EFFECT OF ZINC ON THE PERFORMANCE OF RICE VARIETIES

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CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF ZINC ON THE PERFORMANCE OF 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 **PRIA RANI**, Registration No. **19-10332** 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

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Dedicated to
My
Beloved Parents

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The Author

EFFECT OF ZINC ON THE PERFORMANCE OF RICE VARIETIES

ABSTRACT

The experiment was conducted during December 2020 to June 2021 in the farm of Sher-e-Bangla Agricultural University to study the effect of micronutrient zinc on the performance of rice varieties. The experiment consisted of two factors: Factor A: two varieties *viz*. V_1 (BRRI dhan84) and V_2 (BRRI dhan88) and Factor B: eight Zn treatments *viz*. T_1 (STB-RD; N, P, K, S, Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1}), T_2 (T_1 – Zn; T_1 without Zn), T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application), T_5 (T_1 but Zn applied as foliar application), T_6 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as foliar application) T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) and T_8 (control/native supply of nutrients; no nutrient was applied). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Between two varieties, V_2 (BRRI dhan88) gave best performance on different parameters and gave maximum grain yield (5.62 t ha^{-1}) in comparison to V_1 (BRRI dhan84). This variety also showed maximum nutrient content (organic carbon, P and S) in post harvest soil. Among different treatments, T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed best performance on different growth and yield parameters and gave maximum grain yield (7.12 t ha^{-1}) and also showed higher nutrients content (P, K and S) in post harvest soil compared to other treatments. Among different treatment combinations of variety and zinc, V_2T_4 gave the maximum number of tillers $hill^{-1}$ (17.55), number of effective tillers $hill^{-1}$ (16.11), panicle length (27.34 cm), number of filled grains $panicle^{-1}$ (161.70), grain yield (7.39 t ha^{-1}), straw yield (8.47 t ha^{-1}) and harvest index (46.60%) whereas the minimum was recorded from V_1T_8 (BRRI dhan84 × control/native supply of nutrients; no nutrient was applied). So, the treatment combination of V_2T_4 (BRRI dhan88 × T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) can be considered as the best compared to the rest of the treatment combinations.

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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	=	Mili Litre
M.S.	=	Master of Science
No.	=	Number
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
^oC	=	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

In Bangladesh, rice (*Oryza sativa* L.) is the main crop as a source of food and over 95% people depend on rice for their daily diets and it engages over 85% of the total agricultural labour force in Bangladesh. Agriculture sector contributes about 13.31% to the country's Gross Domestic Product (GDP) and employs more than 49 percent of total labour force (BBS, 2019). Rice is cultivated in Bangladesh throughout the year as *aus*, *aman* or *boro*. Aman (broadcast and transplanted) is generally cultivated from June-July to October-November, Boro from December-January to April-May, and Aus from March-April to June-July. According to BBS (2020) *aus*, *aman* and *boro* produced 2756, 14204 and 19646 metric tons of rice from 2706, 13740 and 11767 thousand acres of land, respectively. Among three growing seasons *Boro* rice occupies the highest area coverage (45% of gross cropping area). There are 2189 thousand acres of land were under hybrid rice cultivation in Bangladesh and produced 4127 metric ton rice (BBS, 2020).

Yearly increment of rice production in Bangladesh needs to be sustained to feed her ever increasing population. But there is a little scope to increase rice area (Sarker *et al*., 2008) rather agricultural land is declining @ 0.7% per annum (BBS, 2011). Despite the steady and significant progress made in rice production over the past 25 years, the recent yield level of modern rice varieties has been reached to a plateau (Bhuiyan, 2002). For breaking the yield ceiling of conventional varieties, HYV and hybrid rice is a viable option and appropriate strategy and also it is readily available (Kumar *et al*., 1998; Longping, 2004).

Variety plays an important role for successful crop production. Significant variation was found due to varietal difference on yield of rice. HYV and hybrid rice varieties have 15-30% yield advantage over local inbred (Julfiquar *et al*., 2009; Abou Khalif, 2009). Slow senescence and more strong photosynthetic capability of flag leaf, higher LAI at grain filling period and higher post heading-CGR plays major role for higher yield formation in hybrid rice. Greater biomass accumulation before heading and higher shoot reserve translocation are the decisive factors of higher yield in HYV rice (Haque *et al*., 2015).

In recent years, there has been an increase in consumer preference for meals notably micronutrients, that are helpful to health and well-being. One-third of the world's population suffers from zinc deficiency (Zhang *et al.*, 2012). Zinc is essential for all humans, animals, and plants (Zou *et al.*, 2012). It is essential for the appropriate functioning of the immune system as well as for children's healthy growth, and physical and mental development. Zn is the 5th leading cause of illness in low-income countries. For effective zinc nutrition, one person requires 15 mg Zn day^{-1} but our food grains contain only 15–35 mg Zn kg^{-1} (Cakmak, 2012), and out of which only 13–35% are bio-available. So, there is a big gap between daily requirements and daily intake and to fulfil the gap our food grains should contain 40-60 mg Zn kg^{-1} (Wei *et al.*, 2012).

Zinc is one of the most important micronutrients essential for plant growth especially for rice grown under submerged conditions. Zn deficiency is the most widespread micronutrient disorder in lowland rice and application of Zn along with NPK fertilizer increases the grain yield dramatically in most cases (Fageria *et al*., 2011; Singh *et al*., 2011).

Plants take up zinc in the form of Zn^{2+} ions. Diffusion is believed to be the dominant mechanism for Zn^{2+} transport to plant roots (Rashid, 2001). The critical index of effective zinc in the soil suitable for rice growth is 1.5 mg kg^{-1} (Yin, 2016). Average up take of zinc is 0.05 kg t^{-1} of grain, of which 60% remains in the straw at maturity (IRRI, 2000). As a result, it is essential to assess the optimum dose of zinc fertilizer for hybrid rice varieties in Bangladesh. Under the aforementioned conditions, the current experiment was carried out with the following goals in mind:

1. To evaluate the performance of the rice varieties under a range of zinc application
2. To find out the optimum zinc level for higher yield and yield components of boro rice.

CHAPTER II

REVIEW OF LITERATURE

Rice is an important food crop in Bangladesh which can contribute largely in the national economy. Investigation on the effect of micronutrient zinc on the performance of zinc enrichment of rice varieties have been progressed in many countries of the world. The proper agronomic practices accelerate its growth and influenced its yield. Therefore, available findings of the effect of variety and zinc management including different fertilizers relevant to the present study have been briefly reviewed under the following heads.

2.1 Varietal performance of rice

An investigation carried out by Rahman *et al.* (2022) to evaluate growth, morphology and yield performance of five hybrid and two inbred salt tolerant rice varieties. It was reported that based on the morphological performance, hybrid rice namely Hira-2 followed by Tejgold and HYV rice namely Binadhan-10 produced the highest grain yield due to increased seed width, 1000 seed weight and total dry matter production.

Khatun (2020) conducted a field experiment with six rice varieties and reported maximum number of filled spikelet/panicle (164.89), maximum 1000-seed weight (27.25 g) and highest grain yield (6.13 t ha^{-1}) in Binadhan-17 compared to BRRI dhan39, BRRI dhan33 and Binadhan-16 while BRRI dhan39 showed lowest grain yield (4.49 t ha^{-1}).

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

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

Mahmood *et al*. (2019) conducted an experiment to evaluate the performance of hybrid *Boro* rice (genotypes) in coastal area of Bangladesh. The experiment consisted of five rice varieties as treatment such as Arize Tej, Tea Sakti, Shathi and BRRI Dhan28. Among the five varieties the Arize Tej gave the highest performance. From the above investigated results, it was observed that the Arize Tej was the most efficient for better growth and higher yield of hybrid *Boro* rice genotypes grown in coastal area of Bangladesh.

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

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

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

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

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

Hosain *et al*. (2014) conducted an experiment to observe the effect of transplanting dates on the yield and yield attributes of exotic hybrid rice varieties. The experiment comprised of three rice varieties (two hybrids-Heera2, Aloron and one inbred- BRRI dhan48) and four transplanting dates *viz*. 16th March, 31st March, 15th April and 30th. BRRI dhan48 produced the highest grain yield (3.51 t ha^{-1}) whereas the hybrid varieties Heera2 (3.03 t ha^{-1}) and Aloron (2.77 t ha^{-1}) achieved lower grain yield due to higher spikelet sterility. BRRI dhan48 produced the highest grain yield (4.91 t ha^{-1}) at 16th March transplanting.

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

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

An experiment was conducted to study morphological, yield and yield contributing characters of four *Boro* rice varieties of which three were local *viz*., Bashful, Poshursail and Gosi; while another one was a high yielding variety

(HYV) BRRI dhan28. The BRRI dhan28 were significantly superior among the cultivars studied. The BRRI dhan28 was shorter in plant height, having more tillering capacity, higher leaf number which in turn showed superior growth character and yielded more than those of the local cultivars. The HYV BRRI dhan28 produced higher number of grains panicle^{-1} and bolder grains resulted in higher grain yield over the local cultivars. Further, BRRI dhan28 had more total dry mass than those of local varieties. The BRRI dhan28 produced higher grain yield (7.41 t ha^{-1}) than Bashful, Poshurshail and Gosi, respectively. Among the local rice cultivars, Gosi showed the higher yielding ability than Bashful and Poshursail (Sarker *et al.,* 2013).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Islam (2015) carried out an experiment to study the effect of zinc and *Boro*n on the growth and yield of T. Aman rice (BRRI dhan34). Two factors were comprised with study viz. factor A: B_0 = 0 kg B ha^{-1}, B_1 = 2 kg B ha^{-1} and B_2 = 4 kg B ha^{-1} and Factor B: Zn_0 = 0 kg Zn ha^{-1}, Zn_1 = 2 kg Zn ha^{-1} and Zn_2 = 4 kg Zn ha^{-1}. Results indicated that the highest straw weight ha^{-1} (8.07 t) was recorded from B_1Zn_1; the number of total tiller hill^{-1} (19.81) and effective tiller hill^{-1} (14.53) were found in B_1Zn_0. Again, the longest panicle (25.28 cm), filled grains panicle^{-1} (143.60), total grains panicle^{-1} (161.40), grain weight ha^{-1} (5.72 t ha^{-1}) and harvest index (45.77%) were recorded from B_2Zn_2. The tallest plant (132.30 cm), non-effective tiller hill^{-1} (5.55) and un-filled grain panicle^{-1} (56.52) were achieved from the treatment combination of B_1Zn_2, B_0Zn_2 and B_0Zn_0 respectively. The treatment combination B_2Zn_2 performed better for increasing the yield of T. Aman rice and improved the nutrient status of post-harvest soil of AEZ 28.

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

Gomaa *et al.* (2015) observed that the highest mean values of yield and its components i.e. panicle weight (2.38 g), number of filled grains $panicle^{-1}$ (112.73), number of panicles m^{-2} (482.2), 1000 grain weight (22.15 g), grain yield (3.80 tons ha^{-1}) and straw yield (5.05 tons ha^{-1}) of rice were recorded from treatment (soil + foliar) of Zn in combination with 50% Mineral Nitrogen + 50% organic Nitrogen.

Shivay *et al*. (2015) observed that application of 5 kg Zn ha^{-1} (soil) + 1 kg Zn ha^{-1} (foliar) recorded the highest grain yield (4.52 t ha^{-1}), straw yield (8.12 t ha^{-1}), tillers m^{-2} (342), grains $panicle^{-1}$ (94), 1,000 grain weight (22.7 g) of rice which was significantly more than soil application of ZnS or Zn-coated urea (ZnCu).

Sharmin (2014) conducted an experiment to find out the influence of sulphur and zinc on yield of transplanted (T.) aman rice. BRRI dhan34 was used as the test crop in this experiment. The experiment consisted of two factors. Factor A: 3 levels of sulphur (S_0: 0 kg S ha^{-1}, S_1: 8.0 kg S ha^{-1}, S_2: 12.0 kg S ha^{-1}) and Factor B: 4 levels of zinc (Zn_0: 0 kg Zn ha^{-1}, Zn_1: 1.0 kg Zn ha^{-1}, Zn_2: 2.0 kg Zn ha^{-1}, Zn_3:

3.0 kg Zn ha^{-1}). For different levels of zinc, the highest yield and yield contributing characters were recorded from Zn_3, whereas the lowest was recorded from Zn_0. Due to the interaction effect of different levels of sulphur and zinc, the maximum number of total tillers $hill^{-1}$ (20.60), the longest panicle (29.65 cm), the highest grain yield (4.00 t ha^{-1}) and the highest straw yield (5.36 t ha^{-1}) were recorded from S_2Zn_3, whereas the minimum result was recorded from S_0Zn_0.

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

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

Kabeya and Shanker (2013) recorded that the treatment receiving 30 kg $ZnSO_4$ ha^{-1} showed the highest SPAD (Soil Plant Analysis Development) value (57) in rice. The highest straw dry matter (41 g) and leaf dry matter (28 g) in rice was also obtained from 30 kg $ZnSO_4$ ha^{-1} treatment, the lowest was obtained in control.

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

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

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

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

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

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

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

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

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

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

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

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

Rahman (2007) conducted a field experiment with an objective of evaluating the effect of S and Zn on the yield, yield components and nutrient uptake by T-Aman (BRRI dhan31). There were twelve treatments taking various doses of Sulphur and Zinc viz. S_0Zn_0 (control), S_0Zn_1, S_0Zn_2, $S_{12}Zn_0$, $S_{12}Zn_1$, $S_{12}Zn_2$, $S_{16}Zn_0$, $S_{16}Zn_1$, $S_{16}Zn_2$, $S_{20}Zn_0$, $S_{20}Zn_1$ and $S_{20}Zn_2$. The subscripts represent doses in kg ha^{-1}. The application of Sulphur and Zinc had a positive significant effect on tillers hill^{-1}, plant height, panicle length and number of grains panicle^{-1}. The highest grain yield

(4.20 t ha^{-1}) and straw yield (5.62 t ha^{-1}) of BRRI dhan31 was recorded in $S_{20}Zn_2$ treatment. The S_0Zn_0 treatment (control) had the lowest grain (3.01 t ha^{-1}) and straw yield (4.50 t ha^{-1}). Overall results indicate that the application of S and Zn at a rate of 20 kg S and 2 kg Zn ha^{-1} along with recommended dose of N, P, and K is necessary for obtaining maximum grain yield as well as straw yield of T-Aman rice.

Naik and Das (2007) reported that the soil application of Zn @ 1.0 kg ha^{-1} as Zn-EDTA showed the highest grain yield (5.42 t ha^{-1}) of rice, filled grain percentage (90.2%), 1000-grains weight (25.41 g), and number of panicles m^{-2} (452) compared to basal application of $ZnSO_4.7H_2O$.

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

Sarker (2007) conducted a field experiment to find out the performance of Aman rice as influenced by nitrogen and zinc on the yield of BRRI Dhan 39. There were 16 treatments combinations comprising of four levels of N (0, 50, 100 and 150 kg N ha^{-1}) and four levels of Zn (0, 5, 10 and 15 kg Zn ha^{-1}). Plant height, total tillers, effective tillers and panicle length increased significantly with increasing Zn application up to 5 kg Zn ha^{-1}, while the number of filled grain $panicle^{-1}$, grain yield and straw yield enhanced with increasing Zn doses up to 10 kg Zn ha^{-1}. However, the application of 15 kg Zn ha^{-1} had a significant negative effect on grain yield but not on straw yield. The T_{11} (N_2Zn_2) treatment combination at the rate of 100 kg N ha^{-1} and 10 kg Zn ha^{-1} perform better than other treatments in this present trial considering rice yield and yield contributing parameters.

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

Ram *et al*. (2005) observed the maximum number of filled grains $panicle^{-1}$ in rice plants from the combined application of 20 kg $ZnSO_4$ ha^{-1} as basal + three times foliar sprays of 0.5% $ZnSO_4$ solution initiated from 20 DAT at 10 days interval.

Sultana (2005) was conducted a field experiment with an objective of evaluating the effects of S and Zn on the yield, yield components and nutrient uptake of *Boro* rice (cv. BRRI dhan 29). There were seven treatments taking various doses of S and Zn viz. S_0Zn_0 (control), $S_{20}Zn_0$, S_0Zn_3, $S_{20}Zn_3$, $S_{10}Zn_0$, $S_oZn_{1.5}$ and $S_{10}Zn_{1.5}$, the subscripts represent doses in kg ha^{-1}. The application of S and Zn had a significant positive effect on the tillers $hill^{-1}$, plant height, panicle length and grains $panicle^{-1}$. The highest grain (5110 kg ha^{-1}) and straw yields (5812 kg ha^{-1}) of rice were recorded in the $S_{20}Zn_3$ treatment (country's recommended dose). The S_0Zn_0 (control) treatment had the lowest grain (2832 kg ha^{-1}) and straw yields (3199 kg ha^{-1}). Overall results indicate that the application of S and Zn at a recommended rate i.e. 20 kg S and 3 kg Zn ha^{-1} along with recommended rate of N, P and K is necessary for obtaining higher grain yield as well as straw yield of *Boro* rice.

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

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

CHAPTER III

MATERIALS AND METHODS

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

3.1 Description of the experimental site

3.1.1 Experimental period

This research work was carried out within December, 2020 to June, 2021.

3.1.2 Experimental location

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

3.1.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February, the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al*., 1979). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during study period has been presented in Appendix II.

3.1.4 Soil characteristics

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

3.2 Experimental details

3.2.1 Treatment of the experiment

The experiment consisted of two factors:

Factor A: Variety

1. V_1 = BRRI dhan84
2. V_2 = BRRI dhan88

Factor B: Nutrients application

1. T_1 = Soil test based (STB) recommended dose; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1})
2. T_2 = T_1 – Zn (T_1, but without Zn)
3. T_3 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application)
4. T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application)
5. T_5 = T_1 (Zn applied as foliar application)
6. T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application)
7. T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application)
8. T_8 = Control/native supply of nutrients (No nutrient was applied)

There were total 16 (8×2) treatment combinations as a whole *viz.*, V_1T_1, V_1T_2, V_1T_3, V_1T_4, V_1T_5, V_1T_6, V_1T_7, V_1T_8, V_2T_1, V_2T_2, V_2T_3, V_2T_4, V_2T_5, V_2T_6, V_2T_7 and V_2T_8 with 3 replications, total number of plots were 48.

3.2.2 Experimental design and layout

The two factors experiment was laid out in Randomized Complete Block Design (Factorial) with three replications. The whole experimental area was divided into three equal blocks, each representing a replication. The size of each unit plot was 2.50 m × 1.75 m.

3.3 Growing of crops

3.3.1 Seed collection and sprouting

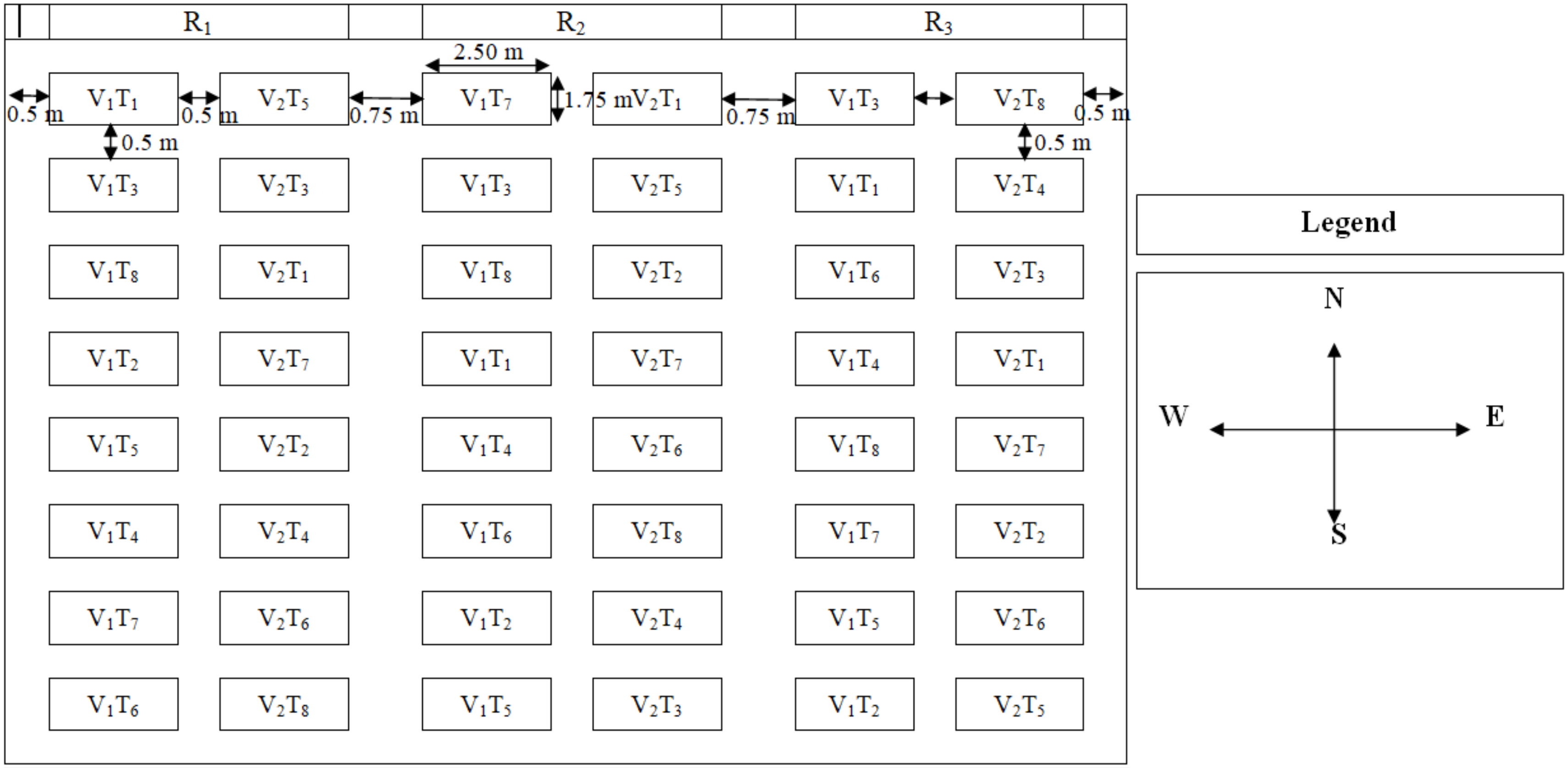
This seeds of the varieties were collected from the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. Clean seeds were soaked in water in a pail for 24 hours to produce seedlings. The imbibed seeds were then placed in gunny bags. After 48 hours, the seeds sprouted and were ready for planting in the seed bed in 72 hours.

3.3.2 Raising of seedlings

The nursery bed was prepared by puddling with repeated ploughing followed by laddering. The sprouted seeds were sown on beds as uniformly as possible at 23rd December, 2020. Irrigation was gently provided to the bed when needed. No fertilizer was used in the nursery bed.

3.3.3 Land preparation

The plot selected for conducting the experiment was opened on the 20th January, 2021 with a power tiller, and left exposed to the sun for a week. After one week the land was harrowed, plowed and cross-plowed several times followed by laddering to obtain good puddle condition. The experimental plot was partitioned into unit plots in accordance with the experimental design at 24 January, 2021.



Treatments

Factor A: Variety

V_1 = BRRI dhan84, V_2 = BRRI dhan88

Factor B: Nutrients application

T_1 = Soil test based (STB) recommended dose; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), $T_2 = T_1$ – Zn (T_1, but without Zn), $T_3 = T_1$ + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), $T_4 = T_1$ + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), $T_5 = T_1$ (Zn applied as foliar application), $T_6 = T_1$ + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), $T_7 = T_1$ + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

Figure 1. Layout of the experimental field

3.3.4 Fertilizers and manure application

The fertilizers N, P, K, S and B in the form of urea, TSP, MoP, Gypsum and borax, respectively. The doses of zinc were applied as per treatment through $ZnSO_4.H_2O$ (monohydrate). The entire amount of TSP, MoP, gypsum and borax were applied during final land preparation. Urea was applied in three instalments.

3.3.5 Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 25th January, 2021 in well puddled plot with spacing of 25 cm × 15 cm. One seedling was transplanted in each hill. After one week of transplanting all plots were checked for any missing hill, which was filled up with extra seedlings of the same source whenever required.

3.4 Intercultural operations

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

3.4.1 Irrigation and drainage

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

3.4.2 Weeding

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

3.4.3 Insect and pest control

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

3.5 Harvesting, threshing and cleaning

Depending on the variety, the crop was harvested after 80-90% of the grains had become straw in color. Harvesting was completed on 5 May 2021. The harvested crop was wrapped individually, correctly labelled, and sent to the threshing floor. For each plot, the grains were dried, cleaned, and weighed. The weight was changed to contain 14% moisture.

3.6 Recording of data

The following data were recorded during experimentation period:

1. Plant height (cm),
2. Length of flag leaf (cm)
3. Number of tillers $hill^{-1}$
4. Number of effective tillers $hill^{-1}$
5. Number of non-effective tillers $hill^{-1}$
6. Panicle length (cm)
7. Number of filled grains $panicle^{-1}$
8. Number of unfilled grains $panicle^{-1}$
9. 1000-grain weight (g)
10. Grain yield (t ha^{-1})
11. Straw yield (t ha^{-1})
12. Harvest Index (%)
13. Analysis of soil (pH, organic carbon, available P and S determination)

3.7 Experimental measurements

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

3.7.1 Plant height (cm)

Plant height was measured in centimeters (cm) at harvest stages for all entries on 5 randomly selected plants from the middle rows. The height was measured from the ground to the tip of the highest panicle.

3.7.2 Length of flag leaf (cm)

The flag leaf length of selected plants from each plot was measured from the base to tip of the flag leaf using a scale. Finally, the average panicle length in centimetres was calculated.

3.7.3 Number of tillers hill^{-1}

Tiller number hill^{-1} was recorded at harvest stage as the average of randomly selected 5 plants from the inner rows of each plot.

3.7.4 Number of effective tillers hill^{-1}

The total number of effective tillers hill^{-1} was counted at the time of harvest from 5 selected hills and average value was recorded.

3.7.5 Number of non-effective tillers hill^{-1}

The total number of non-effective tillers hill^{-1} was counted at the time of harvest from 5 selected hills and average value was recorded.

3.7.6 Panicle length (cm)

The panicles of selected 5 plants from each plot were measured from the neck node to the tip of the panicle using a scale. Finally, the average panicle length in centimetres was calculated.

3.7.7 Number of filled grains panicle^{-1}

All panicles from the 5 selected hills of each plot were threshed. Grain and sterile spikelets were separated. After separation, the filled grains were counted and then number of filled grains panicle^{-1} was calculated.

3.7.8 Number of un-filled grains panicle^{-1}

Grains from all panicles from 5 selected hills were collected and cleaned. Filled grains and unfilled grains were separated. After separation, the unfilled grains were counted and then number of unfilled grains panicle^{-1} was calculated.

3.7.9 1000-grain weight (g)

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

3.7.10 Grain yield (t ha^{-1})

Crop was harvested according to maturity from each of the plot. After threshing, cleaning and sun drying, the grain weight was recorded and adjusted to 14% moisture content. Per plot yield of grain was then converted to t ha^{-1}.

3.7.11 Straw yield (t ha^{-1})

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

3.7.12 Harvest Index (HI) (%)

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage using the following foumula:

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

Here, Biological yield = grain yield + straw yield

3.7.13 pH and nutrient content of post harvest soil

3.7.13.1 pH of post harvest soil

Soil pH was measured with the help of a glass electrode pH meter, the soil water ratio being maintained at 1: 2.5 as described by (Akul *et al.* 1982).

3.7.13.2 Soil Organic carbon content

Organic carbon in the soil sample was determined by the wet oxidation method. The underlying principle was used to oxidize the organic carbon with an excess of 1N $K_2Cr_2O_7$ in presence of conc. H_2SO_4 and conc. H_3PO_3 and titrate the excess $K_2Cr_2O_7$ solution with IN $FeSO_4$. To obtain the content of Organic carbon was calculated by multiplying the percent organic carbon by 1.73 (Van Bemmelen factor) and the results were expressed in percentage.

3.7.13.3 Available phosphorus

Available P was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5 (Olsen *et al.,* 1954). Phosphorus in the extract was then determined by developing blue color with reduction of phosphomolybdate complex and the color intensity was measured calorimetrically at 660 ηm wavelength and readings were calibrated with the standard P curve (Akul *et al.*, 1982).

3.7.13.4 Available sulphur

Available sulphur was extracted from the soil with $Ca(H_2PO_4)_2.H_2O$ (Fox *et al.*, 1964). Sulphur in the extract was determined by the turbidimetric method as described by Hunt (1980) using a Spectrophotometer (LKB Novaspce. 4049).

3.8 Statistical Analysis

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

CHAPTER IV

RESULTS AND DISCUSSION

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

4.1 Growth parameters

4.1.1 Plant height (cm)

Effect of variety

Different rice varieties showed significant influence on plant height (Figure 2 and Appendix IV). Results showed that the highest plant height (91.25 cm) was achieved from the variety V_1 (BRRI dhan84) whereas the lowest plant height (86.39) was found from the variety V_2 (BRRI dhan88). Singh *et al*. (2019), Chowhan *et al*. (2019) and Mahmood (2017) also found that plant height varied significantly among different rice varieties which supported the present investigation.

Effect of zinc

Different doses of zinc showed significant influence on plant height of rice (Figure 3 and Appendix IV). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the highest plant height (101.20 cm) which was statistically identical to the treatment T_3 (T_1 + 1.35kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). Again, the the lowest plant height (74.42 cm) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied). This result was supported by the findings of Islam *et al.* (2008) and Rahman (2007) and they reported that different rate of zing applied to the soil for rice growth, plant height differed significantly due to varietal difference.

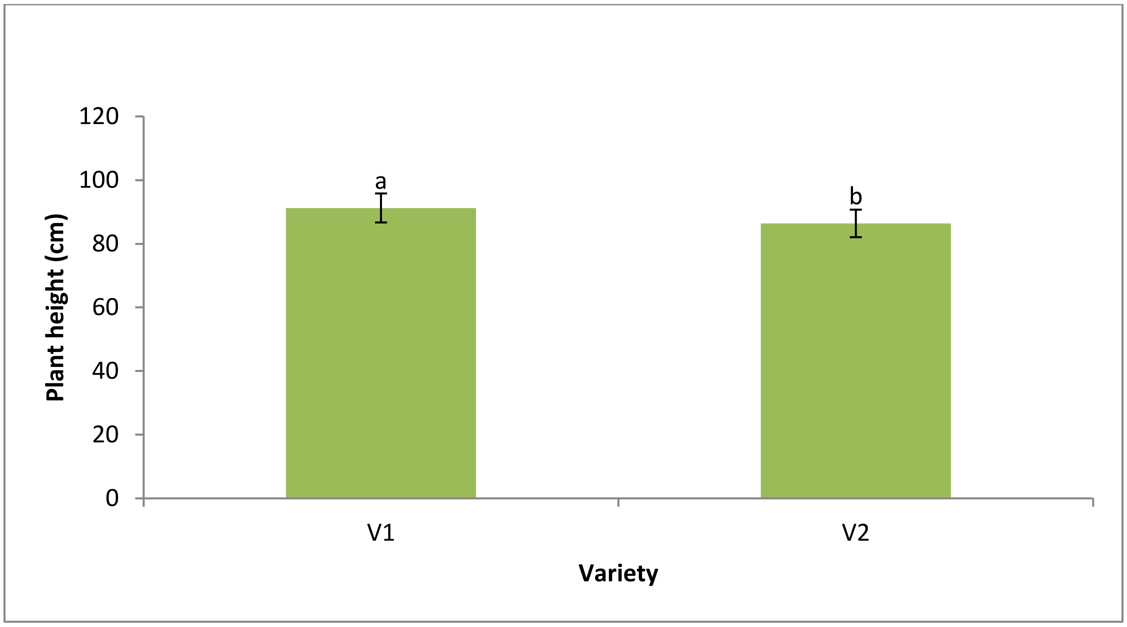


Figure 2. Effect of variety on plant height of rice

V_1 = BRRI dhan84, V_2 = BRRI dhan88

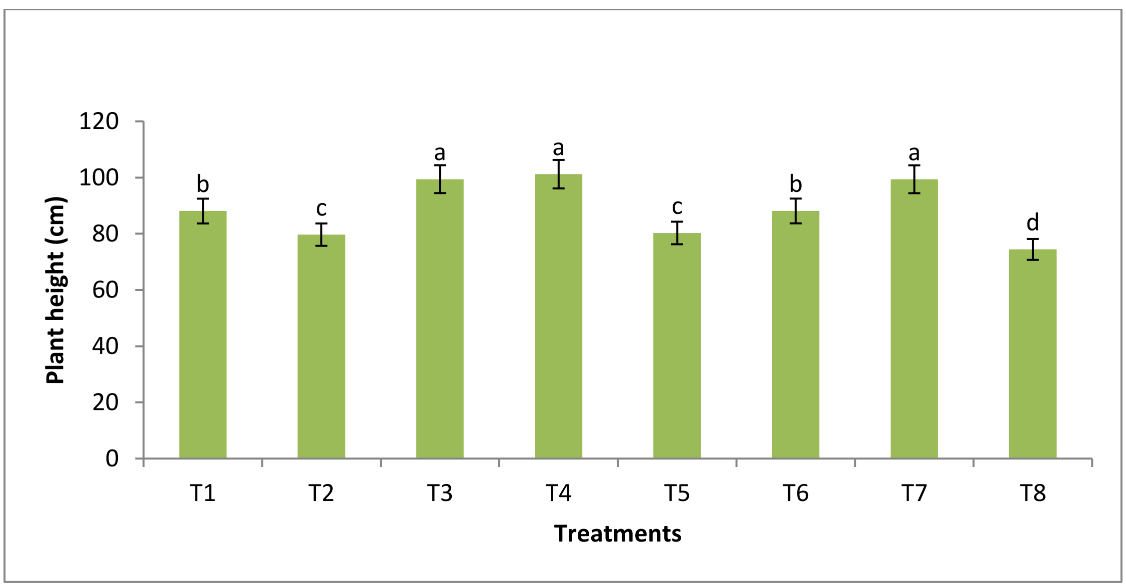


Figure 3. Effect of micronutrient zinc on plant height of rice

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

Combined effect of variety and zinc

Plant height of rice varied significantly due to combined effect of variety and zinc (Table 1 and Appendix IV). The treatment combination of V_1T_4 showed the highest plant height (101.60 cm) which was statistically similar to the treatment combination of V_1T_1, V_1T_3, V_1T_7, V_2T_3 and V_2T_4. Again, the treatment combination of V_2T_8 gave the lowest plant height (70.68 cm) which was significantly different to other treatment combinations.

4.1.2 Length of flag leaf

Effect of variety

Non-significant variation for flag leaf length was found between the varieties of rice (Figure 4 and Appendix IV). However, results indicated that numerically the highest length of flag leaf (24.68 cm) was achieved from the variety V_1 (BRRI dhan84) whereas the lowest length of flag leaf (23.48 cm) was found from the variety V_2 (BRRI dhan88).

Effect of zinc

Different zinc treatment showed significant influence on length of flag leaf of rice (Table 2 and Appendix V). It was observed that treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed the highest length of flag leaf (28.47 cm) which was statistically same to the treatment T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) whereas the lowest length of flag leaf (18.42 cm) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied).

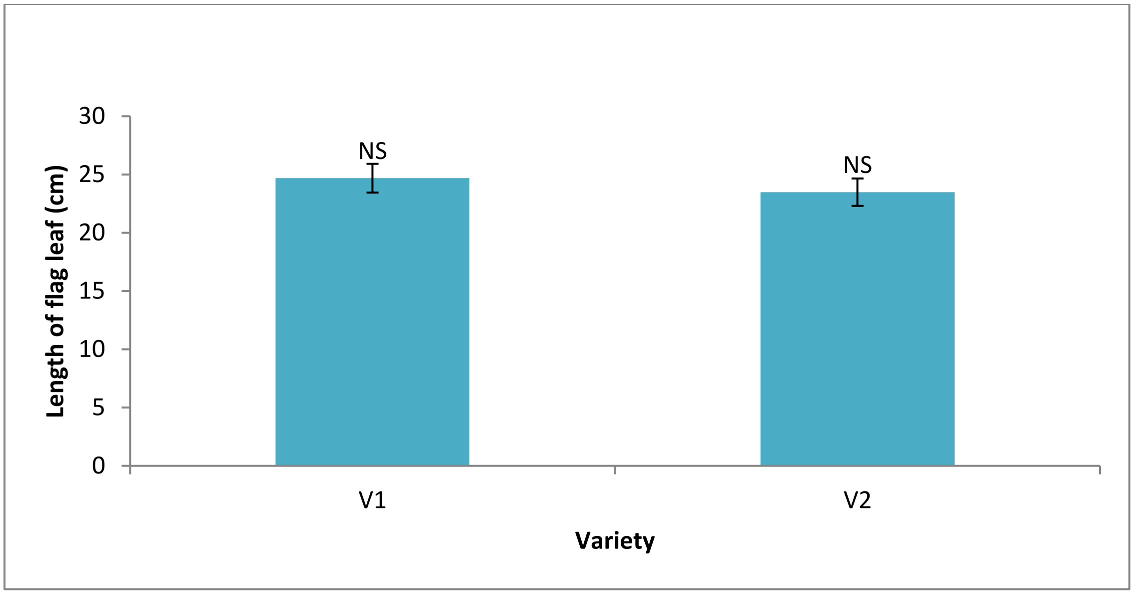


Figure 4. Effect of variety on length of flag leaf of rice

V_1 = BRRI dhan84, V_2 = BRRI dhan88

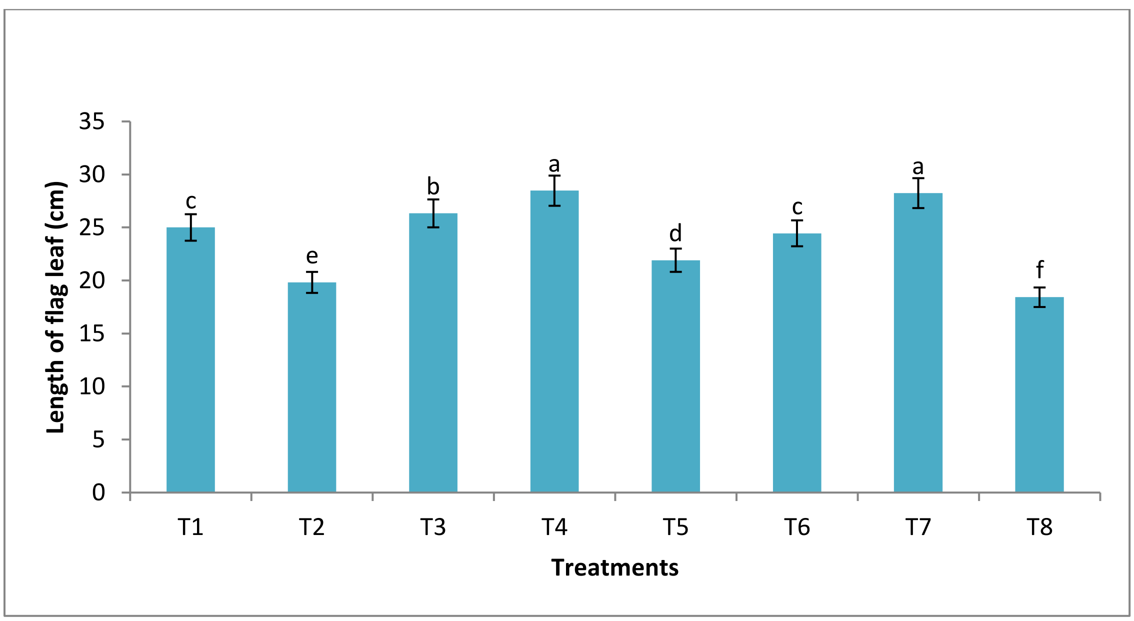


Figure 5. Effect of micronutrient zinc on length of flag leaf of rice

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

Combined effect of variety and zinc

Treatment combination of variety and zinc treatment showed significant variation on length of flag leaf of rice (Figure 5 and Appendix IV). Results showed that the treatment combination of V_1T_4 gave the highest length of flag leaf (29.51 cm) which was statistically similar to the treatment combination of V_1T_7, V_2T_4 and V_2T_7 whereas V_2T_8 gave the lowest length of flag leaf (18.38 cm) that was significantly similar to V_1T_2, V_1T_8 and V_2T_2.

Table 1. Combined effect of variety and micronutrient zinc on the growth performance regarding plant height and length of flag leaf of rice varieties

Treatment	Growth parameters	
	Plant height (cm)	Length of flag leaf (cm)
V_1T_1	95.10 ab	25.61 de
V_1T_2	81.00 c	20.22 hi
V_1T_3	98.31 ab	26.78 bcd
V_1T_4	101.60 a	29.15 a
V_1T_5	81.03 c	22.78 fg
V_1T_6	93.50 b	25.64 de
V_1T_7	101.30 a	28.82 a
V_1T_8	78.15 c	18.45 i
V_2T_1	81.03 c	24.40 ef
V_2T_2	78.37 c	19.41 hi
V_2T_3	100.50 a	25.89 cde
V_2T_4	100.80 a	27.78 ab
V_2T_5	79.52 c	21.05 gh
V_2T_6	82.71 c	23.27 f
V_2T_7	97.50 ab	27.67 abc
V_2T_8	70.68 d	18.38 i
$LSD_{0.05}$	6.591	1.848
CV(%)	4.45	7.98

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

V_1 = BRRI dhan84, V_2 = BRRI dhan88

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

*STB = Soil Test Besis *RD = Recommended dose

4.1.3 Number of tillers hill^{-1}

Effect of variety

Non-significant variation was found on number of tillers hill^{-1} as influenced by different rice varieties (Table 2 and Appendix V). However, results showed that the highest number of tillers hill^{-1} (13.81) was achieved from the variety V_2 (BRRI dhan88) whereas the lowest number of tillers hill^{-1} (13.96) was found from the variety V_1 (BRRI dhan84). This result is in well agreed with the findings of Chowhan *et al*. (2019) and Mahmood (2017) who recorded the signification on number of tillers hill^{-1} among different rice varieties which supported the present study.

Effect of zinc

Significant difference was recorded on number of tillers hill^{-1} of rice due to different doses of zinc (Table 2 and Appendix V). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the highest number of tillers hill^{-1} (16.67) which was statistically similar to the treatment T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). Again, the lowest number of tillers hill^{-1} (11.89) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to other treatments. Paul *et al.* (2021) and Mia (2018) and Khatun *et al*. (2018) also found similar result with the present study and they also reported that Zn application to rice field at different rates showed significant variation on plant height which supported the present findings.

Combined effect of variety and zinc

Different treatment combinations of variety and zinc treatment showed significant variation on number of tillers hill^{-1} of rice (Table 2 and Appendix V). The treatment combination of V_2T_4 showed the highest number of tillers hill^{-1} (17.55) which was statistically similar to the treatment combination of V_1T_4, V_2T_3 and V_2T_7. Again, the treatment combination of V_1T_8 gave the lowest number of tillers hill^{-1} (10.78) which was significantly different to other treatment combinations.

4.1.4 Number of effective tillers hill^{-1}

Effect of variety

Non-significant variation was recorded for the number of effective tillers hill^{-1} between two rice varieties (Table 2 and Appendix V). However, results indicated that numerically the highest number of effective tillers hill^{-1} (12.54) was achieved from the variety V_2 (BRRI dhan88) whereas the lowest number of effective tillers hill^{-1} (12.08) was found from the variety V_1 (BRRI dhan84).

Effect of zinc

Different zinc treatment showed significant influence on number of effective tillers hill^{-1} of rice (Table 2 and Appendix V). It was observed that the maximum number of effective tillers hill^{-1} (14.94) was recorded from the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) which was statistically similar to the treatment T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) whereas the lowest number of effective tillers hill^{-1} (9.28) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to other treatments. Roy (2018) and Podder (2017) also found varied effective tiller number due to different Zn doses which supported the present study.

Combined effect of variety and zinc

There was a significant variation was found due to treatment combination of variety and zinc treatment on number of effective tillers hill^{-1} of rice (Table 2 and Appendix V). Results showed that the maximum number of effective tillers hill^{-1} (16.11) was achieved from the treatment combination of V_2T_4 which was statistically similar to the treatment combination of V_2T_7 whereas the the minimum number of effective tillers hill^{-1} (9.00) was obtained from the treatment combination of V_1T_8 that was significantly similar to V_1T_2, V_2T_2 and V_2T_8.

4.1.5 Number of non-effective tillers hill^{-1}

Effect of variety

There was no significant variation on number of non-effective tillers hill^{-1} by rice varieties (Table 2 and Appendix V). However, numerically it was observed that the variety V_2 (BRRI dhan88) gave the minimum number of non-effective tillers hill^{-1} (1.87) whereas the variety V_1 (BRRI dhan84) showed the highest number of non-effective tillers hill^{-1} (2.27).

Effect of zinc

Various levels of zinc treatment showed non-significant influence on number of non-effective tillers hill^{-1} of rice (Table 2 and Appendix V). However, the minimum number of non-effective tillers hill^{-1} (1.445) was found from the treatment T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) whereas the maximum number of non-effective tillers hill^{-1} (2.61) was observed from the control treatment T_8 (native supply of nutrients; no nutrient was applied). Similar result was also observed by Islam (2015) with the present study.

Combined effect of variety and zinc

There was a non-significant variation was found due to treatment combination of variety and zinc treatment on number of non-effective tillers hill^{-1} of rice (Table 2 and Appendix V). However, the minimum number of non-effective tillers hill^{-1} (1.33) was achieved from the treatment combination of V_2T_7 whereas the maximum number of non-effective tillers hill^{-1} (3.44) was obtained from the treatment combination of V_2T_8.

Table 2. Effect of variety, zinc and combined effect of variety and zinc on the growth performance regarding number of tillers per hill (effective and non-effective tillers) of rice varieties

Treatment	Growth parameters		
	Number of tillers hill^{-1}	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}
Effect of variety			
V_1	13.96	12.08	2.27
V_2	14.81	12.54	1.87
$LSD_{0.05}$	1.524^{NS}	1.037^{NS}	1.271^{NS}
CV(%)	10.80	9.60	5.08
Effect of zinc			
T_1	14.44 bc	12.11 c	2.335
T_2	13.00 cd	10.72 d	2.277
T_3	15.28 ab	13.61 b	1.667
T_4	16.67 a	14.94 a	1.720
T_5	13.94 bc	11.61 cd	2.333
T_6	14.28 bc	12.11 c	2.168
T_7	15.56 ab	14.11 ab	1.445
T_8	11.89 d	9.28 e	2.610
$LSD_{0.05}$	1.831	0.912	1.246^{NS}
CV(%)	10.80	9.60	5.08
Combined effect of variety and zinc			
V_1T_1	14.33 bc	12.11 cd	2.22
V_1T_2	13.00 cd	10.56 def	2.44
V_1T_3	15.00 abc	13.55 bc	1.44
V_1T_4	15.78 ab	13.78 bc	2.00
V_1T_5	13.66 bc	12.11 cd	1.55
V_1T_6	14.22 bc	12.22 cd	2.00
V_1T_7	14.89 bc	13.33 bc	1.56
V_1T_8	10.78 d	9.00 f	1.78
V_2T_1	14.56 bc	12.11 cd	2.45
V_2T_2	13.00 cd	10.89 def	2.11
V_2T_3	15.56 abc	13.67 bc	1.89
V_2T_4	17.55 a	16.11 a	1.44
V_2T_5	14.22 bc	11.11 de	3.11
V_2T_6	14.33 bc	12.00 cd	2.33
V_2T_7	16.22 ab	14.89 ab	1.33
V_2T_8	13.00 cd	9.56 ef	3.44
$LSD_{0.05}$	2.590	1.972	2.94^{NS}
CV(%)	10.80	9.60	5.08

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

V_1 = BRRI dhan84, V_2 = BRRI dhan88

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

*STB = Soil Test Besis *RD = Recommended dose

4.2 Yield contributing parameters

4.2.1 Panicle length (cm)

Effect of variety

Non-significant variation was registered for panicle length of rice varieties (Table 3 and Appendix VI). However, results indicated that the highest panicle length (24.70 cm) was achieved from the variety V_2 (BRRI dhan88) whereas the lowest panicle length (23.48 cm) was found from the variety V_1 (BRRI dhan84).

Effect of zinc

Different zinc treatment exhibited significant influence on panicle length of rice (Table 3 and Appendix VI). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed the highest panicle length (27.06 cm) which was statistically same to the treatment T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). On the other hand, the lowest panicle length (20.71 cm) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was statistically similar to T_2 (T_1 – Zn; T_1 but without Zn). Supported result was also observed by Mia (2018) and Khatun *et al*. (2018) and they reported Zn application to rice had significant influence on panicle length of rice.

Combined effect of variety and zinc

It was observed that the treatment combination of variety and zinc treatment gave statistically significant variation on panicle length of rice (Table 3 and Appendix VI). Results indicated that the treatment combination of V_2T_4 gave the highest panicle length (27.34 cm) which was statistically similar to the treatment combination of V_1T_3, V_1T_4, V_1T_7, V_2T_1, V_2T_3, V_2T_6 and V_2T_7 whereas V_1T_8 gave the lowest panicle length (19.80 cm) that was statistically similar to the treatment combination of V_1T_5, V_1T_6, V_2T_2, V_2T_5 and V_2T_8.

Table 3. Effect of variety, zinc and combined effect of variety and zinc on the yield contributing parameters of rice varieties

Treatment	Yield contributing parameters			
	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	1000 seed weight (g)
Effect of variety				
V_1	23.63	136.07 b	6.44	21.23
V_2	24.70	141.19 a	5.86	20.70
$LSD_{0.05}$	1.433^{NS}	1.503	1.407^{NS}	2.011^{NS}
CV(%)	6.22	14.09	8.04	4.47
Effect of zinc				
T_1	24.67 b	142.70 c	5.61 d	21.12 b
T_2	21.74 cd	129.70 d	7.72 b	19.69 d
T_3	26.61 a	147.80 b	4.95 e	22.22 a
T_4	27.06 a	157.70 a	4.33 f	22.41 a
T_5	22.03 c	133.30 d	6.11 c	20.12 c
T_6	23.62 b	139.90 c	5.78 d	20.90 b
T_7	26.88 a	149.50 b	4.61 f	22.23 a
T_8	20.71 d	108.60 e	10.11 a	19.00 e
$LSD_{0.05}$	1.324	3.857	0.321	0.247
CV(%)	6.22	14.09	8.04	4.47
Combined effect of variety and zinc				
V_1T_1	23.65 bc	141.90 de	5.89 fg	21.50 d
V_1T_2	21.69 cd	127.90 h	8.00 c	19.78 gh
V_1T_3	26.57 a	146.40 cd	5.00 i	22.47 a
V_1T_4	26.78 a	153.70 b	4.66 j	22.69 a
V_1T_5	21.98 cd	131.80 fgh	6.22 e	20.31 f
V_1T_6	22.12 cd	137.00 ef	5.89 fg	21.36 d
V_1T_7	26.46 a	145.20 cd	5.11 hi	22.67 a
V_1T_8	19.80 d	104.70 j	10.78 a	19.03 i
V_2T_1	25.70 ab	143.60 d	5.33 h	20.74 e
V_2T_2	21.80 cd	131.40 gh	7.45 d	19.59 h
V_2T_3	26.66 a	149.10 bc	4.89 ij	21.96 bc
V_2T_4	27.34 a	161.70 a	4.00 k	22.12 b
V_2T_5	22.09 cd	134.80 fg	6.00 ef	19.93 g
V_2T_6	25.12 ab	142.80 d	5.67 g	20.45 f
V_2T_7	27.30 a	153.80 b	4.11 k	21.79 c
V_2T_8	21.62 cd	112.40 i	9.44 b	18.98 i
$LSD_{0.05}$	2.507	5.457	0.298	0.224
CV(%)	6.22	14.09	8.04	4.47

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

V_1 = BRRI dhan84, V_2 = BRRI dhan88

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

*STB = Soil Test Besis *RD = Recommended dose

4.2.2 Number of filled grains panicle^{-1}

Effect of variety

Significant influence was exhibited for the number of filled grains panicle^{-1} of rice varieties (Table 3 and Appendix VI). Results revealed that the highest number of filled grains panicle^{-1} (141.19) was achieved from the variety V_2 (BRRI dhan88) whereas variety V_1 (BRRI dhan84) registered the lowest number of filled grains panicle^{-1} (136.07). Singh *et al*. (2019) and Mahmood (2017) also reported significant variation on number of filled grains panicle^{-1} of rice due to varietal difference which supported the present findings.

Effect of zinc

Different zinc treatment demonstrated significant dissimilarity on number of filled grains panicle^{-1} of rice (Table 3 and Appendix VI). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) expressed the maximum number of filled grains panicle^{-1} (157.70) that was significantly differed to other treatments followed by T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) whereas the minimum number of filled grains panicle^{-1} (108.60) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to other treatments. This result was similar with the findings of Hanifuzzaman *et al.* (2022), Mia (2018) and Roy (2018) who reported significant influence of Zn on number of filled grains panicle^{-1}.

Combined effect of variety and zinc

There was significant distinction among the treatment combinations of variety and zinc treatment on number of filled grains panicle^{-1} of rice (Table 3 and Appendix VI). Results showed that the maximum number of filled grains panicle^{-1} (161.70) was achieved from the treatment combination of V_2T_4 that was significantly differed to other treatment combinations followed by V_1T_4 and V_2T_6 whereas the minimum number of filled grains panicle^{-1} (104.70) was obtained from the treatment combination of V_1T_8 that was significantly different to other treatment combinations.

4.2.3 Number of unfilled grains panicle^{-1}

Effect of variety

There was no significant variation on number of unfilled grains panicle^{-1} by rice varieties (Table 3 and Appendix VI). However, it was observed that the variety V_2 (BRRI dhan88) gave the minimum number of unfilled grains panicle^{-1} (5.86) whereas the variety V_1 (BRRI dhan84) showed the highest number of unfilled grains panicle^{-1} (6.44).

Effect of zinc

Various levels of zinc treatment showed significant influence on number of unfilled grains panicle^{-1} of rice (Table 3 and Appendix VI). Recorded data showed that the minimum number of unfilled grains panicle^{-1} (4.33) was found from the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) which was statistically identical to T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). Again, the the maximum number of unfilled grains panicle^{-1} (10.11) was observed from the control treatment T_8 (native supply of nutrients; no nutrient was applied) followed by T_2 (T_1 – Zn; T_1 but without Zn). Similar result was also found by the findings of Islam (2015) and reported that Zn had significant contribution to reduce unfilled grain per panicle which supported the present findings.

Combined effect of variety and zinc

There was a significant variation was found due to treatment combination of variety and zinc treatment on number of unfilled grains panicle^{-1} of rice (Table 3 and Appendix VI). The minimum number of unfilled grains panicle^{-1} (4.00) was achieved from the treatment combination of V_2T_4 that was significantly same to the treatment combination of V_2T_7 whereas the maximum number of unfilled grains panicle^{-1} (10.78) was obtained from the treatment combination of V_1T_8 followed by V_2T_8.

4.2.4 Weight of 1000 seeds (g)

Effect of variety

Non-significant variation was registered for 1000 grain weight of rice varieties (Table 3 and Appendix VI). However, results indicated that the highest 1000 grain weight (21.23 g) was achieved from the variety V_1 (BRRI dhan84) whereas the lowest 1000 grain weight (20.70 g) was found from the variety V_2 (BRRI dhan88).

Effect of zinc

Different zinc treatment exhibited significant influence on 1000 grain weight of rice (Table 3 and Appendix VI). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed the highest 1000 grain weight (22.41 g) which was statistically same to the treatment T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). On the other hand, the lowest 1000 grain weight (19.00 g) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly differed to other treatments. The result obtained from the present study was similar with the findings of Farzana *et al.* (2021), Mia (2018), Roy (2018) and Podder (2017);

they found considerable variation on 1000 seed weight of rice due to variation on Zn application.

Combined effect of variety and zinc

It was observed that the treatment combination of variety and zinc treatment gave statistically significant variation on 1000 grain weight of rice (Table 3 and Appendix VI). Results indicated that the treatment combination of V_1T_4 gave the highest 1000 grain weight (22.69 g) which was statistically identical to the treatment combination of V_1T_3 and V_1T_7 whereas V_2T_8 gave the lowest 1000 grain weight (18.98 g) which was statistically same to the treatment combination of V_1T_8.

4.3 Yield parameters

4.3.1 Grain yield ha^{-1}

Effect of variety

Significant influence was exhibited for the grain yield of rice varieties (Table 4 and Appendix VII). Results revealed that the highest grain yield ha^{-1} (5.62 t ha^{-1}) was achieved from the variety V_2 (BRRI dhan88) whereas variety V_1 (BRRI dhan84) registered the lowest grain yield ha^{-1} (5.19 t ha^{-1}). This result was in well agreed with the findings of Khatun (2020), Rahman *et al.* (2020), Singh *et al*. (2019) and Hossain *et al.* (2014) who recorded significant variation on grain yield among different varieties of rice.

Effect of zinc

Different zinc treatment demonstrated significant dissimilarity on grain yield of rice (Table 4 and Appendix VII). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) expressed the maximum grain yield ha^{-1} (7.12 t ha^{-1}) that was significantly differed to other treatments followed by T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). On the other hand, the minimum grain yield ha^{-1} (3.55 t ha^{-1}) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to other treatments. The result was in conformity with the findings of Farzana *et al.* (2021), Paul *et al.* (2021), Podder (2017) and Islam (2015); they reported higher grain yield was contributed to zinc effect.

Combined effect of variety and zinc

There was significant distinction among the treatment combinations of variety and zinc treatment on rice grain yield (Table 4 and Appendix VII). Results showed that the maximum grain yield ha^{-1} (7.39 t ha^{-1}) was achieved from the treatment combination of V_2T_4 that was statistically similar to V_2T_7 whereas the minimum grain yield ha^{-1} (3.48 t ha^{-1}) was obtained from the treatment combination of V_1T_8 that was significantly same to the treatment combination of V_2T_8.

4.3.2 Straw yield ha^{-1}

Effect of variety

Rice straw yield varied significantly due to the influence of different rice varieties (Table 4 and Appendix VII). Recorded data showed that the highest rice straw yield ha^{-1} (7.10 t ha^{-1}) was achieved from the variety V_2 (BRRI dhan88) whereas the lowest rice straw yield ha^{-1} (6.73 t ha^{-1}) was found from the variety V_1 (BRRI dhan84). This result was supported by the findings of Singh *et al*. (2019) and Chowhan *et al*. (2019) who found significant variation on straw yield of rice due to varietal difference.

Effect of zinc

Different doses of zinc had significant effect on rice straw yield (Table 4 and Appendix VII). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the highest straw yield ha^{-1} (8.19 t ha^{-1}) which was significantly differed to other treatments followed by T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). Again, the lowest rice straw yield ha^{-1} (5.49 t ha^{-1}) was found from the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to other treatments. Mia (2018) and Khatun *et al*. (2018) also found similar result with the present study and reported that Zn had significant effect on straw to increase its yield significantly.

Combined effect of variety and zinc

Different treatment combinations of variety and zinc treatment showed significant variation on rice straw yield (Table 4 and Appendix VII). Results revealed that the treatment combination of V_2T_4 showed the highest straw yield ha^{-1} (8.47 t ha^{-1}) which was statistically similar to the treatment combination of V_2T_7. Again, the treatment combination of V_1T_8 gave the lowest rice straw yield ha^{-1} (5.38 t ha^{-1}) which was statistically identical to V_2T_8.

4.3.3 Harvest index (%)

Effect of variety

Non-significant variation was registered for harvest index of rice varieties (Table 4 and Appendix VII). However, results indicated that the highest harvest index (43.74%) was attained from the variety V_2 (BRRI dhan88) whereas the lowest harvest index (43.14%) was registered from the variety V_1 (BRRI dhan84).

Significant effect on harvest index among different rice varieties was observed by Chowhan *et al*. (2019) and Sarkar *et al.* (2016).

Effect of zinc

Different zinc treatment exhibited significant influence on harvest index of rice (Table 4 and Appendix VII). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the highest harvest index (46.53%) which was statistically identical to the treatment T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) and T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application). On the other hand, the lowest harvest index (39.27%) was given by the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly differed to other treatments. Islam (2015), Podder (2017) and Roy (2018) also found similar result with the present study and reported Zn had significant effect to increase straw yield of rice.

Combined effect of variety and zinc

It was observed that the treatment combination of variety and zinc treatment gave statistically significant variation on harvest index of rice (Table 4 and Appendix VII). Results indicated that the treatment combination of V_2T_4 gave the highest harvest index (46.60%) which was statistically similar to the treatment combination of V_1T_3, V_1T_4, V_2T_3 and V_2T_7. Similarly, the treatment combination, V_1T_8 gave the lowest harvest index (39.26%) that was statistically similar with the treatment combination of V_1T_2, V_2T_2 and V_2T_8.

Table 4. Effect of variety, zinc and combined effect of variety and zinc on the yield parameters of rice varieties

Treatment	Yield parameters		
	Grain yield ha^{-1} (t)	Straw yield ha^{-1} (t)	Harvest index (%)
Effect of variety			
V_1	5.19 b	6.73 b	43.14
V_2	5.62 a	7.10 a	43.74
$LSD_{0.05}$	0.127	0.136	1.243^{NS}
CV(%)	6.62	8.83	5.05
Effect of zinc			
T_1	5.47 c	6.88 c	44.26 b
T_2	4.16 e	6.14 e	40.39 d
T_3	6.35 b	7.61 b	45.48 a
T_4	7.12 a	8.19 a	46.53 a
T_5	4.68 d	6.48 d	41.88 c
T_6	5.31 c	6.86 c	43.65 b
T_7	6.57 b	7.69 b	46.07 a
T_8	3.55 f	5.49 f	39.27 e
$LSD_{0.05}$	0.242	0.269	1.287
CV(%)	6.62	8.83	5.05
Combined effect of variety and zinc			
V_1T_1	5.30 gh	6.81 ef	43.77 cde
V_1T_2	4.07 i	6.06 h	40.18 fg
V_1T_3	6.19 de	7.48 cd	45.28 abc
V_1T_4	6.86 bc	7.91 bc	46.45 a
V_1T_5	4.34 i	6.28 gh	40.87 f
V_1T_6	5.22 h	6.78 ef	43.50 de
V_1T_7	6.05 ef	7.17 de	45.76 ab
V_1T_8	3.48 j	5.38 i	39.28 g
V_2T_1	5.63 fg	6.95 ef	44.75 bcd
V_2T_2	4.25 i	6.22 gh	40.59 fg
V_2T_3	6.51 cd	7.74 c	45.68 ab
V_2T_4	7.39 a	8.47 a	46.60 a
V_2T_5	5.01 h	6.67 fg	42.89 e
V_2T_6	5.40 gh	6.93 ef	43.80 cde
V_2T_7	7.10 ab	8.21 ab	46.37 a
V_2T_8	3.62 j	5.60 i	39.26 g
$LSD_{0.05}$	0.415	0.454	1.967
CV(%)	6.62	8.83	5.05

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

V_1 = BRRI dhan84, V_2 = BRRI dhan88

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), T_2 = T_1 – Zn (T_1, but without Zn), T_3 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), T_4 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), T_5 = T_1 (Zn applied as foliar application), T_6 = T_1 + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), T_7 = T_1 + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

*STB = Soil Test Besis *RD = Recommended dose

4.4 pH and nutrient status in soil after harvest

4.4.1 pH

Effect of variety

Different rice varieties showed non-significant variation for pH of post harvest soil (Table 5 and Appendix VIII). However, the highest pH of post harvest soil (6.35) was recorded by the variety V_2 (BRRI dhan88) whereas the lowest pH of post harvest soil (6.35) was found by the variety V_1 (BRRI dhan84).

Effect of zinc

Non-significant influence was observed by different zinc treatment on pH of post harvest soil of rice (Table 5 and Appendix VIII). However, it was found that treatment T_4 (T_1 + 5.04 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the highest pH (6.57) followed by T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) (6.56) while the lowest pH (6.06) was given by the treatment T_8 (native supply of nutrients; no nutrient was applied).

Combined effect of variety and zinc

Treatment combination of variety and zinc treatment showed non-significant variation on pH of post harvest soil of rice (Table 5 and Appendix VIII). However, it was observed that the treatment combination of V_2T_4 gave the highest pH of post harvest soil (6.63) whereas V_1T_8 showed the lowest pH of post harvest soil (6.05).

Table 5. Effect of variety, zinc and combined effect of variety and zinc on pH and organic carbon, P and S content in post harvest soil of rice

Treatment	pH and nutrient status in soil after harvest			
	pH	Organic carbon (%)	Available P (ppm)	Available S (ppm)
Effect of variety				
V_1	6.30	0.55	20.52	29.48
V_2	6.35	0.56	20.99	29.87
$LSD_{0.05}$	0.107^{NS}	0.103^{NS}	1.062^{NS}	1.103^{NS}
CV(%)	3.78	4.59	6.37	7.12
Effect of zinc				
T_1	6.14	0.55	18.32 e	28.68 d
T_2	6.22	0.51	18.27 e	29.61 c
T_3	6.45	0.59	23.40 b	30.18 bc
T_4	6.57	0.61	25.09 a	31.12 a
T_5	6.29	0.52	22.33 c	30.09 bc
T_6	6.37	0.56	19.85 d	29.67 c
T_7	6.56	0.62	24.10 b	30.83 ab
T_8	6.06	0.49	14.71 f	27.24 e
$LSD_{0.05}$	0.133^{NS}	0.142^{NS}	0.915	0.927
CV(%)	3.78	4.59	6.37	7.12
Combined effect of variety and zinc				
V_1T_1	6.12	0.55	18.27 ef	28.63 e
V_1T_2	6.18	0.50	18.33 ef	29.27 d
V_1T_3	6.44	0.58	23.37 bc	30.12 c
V_1T_4	6.48	0.60	24.58 ab	30.52 b
V_1T_5	6.27	0.52	22.33 c	30.10 c
V_1T_6	6.33	0.54	19.36 de	29.88 c
V_1T_7	6.55	0.61	23.72 b	30.18 bc
V_1T_8	6.05	0.48	14.20 g	27.15 f
V_2T_1	6.15	0.55	18.36 ef	28.72 e
V_2T_2	6.25	0.51	18.21 ef	29.95 c
V_2T_3	6.45	0.59	23.43 bc	30.23 bc
V_2T_4	6.63	0.61	25.59 a	31.72 a
V_2T_5	6.30	0.52	22.33 c	30.07 c
V_2T_6	6.40	0.57	20.33 d	29.45 d
V_2T_7	6.58	0.63	24.47 ab	31.48 a
V_2T_8	6.07	0.50	15.21 g	27.33 f
$LSD_{0.05}$	0.214^{NS}	0.176^{NS}	1.316	0.388
CV(%)	3.78	4.59	6.37	7.12

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

V_1 = BRRI dhan 84, V_2 = BRRI dhan 88

T_1 = Soil test based (STB) recommended rate; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MOP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), $T_2 = T_1$ – Zn (T_1, but without Zn), $T_3 = T_1$ + 4.05 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), $T_4 = T_1$ + 5.04 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), $T_5 = T_1$ (Zn applied as foliar application), $T_6 = T_1$ + 4.05 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), $T_7 = T_1$ + 5.04 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application), T_8 = Control/native supply of nutrients (No nutrient was applied)

*STB = Soil Test Besis *RD = Recommended dose

4.4.2 Organic carbon content

Effect of variety

Different rice varieties showed non-significant variation for organic carbon content of post harvest soil (Table 5 and Appendix VIII). However, the highest organic carbon content of post harvest soil (0.56%) was given by the variety V_2 (BRRI dhan88) whereas the lowest organic carbon content of soil (0.55%) was shown by the variety V_1 (BRRI dhan84).

Effect of zinc

Non-significant variation was observed by different zinc treatments on organic carbon content in post harvest soil of rice (Table 5 and Appendix VIII). However, it was found that the treatment T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) showed the highest organic carbon content in soil after harvest (0.62%) followed by T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) (0.61%) while the lowest (0.49%) was given by the control treatment T_8 (native supply of nutrients; no nutrient was applied).

Combined effect of variety and zinc

Treatment combination of variety and zinc treatment showed non-significant variation on organic carbon content of post harvest soil of rice (Table 5 and Appendix VIII). However, the treatment combination of V_2T_7 gave the highest organic carbon content in post harvest soil (0.63%) whereas V_1T_8 showed the lowest organic carbon content in soil after harvest (0.48%).

4.4.3 Available phosphorus (P) content

Effect of variety

Different rice varieties showed non-significant variation for available P content in soil after harvest (Table 5 and Appendix VIII). However, the highest P content in soil after harvest (20.99 ppm) was given by the variety V_2 (BRRI dhan88) whereas the lowest P content of soil (20.52 ppm) was shown by the variety V_1 (BRRI dhan84).

Effect of zinc

Non-significant influence was observed by different zinc treatment on available P content in soil after harvest of rice (Table 5 and Appendix VIII). It was found that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed the highest P content in soil after harvest (25.09 ppm) which was followed by T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) (24.10 ppm) and T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) (23.40) while the lowest (14.71 ppm) was given by the control treatment T_8 (native supply of nutrients; no nutrient was applied) which was significantly different from other treatyments.

Combined effect of variety and zinc

Treatment combination of variety and zinc treatment showed significant variation on available P content in soil after harvest of rice (Table 5 and Appendix VIII). The treatment combination of V_2T_4 gave the highest P content in soil after harvest (25.59 ppm) which was statistically similar to V_1T_4 and V_2T_7 whereas V_1T_8 showed the lowest P content in soil after harvest (14.20 ppm) that was statistically same to V_2T_8 (15.21 ppm).

4.4.4 Available sulphur (S) content

Effect of variety

Available S content in soil after harvest was not varied significantly due to the varietal difference (Table 5 and Appendix VIII). However, the highest S content in soil (29.87 ppm) was given by the variety V_2 (BRRI dhan88) whereas the lowest S content of sulphur on soil (29.48 ppm) was shown by the variety V_1 (BRRI dhan84).

Effect of zinc

Data on available S content in soil after harvest of rice varied significantly by different zinc treatment (Table 5 and Appendix VIII). It was observed that the treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed the highest S content in soil (31.12 ppm) which was statistically similar to T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as foliar application) (30.83 ppm) whereas the lowest available S content in soil (27.24 ppm) was given by the control treatment T_8 (native supply of nutrients; no nutrient was applied) that was significantly different to others..

Combined effect of variety and zinc

Combined effect of variety and zinc treatment showed significant variation on S content in soil after harvest of rice (Table 5 and Appendix VIII). The treatment combination of V_2T_4 gave the highest S content in soil (31.72 ppm) which was statistically identical to V_2T_7 whereas V_1T_8 showed the lowest S content of soil after harvest (27.15 ppm) that was statistically identical to V_2T_8.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was carried out during the period of December 2020 to April 2021 at the research farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 to study the effect of micronutrient zinc on the performance of zinc enrichment of rice varieties. Two factors experiment was laid out in Randomized Complete Block Design with three replications. For the present study, two rice varieties *viz*. V_1 = BRRI dhan84 and V_2 = BRRI dhan88 combined with eight zinc treatments *viz*. T_1 = Soil test based (STB) recommended dose; N, P, K, S and Zn @ 83, 15, 56, 13.5 and 2.7 kg ha^{-1} (urea, TSP, MoP, gypsum and zinc sulphate @ 180, 75, 112, 75 and 7.5 kg ha^{-1}), $T_2 = T_1$ – Zn (T_1, but without Zn), $T_3 = T_1$ + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as soil application), $T_4 = T_1$ + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as soil application), $T_5 = T_1$ (Zn applied as foliar application), $T_6 = T_1$ + 1.35 kg ha^{-1} Zn (T_1 + 50% higher Zn applied as foliar application), $T_7 = T_1$ + 2.7 kg ha^{-1} Zn (T_1 + 100% higher Zn applied as foliar application) and T_8 = Control/native supply of nutrients (No nutrient was applied) were considered.

Between two rice varieties, V_1 (BRRI dhan84) showed highest plant height (91.25 cm) that was significantly differed to V_2 (BRRI dhan88) (86.39 cm) but no significant difference was observed for length of flag leaf (cm), number of tillers $hill^{-1}$, number of effective tillers $hill^{-1}$ and number of non-effective tillers $hill^{-1}$ between them. Similarly, variety V_2 (BRRI dhan88) showed significantly the highest number of filled grains $panicle^{-1}$ (141.19), grain yield (5.62 t ha^{-1}), straw yield (7.10 t ha^{-1}) and harvest index (43.74%) whereas V_1 (BRRI dhan84) gave the minimum number of filled grains $panicle^{-1}$ (136.07), grain yield (5.19 t ha^{-1}), straw yield (6.73 t ha^{-1}) and harvest index (43.14%). Again, different varieties showed non-significant variation on pH, organic carbon (OC), available P and S content of post harvest soil.

Maximum parameters of the study varied significantly due to zinc except Number of non-effective tillers hill^{-1}. The treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the maximum plant height (101.20 cm), length of flag leaf (28.47 cm), number of tillers hill^{-1} (16.67), number of effective tillers hill^{-1} (14.94), panicle length (27.06 cm), number of filled grains panicle^{-1} (157.70), 1000 seed weight (22.41 g), grain yield (7.12 t ha^{-1}), straw yield (8.19 t ha^{-1}), and harvest index (46.53%) while the minimum number of unfilled grains panicle^{-1} (4.33) was also achieved from this treatment. Alternatively, the T_8 (control/native supply of nutrients; no nutrient was applied) gave the minimum plant height (74.42 cm), length of flag leaf (18.42 cm), number of tillers hill^{-1} (11.89), number of effective tillers hill^{-1} (9.28), panicle length (20.71 cm), number of filled grains panicle^{-1} (108.60), 1000 seed weight (19.00 g), grain yield (3.55 t ha^{-1}), straw yield (5.49 t ha^{-1}) and harvest index (39.27%) while the maximum number of unfilled grains panicle^{-1} (10.11) was also recorded from this treatment. In terms pH and OC content of post harvest soil, non-significant variation was found among the treatments. Again, available P and S content in post harvest soil differed significantly among the treatments and the highest (25.09 and 31.12 ppm, respectively) were obtained by T_4 (T_1 + 5.04 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) whereas the lowest (14.71 and 27.24 ppm, respectively) were obtained by T_8 (native supply of nutrients; no nutrient was applied) treatment.

Among different treatment combinations of variety and zinc showed significant variation for all the studied parameters except number of non-effective tillers hill^{-1}. The maximum plant height (101.60 cm) and length of flag leaf (29.15 cm) were given by V_1T_4 and the lowest (70.68 cm and 18.38 cm, respectively) were recorded from V_2T_8. Again, the treatment combination, V_2T_4 registered the highest total number of tillers hill^{-1} (17.55), number of effective tillers hill^{-1} (16.11), panicle length (27.34 cm), number of filled grains panicle^{-1} (161.70), grain yield (7.39 t ha^{-1}), straw yield (8.47 t ha^{-1}) and harvest index (46.60%) while the maximum 1000 grain weight (22.69 g) and minimum number of unfilled grains panicle^{-1} (4.00) were recorded from V_1T_4 and V_2T_4, respectively. On the other hand, the treatment combination, V_1T_8 gave the minimum total number of tillers hill^{-1} (10.78), number of effective tillers hill^{-1} (9.00), panicle length (19.80 cm), number of filled grains panicle^{-1} (104.70), grain yield (3.48 t ha^{-1}), straw yield (5.38 t ha^{-1}) and harvest index (39.26%) but the minimum 1000 grain weight (18.98 g) and maximum number of unfilled grains panicle^{-1} (10.78) were recorded from V_2T_8 and V_1T_8, respectively. Regarding nutrients content in post harvest soil, V_2T_4 showed the maximum available P (25.59 ppm) and S (31.72 ppm) content in post harvest soil whereas the lowest (14.20 and 27.15 ppm, respectively) were obtained by V_1T_8 which varied significantly varied among the treatment combinations. pH and OC content of post harvest soil was not varied significantly among the treatment combinations.

Conclusion

Regarding the results mentioned above, the following conclusion can be drawn:

1. The variety V_2 (BRRI dhan88) provided the best performance regarding yield contributing parameters and yield parameters whereas V_1 (BRRI dhan84) showed lower performance. Again, the variety V_2 (BRRI dhan88) showed higher nutrients content in post harvest soil but not significantly differed to V_1 (BRRI dhan84).
2. Among different zinc treatments, treatments, T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) gave the best results in terms of growth, yield contributing parameters and yield parameters of rice compared to other treatments followed by T_7 (T_1 + 2.7 kg ha^{-1} Zn; T_1 +

100% higher Zn applied as foliar application) and T_3 (T_1 + 1.35 kg ha^{-1} Zn; T_1 + 50% higher Zn applied as soil application) whereas control treatment T_8 (no nutrient was applied) performed lowest results.

3. Regarding nutrient status in post harvest soil, P and S varied significantly among different Zn treatments and treatment T_4 (T_1 + 2.7 kg ha^{-1} Zn; T_1 + 100% higher Zn applied as soil application) showed highest result in post harvest soil whereas T_8 (control/native supply of nutrients; no nutrient was applied) showed lowest results. pH and OC content was not varied significantly among the treatments of zinc.
4. The treatment combinations of variety and zinc treatments, V_2T_4 performed best by achieving the highest grain yield, straw yield and harvest index among all other treatments whereas V_1T_8 gave minimum results. So, the treatment combination of V_2T_4 can be well thought-out as the best compared to all other treatment combinations followed V_2T_7. In terms of nutrients content in post harvest soil, P and S varied significantly and the maximum P and S content in post harvest soil was recorded from V_2T_4 whereas the minimum was recorded from V_1T_8 while pH and OC content of post harvest soil was not varied significantly among the different treatment combinations.

Recommendations

Further experiment can be conducted in respect of many other varieties of rice including local, HYV and hybrids with other similar doses of zinc with or without other macro and/or micronutrients at different locations of Bangladesh for final recommendation for best variety with best nutrients recommendation.

REFERENCES

Abid, M., Ahmad, N., Jahangir, M. and Ahmad, I. (2011). Effect of Zinc, Iron and Manganese on growth and yield of Rice (*Oryza sativa. L*). *Pakistan J. Agric Sci.* **39**(3): 127–132.

Abou-Khalif, A.A.B. (2009). Evaluation of some hybrid rice varieties in under different sowing times. *Afr. J. Plant Sci.* **3**(4): 53-58.

Akram, M., Rehman, A., Ahmad, M. and Cheema, A.A. (2007). Evaluation of rice hybrids for yield and yield components in three different environments. *J. Animal and Plant Sci.* **17**(3-4): 70-75.

Akul, B.M., Kathmale, D.K. and Rathod, S.D. (1982). Soil Nutrient Status, Uptake, Yield and Economics of Groundnut-Wheat Cropping Sequence as Influenced by Organic Sources and Fertilizers. *J. Indian Soc. Soil Sci*. **66**(1): 66-75.

Alam, M. A. and Kumar, M. (2015). Effect of zinc on growth and yield of rice var. Pusa Basmati in Saran district of Bihar. *Asian J. Plant Sci. Res*. **5**(2): 82–85.

Apoorva, M.R. (2016). Effect of sources and methods of application of zinc on growth, yield and nutrient uptake in rice. Rajendranagar, Hyderabad. pp. 33–34.

BBS, 2011. Statistics Bangladesh 2011. Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh

BBS. (2016). Yearbook of Agricultural Statistics. Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People’s Republic of Bangladesh.

BBS. (2019). Yearbook of Agricultural Statistics. Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh.

BBS. (2020). Statistical yearbook of Bangladesh. Bangladesh Bureau of Statistics. Statistics Division, Ministry of Planning, Govt. of Peoples Republic of Bangladesh. p. 144.

Bhuiyan, N. I. 2002.The Hybrid Rice Program for Bangladesh. In: "Hybrid Rice in Bangladesh: Progress and Future Strategies". pp. 3-5. Bangladesh Rice Res. Inst. Publication No.138

Boonchuay, P., Cakmak, I., Benjavan, R. and Chanakan, P.U. (2013). Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. *Soil Sci. Plant Nutr.***13**(10): 1-9.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci*. **59**: 39-45.

BRRI (Bangladesh Rice Research Institute). (2016). Krishi Projukti Hat Boi. Bangladesh Rice Research Institute, Joydebpur, Gazipur, Bangladesh.

Cakmak, I. (2012). Harvest plus Zinc Fertilizer Project: Harvest Zinc. *Better Crops.,* **96**(2): 17-19.

Chowhan, S., Hoque, M.I., Ghosh, S.R., Islam, M. and Akter, M.B. (2019). Effect of variety and seedling number on the growth and yield of *boro* rice in Bangladesh. J. Experimental Agric. Int. 41(6): 1-15.

Dixit, V., Parihar, A.K.S., Kumar, A., Singh, D. and Rahi, T.S. (2012). Effect of Sulphur and Zinc on Yield Quality and Nutrient Uptake of Hybrid Rice in Sodic Soil. *Int. J. Env. Sci. Tech.* **1**(1): 53–57.

Edris, K.M., Islam, A.T.M.T., Chowdhury, M.S. and Haque, A.K.M.M. (1979). Detailed Soil Survey of Bangladesh, Dept. Soil Survey, Govt. People's Republic of Bangladesh. p. 112.

Fageria, N. K., Dos Santos, A. B., and Cobucci, T., 2011. Zinc nutrition of lowland rice. Comm. Soil Sci. Plant Anal., **42**: 1719-1727. http://dx.doi.org/10.1080/ 00103624. 2011.584591

FAO. (1988). Production Year Book. Food and Agricultural Organizations of the United Nations Rome, Italy. 42: 190-193.

Farzana, S., Sarkar, A., Hosenuzzaman, M., Galib, M.A.A. and Hoque, M.A. (2021). Effects of zinc on growth and yield of rice cv. BRRI dhan29 under alternate wetting and drying water management practice. Journal of Agriculture, Food and Environment (JAFE). 2: 25-30.

Fox, R. ., Olson, R.A. and Rhoades, H.F. (1964). Evaluating the sulfur status of soils by plants and soil tests. *Soil Sci. Soc. Am. Proc*. **28**: 243-246.

Ghoneim, A.M. (2016). Effect of Different Methods of Zn Application on Rice Growth, Yield and Nutrients Dynamics in Plant and Soil Ueno, H. Asagi, N. and Watanabe, *J. Agric. and Ecol. Res*. **43**: 63–69.

Gomaa, M. A., Radwan, F.I., Kandil, E.E. and Gharib, A.F. (2015). Effect of Nitrogenous Sources and Zinc application Method on Productivity and Quality of Rice (*Oryza sativa* L.). *Middle East J. Applied Sci*. **4**: 913–919.

Gomez, K.A. and Gomez, A.A. (1984). Statistically procedures for agricultural research. 2nd edition. An International Rice Research Institute Book. A wiley-Inter Science Publication, New York, 28. 1984. pp. 442-443.

Hanifuzzaman, M., Uddin, F.M.J., Mostofa, M.G., Sarkar, S.K., Paul, S.K. and Rashid, M.H. (2022). Effect of zinc and boron management on yield and yield contributing characters of Aus rice (*Oryza sativa*). Res. Crop. 23(1): 1-10.

Haque M. M., Pramanik H.R. and Biswas J. K., Iftekharuddaula K.M. and Hasanuzzaman, M. 2015. Comparative Performance of Hybrid and Elite Inbred Rice Varieties with respect to Their Source-Sink Relationship. The Scientific WorldJ : 1-11.

Hosain, M.T., Ahamed, K.U., Haque, M.M., Islam, M.M., Fazle-Bari, A.S.M. and Mahmud, J.A. (2014). Performance of Hybrid Rice (*Oryza sativa* L.) Varieties at Different Transplanting Dates in Aus Season. App. Sci. Report. 5(1): 4: 1-4.

Hunt, J. (1980). Determination of total sulphur in small amounts of plant material. Analyst. https://doi.org/10.1039/an9800500083.

IRRI. (2000). Nutritional disorders and nutrient management in rice. *Int. Rice Res. Ins*. Manila, Philippines.

Islam, M.S. (2005). Yield and yield attributes of transplanted aman rice (BRRI dhan30) as influenced by organic manures and zinc levels.M.S. thesis, Dept. Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Islam, M.S., Parvin, S. and Sarkar, M. A. R. (2008). Yield of fine rice varieties as influenced by integrated management of poultry manure, urea super granules and prilled urea. *J. Environ. Sci. Nat. Res.*, **5**(1): 203-212.

Islam, M.R. (2015). Effect of zinc and *Boro*n on the growth and yield of T. aman rice (BRRI dhan34). M.S. thesis, Dept. soil science, Sher-e-bangla Agricultural University, Dhaka-1207.

Julfiquar,W.A., Haque, M.M., Haque, E.K.G.M.A.and Rashid, A.M. 2009. Current status of Hybrid Rice Research and Future Program in Bangladesh. Proc. Workshop on use and development of hybrid rice in Bangladesh, held at BARC, 18-19, May, 2009.

Kabeya, M.J. and Shankar, A.G. (2013). Effect of different levels of zinc on growth and uptake ability in rice zinc contrast lines (*Oryza Sativa* L.). *Asian J. Plant Sci. Res.* **3**(3): 112– 116.

Kamal, M.M. (2007). Performance of modern boro rice varieties under different planting methods. *J. Bangladesh Agril. Univ*. **5**(1): 43-47, 2007.

Keram, K.S., Sharma, B.L. and Sawarkar, S.D. (2012). Impact of Zn application on yield, Quality, Nutrients uptake and Soil fertility in a medium deep black soil (Vertisol*). Int. J. Sci, Environ and Tech*. **1**(5): 563–571.

Khan, U.M., Qasim, M. and Khan, I. (2007). Effect of Zn fertilizer on rice grown in different soils of Dera Ismail khan. *Sarhad J. Agric*. **23**(4): 123–129.

Khan, U.M., Qasim, M., Subhan, M., Jamil, M. and Ahmed, R.D. (2003). Response rice to different methods of zinc application in calcareous soil., *Pak. J. appl. sci*. **3**(7): 101–109.

Khatun, M.K., Hasan, M.K., Rumi, M.S., Sabagh, A.E.L. and Islam, M.S. (2018). Response of growth and yield attributes of aromatic rice to cow dung and zinc fertilization. *Azarian J. Agril*. **5**(5): 151–159.

Khatun, S. (2020). Growth and Yield Performance of Six Aman Rice Varieties of Bangladesh. *Asian Res. J. Agric*. **12**(2): 1-7

Kretz, R. (1974). Physical constants of minerals. In Weast, R.C., ed., *Handbook of Chemistry and Physics*, 55th edn. Cleveland, OH: Chemical Rubber Co. pp. B193–B197.

Kumar, M., Jha, A.K., Hazarika, S. and Verma, B.C. (2016). Micronutrients (B, Zn, Mo) for Improving Crop Production on Acidic Soils of Northeast India. *The National Academy Sci.* **39**(2): 85–89.

Kumar, R.M., Subbaiah, S. V. and Pillai, K.G. 1998. Response of rice hybrids to different dates of planting in vertisols of Andhra, Pradesh, India. Oryza, 35(3): 258-287.

Longping, Y. 2004. Hybrid rice for food security in the world. FAO Rice Conference 04/CRS.21, Rome, Italy. 12-13 February 2004.

Mahmood, R. (2017). Performance of hybrid Boro rice in coastal area of Bangladesh. *Progressive Agric*. **30**(2): 186-193, 2019.

Mahmood, R., Howlader, M.H.K. and Haque, M.Z. (2019). Performance of hybrid Boro rice in coastal area of Bangladesh. Progressive Agriculture 30 (2): 186-193.

Malik, N.J., Chamon, A.S., Mondol, M.N., Elahi, S.F. and Faiz. (2011). Effect of different levels of Zinc on Growth and Yield of Red Amaranth (*Amaranthus Sp*.) and Rice (*Oryza Sativa*). *J. Bangladesh Ass. Young Res*. **1**: 79–91.

Maqsood, M., M. Irshad, S.A., Wajid and A. Hussain. (2008). Zinc status of rice plant is influenced by different levels and methods of zinc application. *Pak. J. Bio. Sci*. **2**: 1632–1633.

Masum, S.M., Ali, M.H., Hasanuzzaman, M., Chowdhury, I.F., Mandal, M.S.H. and Jerin, R. (2014). Response of variety and population density on yield attributes and yield of boro rice (*Oryza sativa*). Ann. Agric. Res. New Series Vol. 35(4): 355-361.

Mia, M. B. (2018). Influence of zinc application methods on growth and yield of *Boro* rice. M.S. thesis, Dept. Agronomy, Sher-e-bangla Agricultural University, Dhaka-1207.

Mustafa, G., Ehsanullah, N., Akbar, S.A., Qaisrani, A.,Iqbal, H., Khan, Z., Jabran, K., Chattha, A.A., Trethowan, R., Chattha, T. and Atta, B.M. (2011). Effect of Zinc application on growth and yield of rice (*Oryza sativa* L.). *Int. J. Agro Vet. Med. Sci.* **5**(6): 530–535.

Naik, S.K. and Das, D.P. (2007). Effect of split application of zinc on yield of rice (*Oryza sativa* L.) In an inceptisol. *Archives Agron Soil Sci*. **53**(3): 305 –

313.

Natural Resources Conservation Service. (2004). Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42 Version 4.0 (edited by Burt, R.) Washington, D.C.: United States Department of Agriculture Natural Resources Conservation Service. p. 700.

Oahiduzzaman, M. (2013). Effect of zinc and cow dung on growth, yield and nutrient content of transplanted aman rice (BRRI dhan33). M.S. thesis, Dept. Agricultural Chemistry, Sher-e-bangla Agricultural University, Dhaka-1207.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circular*. **939**: 19. Washington, DC: US Department of Agriculture.

Oko, A.O., Ubi, B.E. and Efisue, A.A. (2012). A Comparative Study on Local and Newly Introduced Rice Varieties in Ebonyi State of Nigeria based on Selected Agronomic Characteristics. *Int. J. Agric. Forestry*. **2**(1): 11-17

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy. In Soil Science Society of America. Vol. 1159.

Paul, N.C., Paul, S.C., Paul, S.K. and Salam, M.A. (2021). Response of nitrogen and potassium fertilization on the growth performance of aromatic *Boro*rice. *Archives of Agriculture and Environmental Sci.* **6**(3): 303–309.

Podder,S. (2017).Response of *Boro* rice to foliar spray of zinc and *Boro*n. M.S. thesis, Dept. Agronomy, Sher-e-bangla Agricultural University, Dhaka-1207.

Prasad, R.K., Kumar, V., Prasad, B. and Singh, A.P. (2010). Long-Term Effect of Crop Residues and Zinc Fertilizer on Crop Yield, Nutrient Uptake and Fertility Build-up under Rice-Wheat Cropping System in Calciorthents. *J.*

Indian Soc. Soil Sci. **58**(2): 205–211.

Rahman, A., Salam, M.A., Kader, M.A., Islam, M.S. and Perveen, S. (2020). Growth and yield of *boro* rice (*Oryza sativa* L.) in response to crop establishment methods and varieties. Archives of Agriculture and Environmental Science 5(2): 137-143.

Rahman, A., Yasin, M., Akram, M. and Awan, Z.I. (2002). Response of rice to Zinc application and different N-sources in calcareous soil. *Sci. Vision*. **8**(1): 16–23.

Rahman, M.M. Reza, M.S., Chowhan, S. and Akter, M.B. (2022). Growth and yield performance of seven rice varieties under moderate salinity stress. Bangladesh J. Nuclear Agric. 36(1): 93-104.

Rahman, M.T., Jahiruddin, M., Humauan, M.R., Alam, M.J. and Khan, A.A. (2008). Effect of sulphur and zinc on growth, yield and nutrient uptake of *Boro* rice (cv. BRRI dhan29). *J. Soil Nat*. **2**(3): 10–15.

Rahman,K.M. (2007). Effects of Sulphur and zinc on the yield of T-aman rice (BRRI Dhan-31). M.S. thesis, Dept. soil science, Sher-e-bangla Agricultural University, Dhaka-1207.

Ram, S., Chauhan, R.P.S. and Singh, B.B. (2005). Response of rice (*Oryza sativa*) to zinc application in sodic soil of Uttar Pradesh. *Indian J. Agric. Sci*. **65**(7): 525–527.

Rashid, A. (2001). Secondary and micronutrients; Soil Science. National Book Foundation, Islamabad, p. 372-379.

Reddy, M.G., Murthy, V.S. and Rao, P.G. (2011). Effect of micronutrients on rice. *The Andhra Agric. J.*, **31**(2): 150-153.

Roy, A. (2018). Influence of zinc on yield and quality of aromatic rice. M.S. thesis, Dept. Agronomy, Sher-e-bangla Agricultural University, Dhaka-1207.

Roy, S. K. (2014). Evaluation of growth and yield potentialities of local boro rice varieties in south-west region of Bangladesh. *Life Sci. J.* **11**(10):277-281

Sarkar, N.A.R., Siddique, M.S. and Islam, M.S. 2008. Effect of variety and structural arrangement of rows on the yield and yield components of transplant Boro rice. Bangladesh .J. Agril. Sci. 19(3): 43-51.

Sarkar, S.C., Akter, M., Islam, M.R. and Haque, M.M. (2016). Performance of Five Selected Hybrid Rice Varieties in Aman Season. J. Plant Sci. 4(2): 72-79.

Sarkar, S.K., Sarkar, M.A.R., Islam, N. and Paul, S.K. (2013). Yield and quality of aromatic fine rice as affected by variety and nutrient management-I. *J. Bangladesh Agril. Univ*. **12**(2): 279–284.

Sarker, J.R. (2007). Performance of aman rice as influenced by nitrogen and zinc on the yield of BRRI DHAN 39. M.S. thesis, Dept. soil science, Sher-e-bangla Agricultural University, Dhaka-1207.

Sharmin, M. (2014). Influence of sulphur and zinc on the yield of T. Aman rice (BRRI dhan34). M.S. thesis, Dept. soil science, Sher-e-bangla Agricultural University, Dhaka-1207.

Shivay, Y.S., Prasad, R., Singh, R.K. and Pal, M. (2015). Relative Efficiency of Zinc-Coated Urea and Soil and Foliar Application of Zinc Sulphate on Yield, Nitrogen, Phosphorus, Potassium, Zinc and Iron Biofortification in Grains and Uptake by Basmati Rice (*Oryza sativa* L.). *J. Agric Sci*. **7**(2): 1916–9752.

Shiyam, J.O., Binang, W.B. and Ittah, M.A. (2014). Evaluation of growth and yield attributes of some lowland chinese hybrid rice *(Oryza sativa* L.)

varieties in the Coastal Humid Forest Zone of Nigeria. *J. Agric. Veterinary Sci.*. **7**(2): 70-73.

Singh, A.K., Manibhushan, Meena, M.K. and Upadhyaya, A. (2012). Effect of Sulphur and Zinc on Rice Performance and Nutrient Dynamics in Plants and Soil of Indo Gangetic Plains. *J. Agric Sci*. **5**(4): 1916–9760.

Singh, A.K., Meena, M.K., and Bharati, R.C. (2011). Sulphur and zinc nutrient management in rice-lentil cropping system. International Conference on "Life Science Research for Rural and Agricultural Development" (pp 66-67). 27-29 December, 2011, CPRS Patna (Bihar).

Singh, V., Rachana, Mithare, P. and Kumar, S. (2019). Performance of hybrid rice cultivar (*Oryza sativa* L.) on growth and yield attributes under Agro-Climatic Conditions of Allahabad Uttar Pradesh in Aman Season of Planting. Int. J. Curr. Microbiol. App. Sci. 8(9): 2970-2982.

Sultana, C.W. (2005). An evaluation on the effects of different rates of sulphur and zinc on *Boro* rice. M.S. thesis, Dept. soil science, Bangladesh Agricultural University, Mymensingh.

Tahura, M. S. (2011). Effect of sulphur and zinc on the yield and nutrient content of T. aman rice (*Oryza sativa*).M.S. thesis, Dept. Agricultural Chemistry, Sher-e-bangla Agricultural University, Dhaka-1207.

UNDP. (1988). Land Resource Apprisal of Bangladesh for Agricultural Development Report 2: Agro-ecological Regions of Bangladesh, FAO, Rome, Italy. p. 577.

Walter, E. and Dean, J.R. (1974). Determination of Carbonate and Organic Matter in Calcareous Sediments and Sedimentary Rocks by Loss on Ignition: Comparison with Other Methods. *J. Sedimentary Petrology*. **44**: 242-248.

Wei, Y., Sohag, M.J.I. and Yang, X. (2012). Bio-fortification and bioavailability of rice grain zinc as affected by different forms of foliar zinc fertilization. *Plant and Soil.*, **7**(9): 35–42.

Yin, H.J., Gao, X.P., Stomph, T., Li, L.J., Zhang, F.S. and Zou, C.Q. (2016). Zinc concentration in Rice (*Oryza sativa* L.) Grains and allocation in plants as affected by different zinc fertilization strategies. *Communications Soil Sci. Plant Anal.*, **47**(6): 761–768.

Zhang, Y., Sun, Y., YouLiang, Y.M., karim, R., Xue, Y., Yan, P., Menga, Q., Cui, Z., Cakmak, I., Zhang, F. and Zou, C.Q., (2012). Zinc biofortification of rice through fertilizer application in different location of China. *Field Crops Res.*, **125**: 1–7.

Zou, C.Q., Zhang, Y.Q., Rashid, A., Ram, H., Savali, E., Arisoy, R.Z., Ortiz, M.I., Simunji, S., Wang, Z.H., Sohu, V., Hassan, M., Keya, Y., Onder, O., Lungu, O., Yaqub, M.M., Joshi, A.K., Zelenskiy, Y., Zhang, F.S. and Cakmak, I. (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil.*, **361**: 119–130.

APPENDICES

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

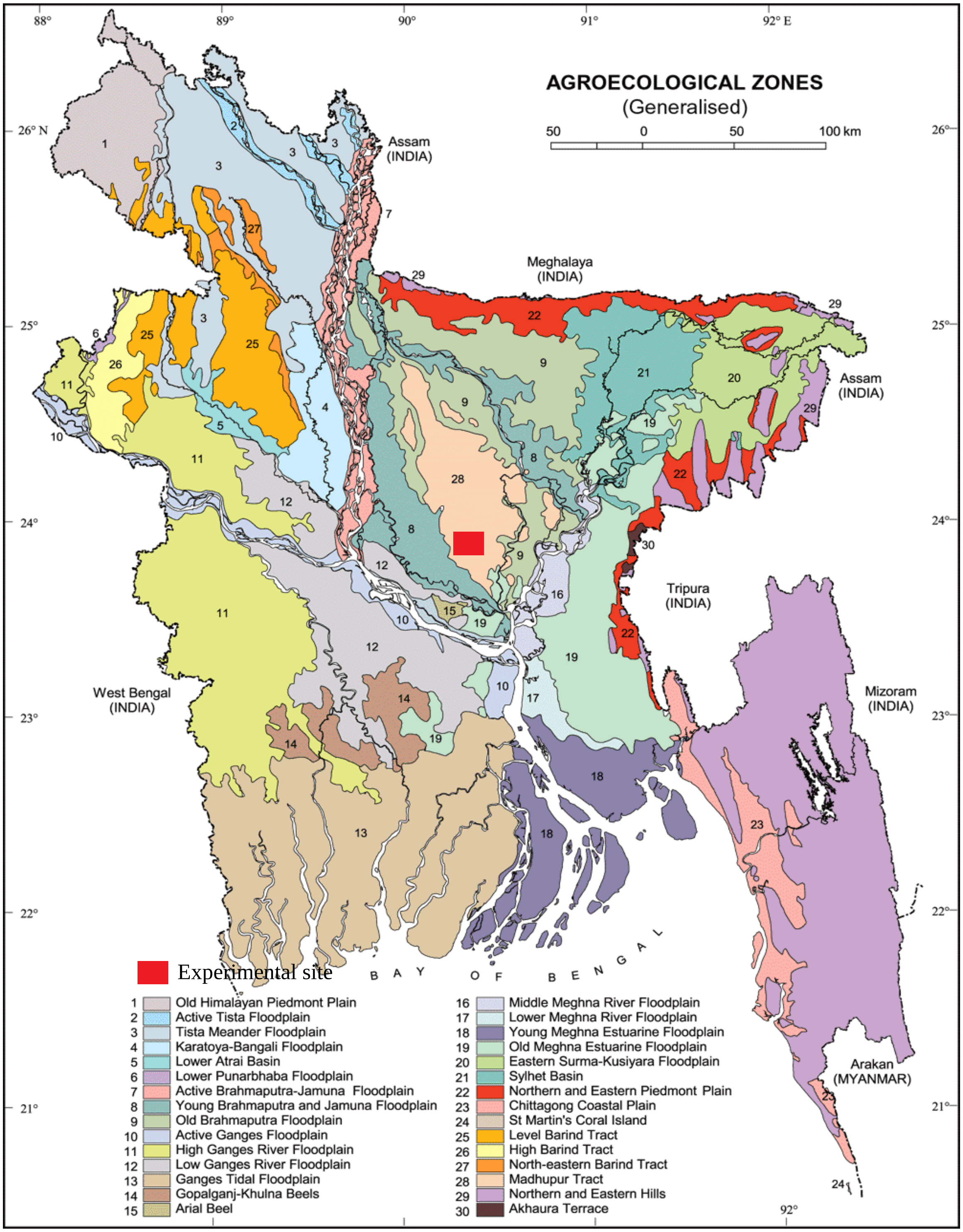


Figure 6. Experimental site

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	25.50	6.70	16.10	54.80	0.0
2021	January	23.80	11.70	17.75	46.20	0.0
2021	February	22.75	14.26	18.51	37.90	0.0
2021	March	35.20	21.00	28.10	52.44	20.4
2021	April	34.70	24.60	29.65	65.40	165.0
2021	May	32.64	23.85	28.25	68.30	182.2

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

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45
Available Zn (ppm)	1.03

Source: Soil Resource Development Institute (SRDI)

Appendix IV. Effect of micronutrient zinc on the growth performance regarding plant height and length of flag leaf of rice varieties

Sources of variation	Degrees of freedom	Mean square of growth parameters	
		Plant height (cm)	Length of flag leaf (cm)
Replication	2	0.379	1.958
Factor A	1	283.77*	17.328*
Factor B	7	635.76*	83.637*
AB	7	45.048*	0.688*
Error	30	15.623	0.228

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

Appendix V. Effect of micronutrient zinc on the growth performance regarding number of tillers per hill (effective and non-effective tillers) of rice varieties

Sources of variation	Degrees of freedom	Mean square of growth parameters		
		Number of tillers $hill^{-1}$	Number of effective tillers $hill^{-1}$	Number of non-effective tillers $hill^{-1}$
Replication	2	2.908	1.394	0.450
Factor A	1	8.636^{NS}	2.516^{NS}	1.829^{NS}
Factor B	7	13.48*	20.71*	0.994^{NS}
AB	7	1.029**	1.638**	1.031^{NS}
Error	30	2.412	1.398	1.117

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

Appendix VI. Effect of micronutrient zinc on the yield contributing parameters of rice varieties

Sources of variation	Degrees of freedom	Mean square of yield contributing parameters			
		Panicle length	Number of filled grains $panicle^{-1}$	Number of unfilled grains $panicle^{-1}$	1000 seed weight
Replication	2	0.341	124.509	0.879	0.013
Factor A	1	13.84^{NS}	315.136*	4.072^{NS}	3.366^{NS}
Factor B	7	38.28*	1368.06*	22.04*	9.824**
AB	7	1.787**	11.253*	0.264**	0.147**
Error	30	2.261	10.711	NUFgrain	0.018

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

Appendix VII. Effect of micronutrient zinc on the yield parameters of rice varieties

Sources of variation	Degrees of freedom	Mean square of yield parameters		
		Grain yield ha^{-1}	Straw yield ha^{-1}	Harvest index
Replication	2	0.002	0.275	2.250
Factor A	1	2.197**	1.595**	7.938^{NS}
Factor B	7	9.209*	4.756*	58.42*
AB	7	0.146**	0.144**	0.652*
Error	30	0.062	0.074	1.392

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

Appendix VIII. Effect of micronutrient zinc on pH and organic carbon, P and S content in post harvest soil of rice

Sources of variation	Degrees of freedom	Mean square of nutrient content in soil			
		pH	Organic carbon	P	S
Replication	2	0.004	0.002	1.103	0.102
Factor A	1	0.013^{NS}	0.007^{NS}	3.076^{NS}	3.014^{NS}
Factor B	7	3.015^{NS}	1.044^{NS}	8.502*	12.433*
AB	7	0.236^{NS}	0.103^{NS}	0.311**	1.144**
Error	30	0.003	0.011	0.214	0.018

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

Plate 1. Harvesting of rice

Plate 2. Post harvest operation of rice on threshing floor

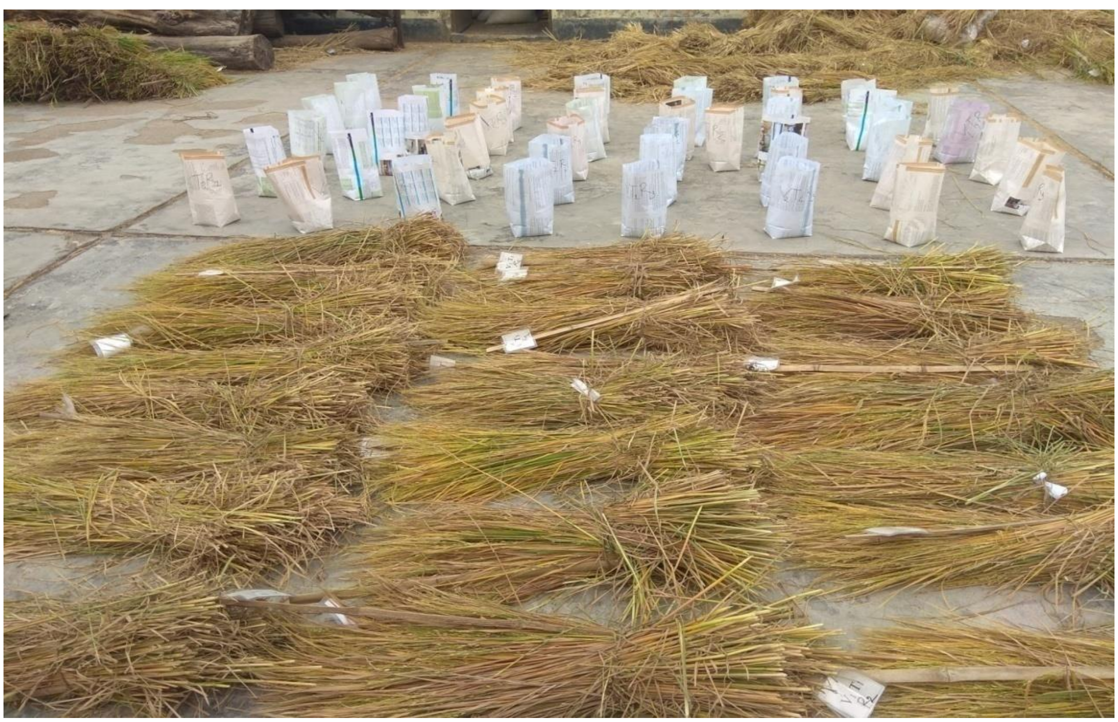


Plate 3. Different harvested rice samples on threshing floor after post harvest operation