-2} (446) and grains $hill^{-1}$ (920) were achieved by V_3 (BRRI dhan88), while the maximum number of panicles m^{-2} (369) and the highest mean grain yield (4.56 t ha^{-1}) were produced by V_1 (BRRI dhan74). Moreover, different varieties showed non-significant variation on Zn content in grain and straw. Considering the combined effect of Zn treatments and variety, the highest number of panicles m^{-2} (425), 100-grain weight (27.1 g) and highest grain yield (5.73 t ha^{-1}) were observed in T_5V_1. In case of Zn content of grain and straw, the maximum (0.218 and 0.573 ppm, respectively) were found in T_5V_1 and T_6V_3, respectively, whereas T_8V_2 gave the minimum Zn content in grain and straw (0.046 and 0.088 ppm, respectively). Based on overall performances, it could be concluded that the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) might be recommended for sustainable cultivation of modern rice varieties to obtain higher yield and better Zinc content.

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DMRT	=	Duncan's Multiple Range Test
et al.,	=	And others
e.g.	=	exempli gratia (L), for example
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
g	=	Gram (s)
i.e.	=	id est (L), that is
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m^2	=	Meter squares
ml	=	MiliLitre
M.S.	=	Master of Science
No.	=	Number
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
^{o}C	=	Degree Celceous
%	=	Percentage
NaOH	=	Sodium hydroxide
GM	=	Geometric mean
mg	=	Miligram
P	=	Phosphorus
K	=	Potassium
Ca	=	Calcium
L	=	Litre
µg	=	Microgram
USA	=	United States of America
WHO	=	World Health Organization

CHAPTER-I

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop and primary food source for more than one-third of world's population (Sarkar *et al.,* 2016). Worldwide, rice provides 27% of dietary energy supply and 20% dietary protein (Mohidem *et al*., 2022). It constitutes 95% of the cereal consumed and supplies more than 80% of the calories and about 50% of the protein in the diet of the general people of Bangladesh (Hossain *et al*., 2008). In Bangladesh, majority of food grains comes from rice. Rice has tremendous influence on agrarian economy of the country. Annual production of rice in Bangladesh is about 36.28 million tons from 11.52 million ha of land (BBS, 2021). According to the U.S. Department of Agriculture (USDA) report in 2021, rice production for the 2020-21 marketing year is expected to rise to 36.3 million tons in Bangladesh as further cultivation of hybrid and high yield varieties increase. The country is expected to import 200,000 tons of rice in the 2020-21 marketing year to ease food security tensions brought on by the COVID-19 pandemic situation (USDA, 2021).

Among three growing seasons (aus, aman and Boro) aman rice occupies the highest area coverage. The aman rice crop occupies 67 per cent of the cropped area of 85.77 ha. In 2020, the amount of land used for high yielding varieties (HYV) is 4.44 million ha, hybrid 0.24 million hectare, local varieties 0.75 million hectares and for broadcast Aman 0.31 million hectares of cultivable land. The total land under the aman crop was 5.71 million hectare (BBS, 2021). Almost 78 % of the land is occupied by the HYV varieties supported by the Department of Agricultural Extension with fertilizers, pesticides and laboratory seeds, while only 12.5 per cent are local/traditional varieties cultivated by the farmers on their own initiatives in low lands (BBS, 2017).

In Bangladesh the average yield of rice is almost less than 50% of the world average rice grain yield. The national mean yield (2.60 t ha^{-1}) of rice in Bangladesh is lower than the potential national yield (5.40 t ha^{-1}) and world average yield (3.70 t ha^{-1}) (Jahan *et al.,* 2015). The lower yield of rice has been attributed to several reasons such as lack of high yielding cultivars, balanced use of fertilizers, adoption of proper plant protection measures, soil salinization, fluctuation of the market prices, lack of knowledge on production technologies and also proper handling of agronomic management practices etc.

Recently in Bangladesh, BRRI, BINA, IRRI, and diverse seed organizations have been presented high-yielding rice varieties and it acquires positive monumental in rice production for the particular three distinct growing seasons (Islam *et al*., 2020). Improving and expanding the world's supply will likewise rely on the development and improvement of rice varieties with better yield potential, and to adopt different traditional and biotechnological approaches for the advancement of high yielding varieties that have resistance against various biotic and abiotic stresses (Kumar *et al*., 2018). Recently various new rice varieties were developed by BRRI with exceptionally high yield potential. Nowadays different high-yielding rice varieties are available in Bangladesh which has more yield potential than different conventional varieties (Kader *et al*., 2020). The growth process of rice plants under different agro-climatic conditions differs due to the specific rice variety (Shelley *et al*., 2016). Compared with conventional varieties, the high-yielding varieties have larger panicles resulting in an average increase of rice grain is 7.27% (Bhuiyan *et al*., 2014). These high-yielding and hybrid rice variety, however, needs further evaluation under the different adaptive condition to interact with different agro-climatic conditions and different fertilizer managements.

In Bangladesh farmers generally use N, P, K and S fertilizers widely whereas, application of micronutrients, such as, Zn, Cu, Mn and B is not a usual practice. Soils inadequate in their supply of micronutrients are alarmingly far reaching across the globe because of intensive cropping, loss of fertile topsoil and losses of nutrients through leaching (Somani, 2008). When micronutrients are in short supply, the growth and yield of crops are severely depressed (IPNI, 2014). Hence, application of micronutrient are of critical importance for sustaining high productivity of rice in Bangladesh.

Among different micronutrient, zinc (Zn) is one of the vital nutrients which is required for various biochemical and metabolic process in rice such as synthesis of cytochromes and nucleotides, auxin metabolism, production of chlorophyll, activation of several enzymes, membrane integrity, metabolism of carbohydrate, cell wall development, gene expression, respiration and pollen development (He *et al*., 2021). Cereals are more prone to Zn deficiency than legumes and resulted in substantial reduction in yield and quality (Prasad and Shivay, 2018). It has been reported that more than 50% of field crops are sensitive to Zn deficiency (Aiqing *et al*., 2021); Zn deficiency in rice is common which decreases the tillering, increases the spikelet sterility and delay the crop maturity (Liu *et al*., 2022). The deficiency of Zn is even more prominent in puddled rice (Farooq *et al*., 2018). Different soil factors such as pH, redox potential, concentration of other nutrients affect the availability of Zn in soil (Liu *et al*., 2019). Adsorption of Zn to clay and $CaCO_3$ under high pH is the primary reason of reduced availability of Zn in calcareous soils (Broadley *et al.*, 2007). Rice is sensitive to low Zn condition which is common in submerged paddy soils. Therefore, plants can absorb more nutrients, especially micronutrients, when applied at proper dose and it is an effective practice to improve both productivity and grain Zn content up to three or four-fold (Cakmak and Kutman, 2018).

Keep these facts in view, an experiment entitled “Effect of Zinc application on the yield and zinc enrichment in grain of different rice varieties” conducted at the Research field of the Bangladesh Rice Research Institute, Regional Station, Sonagazi, Feni, Bangladesh during the period from December 2020 to May 2021 in *Boro* season with the following objectives:

1. To evaluate the performances of the rice varieties under different doses of zinc application
2. To investigate the nutrient content in grain and straw of the rice varieties
3. To find out optimum rate of Zn to obtain better yield with higher Zn content.

CHAPTER 2

REVIEW OF LITERATURE

Variety of rice is one of the vital reasons of yield increase or reduction of rice. So, variety is the most important factor needed to be considered in rice cultivation. Again, micronutrient deficits are growing increasingly severe as a result of increased nutrient demand from more intensive and exploitative agriculture, along with the use of single-nutrient fertilizers and low levels of organic manures. Crop residue management via recycling wastes and manures is the primary mechanism that governs the soil's long-term nutritional balance in rice ecosystems. Among micronutrients, Zinc is very crucial for successful cultivation of rice, especially for modern rice varieties. The response of rice varieties to application of zinc fertilizer has been investigated by many scientists in various parts of the world. Some of the important and informative works and research findings related to the variety and nutrient efficiency especially micronutrient Zn was done at home and abroad has been reviewed under the following headings:

2.1 Varietal performance of rice

Khatun (2020) conducted a field experiment with six rice varieties to determine their growth and yield performance. All the growth and yield contributing attributes varied significantly among the six rice varieties. 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) 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/h) that was significantly different from other varieties. Lowest grain yield observed in BRRI dhan39 (4.49 t/h) that was statistically similar to BRRI dhan33 (4.57 t/h) and Binadhan-7 (4.86 t/h).

Salam *et al*. (2019) carried out 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) 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.

Mahmood (2017) 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. The collected data were analyzed statistically and means were adjudged by DMRT at 5% level of probability. Among the five varieties the Arize Tej gave the highest performance. The Arize Tej was the most efficient for better growth and higher yield of hybrid Boro rice genotypes grown in coastal area of Bangladesh.

Murshida *et al*. (2017) conducted an experiment with three varieties (cv. BRRI dhan28, BRRI dhan29 and Binadhan-14) and four water management systems to examine the effect of variety and water management system on the growth and yield performance of Boro rice. At 100 DAT, the highest plant height, maximum number of tillers hill^{-1}, dry matter of shoot hill^{-1} and dry matter of root hill^{-1} were obtained from BRRI dhan29 and the lowest values were found in Binadhan-14. Variety had significant effect on all the crop characters under study except 1000-grain weight. The highest grain yield was obtained from BRRI dhan29 and the lowest value was recorded from Binadhan-14.

Chamely *et al*. (2015) conducted an experiment with three rice 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. The growth analysis 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.

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.

A study was design by Wagan *et al.* (2015) to compare the economic performance of hybrid and conventional rice production and reported that total costs per hectare of hybrid rice was 148992.23 Rs which was more than conventional rice (140661.68 Rs per hectare). On an average higher yield (196.14 monds per hectare) was obtained from hybrid rice while conventional rice yield (140.14 monds per hectare) was less than hybrid rice. There was 16.64 percent increase in hybrid rice yield comparing with conventional rice which gives additional income to poor farmers.

Jisan *et al*. (2014) carried out an experiment to examine the yield performance of some transplant aman rice varieties as influenced by different levels of nitrogen. The experiment consisted of four varieties *viz*. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57. Among the varieties, BRRI dhan52 produced the tallest plant (117.20 cm), highest number of effective tillers hill^{-1} (11.28), grains panicle^{-1} (121.5) and 1000-grain weight (23.65 g) whereas the lowest values of these parameters were produced by BRRI dhan57. Highest grain yield (5.69 t ha^{-1}) was obtained from BRRI dhan52 followed by BRRI dhan49 (5.15 t ha^{-1}) and the lowest one (4.25 t ha^{-1}) was obtained from BRRI dhan57.

Hossain *et al.* (2014) conducted an experiment at the research farm of SAU on the yield and yield attributes of exotic hybrid rice varieties. Significantly longer panicle was recorded from Heera2 (24.70 cm) which was statistically identical with Aloron (24.52 cm). Both hybrid rice varieties Heera2 (119.8) and Aloron (111.8) produced the highest spikelets panicle^{-1} than that of BRRI dhan48 (105.5). In BRRI dhan48, the highest filled spikelets panicle^{-1} (79.53) was recorded. This was may be due to lower sensitiveness of BRRI dhan48 to high temperature and low sunshine hour at grain filling stage compared to test hybrid varieties. The highest spikelet filling percent was recorded from BRRI dhan48 (74.43%) due to favorable environmental condition at grain filling stage. Aloron produced heavier grain size than that of Heera2 and BRRI dhan48. BRRI dhan48 gave significantly higher grain yield 3.51 t ha^{-1} over the tested hybrid varieties Heera2 (3.03 t ha^{-1}) and Aloron (2.77 t ha^{-1}).

Biological yield did not varied significantly among studied hybrid and inbred rice varieties. The highest HI was obtained from BRRI dhan48 while it was lowest in Aloron.

Akter (2014) investigated the growth, yield and nutrient content of 15 *Boro* rice cultivars. BR 15, BRRI dhan29 and BRRI dhan28 were the three rice cultivars having high potentials for grain and straw production during *Boro* season. The highest yield was recorded 5.26 t ha^{-1} which is still very low compared to other rice growing countries of the world. Chola *Boro* and Sada bore are two local land races having potentials for producing higher number of effective tillers and higher 1000 grain weight. Sada *Boro* and Chola *Boro,* two local cultivars were found very high in grain nitrogen content compared to other test cultivars.

Islam *et al*. (2013) conducted an experiment to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38. The tallest plant (142.7 cm), the highest number of effective tillers $hill^{-1}$ (10.02), number of grains $panicle^{-1}$ (152.3), panicle length (22.71cm), 1000-grain weight (15.55g) and grain yield (3.71 t ha^{-1}) were recorded in BRRI dhan34. The highest grain protein content (8.17%) was found in BRRI dhan34 whereas the highest aroma was found in BRRI dhan37 and BRRI dhan38.

Haque *et al.* (2013) conducted an experiment to evaluate some physiological traits and yield of three hybrid rice varieties (BRRI hybrid dhan 2, Heera 2, and Tia) in comparison to BRRI dhan48 in *Aus* season. Compared to BRRI dhan 48, 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. Heera 2 and BRRI hybrid dhan 2 maintained significantly higher chlorophyll a, b ratio over Tia and BRRI dhan 48 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.

Yao *et al.* (2012) found insignificant difference in grain yield between the cv. AWD and CF. On average, YLY6 produced 21.5% higher yield than HY3 under AWD conditions. Like grain yield, YLY6 showed consistently higher water productivity and physiological nitrogen use efficiency than HY3. Both total dry weight and harvest index contributed to higher grain yield of YLY6.

Sritharan and Vijayalakshmi (2012) evaluated the physiological traits and yield potential of six rice cultivars *viz.,* PMK 3, ASD 16, MDU 3, MDU 5, CO 47 and RM 96019. The plant height, total dry matter production and the growth attributes like leaf area index, crop growth rate and R:S ratio were found to be higher in the rice cultivar PMK 3 that showed significant correlation with yield. Yield and yield components like number of productive tillers, fertility co-efficient, panicle harvest index, grain weight and harvest index were found to be higher in PMK 3.

Panwar *et al.* (2012) evaluated the performance of rice varieties. Growth parameters *viz.* plant height (cm), No. of tillers m, leaf area index and dry matter accumulation (g) was highest in JGL-3844 over rest of varieties. The effective tillers m^{-2} (331.6), panicle length (25.63), grains $panicle^{-1}$ (68.23), sterility percent (12.1%), grain yield (60.9 q ha^{-1}) and straw yield (92.58 q ha^{-1}) yield were also highest in variety JGL-3844.

Islam *et al*. (2009) conducted a pot experiments with Hybrid variety Sonarbangla-1 and inbred modern variety BRRI dhan 31 and BRRI hybrid dhan-l to compare the growth and yield behavior of hybrid and inbred rice varieties under controlled condition. BRRI dhan 3l had about 10-15% higher plant height, very similar tillers/plant, 15-25% higher leaf area at all days after transplanting (DAT) compared to Sonarbangla-1. Sonarbangla-1 had about 40% higher dry matter production at 25 DAT but had very similar dry matter production at 50 and 75 DAT, 4-11% higher rooting depth at all DATs, about 22% higher root dry weight at 25 DAT, but 5-10% lower root dry weight at 50 and 75 DAT compared to BRRI dhan31. 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 dhan 31.

Alam *et al.* (2012) found that the cultivar BRRI dhan33 gave significantly tallest plant (113.17 cm), while the shortest plant was found in BRRI dhan32 cultivar (105.07 cm). Among the cultivars, BR11 produced the maximum total tillers $hill^{-1}$ (12.33), maximum fertile spikelets $panicle^{-1}$ (103.83) while the lowest fertile spikelets $panicle^{-1}$ (102.10) and minimum total tillers $hill^{-1}$ (10.17) were found in BRRI dhan32. BR11 also produced the highest 1000-grain weight (23.79g) and highest grain yield (5.92 t ha^{-1}) while BRRI dhan33 produced the lowest 1000-grain weight (21.69 g) and grain yield. The cultivar BR11 produced the highest grain yield, it might be due to the highest number of total tillers $hill^{-1}$, number of effective tillers $hill^{-1}$ and 1000-grain weight and lowest number of sterile spikelets $panicle^{-1}$.

Hossain *et al.* (2008) reported that all the yield contributing characters differed significantly due to cultivar. The tallest plant was observed in Chinigura (162.8 cm) which was statistically similar to Kataribhog. Kalizira produced the maximum number of grains $panicle^{-1}$ (135.90). Among the cultivars, BRRI dhan 38 gave the maximum grain yield (4.00 t ha^{-1}).

Five varieties were evaluated by Ndaeyo*et al.* (2008). Among the varieties, the variety WAB224-8-HB produced the highest grain yield (4.73 and 4.40 t ha^{-1}) followed by WAB189-B-B-B-8-HB (4.37 and 4.20 t ha^{-1}) for both years.

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. The experiment was laid out in a randomized complete block design with three replications. 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 $panicle^{-1}$. Among the planning methods, transplanting method produced the maximum grain yield (4.59 t ha^{-1}) because of 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. It may be concluded that the variety BINADHAN-5 may be grown following transplanting method for higher grain yield in Boro season.

2.2 Effect of micronutrient zinc on yield and yield attributes of rice

Hasnain *et al.* (2022) conducted a field study was planned to assess the yield response and quality attributes of aromatic rice to three levels of zinc (Zn) and nitrogen (N) under three irrigation regimes (8, 12 and 16-acre inches). Irrigation treatments significantly influenced the growth, yield, and quality attributes; however, maximum improvement was observed by the application of irrigation at 12-acre inches. Among the Zn treatments, application of Zn at 10 kg ha^{-1} was observed to be more responsive to improving the growth and quality parameters of aromatic rice crops. In the case of N treatments, application of N at 140 kg ha^{-1} produced the maximum total tillers, as well as productive tillers per hill, spikelets per panicle, leaf area index, leaf area duration, crop growth rate, total dry matter, harvest index, kernel length, kernel width, and 1,000 kernel weight. Application of

N at 140 kg ha^{-1} not only improved the growth attributes but also increased the net assimilation rate, photosynthetically active radiation, and radiation use efficiency, with respect to total dry matter and kernel yield. The maximum percentage of normal kernels and minimum percentage of opaque, abortive, and chalky kernels were also recorded by application of N at 140 kg ha^{-1}. The outcomes of current experiments depicted that application of irrigational water, zinc, and nitrogen at 12-acre inches, 10, and 140 kg ha^{-1}, respectively, are responsible to achieve maximum resource utilization efficiency, along with increased yield and quality of rice.

Islam *et al.* (2021) reported Zinc (Zn) deficiency is widespread nutrient disorder in lowland rice growing areas in Asia, especially in Bangladesh. Intensive cropping with modern varieties causes depletion of inherent nutrient reserves in soils. The application of Zn fertilizers results in higher crop productivity and increases Zn concentration in crops. A field experiment was conducted to evaluate the effect of Zn application on growth, yield, and grain-Zn concentration in eight varieties of rice. The experiment was laid out in a split plot design with a distribution of Zn rates (0 kg ha^{-1} and 3 kg ha^{-1} from ZnO) to the main plots and rice varieties (BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57, Kalizira, Biroin, Gainja and Khirshapath) to the sub-plots. Zinc application improved effective tillers $hill^{-1}$, grains $panicle^{-1}$ and 1000-grain weight which impacted the grain yield of rice. Among the eight rice varieties, a significant increase of grain yield was recorded in BRRI dhan49, BRRI dhan52, BRRI dhan56 and BRRI dhan57 due to the application of Zn. Zinc concentration of grain significantly increased in all rice varieties except Biroin. The highest grain-Zn concentration (19.1 mg kg^{-1}) was noted in BRRI dhan57 with 3 kg ha^{-1} Zn and the lowest value (11.3 mg kg^{-1}) was observed in BRRI dhan52 without Zn application. The highest percent increase of grain Zn concentration over control was obtained in high yielding rice variety BRRI dhan49 and the lowest Zn concentration was found in local rice variety Biroin.

Hoque *et al.* (2021) reported insufficient zinc (Zn) and water are key concerns in agricultural production, resulting in lower yields and nutritional qualities. The goal of the study was to figure out how water management and Zn application rates affect the growth and yield of rice. The experiment was carried out in a split-plot design with three replications. 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. In Bangladesh, farmers involved in rice cultivation maybe benefited following the treatment of 150% Zn and AWD irrigation systems.

Alwahibi *et al.* (2020) reported continuous cropping of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) deplete soil fertility and reduce crop productivity as well as zinc (Zn) concentrations in rice grains and straw. Low Zn concentrations in rice grains have a negative impact on human health, while low Zn concentration in rice straw creates a nutritional problem for animals. The current high yielding rice varieties and hybrids remove large quantities of Zn from the soils, lowering the residual concentrations of soil Zn for the subsequent crop (e.g., wheat). Field experiments were conducted on farmers field in Malakand with the objective to evaluate the impact of various combinations of phosphorus (0, 40, 80, and 120 kg ha^{-1}) and Zn levels (0, 5, 10, and 15 kg ha^{-1}) on bio-fortification of Zn in grains and straw of rice genotypes (Bamati-385) vs. coarse (Fakhre-e-Malakand and Pukhraj).

The results revealed that Zn bio-fortification in rice genotypes increased with the integrated use of both nutrients (P + Zn) when applied at higher rates (80 and 120 kg P ha^{-1}, and 10 and 15 kg Zn ha^{-1}, respectively). The bio-fortification of Zn in both grains and straw was higher in the coarse than fine rice genotypes (Pukhraj>Fakhre-e-Malakand>Basmati-385). It was concluded from this study that the application of higher P and Zn levels increased Zn contents in rice parts (grains and straw) under the rice-wheat system. We also concluded from this study that Zn concentrations in rice grains and straw are influenced by plant genetic factors and Zn management practices.

Singh *et al.* (2020) conducted a study which entitled Effect of Zinc and silicon on growth and yield of aromatic rice in north western plain zone of India during kharif 2018 at Student Instructional Cum-Research Farm, IFTM University, Moradabad, India. 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 under randomized block design with three replications. 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.

Roy (2018) conducted an experiment at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period of June to December 2017 to find out the influence of zinc on yield and quality of aromatic rice. Aromatic rice cultivars Dulhabhog, Chinigura, Khoisanne and Chiniatab were used in this experiment. The experiment consisted of two factors *viz*., Factor A: 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}; and Factor B: Four cultivars of aromatic rice such as- V_1: Dulhabhog, V_2: Chinigura, V_3: Khoisanne and V_4: Chiniatab. The two factors experiment was laid out in a split-plot design with three replications. Zn level were assigned to main plot and variety to sub plot. Data were recorded on yield attributes, yield and quality of aromatic rice. The result revealed that zinc level had no significant effect on grain yield. Results also 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, protein content, proline content and grain 2-Acetyl-1-pyrroline (2-AP) content increased with increasing zinc level. But Zn level had no significant effect on 1000 grains weight, grain yield, harvest index and amylose content among the four aromatic rice varieties. The highest grain yield was observed from V_1, highest proline content was found from V_2 and maximum grain 2-AP content was found from V3. Among the 16 treatment combinations, the highest plant height (54.77, 87.76, 120.78, 127.49 and 130.79 cm) was observed from Zn_4V_1 at different date. The highest grain yield (2.94 ha^{-1}) was found from Zn_4V_1. The highest proline content (26.74 mg g^{-1}) was recorded from Zn_4V_2 on dry weight (DW) basis. The highest grain-2AP content (1.41 μg g^{-1}) was recorded from Zn_4V_3 on dry weight (DW) basis. So it may be concluded that applications 4.0 kg Zn ha^{-1} on aromatic rice variety Dulhabhog showed the superior characters among the other treatments in consideration of yield and quality. On the other hand, application of 4 kg Zn ha^{-1} and aromatic rice variety Khoisanne showed the best performance in case of protein, amylose and 2-AP content but not on proline.

Ghasal *et al*. (2018) carried out a two-year field study to assess the effect of Zn application on Zn content and uptake at several growth stages and in several parts of the rice kernel: hull, bran, and the white rice kernel. Variety 'PB 1509' with 1.25 kg Zn ha^{-1} as Zn-EDTA + 0.5% foliar spray at maximum tillering (MT) and panicle initiation (PI) stage registered the highest Zn content hull, bran, and the white rice kernel. The variety 'PB 1401' showed the highest Zn uptake in rice straw, while 'PB 1509' showed the highest Zn uptake in hull and white rice kernel. Application of 1.25 kg Zn ha^{-1} (Zn-EDTA) + 0.5% foliar application at MT and PI and 2.5 kg Zn ha^{-1} $ZnSO_4.7H_2O$ (Zn-SHH) + 0.5% foliar application at MT and PI resulted in higher Zn uptake than other treatments. Zn-EDTA along with 0.5% FS, despite the application of a lower quantity of Zn leading to the highest Zn mobilization efficiency index and Zn-induced nitrogen recover efficiency, produced the highest kernel yield.

Khatun *et al*. (2018) conducted a field experiment at the Agronomy Research Field, Department of the Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during Aman season 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} cowdung 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.

Lei *et al*. (2017) carried out a study to investigate the exogenous mixed application of micro-nutrients on yield quality, 2-acetyle-1-pyrroline (2-AP) and mineral content accumulation in the grains of two aromatic rice cultivars i.e., Xiangyaxiangzhan and Guixiangzhan. Two mixtures containing different proportions of micro-nutrients i.e., mixture-1 (40% zinc sulfate, 6% manganese sulfate, 1% ferric chloride, 50% proline, and 3% sodium selenite) and mixture-II (containing 1% gibberellic acid, 8% zinc sulfate, potassium 76% di-hydrogen phosphate, 8% manganese sulfate, and 7% copper sulfate) were exogenous applied at full heading stage at 1.5 kg ha^{-2} (T_1) and 3 kg ha^{-2} (T_2) diluted in 750 L water while plots with only water application were served as control (CK). Results revealed that exogenous application of mixed micro-nutrients notably increased yield in terms of improved grain numbers $panicle^{-1}$, filled grain (%), 1000-grain weight, grain yield, grain 2-AP and zinc (Zn) contents.

Ali *et al*. (2016) reported Zinc deficiency is a barrier in achieving higher rice yield and also a cause of zinc malnutrition in developing countries. Various approaches are under study for zinc fertilization to meet the crop requirement. Thus this study was carried out to see the impact of root applied zinc on rice productivity under variable irrigation regimes for two consecutive years 2009-2010. Various levels of zinc fertilization: (Zn_1) 0, (Zn_2) 8, (Zn_3) 10, (Zn_4) 12 and (Zn_5) 14 kg ha^{-1} were applied to soil under different irrigation regimes; 6 (I_1), 8 (I_2), 10 (I_3), 12 (I_4) and 14 (I_5) irrigations. Two sites from major rice producing areas were selected for comparison. Rice plants significantly improved growth in terms of LAI, LAD and NAR with an increase in zinc and irrigation levels while the major increase was observed with 14kg zinc ha^{-1} under 12 irrigations. The crop plants were highly efficient in using available radiation when grown under 12 irrigations with 14kg Zn ha^{-1}. The paddy yield and yield parameters were correlated with higher growth rate and performed best under the treatment combination of I_4Zn_5. Likewise, zinc fertilization under optimum moisture condition was also economically sustained. Rice growth and yields were substantially poor at lower application of zinc fertilizer and irrigation during both the years under different ecological regions.

Amanullah *et al*. (2016) reported Phosphorus (P) and zinc (Zn) deficiencies are the major problems that decrease crop productivity under rice-wheat cropping system. Field experiments were conducted to investigate impacts of P (0, 40, 80 and 120 kg/ha) and Zn levels (0, 5, 10 and 15 kg/ha) on dry matter (DM) accumulation and partitioning, and harvest index of three rice genotypes 'fine (Bamati-385) vs. coarse (F-Malakand and Pukhraj)' at various growth stages (tillering, heading and physiological maturity). The experiments were conducted at farmers' field at Batkhela in Northwestern Pakistan for two years in summer 2011 and 2012. The two year pooled data revealed that there were no differences in percent of DM partitioning into leaves and culms with application of different P and Zn levels, and genotypes at tillering. The highest P level (120 kg/ha) partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The highest Zn level (15 kg/ha) accumulated more DM and partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The hybrid rice (Pukhraj) produced and partitioned more DM into panicles than F-Malak and Basmati-385 at heading and physiological maturity stages. Higher DM accumulation and greater amounts of partitioning into panicles at heading and physiological maturity stages was noticed with increase in P and Zn levels, and the increase was significantly higher in the coarse rice genotypes than fine. We concluded that the growing hybrid rice with application of 120 kg/ha P and 15 kg/ha Zn not only increases total DM accumulation and partitioned greater amounts into the reproductive plant parts (panicles) but also results in higher harvest index.

Sudha *et al*. (2015) conducted a field experiment during Thaladi (Rabi) season 2013–14 to study the effect of zinc application on yield, quality and grain zinc content of different rice genotypes in a split plot design. The main plots were two levels of Zn (no Zn and 100 kg/ha $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 percent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice) and sub-plots were 18 of rice genotypes. The application of zinc significantly increased the plant height, number of productive tillers, filled grains per panicle, panicle length and 1000-grain weight as compared to NPK fertilization alone. The yield of grain (4623 to 7434 kg/ha) and straw (6657 to 10041 kg/ha) of different rice genotypes significantly increased with the application of zinc in which the grain and straw yields were increased by 14 and 16 per cent respectively. Further the quality parameters like starch, amylase, crude protein and zinc content in processed rice grains increased markedly by the application of Zn as compared to NPK alone. Thus the present study indicated that the application of 100 kg/ha $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 percent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice along with 100 percent NPK to rice genotypes enhanced considerably the productivity, quality and zinc content of rice grains.

Rana and Kasif (2013) reported Zinc (Zn) is essential micronutrient for plants, animals and humans. Zn deficiency is widely spread in paddy soils of Pakistan, and has negative impact of national rice production. A field experiment was conducted at the research area of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad to compare rice (*Oryza sativa* L.) yield and nutrients components i.e., nitrogen (N), phosphorus (P), potassium (K) and Zn, of paddy and straw in response to Zinc sulfate ($ZnSO_4.H_2O$), Zinc sulfate heptahydrate ($ZnSO_4.7H_2O$), Zn-ethylene diamine tetraacetate (Zn-EDTA) and zinc oxide (ZnO) as Zn sources which were either incorporated into the soil or applied as foliar spray 14 days after rice transplantation (DAT). Zn application significantly increased the Chlorophyll contents, tillers m^{-2}, total biomass and paddy yield, as well as the Zn concentration in the grain and the straw, except P content in the paddy and straw. Zn-EDTA incorporated in soil (10.0 kg ha^{-1}) resulted in greater values for these parameters as compared to other sources of Zn application. Among the method of Zn application, soil application resulted in higher yield, biomass, N and K contents in the grain and straw. Foliar application caused greater P concentration in both grain and straw, however, chlorophyll, K contents in paddy remained unaffected by method of Zn application. Zn-EDTA proved to be the most efficient source of Zn for rice production.

Singh *et al*. (2012) reported rice is the staple food of more than three billion people in the world, most of who live in Asia. Rice is important crop of Indo Gangetic Plains of Bihar, productivity of system is stagnate and somewhere going down, to ascertain the role of sulphur and zinc an experiment was conducted at main campus of ICAR Research Complex of Eastern Region Patna with four levels of both nutrients i.e. sulphur and zinc, total 16 treatments were tested in Randomized Block Design. Both the nutrients were applied to rice and their direct and residual response was ascertained to rice and lentil in sequence. Based on three years of experimentation, results revealed that rice plant height is significantly affected by sulphur and zinc. Tallest plant (101.7cm) was recorded at maturity with 6kg Zn application Zn. With the advance of stage dry matter accumulation was increased, it was not like the LAI which was decreased after Panicle initiation stage. Highest LAI (4.29) at anthesis was produced in the plots treated with Zn at 6 kg/ha. Dry matter share of root was in general less than 15% across the levels of sulphur and zinc during all the phenological stages. Maximum rice yield (7.63 t/ha) was recorded with combined application of 30kg sulphur and 6kg zinc, whereas corresponding minimum rice yield (7.09 t/ha) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period. Maximum (281.2 kg/ha) nitrogen uptake was recorded with 6kg zinc treatment. However highest uptake of P (91.1 kg/ha) and K (150.4 kg/ha) was recorded in the plot supplemented with no Zn and sulphur at 40 kg/ha, respectively. Soil parameters *viz*., pH, EC and organic carbon content did not influenced with the S and Zn. N, P, K, S and Zn were affected significantly due to sulphur and zinc nutrition.

Khan *et al*. (2007) conducted a pot experiment at Faculty of Agriculture Gomal University Dera Ismail Khan, NWFP, Pakistan during 2001 to evaluate the effect of different levels of soil zinc application on the yield and growth components of rice at eight different soil series of D.I. Khan. Zn as $ZnSO_4.7H_2O$ (21%) was applied @ 0, 5, 10 and 15kg ha^{-1} along with the basal doses of 120 kg N, 90 kg P_2O_5 and 60 kg K_2O ha^{-1}. Thirty days old four seedlings of rice cv. IRRI-6 were grown. The increasing levels of Zn in these soil series significantly influenced yield and yield components of rice. Application of 10 kg Zn ha^{-1} appeared to be an optimum dose for rice crop in these soil series. Tikken soil series gave the highest paddy and straw yield while the Ramak gave the lowest. The interaction between soil series was also found significant for all these series.

Slaton *et al*. (2005) reported Zinc is the most common micronutrient fertilizer applied to rice (*Oryza sativa* L.) in the USA. Preventing yield limitations from Zn deficiency requires knowledge of the proper application rates and times of commercial Zn fertilizers. The objective of this research was to evaluate the Zn nutrition and grain yield response of rice as affected by Zn-fertilizer source and application time. Four field trials were conducted to evaluate several Zn sources applied preplant incorporated (PPI), delayed preemergence (DPRE), and postemergence (POST) before flooding at the four-leaf stage. Zinc treatments included Zn solutions sprayed at 1.1 to 2.2 kg Zn ha^{-1} and dry-granular Zn fertilizers broadcast at 11.2 kg Zn ha^{-1}. Zinc-fertilizer source, averaged across application times, significantly affected grain yield at all sites with Zn fertilization increasing yields by 12 to 180% compared with the unfertilized control. Zinc-application time, averaged across Zn sources, significantly affected grain yield at only one site, which had severe Zn deficiency. Zinc applied PPI (6915 kg grain ha^{-1}) and DPRE (7456 kg grain ha^{-1}) produced similar yields that were greater than Zn applied POST (5526 kg grain ha^{-1}). Zinc solutions sprayed at 1.1 to 2.2 kg Zn ha^{-1} generally produced yields that were comparable with yields from granular fertilizers applied at 11.2 kg Zn ha^{-1}. Fertilization recommendations should reflect the advantages of Zn fertilization performed before crop emergence. Growers can confidently apply Zn fertilizer solutions or granules to the soil surface without incorporation before emergence, with recommended rates (11 kg Zn ha^{-1}) of granular Zn preferred for alkaline, Zn-deficient soils.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the period of December 2020 to May 2021 with a view to investigate the effect of micronutrient zinc on the performance of modern rice varieties. Details of different materials used and methodologies followed to conduct the studies are presented in this chapter.

3.1 Site description

The experiment was carried out at the Bangladesh Rice Research Institute Research field, Sonagazi, Feni, Bangladesh under the Agro-ecological zone of Young Meghna Estuarine Floodplain, AEZ-19. The land area is situated at 22°85´ N latitude and 91°39´E longitude at an altitude of 10 meter above sea level. The experimental site is shown in the AEZ Map of Bangladesh in Appendix I.

3.2 Climate

The experimental area is under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in kharif season (April-September) and less rainfall associated with moderately low temperature during the Rabi season (October-March). The weather data during the study period of the experimental site is shown in Appendix II.

3.3 Soil

The farm belongs to the region that occupies young alluvial land in and adjoining the Meghna estuary. It is almost level with very low ridges and broad depressions. The major soils are grey to olive, deep, calcareous silt loam and silty clay loams and are stratified either throughout or at shallow depth. The experimental area was flat having available irrigation and drainage system. The land was above flood level and sufficient sunshine was available during the experimental period. Prior to conduct the experiment, soil samples from 0-15 cm depths were collected from the experimental field. The analyses were done at Soil Resources and Development Institute (SRDI), Dhaka. The physico-chemical properties of the soil are presented in Appendix III.

3.4 Treatments

The two factorial experiment was carried out in Strip plot design with three replications which is as follows:

Factor A: Nutrient levels

1. T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1})
2. $T_2 = T_1$ – 50% Zn
3. $T_3 = T_1$ – 100% Zn (T_1 but without Zn)
4. $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1})
5. $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1})
6. $T_6 = T_1$ but Zn was applied by spraying
7. T_7 = Soil test based (STB) nutrient rates N, P, K, S and Zn @ 158, 24, 82, 10 and 2 kg ha^{-1}
8. T_8 = Control/native supply of nutrient (No nutrient was applied)

Factor B: Rice varieties

Three modern rice varieties BRRI dhan74, BRRI dhan84 and BRRI dhan88 were selected for the experiment.

Table 1. Salient features of the selected varieties

SN	Variety	Grain yield (t/ha)	Growth duration (day)	Plant ht (cm)	Amylose (%)	Special Characteristics
1	BRRI dhan74	7.1	147	95	24.2	Grain medium bold , Zinc enriched (24.2 mg/kg),
3	BRRI dhan84	6.5	141	96	25.9	Grain medium slender, Zinc enriched (2 7.6 mg/kg)

4	BRRI dhan88	7.0	142	96	26.3	Grain medium slender and white in color, Protein 9.8%

Treatment combinations: Twenty-four treatment combinations are as below:

T_1V_1, T_1V_2, T_1V_3, T_2V_1, T_2V_2, T_2V_3, T_3V_1, T_3V_2, T_3V_3, T_4V_1, T_4V_2, T_4V_3, T_5V_1, T_5V_2, T_5V_3, T_6V_1, T_6V_2, T_6V_3, T_7V_1, T_7V_2, T_7V_3, T_8V_1, T_8V_2 and T_8V_3.

Initial soil Status

Initial Soil characteristics of the Experimental Field in Boro 2020-2021 at BRRI Regional Station, Sonagazi, Feni

Season	pH	TOC (%)	TSN (%)	P_{Olsen} (ppm)	$K_{exch.}$ (me/100g)	S (ppm)	Zn (ppm)
Boro 2020-21	5.8	1.24	0.063	6.4	0.22	55	18

NB: Soil characteristics: TOC=Total organic carbon, TSN=Total soil nitrogen, P= Phosphorus, K = potassium, S = Sulfur, and Zn = Zinc.

3.5 Plant materials and collection of seeds

Three modern rice varieties *viz*. BRRI dhan74, BRRI dhan84 and BRRI dhan88 were used as plant materials for the present study. The seeds of these varieties were collected from BRRI, Joydebpur, Gazipur, Bangladesh.

3.6 Seed sprouting

Healthy seeds were kept in water bucket for 24 hours and then it was kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown after 72 hours.

3.7 Preparation of nursery bed and seed sowing

As per BRRI recommendation, seedbed was prepared with 1m wide adding nutrients as per the requirements of soil. Seeds were sown in the seed bed on December, 2020 in order to transplant the seedlings in the main field.

3.8 Preparation of experimental land

The plot selected for the experiment was opened in the first week of December 2020 with a power tiller, and was exposed to the sun for a week, after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed, and finally obtained a desirable field for transplanting of the seedlings.

3.9 Fertilizer application

The doses of fertilizers were applied as per treatment to the experimental plot. The fertilizers N, P, K, S and Zn in the form of urea, TSP, MoP, gypsum and zinc sulfate, respectively were applied. The entire amount of TSP, MoP, gypsum and zinc sulfate were applied during the final land preparation. Urea was applied in three equal installments at seedling establishment, tillering and before panicle initiation.

3.10 Experimental design and layout

The experiment was laid out in a Strip Plot Design with three replications. The experimental field was divided into three equal blocks. Each block was first divided into 24 sub plots where treatment combinations (different nutrient treatments and varieties of rice) were assigned. Each sub plot was considered as one replication. Thus, the total number of unit plots was 24×3=72. The size of the unit plot was 3m × 2m. The distance maintained between the row was 0.5m and between column was 0.5m. The treatments (varieties) were randomly assigned to the plots within each block.

3.11 Uprooting of seedlings

The nursery bed was made wet by application of water one day before uprooting the seedlings. The seedlings were uprooted on 20 December, 2020 without causing much mechanical injury to the roots.

3.12 Transplanting of seedlings in the field

The seedlings were transplanted in the main field on December 21, 2020 with a spacing 20 cm from hill to hill and 20 cm from row to row.

3.13 Intercultural operations

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the rice seedlings.

3.13.1 Irrigation and drainage

Flood irrigation was given to maintain a constant level of standing water up to 3 cm at the early stages to enhance tillering and 4-5 cm in the later stage to discourage late tillering. The field was finally dried out at 15 days before harvesting.

3.13.2 Gap filling

Gap filling was done for all of the plots at 10 days after transplanting (DAT) by planting same aged seedlings.

3.13.3 Weeding

The crop was infested with some common weeds, which were controlled by uprooting and remove them three times from the field during the entire period of experiment. Weeding was done after 15, 35 and 55 days of transplanting.

3.13.4 Plant protection

There were some incidence in insects specially grass hopper, stem borer, rice ear cutting caterpillar, thrips and rice bug which was controlled by spraying Curatter 5G and Sumithion. Brown spot of rice was controlled by spraying Tilt.

3.14 General observation of the experimental field

The field was observed time to time to detect visual difference among the treatments and any kind of infestation by weeds, insects and diseases so that considerable losses by pest was minimized.

3.15 Harvesting, threshing and cleaning

The rice plant was harvested depending upon the maturity of the plant and harvesting was done manually from each plot. Harvesting was done on 15 May 2021. The harvested crop of each plot was bundled separately, properly tagged and brought to threshing floor. Enough care was taken for harvesting, threshing and also cleaning of rice seed. Fresh weight of grain and straw were recorded plot wise. The grains were cleaned and finally the weight was adjusted to a moisture content of 12%. The straw was sun dried and the yields of grain and straw plot^{-1} were recorded and converted to ton ha^{-1}.

3.16 Recording of data

The following data were recorded during the study period:

3.16.1 Growth parameters

1. Plant height (cm)
2. Number of tillers hill^{-1}
3. Number of tillers m^{-2}

3.16.2 Yield contributing parameters

1. Days to first flowering
2. Days to maturity
3. Number of panicle hill^{-1}
4. Number of panicles m^{-2}

3.16.3 Yield parameters

1. Weight of 1000 grains (g)
2. Number of grains hill^{-1}
3. Grain weight hill^{-1}
4. Grain yield (t ha^{-1})

3.16.4 Quality parameters

1. Zn content in grain
2. Zn content in straw

3.17 Procedures of recording data

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

3.17.1 Growth parameters

Plant height

The height of plant was recorded in centimeter (cm) at the time of harvest. Data were recorded as the average of same 5 plants pre-selected at random from the inner rows of each plot. The height was measured from the ground level to the tip of the plant with a meter scale.

Number of tillers hill^{-1}

Number of tillers hill^{-1} was counted from the average of similar 5 plants pre-selected at random from the inner rows of each plot.

Number of tillers m^{-2}

The total number of tillers was counted from 1 m^2 areas from the inner rows of each plot and total tillers were counted.

3.17.2 Yield contributing parameters

Days to 50% flowering

Days to 50% flowering were counted from first flower initiation to 50% flowers appeared in plants of each plot and it was measured in days.

Days to maturity

Days to maturity were counted from transplanting date to harvesting time in plants of each plot.

Number of panicles hill^{-1}

The total number of panicles from effective tillers was counted from 5 selected hills and average value was recorded.

Number of panicles m^{-2}

From the inner rows of each plot, 1m^{-2} areas was marked and total panicles were counted replication wise.

3.17.3 Yield parameters

Weight of 1000 grain (g)

One thousand cleaned dried grains were counted randomly from each plot and weighed by using a digital electric balance when the grains retained 12% moisture and the mean weight was expressed in gram.

Number of grains panicle^{-1}

The total number of grains was collected randomly from randomly selected 5 hills of a plot and also number of panicles was also counted and then average number of grains panicle^{-1} was recorded.

Grain weight hill^{-1}

Total grains were collected from randomly selected 5 hills of a plot and separated grains were weighed and then average weight was recorded.

Grain yield (t ha^{-1})

Grain from each plot area was thoroughly sun dried till constant weight was attained. Then yield per hectare was determined based on net plot area.

3.17.4 Determination of Zn content in grain and straw

To obtain nutrient concentration in straw and seed, it was sampled and analysis was done maintaining appropriate procedure. The Zn content in the acid digest was determined directly by Atomic Absorption Spectrophotometer (Model- UNICAM 969, England) (Yoshida *et al*., 1976).

3.18 Statistical analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among the treatment by using the MSTAT-C computer package program. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatments means was estimated by the Least Significant Difference Test (LSD) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The present study was carried out to evaluate the effect of micronutrient zinc on the performance of modern rice varieties. The results of the study have been presented and discussed with the help of table and graphs and also possible interpretations have been given under the following headings:

4.1 Growth parameters

4.1.1 Plant height (cm)

Effect of micronutrient Zn treatments

Different treatments of Zn applied to rice had significant influence on plant height (Figure 1 and Appendix IV). The treatment T_1 (Recommended rate of urea, TSP, MoP, gypsum, and zinc sulfate) showed the tallest plant (90.70 cm) that was significantly similar to the treatment T_2 (T_1 – 50% Zn), T_3 (T_1 – 100% Zn; T_1 but without Zn) and T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}). The smallest plant (75.33 cm) was recorded from the control treatment T_8 (no nutrient was applied) that was significantly differed to other treatments.

Effect of different rice varieties

Different rice varieties showed significant variation on plant height (Figure 2 and Appendix IV). The variety V_2 (BRRI dhan84) gave the tallest plant (93.42 cm) and significant similar result was observed by the variety V_1 (BRRI dhan74). The variety V_3 (BRRI dhan88) performed the smallest plant (76.96 cm) and it was significantly different to other rice varieties. Salam *et al*. (2019) and Murshida *et al*. (2017) also observed significant variation on plant height of rice among different varieties which supported the present findings of the study.

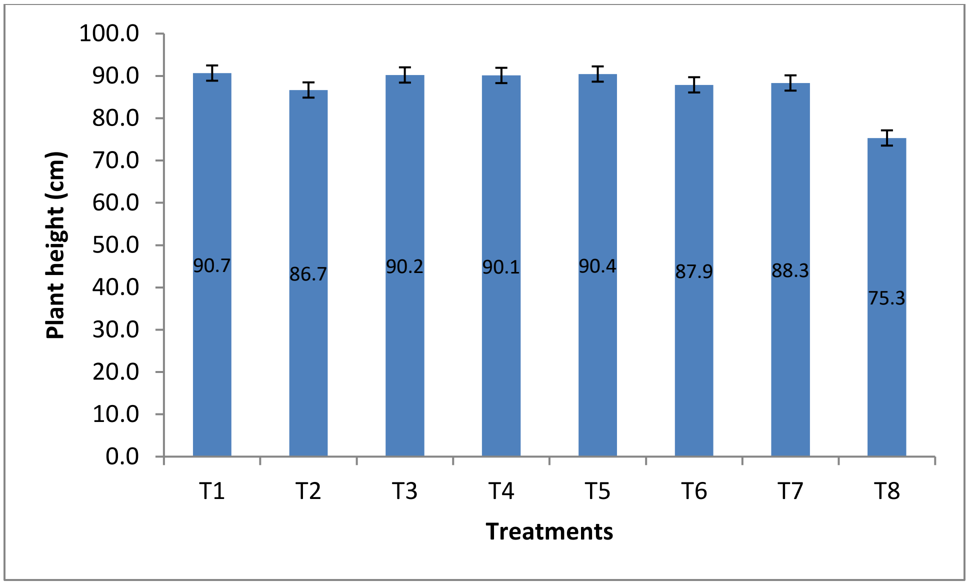

Figure 1. Plant height of rice as influenced by different Zn treatment

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

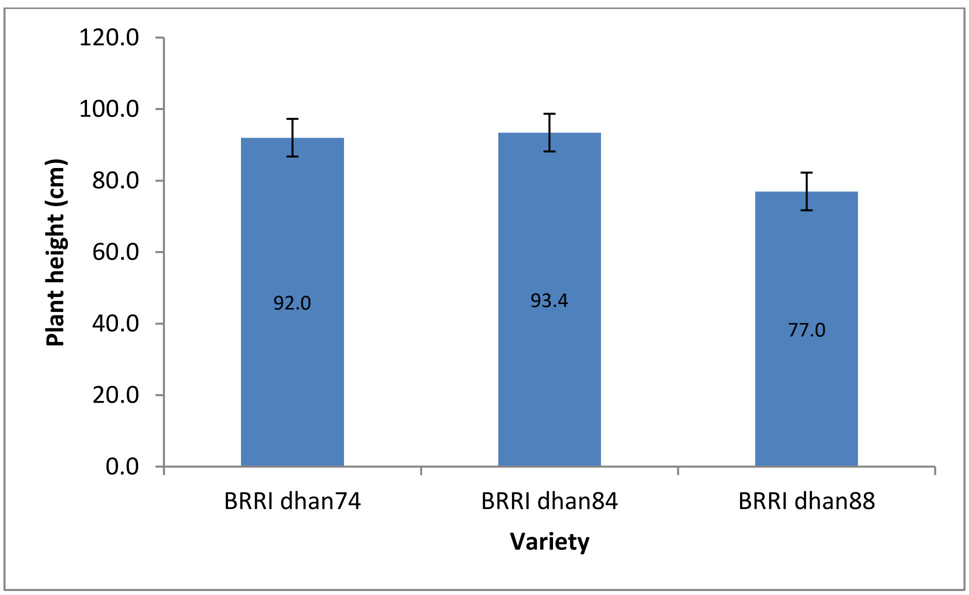

Figure 2. Plant height of rice as influenced by different rice varieties

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

Combined effect of micronutrient Zn treatments and rice varieties

Plant height of rice varied significantly due to combined effect of micronutrient Zn and variety (Table 1 and Appendix IV). The treatment combination of T_5V_2 gave the tallest plant (98.67 cm) which was statistically similar to the treatment combinations of T_1V_1 and T_3V_2. Again, T_8V_3 gave the smallest plant (66.00 cm) and it was significantly different with other treatment combination.

4.1.2 Number of tillers hill^{-1}

Effect of micronutrient Zn treatments

Application of different micronutrient Zn treatments showed significant influence on number of tillers hill^{-1} (Figure 3 and Appendix IV). The highest number of tillers hill^{-1} (14.22) was found from the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) that was followed T_3 (T_1 – 100% Zn; T_1 but without Zn) and T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}). The lowest number of tillers hill^{-1} (7.80) was recorded from control treatment T_8 (no nutrient was applied) and it was significantly different from other treatments. Hasnain *et al.* (2022) reported that soil application of Zn had significant effect on tiller production and at 10 kg ha^{-1} was more responsive to produce higher tiller number which supported the present findings. Islam *et al.* (2021) and Singh *et al.* (2020) also found similar result with the present study.

Effect of different rice varieties

Different rice varieties showed significant variation for number of tillers hill^{-1} (Figure 4 and Appendix IV). The highest number of tillers hill^{-1} (13.43) was achieved from the variety V_3 (BRRI dhan88) and it differed significantly with other varieties followed by V_1 (BRRI dhan74). The lowest number of tillers hill^{-1} (11.41) was found from the variety V_2 (BRRI dhan84). Similar result was also observed by

Salam *et al*. (2019), Chamely *et al*. (2015) and Jisan *et al*. (2014) who observed that different rice varieties had significant role in variation to tiller production.

Table 1. Growth parameters of rice as influenced by combined effect of different Zn treatment and variety

Treatment combinations	Growth parameters		
	Plant height (cm)	Number of tillers hill^{-1}	Number of tillers m^{-2}
T_1V_1	97.67 ab	13.33 ef	442.70 d
T_1V_2	95.00 abcd	12.00 ghi	401.00 gh
T_1V_3	79.33 fgh	13.33 ef	444.30 d
T_2V_1	89.00 e	12.33 gh	408.30 fg
T_2V_2	94.67 bcd	11.67 hij	382.30 ij
T_2V_3	76.33 h	15.00 b	494.00 b
T_3V_1	94.00 bcd	14.67 bc	485.00 b
T_3V_2	96.67 ab	12.67 fg	415.70 f
T_3V_3	78.67 fgh	13.67 de	459.30 c
T_4V_1	94.33 bcd	13.33 ef	439.70 d
T_4V_2	96.00 abc	12.67 fg	416.70 ef
T_4V_3	79.33 fgh	14.33 bcd	467.30 c
T_5V_1	94.33 bcd	14.00 cde	465.70 c
T_5V_2	98.67 a	12.00 ghi	392.70 hi
T_5V_3	80.33 fg	16.67 a	557.70 a
T_6V_1	92.67 cde	12.67 fg	427.00 e
T_6V_2	92.00 de	10.97 j	370.30 k
T_6V_3	79.00 fgh	14.67 bc	490.70 b
T_7V_1	92.00 de	11.67 hij	384.30 ij
T_7V_2	96.33 abc	11.33 ij	374.00 jk
T_7V_3	76.67 gh	12.00 ghi	396.30 h
T_8V_1	82.00 f	7.63 k	254.70 l
T_8V_2	78.00 gh	7.97 k	264.70 l
T_8V_3	66.00 i	7.80 k	260.30 l
$LSD_{0.05}$	3.898	0.823	11.18
CV(%)	4.07	11.78	11.72

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

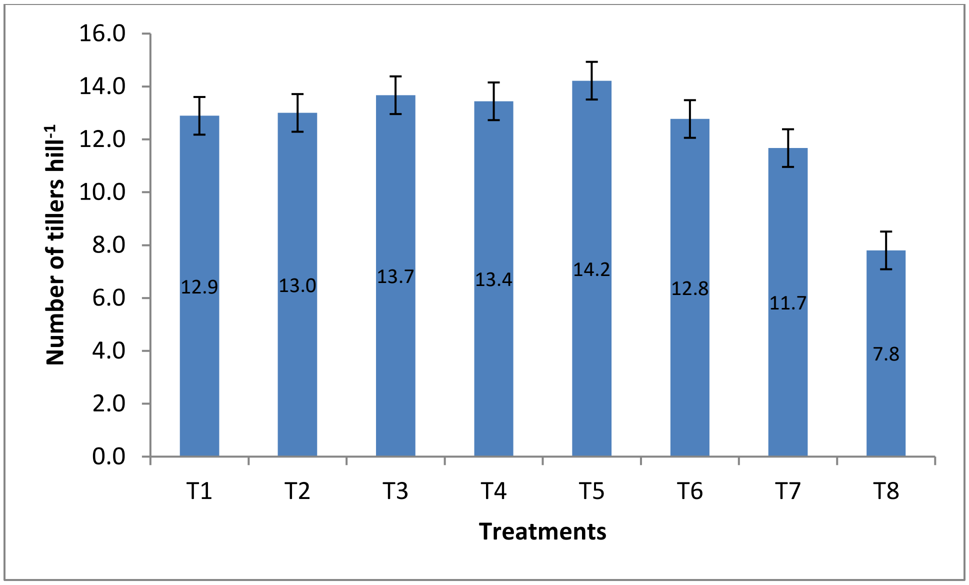

Figure 3. Number of tillers hill^{-1} as influenced by different Zn treatment

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

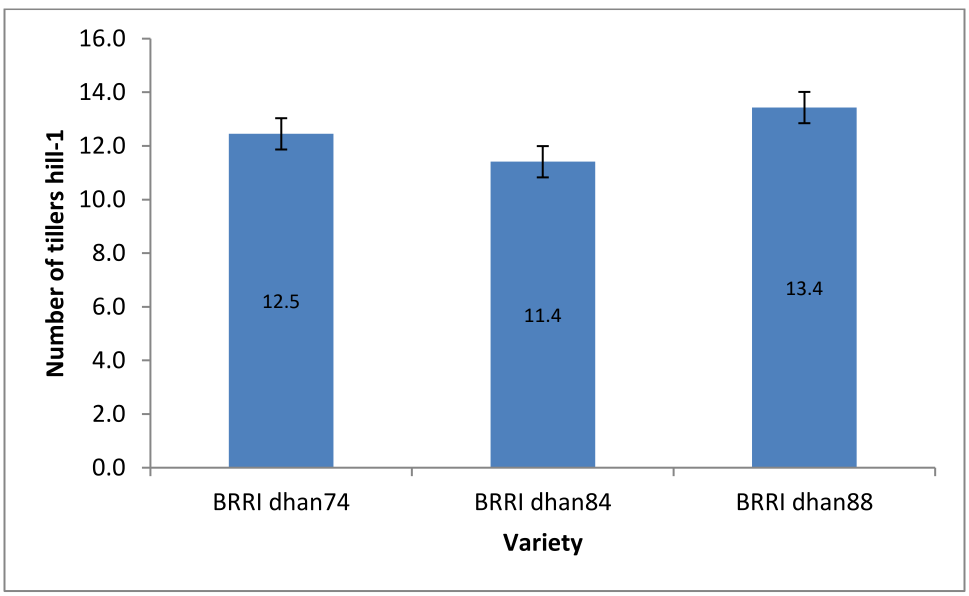

Figure 4. Number of tillers hill^{-1} as influenced by different rice varieties

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

Combined effect of micronutrient Zn treatments and rice varieties

Treatment combination of micronutrient Zn treatments and variety showed significant variation on number of tillers hill^{-1} of rice (Table 1 and Appendix IV). The treatment combination of T_5V_3 showed the highest number of tillers hill^{-1} (16.67) and it was significantly different with other treatment combinations. The next highest number of tillers hill^{-1} (15.00) was observed for T_2V_3 treatment combination. T_8V_3 gave the lowest number of tillers hill^{-1} (57.80) and it was significantly same to the treatment combination T_8V_1 and T_8V_2.

4.1.3 Number of tillers m^{-2}

Effect of micronutrient Zn treatments

Significant variation was observed on number of tillers m^{-2} by different Zn treatments (Figure 5 and Appendix IV). The treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) gave the highest number of tillers m^{-2} (472.00) followed by T_3 (T_1 – 100% Zn; T_1 but without Zn). The lowest number of tillers m^{-2} (259.90) was recorded from control treatment T_8 (no nutrient was applied) and it was significantly different from other treatments. Islam *et al.* (2021) and Singh *et al.* (2020) also reported positive Zn effect on tiller production and Zn was positively contributed to produce higher tillers which supported the present study. Hasnain *et al.* (2022) and Salam *et al*. (2019) also found similar result with the present findings.

Effect of different rice varieties

There was a significant variation on number of tillers m^{-2} influenced by different rice varieties (Figure 6 and Appendix IV). The highest number of tillers m^{-2} (446.30) was achieved from the variety V_3 (BRRI dhan88) and it differed significantly with other varieties followed by V_1 (BRRI dhan74). The lowest number of tillers m^{-2} (377.20) was found from the variety V_2 (BRRI dhan84). Panwar *et al.* (2012) also reported significant effect on tiller production for unit area due to varietal performance which supported the present study. Jisan *et al*. (2014) and Chamely *et al*. (2015) also found similar result with the present study.

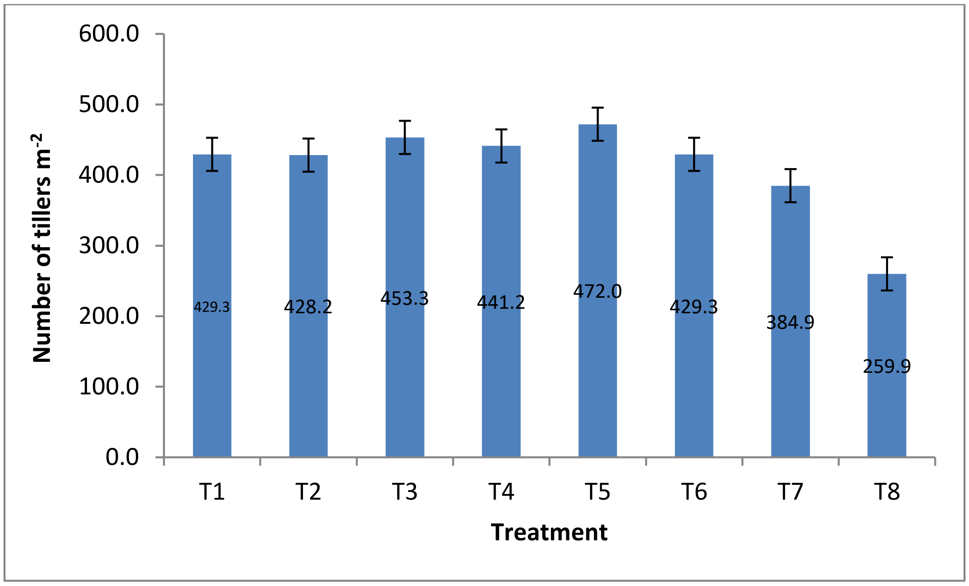

Figure 5. Number tillers m^{-2} of rice as influenced by different Zn treatment

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

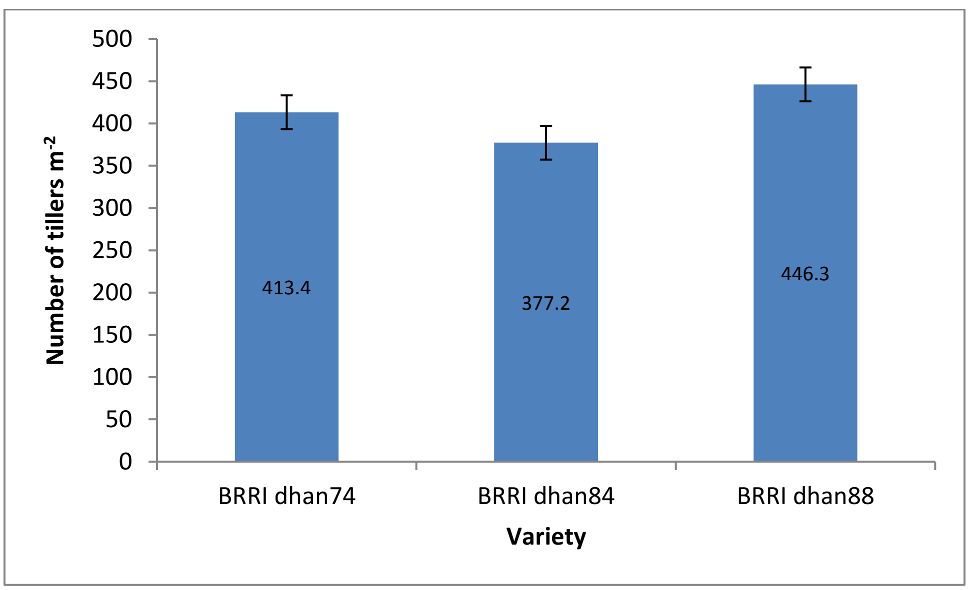

Figure 6. Number tillers m^{-2} as influenced by different rice varieties

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

Combined effect of micronutrient Zn treatments and rice varieties

Variation on number of tillers m^{-2} of rice was statistically significant among different treatment combinations of micronutrient Zn treatments and variety (Table 1 and Appendix IV). The treatment combination of T_5V_3 showed the highest number of tillers m^{-2} (557.70) followed by T_2V_3, T_3V_1 and T_6V_3 and it was significantly different with other treatment combinations. Again, T_8V_3 gave the lowest number of tillers m^{-2} (260.30) and it was statistically similar to the treatment combination T_8V_1 and T_8V_2.

4.2 Yield contributing parameters

4.2.1 Days to 50% flowering

Effect of micronutrient Zn treatments

Different micronutrient Zn treatments applied to rice showed non-significant variation on days to 50% flowering (Table 2 and Appendix V). However, treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) gave the maximum days to 50% flowering (112.80 days) and the minimum days to 50% flowering (110.80 days) was recorded from the treatment T_3 (T_1 – 100% Zn; T_1 but without Zn).

Effect of different rice varieties

Different rice varieties showed significant variation on days to 50% flowering (Table 2 and Appendix V). The variety V_1 (BRRI dhan74) showed the maximum days to 50% flowering (115.50 days) and it was varied significantly with other varieties followed by V_2 (BRRI dhan84). The minimum days to 50% flowering (108.50 days) was recorded from the variety V_3 (BRRI dhan88).

Combined effect of micronutrient Zn treatments and rice varieties

Days to 50% flowering of rice varied significantly due to combined effect of micronutrient Zn treatments and varieties (Table 3 and Appendix V). The treatment combination of T_5V_1 showed the maximum days to 50% flowering (117.00 days) and this was significantly similar to the treatment combinations of T_3V_1, T_4V_3, T_6V_1 and T_7V_1 whereas T_3V_3 gave the minimum days to 50% flowering (106.30 days) that differed significantly with other treatment combinations.

Table 2. Yield contributing parameters of rice as influenced by different Zn treatment as well as different rice varieties

Treatments	Yield contributing parameters			
	Days to 50% flowering	Days to maturity	Number of panicles hill^{-1}	Number of panicles m^{-2}
Effect of different Zn treatments				
T_1	112.70	140.80 a	11.11 b	371.80 b
T_2	111.30	140.60 a	10.70 b	356.00 d
T_3	110.80	140.10 a	11.00 b	367.00 c
T_4	111.20	141.00 a	10.91 b	365.60 c
T_5	112.80	140.70 a	11.56 a	385.00 a
T_6	111.20	140.80 a	11.08 b	369.70 b
T_7	111.20	140.40 a	9.76 c	325.00 e
T_8	111.70	137.70 b	6.50 d	217.10 f
$LSD_{0.05}$	2.901^{NS}	1.376	0.440	2.401
CV(%)	6.98	531	13.75	9.67
Effect of variety				
V_1	115.50 a	138.30 b	11.07 a	369.60 a
V_2	110.80 b	145.80 a	9.47 c	315.70 c
V_3	108.50 c	136.70 c	10.44 b	348.60 b
$LSD_{0.05}$	0.802	1.028	0.263	3.153
CV(%)	6.79	7.04	11.01	11.53

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 = T_1 – 50% Zn, T_3 = T_1 – 100% Zn (T_1 but without Zn), T_4 = T_1 + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), T_5 = T_1 + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), T_6 = T_1 but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

4.2.2 Days to maturity

Effect of micronutrient Zn treatments

Among the treatments of micronutrient Zn, significant variation was found for days to maturity (Table 2 and Appendix V). The treatment T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}) gave the maximum days to maturity (141 days) and this was statistically same to T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 (T_1 – 50% Zn), T_3 (T_1 – 100% Zn; T_1 but without Zn), T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}), T_6 (T_1 but Zn was applied by spraying) and T_7 (Soil test based; STB) whereas control treatment T_8 (no nutrient was applied) gave the minimum days to maturity (137.70 days).

Effect of different rice varieties

Different rice varieties showed significant variation on days to maturity (Table 2 and Appendix V). The variety V_2 (BRRI dhan84) showed the maximum days to maturity (145.80 days) and it was varied significantly with other varieties followed by V_1 (BRRI dhan74), whereas the minimum days to maturity (136.70 days) was recorded by the variety V_3 (BRRI dhan88).

Combined effect of micronutrient Zn treatments and rice varieties

Days to maturity of rice varied significantly due to combined effect of micronutrient Zn treatments and varieties (Table 3 and Appendix V). The treatment combination of T_5V_1 showed the maximum days to maturity (146.70 days) and this was significantly similar to the treatment combinations of T_1V_1, T_2V_1, T_3V_1, T_5V_1, T_6V_1 and T_7V_1. The combination T_8V_3 gave the minimum days to maturity (134.30 days) and it was statistically similar with T_3V_3 and T_8V_2.

4.2.3 Number of panicles hill^{-1}

Effect of micronutrient Zn treatments

Different treatments of Zn applied had significant influence on number of panicles hill^{-1} (Table 2 and Appendix V). The treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) gave the highest number of panicles hill^{-1} (11.56) and it was significantly different from the treatment. Again, the lowest number of panicles hill^{-1} (6.50) was recorded from the control treatment T_8 (no nutrient was applied) that was significantly differed to other treatments. Hasnain *et al.* (2022), Islam *et al.* (2021) and Singh *et al.* (2020) also observed similar result with the present study.

Effect of different rice varieties

Different rice varieties showed significant variation on number of panicles hill^{-1} (Table 2 and Appendix V). The variety V_1 (BRRI dhan74) gave the highest number of panicles hill^{-1} (11.07) and it was significantly different from other varieties followed by V_3 (BRRI dhan88). The variety V_2 (BRRI dhan84) performed the lowest number of panicles hill^{-1} (9.47) and it was significantly different to other rice varieties. The result obtained from the present study was similar with the findings of Salam *et al*. (2019), Chamely *et al*. (2015) and Jisan *et al*. (2014).

Combined effect of micronutrient Zn treatments and rice varieties

Number of panicles hill^{-1} varied significantly due to combined effect of micronutrient Zn and variety (Table 3 and Appendix V). The treatment combination of T_5V_2 gave the highest number of panicles hill^{-1} (12.67) and this treatment was statistically similar to the treatment combinations of T_3V_1, T_3V_3 and T_6V_3. T_8V_2 gave the lowest number of panicles hill^{-1} (6.13) and it was statistically similar with T_8V_3.

Table 3. Yield contributing parameters of rice as influenced by combined effect of different Zn treatment and variety

Treatment combinations	Yield contributing parameters			
	Days to 50% flowering	Days to maturity	Number of panicles hill^{-1}	Number of panicles m^{-2}
T_1V_1	114.70 bc	145.70 ab	11.33 c	380.70 cd
T_1V_2	112.30 d	139.00 cd	10.33 d	346.00 e
T_1V_3	111.00 def	138.30 cd	11.67 bc	388.70 c
T_2V_1	115.30 bc	145.70 ab	9.90 def	329.00 gh
T_2V_2	110.30 efg	138.30 cd	9.53 ef	314.00 j
T_2V_3	108.30 hi	137.70 cde	11.67 bc	384.30 cd
T_3V_1	116.00 ab	146.30 a	12.33 ab	407.70 b
T_3V_2	110.00 fg	139.30 cd	10.33 d	344.70 ef
T_3V_3	106.30 j	134.70 f	12.00 abc	402.70 b
T_4V_1	115.70 ab	139.70 c	11.33 c	376.70 d
T_4V_2	110.00 fg	146.70 a	10.07 de	334.00 g
T_4V_3	108.00 i	137.00 de	11.33 c	386.00 c
T_5V_1	117.00 a	146.30 a	12.67 a	425.00 a
T_5V_2	112.00 d	137.70 cde	9.90 def	331.30 gh
T_5V_3	109.30 ghi	137.70 cde	11.43 c	385.30 cd
T_6V_1	116.00 ab	146.30 a	11.27 c	381.30 cd
T_6V_2	109.70 fgh	139.00 cd	9.30 f	310.00 j
T_6V_3	108.00 i	137.00 de	12.53 a	417.70 a
T_7V_1	115.70 ab	145.70 ab	9.80 def	323.30 hi
T_7V_2	110.00 fg	138.30 cd	9.37 ef	315.00 ij
T_7V_3	108.00 i	137.30 cde	10.10 de	336.70 fg
T_8V_1	114.00 c	143.30 b	6.90 g	230.70 k
T_8V_2	111.70 de	135.30 ef	6.13 h	204.70 m
T_8V_3	109.30 ghi	134.30 f	6.47 gh	216.00 l
$LSD_{0.05}$	1.564	2.399	0.7621	8.917
CV(%)	6.79	7.04	11.01	11.53

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 = T_1 – 50% Zn, T_3 = T_1 – 100% Zn (T_1 but without Zn), T_4 = T_1 + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), T_5 = T_1 + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), T_6 = T_1 but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

4.2.4 Number of panicles m^{-2}

Effect of micronutrient Zn treatments

Application of different micronutrient Zn treatments showed significant influence on number of panicles m^{-2} (Table 2 and Appendix V). The highest number of panicles m^{-2} (385.00) was found from the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) followed by T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) and T_6 (T_1 but Zn was applied by spraying). The lowest number of panicles m^{-2} (217.10) was recorded from control treatment T_8 (no nutrient was applied) and it was significantly different from other treatments.

Effect of different rice varieties

Different rice varieties showed significant variation for number of panicles m^{-2} (Table 2 and Appendix V). The highest number of panicles m^{-2} (369.60) was achieved from the variety V_1 (BRRI dhan74) followed by V_3 (BRRI dhan88)and it differed significantly with other varieties. The lowest number of panicles m^{-2} (315.70) was found from the variety V_2 (BRRI dhan84).

Combined effect of micronutrient Zn treatments and rice varieties

Treatment combination of micronutrient Zn and variety showed significant variation on number of panicles m^{-2} of rice (Table 3 and Appendix V). The treatment combination of T_5V_3 showed the highest number of panicles m^{-2} (425.00) and it was significantly same with T_6V_3. Again, T_8V_2 gave the lowest number of panicles m^{-2} (204.70) and it was significantly differed to other treatment combinations.

4.3 Yield parameters

4.3.1 Weight of 1000 seeds

Effect of micronutrient Zn treatments

Application of micronutrient Zn treatments showed non-significant variation on 1000 seed weight of rice (Table 4 and Appendix VI). However, the treatment T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) gave the maximum 1000 seed weight (23.34 g) and the minimum 1000 seed weight (22.35 g) was performed by control treatment T_8 (no nutrient was applied). Islam *et al.* (2021) reported Zinc application improved 1000-grain weight which supported the present study.

Effect of different rice varieties

The recorded data on 1000 seed weight varied significantly due to varietal performance of rice (Table 4 and Appendix VI). The maximum 1000 seed weight (27.73 g) was registered from the variety V_1 (BRRI dhan74) followed by V_2 (BRRI dhan84). The minimum 1000 seed weight (19.86 g) was recorded from the variety V_3 (BRRI dhan88). Khatun (2020) and Salam *et al*. (2019) also obtained significant variation on 1000 seed weight among different varieties of rice which supported the present findings.

Combined effect of micronutrient Zn treatments and rice varieties

Treatment combination of micronutrient Zn treatments and variety showed significant variation on 1000 seed weight of rice (Table 5 and Appendix VI). The treatment combination of T_1V_1 gave the maximum 1000 seed weight (28.88 g) and this was statistically similar to the treatment combinations of T_2V_1, T_3V_1, T_4V_1, T_5V_1, T_6V_1 and T_7V_1. the combination T_8V_3 gave the minimum 1000 seed weight (19.26 g) and it was statistically similar to T_2V_2, T_2V_3, T_3V_3, T_4V_2, T_5V_2, T_5V_3, T_6V_2, T_6V_3, T_7V_3 and T_8V_2.

Table 4. Yield parameters of rice as influenced by different Zn treatment as well as different rice varieties

Treatments	Yield parameters			
	1000 seed weight (g)	Number of grains $hill^{-1}$	Grain weight $hill^{-1}$ (g)	Grain yield ha^{-1} (t)
Effect of different Zn treatments				
T_1	23.34	988.00 a	22.72 a	4.82 c
T_2	23.09	953.40 c	21.91 a	4.33 e
T_3	23.05	775.30 g	17.63 d	4.58 d
T_4	23.17	840.20 e	18.79 c	5.00 b
T_5	22.67	978.33 b	22.60 a	5.28 a
T_6	22.81	906.80 d	20.43 b	4.54 d
T_7	23.16	791.80 f	17.92 cd	4.32 e
T_8	22.35	479.70 h	10.64 e	2.00 f
$LSD_{0.05}$	1.202^{NS}	5.050	0.997	0.169
CV(%)	4.51	10.34	11.53	9.19
Effect of variety				
V_1	27.73 a	714.20 b	19.81 a	4.56 a
V_2	21.41 b	917.50 a	19.74 a	4.36 b
V_3	19.86 c	920.30 a	18.25 b	4.16 c
$LSD_{0.05}$	0.714	9.850	1.030	0.166
CV(%)	5.51	11.01	13.73	11.74

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 = T_1 – 50% Zn, T_3 = T_1 – 100% Zn (T_1 but without Zn), T_4 = T_1 + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), T_5 = T_1 + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), T_6 = T_1 but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

4.3.2 Number of grains $hill^{-1}$

Effect of micronutrient Zn treatments

Application of different micronutrient Zn treatments exhibited significant influence on number of grains $hill^{-1}$ (Table 4 and Appendix VI). The highest number of grains $hill^{-1}$ (988.00) was found from the treatment T_1 (Recommended rate: N, P, K, S and

Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) that was followed T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}). The lowest number of grains $hill^{-1}$ (479.70) was recorded from control treatment T_8 (no nutrient was applied) and it was significantly different from other treatments. Supported result was also observed by the findings of Islam *et al.* (2021), Hoque *et al.* (2021) and Singh *et al.* (2020) who reported positive effect of zinc on higher number of grains per panicle which resulted higher yield of rice.

Effect of different rice varieties

Different rice varieties showed significant variation for number of grains $hill^{-1}$ (Table 4 and Appendix VI). The highest number of grains $hill^{-1}$ (920.30) was achieved from the variety V_3 (BRRI dhan88) and it was statistically identical to the variety V_2 (BRRI dhan84). The lowest number of grains $hill^{-1}$ (714.20) was found from the variety V_1 (BRRI dhan74). This result is in agreed with the findings of Chamely *et al*. (2015) and Salam *et al*. (2019); they reported vital difference on grain production regarding grains per panicle due to varietal difference.

Combined effect of micronutrient Zn treatments and rice varieties

Treatment combination of micronutrient Zn and variety showed significant variation on number of grains $hill^{-1}$ of rice (Table 5 and Appendix VI). The treatment combination of T_1V_3 showed the highest number of grains $hill^{-1}$ (1161.00) and it was statistically same to the treatment combinations of T_1V_2 and T_2V_2. Again, T_8V_1 gave the lowest number of grains $hill^{-1}$ (986.00) and it was significantly different with other treatment combinations.

Table 5. Yield parameters of rice as influenced by combined effect of different Zn treatment and variety

Treatment combinations	Yield parameters			
	1000 seed weight (g)	Number of grains hill^{-1}	Grain weight hill^{-1} (g)	Grain yield ha^{-1} (t)
T_1V_1	28.88 a	738.70 h	21.27 cd	5.38 b
T_1V_2	21.35 de	1145.00 a	24.31 b	4.41 i
T_1V_3	23.52 c	1161.00 a	27.07 a	4.67 fg
T_2V_1	27.35 ab	699.30 i	19.14 fgh	3.37 k
T_2V_2	19.91 def	1141.00 a	22.02 cd	5.12 c
T_2V_3	19.48 ef	999.80 c	19.51 efg	4.49 hi
T_3V_1	27.68 ab	661.50 j	18.31 ghi	4.86 de
T_3V_2	21.47 cde	802.70 g	17.39 hij	4.76 ef
T_3V_3	20.00 def	861.70 e	17.18 ij	4.12 j
T_4V_1	28.49 ab	588.20 k	16.72 ij	5.21 c
T_4V_2	20.65 def	991.70 c	20.54 def	4.89 de
T_4V_3	20.36 def	940.80 d	19.10 fgh	4.91 d
T_5V_1	27.51 ab	986.00 c	27.12 a	5.73 a
T_5V_2	20.76 def	916.80 d	19.09 fgh	5.45 b
T_5V_3	19.74 def	1033.00 b	20.41 def	4.66 fg
T_6V_1	26.85 ab	849.20 ef	22.51 c	5.09 c
T_6V_2	21.28 def	829.20 fg	17.69 hij	4.04 j
T_6V_3	20.30 def	1042.00 b	21.10 cde	4.49 hi
T_7V_1	28.47 ab	558.80 l	15.97 j	4.59 gh
T_7V_2	21.72 cd	973.80 c	21.11 cde	4.39 i
T_7V_3	19.82 def	842.80 ef	16.69 ij	3.99 j
T_8V_1	26.63 b	418.30 n	11.25 k	2.26 l
T_8V_2	20.50 def	519.80 m	10.70 k	1.91 m
T_8V_3	19.26 f	501.00 m	9.98 k	1.84 m
$LSD_{0.05}$	2.084	27.86	1.758	0.137
CV(%)	5.51	11.01	13.73	11.74

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

4.3.3 Grain weight $hill^{-1}$

Effect of micronutrient Zn treatments

Different treatments of Zn had significant effect on grain weight $hill^{-1}$ (Table 4 and Appendix VI). The treatment T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) showed the highest grain weight $hill^{-1}$ (22.72 g) that was significantly same to the treatment T_2 (T_1 – 50% Zn), T_3 (T_1 – 100% Zn; T_1 but without Zn) and T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}). The lowest grain weight $hill^{-1}$ (10.64 g) was recorded from the control treatment T_8 (no nutrient was applied) that was significantly differed to other treatments.

Effect of different rice varieties

Different rice varieties showed significant variation on grain weight $hill^{-1}$ (Table 4 and Appendix VI). The variety V_1 (BRRI dhan74) gave the highest grain weight $hill^{-1}$(1981 g) and statistically similar result was observed by the variety V_2 (BRRI dhan84). The variety V_3 (BRRI dhan88) presented the lowestgrain weight $hill^{-1}$ (18.25 g) and it was significantly different to other rice varieties.

Combined effect of micronutrient Zn treatments and rice varieties

Grain weight $hill^{-1}$ of rice varied significantly due to combined effect of micronutrient Zn and variety (Table 5 and Appendix VI). The treatment combination of T_5V_1 gave the highest grain weight $hill^{-1}$ (27.12 g) and this result was statistically same to the treatment combinations of T_1V_3. Again, T_8V_3 gave the lowest grain weight $hill^{-1}$ (9.98 g) and it was statistically same with T_8V_1 and T_8V_2.

4.3.4 Grain yield ha^{-1}

Effect of micronutrient Zn treatments

Grain yield of rice differed significantly due to different micronutrient Zn treatments (Table 4 and Appendix VI). The treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40

kg ha^{-1}) gave the highest grain yield (5.28 t ha^{-1}) and this treatment showed signification variation to other treatments on grain yield followed by T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}). Again, the lowest grain yield (2.00 t ha^{-1}) was given by the control treatment T_8 (no nutrient was applied) and this was also significantly varied to other treatments. Hasnain *et al.* (2022) reported that Zn had significant positive effect to produce higher effective tiller number, panicle number, seeds per panicle and 1000 seed weight which resulted higher grain yield of rice; the present investigation was supported by the findings. Similar result was also observed by the findings of Islam *et al.* (2021), Hoque *et al.* (2021), Singh *et al.* (2020) and Roy (2018).

Effect of different rice varieties

Different rice varieties had significant variation on grain yield (Table 4 and Appendix VI). The highest grain yield (4.56 t ha^{-1}) was achieved from the variety V_1 (BRRI dhan74) and this variety gave significant variation with other varieties followed by the variety V_2 (BRRI dhan84). The lowest grain yield (4.16 t ha^{-1}) was found from the variety V_3 (BRRI dhan88). Salam *et al*. (2019), Chamely *et al*. (2015) and Jisan *et al*. (2014) observed that different variety had different capacity to produce effective tiller, panicle length, grains per panicle and 1000 seed weight which resulted yield variation on yield of rice among different rice varieties; this findings also supported the present study.

Combined effect of micronutrient Zn treatments and rice varieties

Treatment combination of different micronutrient Zn treatments and variety exhibited statistically significant variation on grain yield of rice (Table 5 and Appendix VI). The treatment combination of T_5V_1 revealed the highest grain yield (5.73 t ha^{-1}) and this grain yield varied significantly with other treatment combinations followed by T_1V_1 and T_5V_2. The lowest grain yield (1.84 t ha^{-1}) was given by T_8V_3 and this result was statistically identical to T_8V_2.

4.4 Quality parameters

4.4.1Zn content in rice grain

Effect of micronutrient Zn treatments

Application of micronutrient Zn treatments to ricehad significant variation on Zn content in rice grain (Table 6 and Appendix VII). The treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) gave the maximumZn content in rice grain (0.136 ppm) that was significantly varied with other treatments. Thecontrol treatment T_8 (no nutrient was applied) gave the minimum Zn content in rice grain (0.064 ppm) that was not significantly different to other treatments except T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) treatment. Alwahibi*et al.* (2020) reported Zn concentration in grain depends on application of Zn rate in rice field or residual Zn effect on rice field which supported the present findings.

Effect of different rice varieties

The recorded data on Zn content in rice grain was not varied significantly due to varietal different of rice (Table 6 and Appendix VII). However, the maximum Zn content in rice grain (0.095 ppm) was registered from the variety V_1 (BRRI dhan74) and the minimum Zn content in rice grain (0.070 ppm) was recorded from the variety V_2 (BRRI dhan84).

Combined effect of micronutrient Zn treatments and rice varieties

Zn content of rice grain of rice varied significantly due to combined effect of micronutrient Zn and varieties of rice (Table 7 and Appendix VII). The treatment combination T_5V_1 gave the maximum Zn content in rice grain (0.218 ppm) and this result was significantly different from other treatment combinations followed by

T_6V_3. Again, the treatment combination T_8V_2 gave the minimum Zn content in rice grain (0.046 ppm) and it was significantly same to the treatment combination of T_4V_1.

Table 6. Quality parameters of rice as influenced by different Zn treatment as well as different rice varieties

Treatments	Quality parameters	
	Zn content in grain (ppm)	Zn content in straw (ppm)
Effect of different Zn treatments		
T_1	0.090 b	0.137 d
T_2	0.084 b	0.167 cd
T_3	0.074 b	0.263 b
T_4	0.075 b	0.198 c
T_5	0.136 a	0.142 d
T_6	0.083 b	0.403 a
T_7	0.065 b	0.143 d
T_8	0.064 b	0.126 d
$LSD_{0.05}$	0.042	0.052
CV(%)	10.36	11.42
Effect of variety		
V_1	0.095	0.200
V_2	0.070	0.179
V_3	0.087	0.213
$LSD_{0.05}$	0.026^{NS}	0.048^{NS}
CV(%)	12.80	10.52

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

4.4.2 Zn content in straw

Effect of micronutrient Zn treatments

Different micronutrient Zn treatments to rice had significant effect on Zn content in rice straw (Table 6 and Appendix VII). The treatment T_6 (T_1 but Zn was applied by spraying) gave the maximum Zn content in rice straw (0.403 ppm) and it showed significant difference with other treatments followed by T_3 (T_1 – 100% Zn; T_1 but without Zn). The control treatment T_8 (no nutrient was applied) gave the minimum Zn content in rice straw (0.126 ppm) that was not significantly different to T_7 (Soil test based; STB) treatment. Alwahibi *et al.* (2020) also found similar result with the present study and reported that higher rate of Zn application to soil or higher residual Zn in rice field significantly increased Zn concentration in rice straw.

Effect of different rice varieties

Different rice varieties had non-significant influence on the Zn content in rice straw (Table 6 and Appendix VII). However, the maximum Zn content in rice straw (0.213 ppm) was registered from the variety V_3 (BRRI dhan88) and the minimum Zn content in rice straw (0.179 ppm) was recorded from the variety V_2 (BRRI dhan84).

Combined effect of micronutrient Zn treatments and rice varieties

Zn content of rice straw varied significantly due to combined effect of micronutrient Zn and varieties of rice (Table 7 and Appendix VII). The treatment combination T_6V_3 gave the maximum Zn content in rice straw (0.573 ppm) and this result was significantly different from other treatment combinations followed by T_6V_1. Again the treatment combination T_8V_2 gave the minimum Zn content in rice straw (0.088 ppm) and it was significantly similar to the treatment combination of T_1V_1, T_2V_2, T_2V_3, T_4V_2 and T_5V_2.

Table 7. Quality parameters of rice as influenced by combined effect of different Zn treatment and variety

Treatment combinations	Quality parameters	
	Zn content in grain	Zn content in straw
T_1V_1	0.101 bc	0.128 ef
T_1V_2	0.086 bc	0.196 de
T_1V_3	0.082 bc	0.404 bc
T_2V_1	0.081 bc	0.142 def
T_2V_2	0.062 bc	0.110 ef
T_2V_3	0.108 bc	0.127 ef
T_3V_1	0.078 bc	0.161 def
T_3V_2	0.063 bc	0.151 def
T_3V_3	0.069 bc	0.224 d
T_4V_1	0.051 c	0.146 def
T_4V_2	0.071 bc	0.120 ef
T_4V_3	0.102 bc	0.328 c
T_5V_1	0.218 a	0.145 def
T_5V_2	0.093 bc	0.131 ef
T_5V_3	0.078 bc	0.148 def
T_6V_1	0.078 bc	0.457 b
T_6V_2	0.064 bc	0.178 def
T_6V_3	0.125 b	0.573 a
T_7V_1	0.064 bc	0.154 def
T_7V_2	0.076 bc	0.139 def
T_7V_3	0.055 bc	0.136 def
T_8V_1	0.087 bc	0.154 def
T_8V_2	0.046 c	0.088 f
T_8V_3	0.073 bc	0.195 de
$LSD_{0.05}$	0.074	0.090
CV(%)	12.80	10.52

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), T_2 = T_1 – 50% Zn, T_3 = T_1 – 100% Zn (T_1 but without Zn), T_4 = T_1 + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), T_5 = T_1 + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), T_6 = T_1 but Zn was applied by spraying, T_7 = Soil test based (STB), T_8 = Control/native supply of nutrient (No nutrient was applied)

V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88

CHAPTER V

SUMMARY AND CONCLUSIONS

The experiment was carried out during the period of December 2020 to May 2021 at Bangladesh Rice Research Institute research field, Sonagazi, Feni, Bangladesh to find out the effect of micronutrient zinc on the performance of modern rice varieties. The experiment consisted of two factors: Factor A: zinc application (8 levels) *viz*. T_1 = Recommended rate: Urea, TSP, MoP, Gypsum, and Zinc sulfate (Monohydrate) @ 270, 112, 150 and 11 kg ha^{-1} (N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}), $T_2 = T_1$ – 50% Zn, $T_3 = T_1$ – 100% Zn (T_1 but without Zn), $T_4 = T_1$ + 50% higher Zn ($ZnSO_4$: 13.20 kg ha^{-1}), $T_5 = T_1$ + 100% higher Zn ($ZnSO_4$: 15.40 kg ha^{-1}), $T_6 = T_1$ but Zn was applied by spraying, T_7 = Soil test based (STB) and T_8 = Control/native supply of nutrient (No nutrient was applied) and Factor B: three rice varieties *viz*. V_1 = BRRI dhan74, V_2 = BRRI dhan84, V_3 = BRRI dhan88. The experiment was laid out in Split Plot Design with three replications. Data on different growth, yield contributing parameters, and Zn content in rice grain and straw were recorded and analyzed statistically.

Different levels of micronutrient zinc (Zn) showed significant variation on most of the studied parameters regarding growth, yield and yield contributing parameters, yield and Zn content of rice. Results revealed that the maximum plant height (90.44 cm), number of tillers $hill^{-1}$ (14.22) and number of tillers m^{-2} (472.00) were recorded from the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) but the control treatment T_8 (no nutrient was applied) gave the minimum plant height (75.33 cm), number of tillers $hill^{-1}$ (7.80) and number of tillers m^{-2} (259.90) and these parameters were recorded at the time of harvest. The highest days to 50% flowering (112.80 days) and days to maturity (141.00 days) were recorded from T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) and T_4 (T_1 + 50% higher Zn; $ZnSO_4$: 13.20 kg ha^{-1}), respectively, whereas the lowest (110.80 and 137.70 days,) were recorded from treatment T_3 (T_1 – 100% Zn; T_1 but without Zn) and T_8 (control; no nutrient was applied), respectively. Again, the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) showed the highest number of panicles $hill^{-1}$ (11.56), number of panicles m^{-2} (385.00) and grain yield (5.28 t ha^{-1}) but treatment T_1 (Recommended rate: N, P, K, S and Zn @ 124, 22, 75, 20 and 4 kg ha^{-1}) gave the highest number of grains $hill^{-1}$ (988.00) and grain weight $hill^{-1}$ (22.72 g) but the control treatment T_8 (no nutrient was applied) provided the lowest number of panicles $hill^{-1}$ (6.50), number of panicles m^{-2} (217.10), number of grains $hill^{-1}$ (479.70), grain weight $hill^{-1}$ (10.64 g) and grain yield (2.00 t ha^{-1}). Similarly, Treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) also showed maximum Zn content in grain (0.136 ppm) but the maximum Zn content in straw (0.403 ppm) was acquired from T_6 (T_1 but Zn was applied by spraying) whereas the minimum (0.064 and 0.126 ppm, respectively) were recorded from control treatment T_8 (no nutrient was applied).

Among three rice varieties, V_2 (BRRI dhan84) performed the highest plant height (93.42 cm) whereas the lowest (76.96 cm) was recorded from V_3 (BRRI dhan88). Again, the highest number of tillers $hill^{-1}$ (13.43) and number of tillers m^{-2} (446.30) were achieved by V_3 (BRRI dhan88), whereas V_2 (BRRI dhan84) gave the lowest results (11.41 and 377.20, respectively). The highest days required for 50% flowering (115.50 days) and the highest days to maturity (145.80 days) was recorded by V_1 (BRRI dhan74) and V_2 (BRRI dhan84), respectively, while the minimum days to 50% flowering and maturity (108.50 and 136.70 days, respectively) were achieved by V_3 (BRRI dhan88). The maximum number of panicles $hill^{-1}$ (11.07), number of panicles m^{-2} (369.60), grain weight $hill^{-1}$ (19.81 g) and grain yield (4.56 t ha^{-1}) were produced by V_1 (BRRI dhan74) but the maximum number of grains $hill^{-1}$ (920.30) was found by V_3 (BRRI dhan88) whereas V_2 (BRRI dhan84) showed minimum number of panicles $hill^{-1}$ (9.47), number of panicles m^{-2} (315.70) while the variety V_3 (BRRI dhan88) gave minimum grain weight $hill^{-1}$ (18.25 g) and grain yield (4.16 t ha^{-1}). Different varieties showed non-significant variation on Zn content in grain and straw among them, however, the maximum Zn content in grain (0.095 ppm) and in straw (0.213 ppm) were recorded from V_1 (BRRI dhan74) and V_3 (BRRI dhan88), respectively, whereas V_2 (BRRI dhan84) gave the lowest Zn content in grain and straw (0.070 and 0.179 ppm, respectively).

Considering the combined effect of Zn treatments and variety showed all the studied parameters significant. The highest plant height (98.67 cm) was recorded from T_5V_2 but T_5V_3 gave the highest number of tillers hill^{-1} (16.67) and number of tillers m^{-2} (557.70), whereas T_8V_3 showed the lowest plant height (66.00 cm), number of tillers hill^{-1} (7.80) and number of tillers m^{-2} (260.30). Again, the maximum days to 50% flowering (117.00 days) and maturity (146.70 days) were recorded from T_5V_1 and T_4V_2 while the highest number of panicles hill^{-1} (12.67), panicles m^{-2} (425.00), grain weight hill^{-1} (27.12 g) and grain yield (5.73 t ha^{-1}) were given by T_5V_1, whereas the highest 1000 seed weight (28.88 g) and number of grains hill^{-1} (1161.00) were recorded from T_1V_1 and T_1V_3, respectively. Reversely, the lowest number of panicles hill^{-1} (6.13) and panicles m^{-2} (204.70) were recorded from T_8V_2 but the lowest number of grain weight hill^{-1} (418.30) was recorded from T_8V_1 whereas T_8V_3 produced the lowest grain weight hill^{-1} (9.98 g) and grain yield (1.84 t ha^{-1}). In case of Zn content of grain weight and straw, the maximum (0.218 and 0.573 ppm, respectively) were given by T_5V_1 and T_6V_3 , respectively whereas T_8V_2 gave the minimum Zn content in grain and straw (0.046 and 0.088 ppm, respectively).

Conclusions:

From the present study, the following conclusion may be drawn –

1. Among the varieties, BRRI dhan74 and BRRI dhan84 was considered as Zn enriched varieties and BRRI dhan88 variety was considered as without Zn.
2. Individual effect of micronutrient zinc on growth and yield of rice was found significant for most of the parameters except days to 50% flowering and 1000

seed weight (g). Treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) gave the promising result on grain yield of rice with achieving of higher number of panicles $hill^{-1}$ (11.56), number of panicles m^{-2} (385.00) and grain weight $hill^{-1}$ (22.60 g) compared to control.

3. Different rice varieties showed significant variation on maximum parameters of the study except Zn content in grain and straw. The variety V_1 (BRRI dhan74) showed best performance regarding yield contributing parameters, yield and quality of rice and this variety showed the yield of 4.56 t ha^{-1} with highest grain weight $hill^{-1}$ (19.81 g).
4. Treatment combination of Zn treatments and variety, T_5V_1 gave the maximum number of tillers $hill^{-1}$ (16.67), number of tillers m^{-2} (557.70), number of panicles $hill^{-1}$ (12.67), number of panicles m^{-2} (425.00) and grain weight $hill^{-1}$ (27.12 g) which resulted the maximum grain yield of rice (8.53 t ha^{-1}) with this treatment combination compared to others.
5. Regarding Zn content of rice grain, T_5V_1 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1} with BRRI dhan74) showed maximum Zn enrichment (0.218 ppm) but maximum Zn enrichment in straw (0.573 ppm) was recorded from T_6V_3 (T_1 but Zn was applied by spraying with BRRI dhan88).
6. Therefore, the treatment combination, T_5V_1 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1} with BRRI dhan74) can be considered as best regarding yield of rice and Zn enrichment in grain compared to other treatment combination.

Recommendation

Based on overall performances, it could be concluded that the treatment T_5 (T_1 + 100% higher Zn; $ZnSO_4$: 15.40 kg ha^{-1}) might be recommended for sustainable cultivation of modern rice varieties to obtain higher yield and better Zinc content. Further research works at different regions of the country are needed to be carried out for the confirmation of the present findings.

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APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location

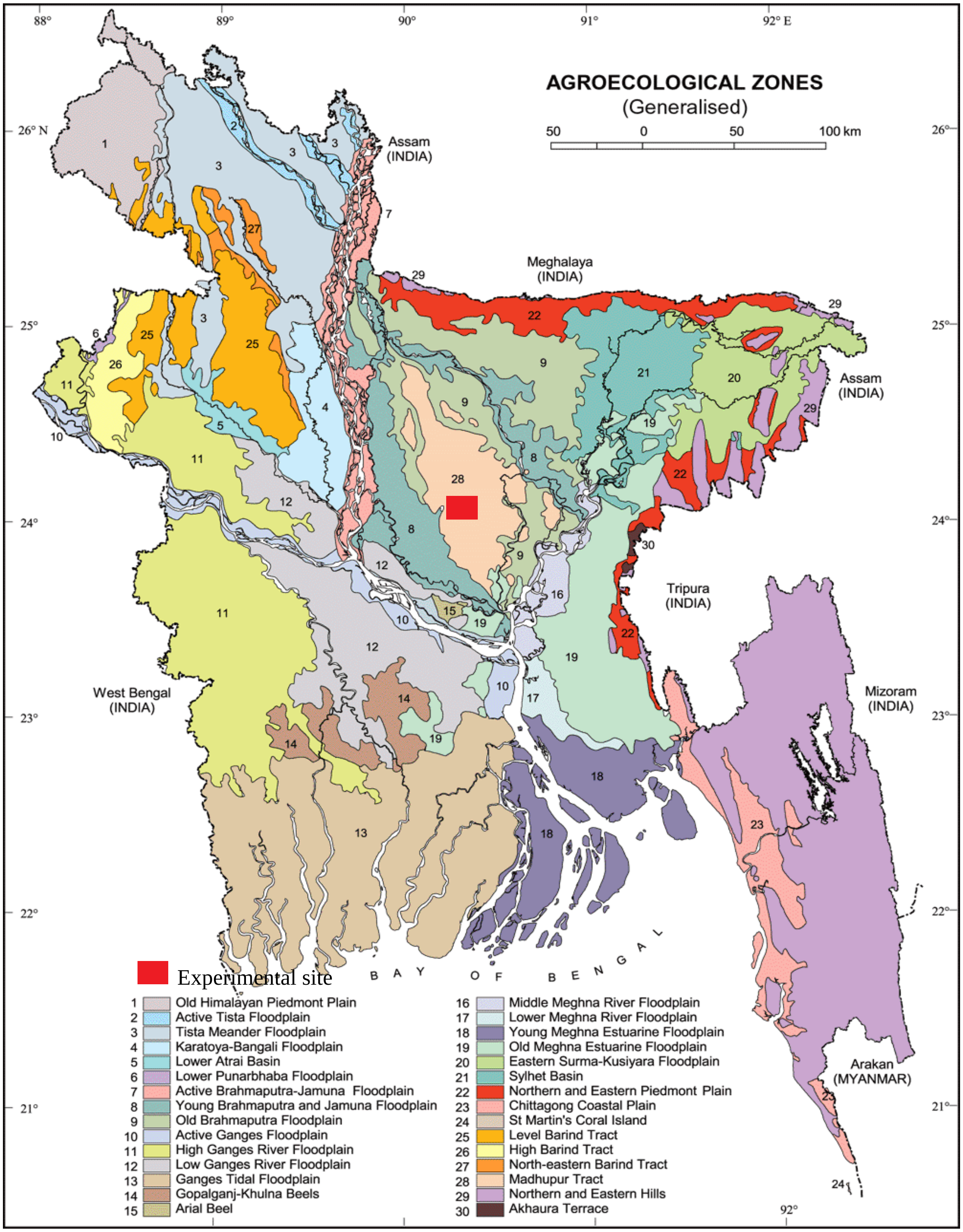

Figure. 7. Experimental site

Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from December 2020 to May 2021.

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2020	December	23.26	11.23	17.30	69.80	0.0
2021	January	26.60	12.34	18.74	72.08	0.0
2021	February	31.31	17.01	24.16	73.13	0.0
2021	March	34.03	21.84	27.92	64.99	0.0
2021	April	35.72	24.33	30.02	70.90	3.0
2021	May	34.06	26.76	30.41	75.77	125.0

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix III. Characteristics of experimental soil analyzed at Bangladesh Rice Research Institute (BRRI), Sonagazi, Feni.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	BRRI, Sonagazi, Feni
AEZ	19
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

Source: Bangladesh Rice Research Institute (BRRI)

B. Physical and chemical properties of the initial soil at BRRI Regional Station, Sonagazi, Feni.

Characteristics	**Value**
%Silt	68
% Clay	29
%Silt+ Clay	97
Textural class	Silty Clay Loam (USDA)
pH	6.2
Organic carbon (%)	1.24
Organic matter (%)	2.13
Total N (%)	0.063
Available P (ppm)	6.4
Exchangeable K (meq/100 g soil)	0.22
Available S (ppm)	55.00

Source: Bangladesh Rice Research Institute (BRRI)

Appendix IV. Mean square of growth parameters of rice as influenced by different Zn treatment as well as different rice varieties

Sources of variation	Degrees of freedom	Mean square of growth parameters		
		Plant height (cm)	Number of tillers hill^{-1}	Number of tillers m^{-2}
Replication	2	91.292	2.768	2637.514
Factor A	7	234.617*	36.564*	39726.79*
Error	14	312.306	99.356	8154.942
Factor B	2	1996.54*	24.613*	28658.39*
AB	14	12.081*	2.680**	2977.246*
Error	32	12.701	0.251	46.296

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

Appendix V. Mean square of yield contributing parameters of rice as influenced by different Zn treatment as well as different rice varieties

Sources of variation	Degrees of freedom	Mean square of yield contributing parameters			
		Days to first flowering	Days to maturity	Number of panicles hill^{-1}	Number of panicles m^{-2}
Replication	2	5.181	0.681	1.431	1975.014
Factor A	7	4.762^{NS}	10.794*	23.90*	26623.99*
Error	14	7.006	2.109	3.667	6885.522
Factor B	2	307.34*	563.09*	15.67*	17722.09*
AB	14	3.363**	2.669**	1.688**	1916.891*
Error	32	0.905	2.130	0.215	29.434

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

Appendix VI. Mean square of yield parameters of rice as influenced by different Zn treatment as well as different rice varieties

Sources of variation	Degrees of freedom	Mean square of yield parameters			
		1000 seed weight (g)	Number of grains hill^{-1}	Grain weight hill^{-1} (g)	Grain yield ha^{-1} (t)
Replication	2	8.561	53163.566	52.723	4.540
Factor A	7	1.213^{NS}	241936.88*	126.35*	9.143*
Error	14	1.757	53816.808	24.661	0.657
Factor B	2	417.6	512709.26*	15.775*	0.988**
AB	14	1.970	30582.875*	16.418*	0.698**
Error	46	1.608	287.323	1.144	0.382

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

Appendix VII. Mean square of quality parameters of rice as influenced by different Zn treatment as well as different rice varieties

Sources of variation	Degrees of freedom	Mean square of quality parameters	
		Zn content in grain	Zn content in straw
Replication	2	0.001	0.041
Factor A	7	0.005**	0.080**
Error	14	0.002	0.012
Factor B	2	0.004^{NS}	0.007^{NS}
AB	14	0.003**	0.031**
Error	32	0.002	0.003

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

Appendix VIII. Field layout of the experiment

V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V3	V2	V1	V3	V2	V1	V3	V2
V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V2	V1	V3	V2	V1	V3	V2	V1
V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V1	V3	V2	V1	V3	V2	V1	V3
T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T4**	**T6**	**T7**	**T1**	**T3**	**T8**	**T2**	**T5**	**T7**	**T6**	**T8**
R1								**R2**										

Factor A. Nutrient levels

T_1 = Recommended rate: Urea, TSP, MOP, Gypsum & Zinc sulfate (Monohydrate) @ 270, 112, 150, 112 & 11 kg ha
75, 20 and 4.0 kg ha^{-1})

$T_2 = T_1$-50% Zn

$T_3 = T_1$ –100% Zn (T_1, but without Zinc)

$T_4 = T_1$ + 50% higher Zn (ZnSO4: 13.2 kg ha^{-1})

$T_5 = T_1$ + 100% higher Zn (ZnSO4: 15.4 kg ha^{-1})

$T_6 = T_1$ but Zn will be applied by spraying

T_7 = Soil test based (STB)

T_8 = Control/Native supply of nutrient (No nutrient will be applied)

Factor B. Rice variety: V_1=BRRI dhan74, V_2=BRRI dhan84, V_3=BRRI dhan88

Figure 8 Field layout of the Experiment

Plate 1. Prepared experiment field showing layout

Plate 2. Transplantation of rice seedlings in the experiment field

Plate 3. Maturity stage of rice (time of harvesting)

Plate 4. Harvesting of rice from 1 m^{-2} area (sample) in the experiment field

Plate 5. Collection of harvested sample of rice from 1 m^{-2} area in the experiment field

Plate 6. Post harvest operation (sample) of rice

Plate 7. Grain counting for 1000 seed weight

Plate 8. Weighing of 1000 grains