INFLUENCE OF ZINC ON YIELD AND QUALITY OF AROMATIC RICE

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CERTIFICATE

This is to certify that the thesis entitled '**Influence of Zinc on Yield and Quality of Aromatic Rice**' submitted to the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE in AGRONOMY**, embodies the results of a piece of bona fide research work carried out by **ANANYA ROY**, Registration No. **12-04962** 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.

Dated: June, 2018
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TO

MY BELOVED PARENTS

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ABSTRACT

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period of June to December 2017 to find out the influence of zinc on yield and quality of aromatic rice. Aromatic rice cultivars Dulhabhog, Chinigura, Khoisanne and Chiniatab were used in this experiment. The experiment consisted of two factors viz., Factor A: Four levels of zinc (Zn) such as-Zn_1: 2.5 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 3.5 kg Zn ha^{-1}, Zn_4: 4.0 kg Zn ha^{-1}; and Factor B: Four cultivars of aromatic rice such as- V_1: Dulhabhog, V_2: Chinigura, V_3: Khoisanne and V_4: Chiniatab. The two factors experiment was laid out in a split-plot design with three replications. Zn level were assigned to main plot and variety to sub plot. Data were recorded on yield attributes, yield and quality of aromatic rice. The result revealed that zinc level had no significant effect on grain yield. Results revealed that supplementation of zinc and/or different varieties had significant effect on most of the yield and quality contributing parameters. Effective tillers, filled grains, weight of milled rice, protein content, proline content and grain 2-Acetyl-1-pyrroline (2-AP) content increased with increasing zinc level. But Zn level had no significant effect on 1000 grains weight, grain yield, harvest index and amylose content among the four aromatic rice varieties. The highest grain yield was observed from V_1, highest proline content was found from V_2 and maximum grain 2-AP content was found from V_3. Among the 16 treatment combinations, the highest plant height (54.77, 87.76, 120.78, 127.49 and 130.79 cm, respectively) was observed from Zn_4V_1 at different date, respectively. The highest grain yield (2.94 ha^{-1}) was found from Zn_4V_1. The highest proline content (26.74 mg g^{-1}) was recorded from Zn_4V_2 on dry weight (DW) basis. The highest grain-2AP content (1.41 µg g^{-1}) was recorded from Zn_4V_3 on dry weight (DW) basis. So it may be concluded that applications 4.0 kg Zn ha^{-1} on aromatic rice variety Dulhabhog showed the superior characters among the other treatments in consideration of yield and quality. On the other hand, application of 4 kg Zn ha^{-1} and aromatic rice variety Khoisanne showed the best performance in case of protein, amylose and 2-AP content but not on proline.

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CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.), belongs to the family Poaceae, is the most important cereal crop in tropical and subtropical regions (Singh *et al*., 2012). It is the staple food for more than 50% of the world's population (Jahan *et al.*, 2017) and is grown in more than a hundred of countries across the world. A total of 474.86 million metric tons was produced from 159.64 million hectares of land in 2014-15 (USDA, 2015). Rice provides for 21% of the calorific intake of the world and 76% of the calorific intake of the total population of south-east Asian region countries (Fitzgerald *et al*., 2009). Above 90% of total produced rice is consumed in Asia (FAO, 2014). Rice grain has shaped the culture and economy of billions of world people (Farooq *et al.,* 2009). Bangladesh ranks 4th in both area and production and 6th in per hectare production of rice (Sarkar *et al*., 2016).

In Bangladesh, rice covers an area of about 11,420,725 ha and total production is about 34,710,417 metric tons (BBS, 2015). According to FAO (2014) the average yield of rice of Bangladesh is about 2.92 t ha^{-1} which is very low compared to other rice growing countries like Korea (6.30 t ha^{-1}), China (6.30 t ha^{-1}) and Japan (6.60 t ha^{-1}). About two millions of people are adding every year which will be 30 million over the next 20 years and thus, to meet up the food supply for this over population, Bangladesh needs 37.26 million tons of rice for the year 2020 (BRRI, 2011). Population growth in Bangladesh demand a continuous increase of rice production and the highest priority has been given for this (Bhuiyan, 2004). World food security become challenged for increasing food demand and estimated that about 114 million tonnes of additional rice will be needed by 2035 which is equivalent to overall increase of 26% for next 25 years (Kumar and Ladha, 2011). Rice production has to be increased at least 60% by 2020 to meet up food requirement of the increasing population (Masum, 2009). Thus, the population by the year 2030 will swell progressively to 223 million which will demand additional 48 million tons of food grains (Julfiquar *et al*., 2008).

Rice yields are either stagnating or declining in post green revolution era mainly due to different factors that are related to crop production (Prakash, 2010). The reasons for low productivity of rice includes numerous factors but the major reason attributed to prevalence of local varieties instead of high yielding varieties and without practicing proper management and fertlization (Mandira *et al*., 2016). Micronutrients, though needed in smaller amounts, play a major role in the production and productivity of rice. Zinc (Zn) is the fourth most deficient nutrient element in soils and its deficiency causes severe yield reduction in rice (Suman and Sheeja, 2018; Alam *et al*., 2012). Depending on the aroma and fineness, two types of rice varieties viz. aromatic (fine) and nonaromatic (coarse) rice are producing in Bangladesh. The most important aromatic rice varieties in Bangladesh are Chinisagara, Badshabhog, Kataribhog, Kalizira, Tulsimla, Dulabhog, Basmati, Banglamoti (BRRI dhan50), BRRI dhan34, BRRI dhan37 and BRRI dhan38 (Sarkar *et al*., 2014). Aromatic rice is precious for its special aroma, unique flavor, fineness, taste good quality etc. and the market price of these rice is much higher than non-aromatic rice.

Zn is one of the vital nutrients which is required for various biochemical and metabolic process in rice such as synthesis of cytochromes and nucleotides, auxin metabolism, production of chlorophyll, activation of several enzymes, membrane integrity, metabolism of carbohydrate, cell wall development, gene expression and respiration (Broadley *et al*., 2007). Among the essential nutrient, Zn plays a major role in the growth and development of rice (Chaudhary *et al*., 2007). Zn deficiency is considered to be the most important nutritional stresses limiting rice production in Asia (Rehman *et al*., 2012). Zinc deficiency decreases the tillering, increases the spikelet sterility and delay the crop maturity (Tian *et al*., 2009; IRRI, 2000). Leaf chlorosis, shortened internodes, stunted growth and tiny leaves are the deficiency symptoms of zinc (Cakmak, 2002). Tang and Wu (2006) found that Zn application could improve the growth and quality of aromatic rice. Except growth and yield, Zn could also improve rice aroma by enhancing the biosynthesis of 2-Acetyl-1-pyrroline (2-AP) in rice plants (Lie *et al*., 2017).

Aromatic rice is precious for its special aroma, unique flavor and good quality (Baradi and Martinez, 2015; Ashraf *et al*., 2017). Thai 'jasmine' and Pak-Indian 'basmati' varieties are highly valued by consumers globally and gaining popularities in international markets (Huang *et al*., 2012), while the sale-price of aromatic rice is higher than non-aromatic rice (You *et al*., 2012). The production of aromatic rice in Bangladesh during 2013 is approximately 0.30 million tons from 0.16 million ha of land which is so far from the national average, and hence the yield needs to be increased by 53.3% (Mahamud *et al*., 2013). The demand for scented fine grain rice has been increased due to economic development of the people of Bangladesh (Ali *et al*., 2016). Most of the well-off people preferred long, slender scented fine rice (Mannan *et al*., 2012; Sarkar *et al*., 2014). Despite a huge market demand at present area of aromatic rice cultivation is less than 2% of the national rice coverage of Bangladesh (Ashrafuzzaman *et al*., 2009).

Production of aromatic rice can be increased by the selection of appropriate variety and nutrient management. It was revealed that chemical fertilizer ($N:P_2O_5:K_2O$ @ 125:62.5:62.5) produced equivalent yield with good quality grain compared to the highest level of fertilizer ($N: P_2O_5:K_2O$ @ 150:75:75) alone showing the reduction of 25% cost on chemical fertilizer (Murali and Setty, 2004). The 2-Acetyl-1-pyrroline (2-AP), popcorn like flavor compound and a main active flavor component of aromatic rice (Buttery and Ling, 1982) and its characteristics in sensory evaluation showed the strong correlation with its contents (Ishitani and Fushimi, 1994). It is important to preserve the content and maintain flavor of aromatic rice. From the above content the experiment was conducted with the following objectives-

1. To study the effect of zinc on yield and quality of aromatic rice.
2. To find out the optimum level of zinc and suitable variety for producing good quality aromatic rice.

Chapter 2

Review of literature

CHAPTER II

REVIEW OF LITERATURE

Rice is the staple food more than three billion people in the world and around 90% of rice is grown and consumed in south and Southeast Asia, the highly populated area. Bangladesh produces different high yielding rice varieties and most of them have excellent production. Most of the rice varieties of Bangladesh have been developed by IRRI, BRRI and BINA. Variety itself is the genetical factor which contributes on yield and yield components and it can be classified as aromatic and non-aromatic rice by aroma. Different researcher reported the effect of rice varieties on yield contributing component and grain yield both aromatic and non-aromatic rice. Application of Zn either as foliar spray or soil application caused significant improvement in growth and yield attributes and yield of rice. Some of the important and informative works and research findings related to the morpho-physiological attributes, yield contributing characters and yield of aromatic and non-aromatic rice, and effect of Zn so far been done at home and abroad, reviewed in this chapter under the following headings-

2.1 Effect of zinc on yield and yield attributes of rice

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

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

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

Kabeya and Shankar (2013) reported that rice is the worlds’ most important cereal and potentially an important source of zinc (Zn) and Zn deficiency being a major constraint to reduce the potential yield of rice. To improve Zn delivery by rice, plant Zn uptake and internal allocation need to be better investigated. The highest effect was observed when treated with 30 kg $ZnSO_4$ ha^{-1} irrespective of zinc groups. However, high zinc groups showed better uptake ability in zinc content and overall performance in growth characteristics.

A field experiment was conducted by Dixit *et al*. (2012) to study the effect of sulphur and zinc on yield, quality and nutrient uptake by hybrid rice grown in sodic soil and that positive response of hybrid rice to zinc application was noticed significantly up to the zinc dose @ 10 kg ha^{-1}.

An experiment was carried out by Singh *et al.* (2012) at Sari, Mazandaran, Iran and reported that the maximum panicle number m^{-2} and harvest index were observed with 4 kg Zn ha^{-1} and the least of those was obtained in control treatment. The highest zinc content in grain, zinc uptake in grain and straw, and nitrogen uptake in grain were observed with 4 kg Zn ha^{-1}, as the most zinc content in straw, nitrogen, potassium, phosphorus and sulphur content in grain and straw were observed highest with application of 4 and 2 kg Zn ha^{-1}.

Muthukumararaja and Sriramachandrasekhara (2012) reported that zinc deficiency in flooded soil is impediment to obtain higher rice yield. Zinc deficiency is corrected by application of suitable zinc fertilizer. The results revealed that rice responded significantly to graded dose of zinc. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1}, which was about 100% and 86% greater than control (no zinc) respectively. The highest zinc concentration and uptake in grain and straw and DTPA-Zn at all stages was noticed at 7.5 mg Zn kg^{-1}.

The study was conducted by Mustafa *et al*. (2011) at agronomic research area, University of Agriculture, Faisalabad, 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 per m^2 (249.80) were noted with basal application at the rate 25 kg ha^{-1} of $ZnSO_4$ (21% Zn) and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5% Zn solution. Maximum paddy yield (5.21 t ha^{-1}) was achieved in treatment Zn_2 (Basal application at the rate of 25 kg ha^{-1} of $ZnSO_4.7H_2O$) and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn_7 (foliar application at 75 DAT @ 0.5% Zn solution).

Naik and Das (2007) carried out an experiment with Zn fertilization and reported that the soil application of Zn at 1.0 kg ha^{-1} as Zn-EDTA (T_7) recorded highest grain yield of 5.42 t ha^{-1}, filled grain percentage of 90.2%, 1000-grain weight of 25.41 g and number of panicles m^{-2} of 452. The Zn content of grain and straw were also found to be maximum in the treatment T_7 i.e. 38.19 and 18.27 mg Zn kg^{-1}, respectively.

A study was carried out by Cheema *et al*. (2006) to evaluate the effect of four zinc levels on the growth and yield of coarse rice cv. IR-6 at Faisalabad, Pakistan. Four zinc levels viz., 2.5, 5.0, 7.5 and 10.kg $ZnSO_4$ ha^{-1} increased yield and yield component as compared with control. Plant height, number of tillers $hill^{-1}$, panicle bearing tillers, number of primary and secondary spikelets, panicle size, 1000 grain weight, paddy and straw yield and harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

A field experiment was conducted by Ullah *et al.* (2001) in Mymensingh, Bangladesh, to study the effect of zinc sulfate (0, 10, and 20 kg ha^{-1}) on rice cv. BR30. Plant height; tiller number; 1000-grain weight; grain and straw yields; and grain, straw, and soil Zn contents increased with zinc sulfate application. The tallest plants (75.667 cm) and the highest number of tillers (10.60 $hill^{-1}$), 1000-grain weight (28.700 g), and the concentration of Zn in straw (101.93 ppm) and grain (73.33 ppm) were obtained with 20 kg zinc sulfate ha^{-1}.

2.2. Effect of varieties on yield and yield attributes of rice

2.2.1 Plant height of different rice varieties

Sumon *et al.* (2018) conducted a study to evaluate the growth, yield and proximate composition of aromatic rice varieties in Aman season at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic rice varieties in main plots and six fertilizer levels in subplots. From the findings they sated that 'Raniselute' variety produced the highest plant height.

Jisan *et al.* (2014) carried out and experiment at Bangladesh Agricultural University, Mymensingh with a view to examine the yield performance of some transplant *Aman* rice varieties. The experiment consisted of four varieties viz. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 and four levels of nitrogen. Data revealed that among the varieties, BRRI dhan52 produced the tallest plant (117.20 cm), whereas the lowest plant height by BRRI dhan57.

Sarkar *et al.* (2014) conducted an experiment at Bangladesh Agricultural University, Mymensingh, to study the yield and quality of aromatic fine rice. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38 and eight nutrient managements. Results revealed that the tallest plant (142.7 cm) were recorded in BRRI dhan34.

An experiment was conducted by Haque and Biswash (2014) with five varieties of hybrid rice and one hybrid and two checks from Bangladesh Rice Research Institute (BRRI). Varieties was Sonarbangla-1, Jagoron, Hira, Aloron, Richer, BRRI hybrid dhan1 and two checks was BRRI dhan28 and BRRI dhan29 and the highest plant height was 101.5 cm was recorded from BRRI dhan28 and the lowest plant height from Richer (82.5 cm).

Bhuiyan *et al.* (2014) carried out an experiment with aimed to determine the adaptability and performance of different hybrid rice varieties and to identify the best hybrid rice variety. Based on the findings of the study it was revealed that the different hybrid rice varieties had significant effects on plant height at maturity.

To study the effect of nitrogen fertilizer and seedling age on Giza 178, H1 and Sakha 101 field experiments was conducted by Salem *et al*. (2011) at the Rice Research and Training Center (RRTC), Sakha, Kafr-El Sheikh Governorate, Egypt during summer seasons. The results indicated that Sakha 101 variety surpassed than other varieties in terms of plant height.

Khalifa (2009) conducted a field experiment at the experimental farm of Rice research and training centre (RRTC), Sakha, Kafr-El sheikh governorate, Egypt rice season for physiological evaluation of some hybrid rice varieties under different sowing dates. Four hybrid rice H_1, H_2, GZ 6522 and GZ 6903 was evaluated at six different sowing dates. Results indicated that H_1 hybrid rice variety surpassed other varieties in terms of plant height.

Masum *et al*. (2008) observed that plant height of rice affected by varieties in *Aman* season where Nizershail produced the taller plant height than BRRI dhan44 at different days after transplanting (DAT).

Mandavi *et al.* (2004) found from their experiment that plant height was negatively correlated with grain yield. Thus, in improved genotypes, plant height was not a limiting factor for grain yield because of reduced lodging and conducted better translocation of assimilates.

Murthy *et al.* (2004) conducted an experiment with six varieties of rice genotypes namely Mangala, Madhu, J-13, Sattari, CR 666-16 and Mukti, and the findings revealed that the variety Mukti gave the longest plant compared to the others of their experiment.

Ghosh (2001) carried out an experiment with four rice hybrids and four high yielding rice cultivars and concluded that hybrids have higher plant height as compared with high yielding varieties. Pruneddu and Spanu (2001) conducted an experiment and found that plant height ranged from less than 65 cm to 80-85 cm in Mirto, Tejo, Gladio, Lamone and Timo.

2.2.2 Tillering pattern of different rice varieties

Sumon *et al*. (2018) conducted a study was conducted to evaluate the growth, yield and proximate composition of aromatic rice varieties in Aman season at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic rice varieties in main plots and six fertilizer levels in subplots. From the findings they sated that 'BRRI dhan34' gave the maximum number of effective tillers hill^{-1} (12.74).

Sarkar *et al*. (2016) carried out an experiment to evaluate the performance of five hybrid rice varieties namely Shakti 2, Suborna 8, Tia, Aloron and BRRI hybrid dhan 2 in *Aman* season with an inbred BRRI dhan33 as checked. The result showed that the hybrid varieties exhibited superiority in respect of tillers hill^{-1} and these hybrid varieties showed higher effective tillers hill^{-1}.

Haque and Biswash (2014) experimented with five varieties of hybrid rice which was collected from different private seed companies and one hybrid and two checks from BRRI. Varieties were Sonarbangla-1, Jagoron, Hira, Aloron, Richer, BRRI hybrid dhan1 and two checks was BRRI dhan28 and BRRI dhan29. In case of no. of effective tillers, Hira showed the best performance (17.7) and Sonarbangla-1 showed the least performance (13.3).

Bhuiyan *et al*. (2014) conducted an experiment with aimed to determine the adaptability and performance of different hybrid rice varieties and to identify the best hybrid rice variety. Based on the findings of the study, the different hybrid rice varieties evaluated had significant effects on number of tillers, number of productive tillers. RGBU010A × SL8R is therefore recommended as planting material among hybrid rice varieties because it produced more productive tillers.

Sarkar *et al*. (2014) conducted an experiment at Bangladesh Agricultural University, Mymensingh, to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38 and eight nutrient managements. Results revealed that the highest number of effective tillers hill^{-1} (10.02) was recorded in BRRI dhan34.

Jisan *et al*. (2014) carried out and experiment at Bangladesh Agricultural University, Mymensingh with a view to examine the yield performance of some transplant *Aman* rice varieties. The experiment consisted of four varieties viz. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 and four levels of N. Among the varieties, BRRI dhan52 produced the highest number of effective tillers hill^{-1} (11.28), while the lowest were produced by BRRI dhan57.

A field experiment was conducted by Khalifa (2009) at the experimental farm of Rice research and training centre (RRTC), Sakha, kafr-El sheikh governorate, Egypt for physiological evaluation of some hybrid rice varieties under different sowing dates. Four hybrid rice H_1, H_2, GZ 6522 and GZ 6903 was evaluated at six different sowing dates. Results indicated that H_1 hybrid rice variety surpassed other varieties in consideration of effective and total tillers hill^{-1}.

Masum *et al*. (2008) stated that number of total tillers hill^{-1} was significantly influenced by cultivars at all crop growth stages. Nizersail was achieved maximum (25.63) tiller at 45 DAT, whereas BRRI dhan44 gave the maximum tillers (18.92) around panicle initiation stage at 60 DAT from.

Murthy *et al.* (2004) conducted an experiment with six varieties of rice genotypes Mangala, Madhu, J-13, Sattari, CR 666-16 and Mukti, and observed that Mukti gave the highest tillers hill^{-1} compared to the others. Song *et al.* (2004) found that hybrids produced a significantly higher number of tillers than their parental species and Minghui-63 had the least number of tillers.

Bhowmick and Nayak (2000) conducted an experiment with two hybrids (CNHR2 and CNHR3) and two high yielding varieties (IR36 and IR64) of rice and five levels of nitrogenous fertilizers. They observed that CNHR2 produced more number of productive tillers (413.4/m^2) than other tested varieties.

2.2.3 Dry matter content of different rice varieties

Sumon *et al*. (2018) conducted a study to evaluate the growth, yield and proximate composition of aromatic rice varieties in Aman season at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic rice varieties in main plots and six fertilizer levels in subplots. From the findings they sated that 'Raniselute' variety produced the highest dry matter weight hill^{-1} compared to the other rice varieties.

Sarkar *et al*. (2016) carried out an experiment to evaluate the performance of five hybrid rice varieties namely Shakti 2, Suborna 8, Tia, Aloron and BRRI hybrid dhan 2 in *Aman* season with an inbred BRRI dhan33 as checked. The result showed that the hybrid varieties exhibited superiority in respect of total dry matter (TMD) hill^{-1} and the highest TDM hill^{-1} (84.0 g) was observed Tia and lowest TDM hill^{-1} (70.10 g) was observed in BRRI dhan33.

Field experiments were conducted by Haque *et al*. (2015) including two popular indica hybrids (BRRI hybrid dhan2 and Heera2) and one elite inbred (BRRI dhan45) rice varieties. Both hybrids accumulated higher amount of biomass before heading and exhibited greater remobilization of assimilates to the grain in early plantings compared to the inbred variety.

In order to evaluate the response to planting date in rice hybrids line dry method of working, was carried out by Shaloie *et al*. (2014) at the Agricultural Research Station, Agriculture and Natural Resources Research Center of Khuzestan Shavuor. Hybrid rice Hb2 and Hb1 was used in the sub plots. Results showed traits was significantly affected in terms of dry matter and mentioned trait was more in hybrid Hb_2 than Hb_1.

Xie *et al.* (2007) found that Shanyou-63 variety gave the higher yield (12 t ha^{-1}) compared to Xieyou46 variety (10 t ha^{-1}). Masum *et al*. (2008) found that total dry matter production differed due to varieties. Total dry matter of BRRI dhan44 Nizershail significantly varied at different sampling dates.

Amin *et al.* (2006) conducted a field experiment to find out the influence of variable doses of N fertilizer on growth, tillering and yield of three traditional rice varieties (*viz.* Jharapajam, Lalmota, Bansful Chikon) was compared with that of a modern rice variety (*viz.* KK-4) and reported that traditional varieties accumulated higher amount of vegetative dry matter content in different growth stages than the modern variety.

Amin *et al.* (2006) conducted a field experiment to find out the influence of variable doses of N fertilizer on growth, tillering and yield of three traditional rice varieties (Jharapajam, Lalmota, Bansful Chikon) was compared with that of a modern variety (KK-4). The findings of the study revealed that traditional varieties accumulated higher amount of vegetative dry matter content than the modern rice variety.

Mandavi *et al.* (2004) carried out an experiment to study on the morphological and physiological indicators of rice genotypes, a field experiment was conducted at the Rice Research Institute of Iran. In that study, Onda had the greater total dry matter (TDM) among other genotypes (this genotype also had the highest grain yield). Higher TDM was obtained from improved genotype than traditional genotypes (1445 and 1626 GDD, respectively). At flowering the dry matter weight was higher for Jasesh and was lower for Ramazan Ali Tarom (923.93 g m^{-2} and 429 g m^{-2}, respectively). So the photosynthetic potential of improved genotypes was higher as reflected by their TDM which had positive correlation with the grain yield of these varieties.

Sharma and Haloi (2001) conducted an experiment in Assam during the kharif season with 12 varieties of scented rice cultivars to assess the yield attributes and yield and observed that cv. Kunkuni Joha consistently maintained a higher rate of dry matter production in compared to the other varieties of this experiment at all the growth stages and the highest dry matter accumulation was observed in cv. Kunkuni Joha at the panicle initiation stage.

2.2.4 Yield attributes of different rice varieties

Sumon *et al.* (2018) conducted a study to evaluate the growth, yield and proximate composition of aromatic rice varieties in Aman season at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic rice varieties and six fertilizer levels. From the findings they sated that 'BRRI dhan34' produced the highest panicle length (27.93 cm), number of filled grains panicle^{-1} (192.5), 1,000-grain weight (17.22 g) and grain yield (2.26 t ha^{-1}).

Sarkar *et al.* (2016) carried out an experiment to evaluate the performance of five hybrid rice varieties namely Shakti 2, Suborna 8, Tia, Aloron and BRRI hybrid dhan2 in *Aman* season with an inbred BRRI dhan33 as checked and these hybrid varieties also showed higher 1000-grain over the inbred.

Dou *et al.* (2016) carried out an experiment with the objective to determine the effects of water regime/soil condition, cultivar ('Cocodrie' and 'Rondo'), and soil texture on rice grain yield, yield components and water productivity using a greenhouse trial. The spikelet number of Cocodrie was 29% greater than that of Rondo, indicating that rice cultivar had greater effect on spikelet number.

An experiment was conducted by Hosain *et al.* (2014) at the research farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during *Aus* season 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). Hybrid varieties Heera2 (3.03 t ha^{-1}) and Aloron (2.77 t ha^{-1}) gave the higher spikelet sterility.

Sarkar *et al.* (2014) conducted an experiment at Bangladesh Agricultural University, Mymensingh, to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38 and eight nutrient managements. Results revealed that the number of grains panicle^{-1} (152.3), panicle length (22.71 cm) and 1000-grain weight (15.55 g) were recorded in BRRI dhan34.

Haque and Biswash (2014) experimented with five varieties of hybrid rice which was collected from different private seed companies and one hybrid and two checks from Bangladesh Rice Research Institute (BRRI). Varieties were Sonarbangla-1, Jagoron, Hira, Aloron, Richer, BRRI hybrid dhan1 and two checks were BRRI dhan28 and BRRI dhan29. In panicle length status, Richer showed the best performance (27.7 cm) while BRRI dhan28 showed the least performance (26 cm). Number of filled grains panicle^{-1} was the highest for BRRI dhan29 (163.3), whereas, Jagoron only 118. Number of total grains was highest in BRRI dhan29 (201.7) and for Jagoron it was only 133.7. On the other hand, for 1000-grain weight, Aloron was the best than other hybrids.

Bhuiyan *et al.* (2014) conducted an experiment with aimed to determine the adaptability and performance of different hybrid rice varieties and to identify the best hybrid rice variety in terms of yield and recommend it to rice farmers. Based on the findings of the study, the different hybrid rice varieties evaluated had significant effects on number of filled and unfilled grains, length of panicle and yield. RGBU010A × SL8R is therefore recommended as planting material among hybrid rice varieties because it produced longer panicles and heavy seeds. In the absence of this variety, RGBU02A × SL8R, RGBU003A × SL8R and RGBU0132A × SL8R may also be used as planting material.

In order to evaluate the response to planting date in rice hybrids Line dry method of working, was carried out by Shaloie *et al.* (2014) at the Agricultural Research Station, Agriculture and Natural Resources Research Center of Khuzestan Shavuor. Hybrid rice Hb2 and Hb1 was used in the sub plots. Results showed traits was significantly affected in terms of panicle length, fertility percentage, and mentioned traits was more in hybrid Hb_2 than Hb_1.

Jisan *et al*. (2014) carried out and experiment at Bangladesh Agricultural University, Mymensingh with a view to examine the yield performance of some transplant *Aman* rice varieties as influenced by different levels of nitrogen. The experiment consisted of four varieties viz. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 and four levels of N. Among the varieties, BRRI dhan52 produced the grains panicle^{-1} (121.5) and 1000-grain weight (23.65 g), whereas the lowest values of these parameters was produced by BRRI dhan57.

Forty five aromatic rice genotypes were evaluated by Fatema *et al*. (2011) to assess the genetic variability and diversity on the basis of nine characters. Significant variations were observed among the genotypes for all the characters. Thousand grain weight have been found to contribute maximum towards genetic diversity in 45 genotypes of aromatic rice.

Two field experiments was conducted by Salem *et al*. (2011) at the Rice Research and Training Center (RRTC), Sakha, Kafr-El Sheikh Governorate, Egypt during summer seasons to study the effect of nitrogen fertilizer and seedling age on Giza 178, H1 and Sakha 101. The results indicated that Sakha 101 variety surpassed than other varieties in terms of 1000 seeds weight.

Islam *et al.* (2010) studied yield potential of 16 rice genotypes including 12 hybrids, 3 inbreds and 1 New Plant Type (NPT) at the International Rice Research Institute (IRRI) farm under optimum crop management to achieve maximum attainable yield during the wet season (WS) of 2004 and dry season (DS) of 2005. Yield and yield components was determined at maturity. Hybrid produced higher spikelets panicle^{-1} and 1000-grain weight than inbred rice. Spikelet filling percent was higher in inbred than hybrid rice. The NPT rice genotype had the lowest spikelet filling percent, but the highest 1000-grain weight across the season.

A field experiment was conducted by Khalifa (2009) at the experimental farm of Rice research and training centre (RRTC), Sakha, kafr-El sheikh governorate, Egypt rice season for physiological evaluation of some hybrid rice varieties under different sowing dates. Four hybrid rice H_1, H_2, GZ 6522 and GZ 6903 was evaluated at six different sowing dates. Results indicated that H_1 hybrid rice variety surpassed other varieties for studied characters except for number of days to panicle initiation and heading date.

Islam *et al.* (2009) conducted pot experiments during T. *Aman* season in net house at Bangladesh Rice Research Institute (BRRI). Hybrid variety Sonarbangla-1 and inbred modern variety BRRI dhan31 was used in both the seasons. BRRI dhan3l had higher panicles plant^{-1} than Sonarbangla-1, but Sonarbangla-1 had higher number of grains panicle^{-1}, 1000-grain weight.

Wang *et al*. (2006) studied the effects of plant density and row spacing (equal row spacing and one seedling hill^{-1}, equal row spacing and 3 seedlings hill^{-1}, wide-narrow row spacing and one seedling hill^{-1}, and wide-narrow row spacing and 3 seedlings hill^{-1} on the yield and yield components of hybrids and conventional cultivars of rice. Compared with conventional cultivars, the hybrids had larger panicles, highest total grains, resulting in an average yield increase of 7.27%.

Chaturvedi *et al.* (2004) evaluated newly released commercial rice hybrids (DRRH 1, PHB 71, Pro-Agro 6201, KHR 2, ADTHR 1, UPHR 1010 and Pant Sankar Dhan 1) and two high yielding varieties as checks (Pant Dhan 4 and Pant Dhan 12) for their agronomic and morpho-physiological traits in a field experiment. Hybrids although could not excel the best HYV owing to high percentage of spikelet sterility but they showed potential for higher yield as these produced large sink (higher number of spikelets m^{-2}).

Guilani *et al*. (2003) carried out an experiment on crop yield and yield components of rice cultivars (Anboori, Champa and LD183) in Khusestan, Iran. They observed that grain number panicle^{-1} was not significantly different among cultivars. The highest grain number panicle^{-1} was obtained with Anboori. Grain fertility percentages were different among cultivars. Among cultivars, LD183 had the highest grain weight.

2.2.5 Yield of different rice varieties

Sumon *et al*. (2018) conducted a study to evaluate the growth, yield and proximate composition of aromatic rice varieties in Aman season at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic rice varieties and six fertilizer levels. From the findings they sated that 'Raniselute' variety produced the highest straw yield (7.81 t ha^{-1}), biological yield (9.05 t ha^{-1}) and 'BRRI dhan34' gave the maximum grain yield (2.26 t ha^{-1}).

Chowdhury *et al*. (2016) conducted an experiment was at Bangladesh Agricultural University, Mymensingh with a view to finding out the effect of variety and level of nitrogen on the yield performance of fine aromatic rice. The experiment consisted of three varieties viz. Kalizira, Binadhan-13 and BRRI dhan34, and six levels of nitrogen. The highest grain yield (3.33 t ha^{-1}) was obtained from Binadhan-13 followed by BRRI dhan34 (3.16 t ha^{-1}) and the lowest grain yield was found in Kalizira (2.11 t ha^{-1}).

Yield test of 41 entries, 32 new hybrids, 8 male parents restore lines and 1 inbred variety, was conducted by Huang and Yan (2016) on the farm of University of Arkansas at Pine Bluff (UAPB). Results showed that the yields of 7 hybrids were 25.7%-30.7% higher than check Francis. Hybrid 28s/BP23R had the highest yield, 10846.6 kg/hectare and over check by 30.7%. The yield of hybrid 28s/PB-24, was 10628.9 kg/hectare and over check by 28.1%. The yields of hybrid 28s/PB-22 and 33A/PB24 were 10549.8 and 10539.8 kg/hectare and over check by 27.1% and 27.0%, respectively.

Sarkar *et al*. (2016) carried out an experiment to evaluate the performance of five hybrid rice varieties namely Shakti 2, Suborna 8, Tia, Aloron and BRRI hybrid dhan 2 in *Aman* season with an inbred BRRI dhan33 as checked. 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.

A study was conducted by Mandira *et al*. (2016) in South Tripura district of Tripura for three consecutive kharif seasons to evaluate the performance of rice variety gomati at farmers field under rainfed conditions. The gomati variety of rice was found superior over farmers' existing practices with local varieties. Rice variety gomati with improved production technologies followed in FLDs, increased mean grain yield by 41.62% over farmers' existing practices with only Rs. 1817 ha^{-1} extra expenditure on inputs.

A study was design by Wagan *et al*. (2015) to compare the economic performance of hybrid and conventional rice production and reported that total costs per hectare of hybrid rice was 148992.23 Rs per hectare which was more then conventional rice was 140661.68 Rs ha^{-1}. On an average higher yield (196.14 monds ha^{-1}) was obtained from hybrid rice while conventional rice yield (140.14 monds ha^{-1}) was less then hybrid rice. There was 16.64 percent increase in hybrid rice yield comparing with conventional rice which gives additional income to poor farmers.

Field experiments were conducted by Haque *et al*. (2015) including two popular indica hybrids (BRRI hybrid dhan2 and Heera2) and one elite inbred (BRRI dhan45) rice varieties. Both hybrid varieties out yielded the inbred. However, the hybrids and inbred varieties exhibited statistically identical yield in late planting. Results suggest that greater remobilization of shoot reserves to the grain rendered higher yield of hybrid rice varieties.

Sarkar *et al*. (2014) conducted an experiment at Bangladesh Agricultural University, Mymensingh, to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38 and eight nutrient managements. Results revealed that the highest grain yield (3.71 t ha^{-1}) were recorded in BRRI dhan34.

Kanfany *et al*. (2014) conducted an experiment by at the Africa Rice Sahel Regional Station during two wet seasons with the aim of assessing the performances of introduced hybrid cultivars along with an inbred check cultivar under low input fertilizer levels. There were significant cultivar effects for all traits. The grain yield of rice hybrids (bred by the International Rice Research Institute) was not significantly higher than that of the check cultivar widely grown in Senegal.

An experiment was conducted by Hosain *et al*. (2014) at the research farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during *Aus* season (March to July 2010) 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). BRRI dhan48 produced the highest grain yield (3.51 t ha^{-1}).

Jisan *et al*. (2014) carried out and experiment at, Bangladesh Agricultural University, Mymensingh with a view to examine the yield performance of some transplant *Aman* rice varieties as influenced by different levels of nitrogen. The experiment consisted of four varieties viz. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 and four levels of N. Data revealed that highest grain yield (5.69 t ha^{-1}) was obtained from BRRI dhan52 followed by BRRI dhan49 (5.15 t ha^{-1}) and the lowest one (4.25 t ha^{-1}) was obtained from BRRI dhan57.

Bhuiyan *et al*. (2014) conducted an experiment with aimed to determine the adaptability and performance of different hybrid rice varieties and to identify the best hybrid rice variety in terms of yield and recommend it to rice farmers. Findings revealed that different hybrid rice varieties had significant effects on yield. RGBU010A × SL8R is therefore recommended as planting material among hybrid rice varieties because it produced favorable yield.

Haque and Biswash (2014) experimented with five varieties of hybrid rice which was collected from different private seed companies and one hybrid and two checks from Bangladesh Rice Research Institute (BRRI). Varieties were Sonarbangla-1, Jagoron, Hira, Aloron, Richer, BRRI hybrid dhan1 and two checks were BRRI dhan28 and BRRI dhan29. In case of biological yield (g), BRRI dhan29 showed highest yield (49.6 g) and Hira only 18 g.

An experiment was carried out by Alam *et al*. (2012) at Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi to study the effect of variety, spacing and number of seedlings hill^{-1} on the yield potentials of transplant *Aman* rice. The experiment consisted of three high yielding varieties viz. BRRI dhan32, BRRI dhan33 and BR11, four levels of spacing and four levels of number of seedlings hill^{-1}. Variety had significant effects on almost all the yield component characters and yield. Variety BR11 produced the highest grain yield (5.92 t ha^{-1}).

Samonte *et al*. (2011) reported that the two elite lines recommended for release are high yielding in Texas. RU0703190 is also very early maturing conventional long grain rice. The high yield potential of these new releases will impact grain production of rice farmers and their income.

Roy (2006) screened and evaluated several *indica/japonica* (I/J) lines was by for higher grain yield in the *Boro* season. The highest grain yield of 9.2 t ha^{-1} was obtained from selected I/J line IR58565-2B-12-2-2, which was equal to that of indica hybrid CNHR3 and significantly higher than that of modern variety IR36.

Above cited reviews revealed that application Zn and different rice variety significantly influences the growth, yield attributes and as well as yield of rice. The literature revealed that the effects of Zn on rice and comparative study of different aromatic rice variety have not been studied well and have no definite conclusion in this aspects for the production of aromatic rice in the agro climatic condition of Bangladesh.

Chapter 3

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the influence of zinc on yield and quality of aromatic rice. The details of the materials and methods i.e. experimental period, location, soil and climatic condition of the experimental site, experimental treatment and design, growing of crops, data collection and analysis procedure that followed for the conduction of this experiment has been presented below under the following headings and sub-headings:

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the period of June to December 2017.

3.1.2 Experimental location

The present experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is $23^0 74^/$N latitude and $90^0 35^/$E longitude with an elevation of 8.2 meter from sea level. Experimental location presented in Appendix I.

3.1.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February, the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al*., 1979). During the experimental period the maximum temperature (36.8^0C), highest relative humidity (87%) and highest rainfall (573 mm) was recorded for the month of July, 2017, whereas the minimum temperature (22.6^0C), minimum relative humidity (74%) and no rainfall was recorded for the month of December, 2017. 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 Modhupur Tract”, AEZ-28 (FAO, 1988). Top soil was Silty Clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. The experimental area having available irrigation and drainage system and situated above flood level. The soil having a texture of sandy loam organic matter 1.15% and composed of 26% sand, 43% silt and 31% clay. Details morphological, physical and chemical properties of the experimental field soil are presented in Appendix III.

3.2 Experimental details

3.2.1 Planting material

Aromatic rice cultivars Dulhabhog, Chinigura, Khoisanne and Chiniatab were used as the test crops in this experiment.

3.2.2 Treatment of the experiment

The experiment consisted of two factors:

Factor A: Levels of Zn (4 levels) as

i. Zn_1: 2.5 kg Zn ha^{-1} (Receommended Dose)

ii. Zn_2: 3.0 kg Zn ha^{-1}

iii. Zn_3: 3.5 kg Zn ha^{-1}

iv. Zn_4: 4.0 kg Zn ha^{-1}

Factor B: Aromatic rice variety (4 varieties) as

i V_1: Dulhabhog

ii. V_2: Chinigura

iii. V_3: Khoisanne

iv. V_4: Chiniatab

There were total 16 (4×4) combination as a whole viz., Zn_1V_1, Zn_1V_2, Zn_1V_3, Zn_1V_4, Zn_2V_1, Zn_2V_2, Zn_2V_3, Zn_2V_4, Zn_3V_1, Zn_3V_2, Zn_3V_3, Zn_3V_4, Zn_4V_1, Zn_4V_2, Zn_4V_3 and Zn_4V_4.

3.2.3 Experimental design and layout

The two factors experiment was laid out in split-plot design with three replications. An area of 443.45 m^2 (24.5 m × 18.1 m) was divided into 3 blocks. The four levels of Zn were assigned in the main plot and 4 aromatic rice varieties in the sub-plot. The size of the each unit plot was 2.0 m × 1.6 m. The space between two blocks, main and two plots and sub plots were 1.0 m, 0.75 m and 0.5 m, respectively. Each plot and sub-plot were separated by raised border. The layout of the experiment presented in Figure 1.

3.3 Growing of crops

3.3.1 Seed collection and sprouting

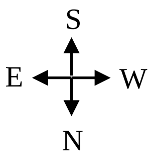
Seeds of different aromatic rice varieties were collected from BRRI (Bangladesh Rice Research Institute), Gazipur and local market just 20 days ahead of the sowing of seeds in seed bed. For seedlings clean seeds were immersed in water in a bucket for 24 hours. The imbibed seeds were then taken out of water and kept in gunny bags. The seeds started sprouting after 48 hours which were suitable for sowing 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 18th June, 2017. 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 in the 15th June 2017 with a power tiller, and left exposed to the sun for a week. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain good puddle condition. Weeds and stubbles were removed. The experimental plot was partitioned into unit plots in accordance with the experimental design at 23th June, 2017. Organic and inorganic manures as indicated 3.3.4 were mixed with the soil of each unit plot.



Plot size = 2.0 m × 1.6 m
Sub-plot to Sub-plot: 0.5 m
Plot to plot: 0.75 m
Replication to replication: 1.0 m

Factor A: Levels of Zn (4) as
i. Zn_1: 2.5 kg Zn ha^{-1}
ii. Zn_2: 3.0 kg Zn ha^{-1}
iii. Zn_3: 3.5 kg Zn ha^{-1}
iv. Zn_4: 4.0 kg Zn ha^{-1}

Factor B: Aromatic rice variety (4) as
i V_1: Dulhabhog
ii. V_2: Chinigura
iii. V_3: Khoisanne
iv. V_4: Chiniatab

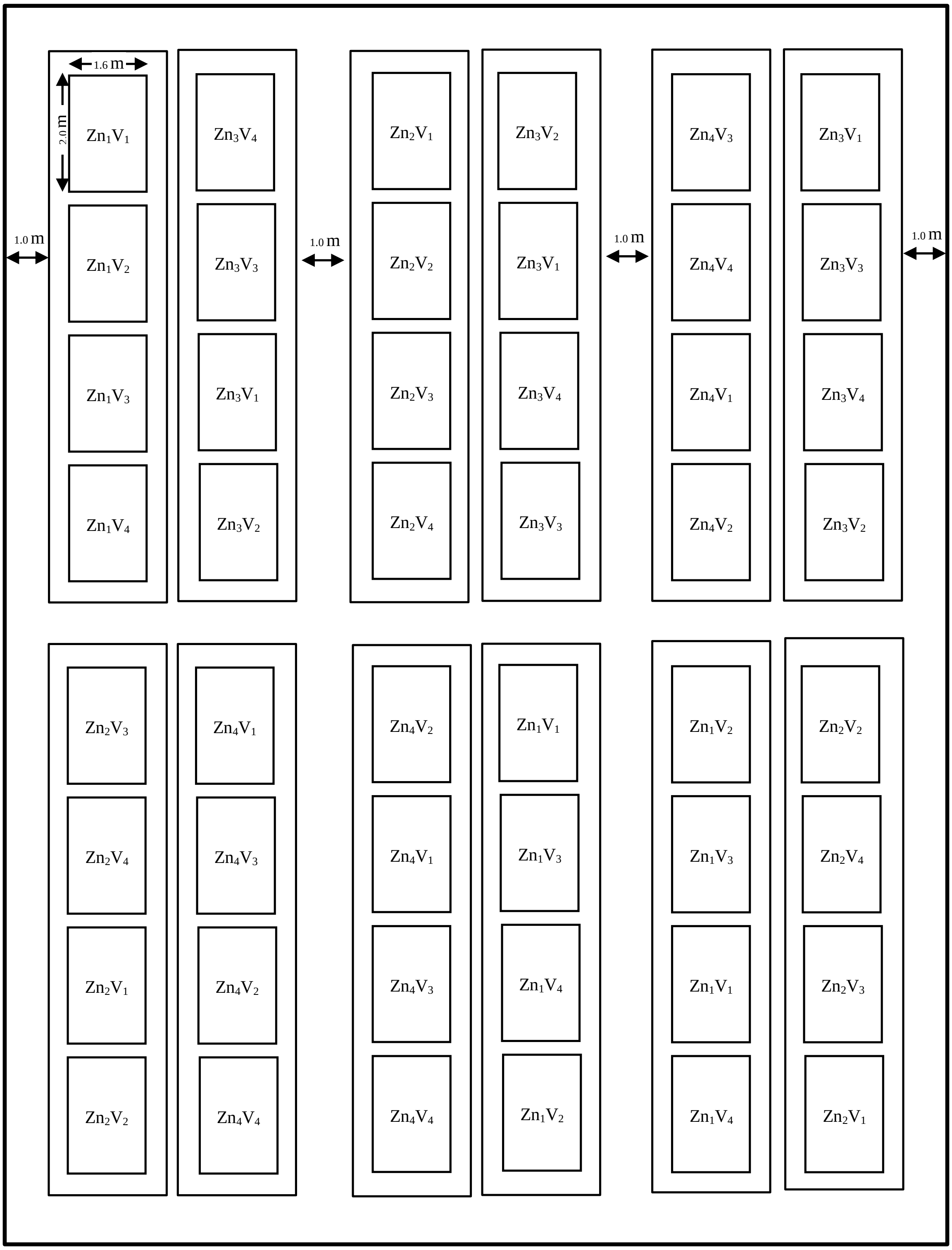


Figure 1. Layout of the experimental plot

3.3.4 Fertilizers and manure application

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MoP, Gypsum, zinc sulphate and borax, respectively. Urea, TSP, MoP, Gypsum and borax were applied @ 80, 60, 90, 12 and 10 kg ha^{-1} (BRRI, 2016). Vermocompost were applied @ 76.8 kg ha^{-1} in each plot. Zn were applied as per treatment. The entire amount of Vermocompost, TSP, MoP, gypsum, zinc sulphate and borax were applied during final land preparation. Urea was applied in three equal installments as top dressing at early and maximum tillering and panicle initiation stages.

3.3.5 Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 26^{th} July, 2017 in well puddled plot with spacing of 20 × 15 cm. Two seedlings 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.

3.3.6 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.

3.3.6.1 Irrigation and drainage

In the early stages to establishment of the seedlings irrigation was provided to maintain a constant level of standing water upto 6 cm and then maintained the amount drying and wetting system throughout the entire vegetative phase. No water stress was encountered in reproductive and ripening phase. The plot was finally dried out at 15 days before harvesting.

3.3.6.2 Weeding

Weeding was done to keep the plots free from weeds, which ultimately ensured better growth and development of the seedlings. The weeds were uprooted carefully at 20 DAT (days after transplanting) and 40 DAT by mechanical means.

3.3.6.3 Insect and pest control

Furadan were applied at 15 DAT in the plot. Leaf roller (*Chaphalocrosis medinalis*) was found and used Malathion @ 1.12 L ha^{-1} at 25 DAT using sprayer but no diseases infection was observed in the field.

3.4 Harvesting, threshing and cleaning

The crop was harvested at full maturity based on variety when 80-90% of the grains were turned into straw color. The harvested crop was bundled separately, properly tagged and brought to threshing floor. The grains were dried, cleaned and weighed for individual plot. The weight was adjusted to 12% moisture content. Yields of rice grain and straw were recorded from each plot.

3.5 Data recording

3.5.1 Plant height

The height of plant was measured in centimeter (cm) from the ground level to the tip of the plant at 20, 40, 60, 80 DAT and at harvest. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot.

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

Number of tillers $hill^1$ was recorded at 20, 40, 60, 80 DAT and at harvest as the average of randomly selected 5 plants from the inner rows of each plot.

3.5.3 Chlorophyll content in flag leaf

Flag leaves were sampled from 5 plants at flowering stage and a segment of 20 mg from middle portion of flag leaf was used for chlorophyll content estimation on fresh weight basis extracting with 80% acetone and for that double beam spectrophotometer (Model: U-2001, Hitachi, Japan) were used according to Witham *et al*. (1986).

3.5.4 Effective tillers $hill^{-1}$

The total number of effective tillers $hill^{-1}$ was counted as the number of panicle bearing tillers during harvesting. Data on effective tillers $hill^{-1}$ were counted from 5 selected hills and average value was recorded.

3.5.5 Non-effective tillers hill^{-1}

The total number of non-effective tillers hill^{-1} was counted as the number of non-panicle bearing tillers during harvesting. Data on non-effective tillers hill^{-1} were counted from 5 selected hills and average value was recorded.

3.5.6 Panicle length

The length of panicle was measured with a meter scale from 5 selected panicle and the average length was recorded as per panicle in cm.

3.5.7 Filled grains panicle^{-1}

The total numbers of filled grains were collected randomly from selected 5 panicle of a plot on the basis of grain in the spikelet and then average numbers of filled grains panicle^{-1} was recorded.

3.5.8 Unfilled grains panicle^{-1}

The total numbers of unfilled grains was collected randomly from selected 5 plants of a plot on the basis of not grain in the spikelet and then average numbers of unfilled grains panicle^{-1} was recorded.

3.5.9 Total grains panicle^{-1}

The total numbers of grains was calculated by adding filled and unfilled grain selected 5 plants of a plot and average numbers of grains panicle^{-1} was recorded.

3.5.10 Weight of 1000-grains

One thousand grains were counted randomly from the total cleaned harvested grains and then weighed in grams and recorded.

3.5.11 Grain yield

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

3.5.12 Straw yield

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

3.5.13 Biological yield

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

Biological yield = Grain yield + Straw yield.

3.5.14 Harvest index

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

$$HI = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (total dry weight)}} \times 100$$

3.5.15 Length of grain rice

Ten (10) milled grain rice was selected from the bulk sample after milling of each entry were measured for their length by slide calipers.

3.5.16 Breadth of grain rice

Ten (10) milled grain rice was selected from the bulk sample after milling of each entry were measured for their breadth by slide calipers.

3.5.17 Weight of milled rice

After milling of 100 g brown rice milled rice were weighted by digital weighing machine and recorded in gram (g).

3.5.18 Weight of head rice

Unbroken head rice were identified after milling of 100 g brown rice of each entry and weighted by digital weighing machine and recorded in gram (g).

3.5.19 Weight of broken rice

Broken head rice were identified after milling of 100 g brown rice of each entry and weighted by digital weighing machine and recorded in gram (g).

3.5.20 Rice and husk ratio

After milling of 100 g brown rice weight of husk was taken and ratio of rick and husk was estimated.

3.5.21 Protein content

The protein content of rice grains was determined by the Micro-Kjeldahl method using automated nitrogen determination system (AOAC, 1990).

3.5.22 Amylose content

The amylose content of the rice samples was carried out using method by Juliano (1971). Hundred mg of the powdered rice sample was taken in a volumetric flask and added 1 ml of 95% ethanol and 9 ml of 1 NaOH then heated in boiling water bath to gelatinize starch. 5 ml of the starch extract was taken in 100 ml volumetric flask. 1 ml of 1N acetic acid and 2 ml iodide solution was added to the starch extract and the volume was made up to 100 ml. The solution was shaken and allowed to stand for 20 min. Then the absorbance was measured at 620 nm using Agilent Technologies Cary 60 UV-VIS spectrophotometer and amylose content was determined with reference to the standard curve of potato amylose and expressed in per cent basis.

3.5.23 Zn content

The samples of rice grains were ground for Zn analyses with a milling machine and sieved. Thereafter, the samples were digested using a di-acid [perchloric acid ($HClO_4$) + nitric acid (HNO_3) in 3:10 ratio]. After digestion in the aliquot of samples, Zn was estimated with the help of atomic absorption spectrophotometer (Perkin Elmer; Model-A. Analyst 100) as described by Prasad *et al*. (2006).

3.5.24 Proline content

The proline content of rice grains were measured according to the method established by Bates *et al*. (1973). Grains in which the weight was almost 0.3 g, were homogenized in a 4 ml solution of 3% sulfosalicylic acid and cooled after bringing to a boil for 10 min. Samples were filtered and 2 ml of the filtrate was mixed with 3 ml ninhydrin reagent (2.5 g ninhydrin in 60 ml glacial acetic acid and 40 mL 6 M phosphoric acid) and 2 ml glacial acetic acid. For the extraction of proline, the mixture was boiled for 30 min and 4 ml toluene was added to the cooled liquid. The extract was centrifuged at 4000 rpm for 5 min, and proline absorbance was detected at 520 nm and concentration expressed as $\mu g\ g^{-1}$.

3.5.25 Grain-2AP content

The 2-AP content in grain was estimated using the method described by Huang *et al*. (2012), prior to analysis, grains were ground by mortar and pestle. Approximately 10 g grains were mixed homogeneously with 150 ml purified water into a 500 ml round-bottom flask attached to a continuous steam distillation extraction head. The mixture was boiled at 150^0C in an oil pot. A 30 ml aliquot of dichloromethane was used as the extraction solvent and was added to a 500 ml round-bottom flask attached the other head of the continuous steam distillation apparatus, and this flask was boiled in a water pot at 53^0C. The continuous steam distillation extraction was linked with a cold water circulation machine in order to keep temperature at 10^0C. After approximately 35 min, the extraction was complete. Anhydrous sodium sulfite was added to the extract to absorb the water. The dried extract was filtered by organic needle filter and analyzed for 2-AP content by GCMS-QP 2010 Plus. High purity helium gas was used as the carrier gas at flow rate of 2 ml/min. The temperature gradient of the GC oven was as follows: 40^0C (1 min), increased at 2^0C min^{-1} to 65^0C and held at 65^0C for 1 min, and then increased to 220^0C at 10^0C min^{-1}, and held at 220^0C for 10 min. The retention time of 2-AP was confirmed at 7.5 min. Each sample had three replicates, and 2-AP was expressed as μg g^{-1}.

Protein, amylose, zinc, proline and grain 2-AP content were measured at Bangladesh Rice Research Institute (BRRI) and Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka.

3.6 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among different treatments. The analysis of variance of all the recorded parameters performed using MSTAT-C software. The difference of the means value was separated by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

Chapter 4

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the influence of zinc on yield and quality of aromatic rice. The analyses of variance (ANOVA) of the data on yield attributes, yield and quality of aromatic rice are presented in Appendix IV-X. The results of this experiment have been presented and discusses with the help of different table and graphs with possible interpretations under the following headings and sub-headings:

4.1 Yield attributes and yield of aromatic rice

4.1.1 Plant height

Plant height of aromatic rice at 20, 40, 60 and 80 DAT (days after transplanting) and harvest showed statistically significant differences due to different levels of zinc (Table 1). At 20, 40, 60, 80 DAT and harvest, the tallest plant (50.27, 81.00, 110.59, 116.54 and 119.42 cm, respectively) was recorded from Zn_4 (4.0 kg Zn ha^{-1}) which was statistically similar (49.30, 80.30, 109.30, 115.45 and 118.54 cm, respectively) to Zn_3 (3.5 kg Zn ha^{-1}) and followed (46.26, 76.06, 104.98, 109.98 and 113.64 cm, respectively) by Zn_2 (3.0 kg Zn ha^{-1}), whereas the shortest plant (41.97, 70.29, 97.59, 102.35 and 105.67 cm, respectively) was observed from Zn_1 (2.5 kg Zn ha^{-1}). Cheema *et al*. (2006) observed that plant height showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of plant height of aromatic rice at 20, 40, 60 and 80 DAT and harvest for different rice varieties (Table 1). At 20, 40, 60, 80 DAT and harvest, the tallest plant (49.44, 81.64, 110.34, 117.37 and 121.05 cm, respectively) was found from V_1 (Dulhabhog) which was followed (47.34, 77.67, 107.18, 110.85 and 113.78 cm, respectively) by V_4 (Chiniatab) and also (46.93, 76.74, 105.63, 110.04 and 113.22 cm, respectively) by V_2 (Chinigura), while the shortest plant (44.09, 71.61, 99.32, 106.04 and 109.22 cm, respectively) was recorded from V_3 (Khoisanne). Cultivars is the key component

Table 1. Effect of supplementation of zinc and different aromatic rice varieties on plant height at different days after transplanting (DAT) and harvest

Treatments	Plant height (cm) at				
	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
Levels of Zn					
Zn_1	41.97 c	70.29 c	97.59 c	102.35 c	105.67 c
Zn_2	46.26 b	76.06 b	104.98 b	109.98 b	113.64 b
Zn_3	49.30 a	80.30 a	109.30 a	115.45 a	118.54 a
Zn_4	50.27 a	81.00 a	110.59 a	116.54 a	119.42 a
SE value	0.654	0.770	1.985	1.273	1.331
Level of significance	**	**	**	**	**
CV(%)	4.83	3.47	6.51	3.97	4.03
Rice varieties					
V_1	49.44 a	81.64 a	110.34 a	117.37 a	121.05 a
V_2	46.93 a	76.74 b	105.63 a	110.04 b	113.22 b
V_3	44.09 b	71.61 c	99.32 b	106.04 b	109.22 b
V_4	47.34 a	77.67 b	107.18 a	110.85 b	113.78 b
SE value	0.858	0.967	2.042	1.825	1.507
Level of significance	**	**	**	**	**
CV(%)	6.33	4.35	6.70	5.69	4.57

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

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}

V_1: Dulhabhog

V_2: Chinigura

V_3: Khoisanne

V_4: Chiniatab

** = Significant at 1% level

for producing plant height based on their genotypic characters and off course the prevailing environmental conditions of growing season. Sarkar *et al.* (2014) recorded the tallest plant (142.7 cm) from BRRI dhan34 compared with aromatic rice BRRI dhan37 and BRRI dhan38. Similarly different researchers recorded different size of plant in earlier for different rice cultivars (Sumon *et al.*, 2018; Haque and Biswash, 2014; Khalifa, 2009).

Combined effect of different levels of zinc and rice varieties showed significant differences on plant height of aromatic rice at 20, 40, 60 and 80 DAT and harvest (Table 2). At 20, 40, 60, 80 DAT and harvest, the tallest plant (54.77, 87.76, 120.78, 127.49 and 130.79 cm, respectively) was observed from Zn_4V_1 (4.0 kg Zn ha^{-1} and Dulhabhog) treatment combination, whereas the shortest plant (41.50, 63.35, 94.11, 100.47 and 101.13 cm, respectively) was found from Zn_1V_3 (2.5 kg Zn ha^{-1} and Khoisanne) treatment combination.

4.1.2 Number of tillers hill^{-1}

Different levels of zinc varied in terms of number of tillers hill^{-1} of aromatic rice at 20, 40, 60 and 80 DAT and harvest (Figure 2). At 20, 40, 60, 80 DAT and harvest, the highest number of tillers hill^{-1} (4.60, 8.12, 13.65, 14.57 and 15.17, respectively) was found from Zn_4 which was statistically similar (4.55, 8.03, 13.38, 14.32 and 14.98, respectively) to Zn_3 and followed (4.37, 7.40, 12.55, 13.75 and 14.38, respectively) by Zn_2, while the lowest number (4.02, 6.52, 11.57, 12.58 and 13.23, respectively) was recorded from Zn_1. Cheema *et al.* (2006) observed that number of tillers hill^{-1} showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Number of tillers hill^{-1} of aromatic rice at 20, 40, 60 and 80 DAT and harvest showed statistically significant differences in terms of for different rice varieties (Figure 3). At 20, 40, 60, 80 DAT and harvest, the highest number of tillers hill^{-1} (4.58, 7.85, 13.68, 14.98 and 15.87, respectively) was observed from V_1 which was followed (4.48, 7.60, 13.13, 13.87 and 14.78, respectively) by V_4 and also (4.37, 7.53, 13.00, 14.07 and 14.43, respectively) by V_2, whereas the lowest

Table 2. Combined effect of supplementation of zinc and different aromatic rice varieties on plant height at different days after transplanting (DAT) and harvest

Treatments	Plant height (cm) at				
	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
Zn_1V_1	41.81 fg	73.94 de	96.79 ef	100.64 e	105.97 de
Zn_1V_2	42.08 fg	69.73 e	95.21 ef	100.51 e	104.50 de
Zn_1V_3	41.50 g	63.35 f	94.11 f	100.47 e	101.13 e
Zn_1V_4	42.49 e-g	74.14 de	104.25 c-f	107.77 de	111.09 c-e
Zn_2V_1	47.49 c-f	79.02 cd	105.46 b-f	115.07 b-d	119.06 bc
Zn_2V_2	45.16 d-g	77.86 cd	104.12 c-f	107.39 de	111.05 c-e
Zn_2V_3	46.93 c-g	69.83 e	108.88 a-e	115.19 b-d	120.52 bc
Zn_2V_4	45.47 d-g	77.54 cd	101.48 d-f	102.27 e	103.93 de
Zn_3V_1	53.68 ab	85.82 ab	118.32 ab	126.30 ab	128.39 ab
Zn_3V_2	48.23 b-e	75.77 de	107.36 a-f	110.87 c-e	113.30 cd
Zn_3V_3	43.49 e-g	79.15 cd	99.38 d-f	108.04 de	111.80 cd
Zn_3V_4	51.78 a-c	80.46 b-d	112.15 a-d	116.57 a-d	120.67 bc
Zn_4V_1	54.77 a	87.76 a	120.78 a	127.49 a	130.79 a
Zn_4V_2	52.27 a-c	83.60 a-c	115.83 a-c	121.40 a-c	124.03 ab
Zn_4V_3	44.44 d-g	74.12 de	94.90 f	100.45 e	103.42 de
Zn_4V_4	49.61 a-d	78.54 cd	110.85 a-d	116.81 a-d	119.45 bc
SE value	1.717	1.934	4.084	3.649	3.014
Level of significance	*	*	*	**	**
CV(%)	6.33	4.35	6.70	5.69	4.57

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

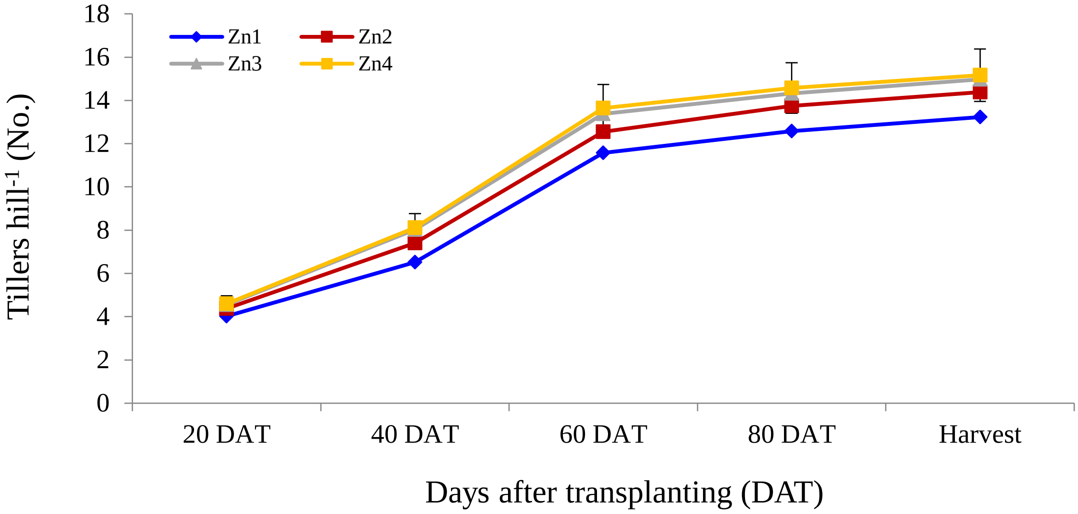
Zn_1: 2.5 kg Zn ha^{-1} | V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} | V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} | V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} | V_4: Chiniatab

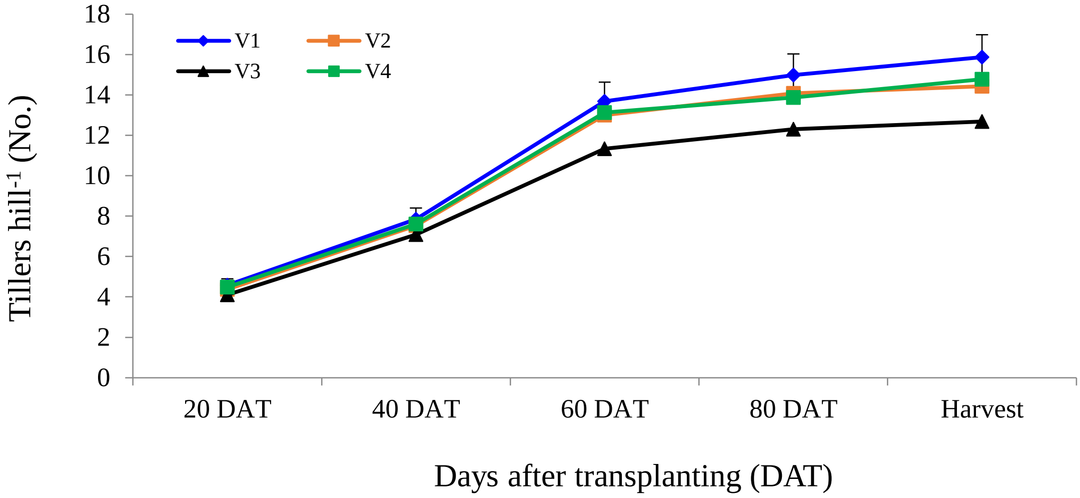
* = Significant at 5% level and ** = Significant at 1% level



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}

Figure 2. Effect of different levels of Zn on tillers hill^{-1} of aromatic rice. (Vertical bars represent SE value at 5% level of probability)



V_1: Dulhabhog V_2: Chinigura

V_3: Khoisanne V_4: Chiniatab

Figure 3. Effect of different variety on tillers hill^{-1} of aromatic rice. (Vertical bars represent SE value at 5% level of probability)

number (4.10, 7.08, 11.33, 12.30 and 12.68, respectively) was found from V_3. Masum *et al.* (2008) reported maximum (25.63) tiller at 45 DAT, then with advancement to age it declined up to maturity, whereas, in the case of BRRI dhan44, maximum (18.92) tiller production was observed around panicle initiation stage at 60 DAT. Khalifa (2009) reported that modern rice variety surpassed other varieties in case of tillers $hill^{-1}$. Sumon *et al.* (2018) sated that 'BRRI dhan34' gave the maximum number of effective tillers $hill^{-1}$ (12.74).

Statistically significant variation was recorded due to the combined effect of different levels of zinc and rice varieties in terms of number of tillers $hill^{-1}$ of aromatic rice at 20, 40, 60 and 80 DAT and harvest (Table 3). At 20, 40, 60, 80 DAT and harvest, the highest number of tillers $hill^{-1}$ (5.00, 8.60, 15.13, 16.53 and 17.33, respectively) was recorded from Zn_4V_1 treatment combination, while the lowest number (3.67, 6.13, 11.07, 11.80 and 12.13, respectively) was observed from Zn_1V_3 treatment combination.

4.1.3 Chlorophyll content in flag leaf

Statistically significant variation was recorded in terms of chlorophyll content in flag leaf of aromatic rice due to different levels of zinc (Table 4). The highest chlorophyll content in flag leaf (42.22 mg g^{-1}) was found from Zn_4 which was statistically similar (41.77 mg g^{-1}) to Zn_3 and followed (41.06 mg g^{-1}) by Zn_2 and the lowest (39.33 mg g^{-1}) was recorded from Zn_1.

Chlorophyll content in flag leaf showed statistically significant variation due to different rice varieties (Table 4). The highest chlorophyll content in flag leaf (42.54 mg g^{-1}) was observed from V_1 which was statistically similar (41.60 mg g^{-1} and 40.84 mg g^{-1}) to V_2 and V_4, while the lowest (39.40 mg g^{-1}) from V_3.

Combined effect of different levels of zinc and rice varieties showed significant differences on chlorophyll content in flag leaf (Table 5). The highest chlorophyll content in flag leaf (47.30 mg g^{-1}) was found from Zn_3V_1 treatment combination and the lowest (35.88 mg g^{-1}) was recorded from Zn_1V_3 treatment combination.

Table 3. Combined effect of supplementation of zinc and different aromatic rice varieties on number of tillers hill^{-1} at different days after transplanting (DAT) and harvest

Treatments	Tillers hill^{-1} (No.) at				
	20 DAT	40 DAT	60 DAT	80 DAT	Harvest
Zn_1V_1	4.27 de	6.87 ef	11.73 e-g	13.67 d-f	14.53 d-f
Zn_1V_2	3.73 f	6.20 f	11.60 e-g	12.13 h	12.67 gh
Zn_1V_3	3.67 f	6.13 f	11.07 g	11.80 h	12.13 h
Zn_1V_4	4.40 b-e	6.87 ef	11.87 e-g	12.73 f-h	13.60 fg
Zn_2V_1	4.33 c-e	7.47 c-e	13.07 c-e	14.00 c-e	14.73 c-f
Zn_2V_2	4.47 b-e	7.53 b-e	12.60 d-f	14.33 c-e	14.60 d-f
Zn_2V_3	4.13 e	7.07 d-f	11.87 e-g	13.33 e-g	13.87 e-g
Zn_2V_4	4.53 b-e	7.53 b-e	12.67 d-f	13.33 e-g	14.33 d-f
Zn_3V_1	4.73 a-c	8.47 ab	14.80 ab	15.73 ab	16.87 ab
Zn_3V_2	4.53 b-e	7.93 a-d	13.40 b-d	14.67 b-d	15.00 c-e
Zn_3V_3	4.33 c-e	7.53 b-e	11.07 g	11.73 h	12.07 h
Zn_3V_4	4.60 a-d	8.20 a-c	14.27 a-c	15.13 bc	16.00 bc
Zn_4V_1	5.00 a	8.60 a	15.13 a	16.53 a	17.33 a
Zn_4V_2	4.80 ab	8.47 ab	14.40 a-c	15.13 bc	15.47 cd
Zn_4V_3	4.20 de	7.60 b-e	11.33 fg	12.33 gh	12.67 gh
Zn_4V_4	4.40 b-e	7.80 a-e	13.73 a-d	14.27 c-e	15.20 cd
SE value	0.136	0.293	0.453	0.365	0.396
Level of significance	*	**	*	**	**
CV(%)	5.38	6.75	6.14	4.58	4.75

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

Table 4. Effect of supplementation of zinc and different aromatic rice varieties on chlorophyll content in flag leaf, effective and non-effective tillers hill^{-1} and panicle length

Treatments	Chlorophyll content in flag leaf (mg g^{-1}) fresh weight basis	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)
Levels of Zn				
Zn_1	39.33 c	9.88 c	3.35 a	22.00 b
Zn_2	41.06 b	11.27 b	3.12 b	23.18 ab
Zn_3	41.77 a	12.07 ab	2.92 c	24.13 a
Zn_4	42.22 a	12.37 a	2.80 c	24.30 a
SE value	0.191	0.251	0.046	0.409
Level of significance	**	**	**	*
CV(%)	1.61	7.63	5.19	6.05
Rice varieties				
V_1	42.54 a	13.10 a	2.77 c	25.43 a
V_2	41.60 a	11.42 b	3.02 b	22.81 bc
V_3	39.40 b	9.18 c	3.50 a	21.84 c
V_4	40.84 ab	11.88 b	2.90 bc	23.55 b
SE value	0.600	0.184	0.047	0.365
Level of significance	**	**	**	**
CV(%)	5.06	5.58	6.39	5.40

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

Table 5. Combined effect of supplementation of zinc and different aromatic rice varieties on chlorophyll content in flag leaf, effective and non-effective tillers hill^{-1} and panicle length

Treatments	Chlorophyll content in flag leaf (mg g^{-1}) fresh weight basis	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)
Zn_1V_1	36.30 g	11.53 cd	3.00 de	22.40 d-g
Zn_1V_2	39.67 e-g	9.33 fg	3.33 bc	20.99 g
Zn_1V_3	35.88 g	8.40 g	3.73 a	20.33 g
Zn_1V_4	45.47 ab	10.27 ef	3.33 bc	23.50 c-f
Zn_2V_1	42.70 b-e	12.00 b-d	2.73 e-g	24.94 bc
Zn_2V_2	39.80 d-g	11.33 de	3.27 cd	22.41 d-g
Zn_2V_3	43.63 a-d	10.27 ef	3.60 ab	23.82 c-e
Zn_2V_4	38.10 fg	11.47 d	2.87 ef	21.55 e-g
Zn_3V_1	47.30 a	14.20 a	2.67 fg	26.97 ab
Zn_3V_2	41.10 c-f	12.33 b-d	2.67 fg	22.50 d-g
Zn_3V_3	39.30 e-g	8.67 g	3.40 bc	22.08 d-g
Zn_3V_4	39.37 e-g	13.07 b	2.93 ef	24.96 bc
Zn_4V_1	44.28 a-c	14.67 a	2.67 fg	27.39 a
Zn_4V_2	45.85 ab	12.67 bc	2.80 ef	25.32 a-c
Zn_4V_3	38.35 fg	9.40 fg	3.27 cd	21.11 fg
Zn_4V_4	40.41 c-f	12.73 b	2.47 g	24.17 cd
SE value	1.201	0.367	0.095	0.730
Level of significance	**	**	*	**
CV(%)	5.06	5.58	6.39	5.40

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

4.1.4 Effective tillers hill^{-1}

Effective tillers hill^{-1} of aromatic rice showed statistically significant differences due to different levels of zinc (Table 4). The highest number of effective tillers hill^{-1} (12.37) was found from Zn_4 which was statistically similar (12.07) to Zn_3 and followed (11.27) by Zn_2, while the lowest number (9.88) was recorded from Zn_1. Mustafa *et al*. (2011) reported maximum productive tillers per m^2 (249.80) were noted with basal application at the rate 25 kg ha^{-1} of $ZnSO_4$ (21% Zn) and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5% Zn solution.

Statistically significant variation was recorded in terms of effective tillers hill^{-1} for different rice varieties (Table 4). The highest number of effective tillers hill^{-1} (13.10) was recorded from V_1 which was followed (11.88 and 11.42) by V_4 and V_2 and they were statistically similar, whereas the lowest number (9.18) was found from V_3. Generally different cultivars produced different number of effective tillers hill^{-1} although different biotic and abiotic factors also influenced it. Khalifa (2009) reported that H_1 hybrid rice variety surpassed other varieties in consideration of effective tillers hill^{-1}.

Combined effect of different levels of zinc and rice varieties showed significant differences on effective tillers hill^{-1} (Table 5). The highest number of effective tillers hill^{-1} (14.67) was recorded from Zn_4V_1 treatment combination, while the lowest number (8.40) was observed from Zn_1V_3 treatment combination.

4.1.5 Non-effective tillers hill^{-1}

Non-effective tillers hill^{-1} of aromatic rice showed statistically significant differences due to different levels of zinc (Table 4). The lowest number of non-effective tillers hill^{-1} (2.80) was recorded from Zn_4 which was statistically similar (2.92) to Zn_3 and followed (3.12) by Zn_2 and the highest number (3.35) was observed from Zn_1.

Statistically significant differences was recorded in terms of non-effective tillers hill^{-1} for different rice varieties (Table 4). The lowest number of non-effective tillers hill^{-1} (2.77) was found from V_1 which was followed (2.90 and 3.02) by V_4 and V_2 and they were statistically similar whereas the highest number (3.50) was recorded from V_3.

Combined effect of different levels of zinc and rice varieties showed significant differences in terms of on non-effective tillers hill^{-1} (Table 5). The lowest number of non-effective tillers hill^{-1} (2.47) was observed from Zn_4V_4 treatment combination, while the highest number (3.73) was found from Zn_1V_3 treatment combination.

4.1.6 Panicle length

Panicle length of aromatic rice showed statistically significant differences due to different levels of zinc (Table 4). The longest panicle (24.30 cm) was found from Zn_4 which was statistically similar (24.13 cm and 23.18 cm) to Zn_3 and Zn_2, whereas the shortest panicle (22.00 cm) was recorded from Zn_1. Cheema *et al.* (2006) observed that panicle size showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of panicle length for different rice varieties (Table 4). The longest panicle (25.43 cm) was observed from V_1 which was followed (23.55 cm and 22.81 cm) by V_4 and V_2 and they were statistically similar, while the shortest panicle (21.84 cm) was found from V_3. Sumon *et al*. (2018) reported from earlier experiment that BRRI dhan34 gave the longest panicle (27.93 cm).

Combined effect of different levels of zinc and rice varieties showed significant differences on panicle length (Table 5). The longest panicle (27.39 cm) was recorded from Zn_4V_1 treatment combination, whereas the shortest panicle (20.33 cm) was observed from Zn_1V_3 treatment combination.

4.1.7 Filled grains panicle^{-1}

Filled grains panicle^{-1} of aromatic rice showed statistically significant differences due to different levels of zinc (Table 6). The highest number of filled grains panicle^{-1} (185.52) was found from Zn_4 which was statistically similar (182.17) to Zn_3 and closely followed (173.67) by Zn_2, while the lowest number (163.37) was recorded from Zn_1. Lei *et al*. (2017) reported that exogenous application of mixed micro-nutrients Zn notably increased filled grains.

Statistically significant variation was recorded in terms of filled grains panicle^{-1} for different rice varieties (Table 6). The highest number of filled grains panicle^{-1} (185.30) was observed from V_1 which was statistically similar (179.47) to V_4 and closely followed (176.33) by V_2, whereas the lowest number (163.62) was found from V_3. Sarkar *et al*. (2014) revealed that the number of grains panicle^{-1} (152.3) in BRRI dhan34.

Combined effect of different levels of zinc and rice varieties showed significant differences on filled grains panicle^{-1} (Table 7). The highest number of filled grains panicle^{-1} (202.13) was recorded from Zn_4V_1 treatment combination and the lowest number (152.00) was observed from Zn_1V_3 treatment combination.

4.1.8 Unfilled grains panicle^{-1}

Unfilled grains panicle^{-1} of aromatic rice showed statistically significant differences due to different levels of zinc (Table 6). The lowest number of unfilled grains panicle^{-1} (22.35) was recorded from Zn_4 which was statistically similar (22.95) to Zn_3. On the other hand, the highest number (26.28) was observed from Zn_1 which was statistically similar (25.55) to Zn_2.

Statistically significant variation was recorded in terms of unfilled grains panicle^{-1} for different rice varieties (Table 6). The lowest number of unfilled grains panicle^{-1} (21.82) was found from V_1 which was followed (23.55 and 24.10) by V_4 and V_2 and they were statistically similar, whereas the highest number (27.67) was recorded from V_3.

Table 6. Effect of supplementation of zinc and different aromatic rice varieties on filled, unfilled and total grains panicle^{-1} and weight of 1000-grains

Treatments	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)	Weight of 1000-grains (g)
Levels of Zn				
Zn_1	163.37 c	26.28 a	189.65 b	13.16
Zn_2	173.67 b	25.55 a	199.22 ab	13.22
Zn_3	182.17 ab	22.95 b	205.12 a	13.41
Zn_4	185.52 a	22.35 b	207.87 a	13.53
SE value	2.688	0.745	3.130	0.114
Level of significance	**	*	*	NS
CV(%)	5.28	10.62	5.41	2.95
Rice varieties				
V_1	185.30 a	21.82 c	207.12 a	13.87 a
V_2	176.33 b	24.10 b	200.43 a	13.06 b
V_3	163.62 c	27.67 a	191.28 b	13.16 b
V_4	179.47 ab	23.55 b	203.02 a	13.24 b
SE value	2.759	0.443	2.879	0.119
Level of significance	**	**	**	**
CV(%)	5.43	6.32	4.97	3.11

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level; ** = Significant at 1% level and NS = Non significant

Table 7. Combined effect of supplementation of zinc and different aromatic rice varieties on filled, unfilled and total grains panicle^{-1} and weight of 1000-grains

Treatments	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)	Weight of 1000-grains (g)
Zn_1V_1	164.13 d-f	23.07 c-e	187.20 de	13.57 bc
Zn_1V_2	162.07 d-f	24.87 bc	186.93 de	12.74 d
Zn_1V_3	152.00 f	30.80 a	182.80 de	12.88 cd
Zn_1V_4	175.27 c-e	26.40 b	201.67 b-d	13.46 b-d
Zn_2V_1	177.87 b-d	21.47 de	199.33 c-e	13.40 b-d
Zn_2V_2	172.13 c-e	26.40 b	198.53 c-e	13.20 cd
Zn_2V_3	177.60 b-d	32.73 a	210.33 a-c	13.09 cd
Zn_2V_4	167.07 d-f	21.60 de	188.67 de	13.19 cd
Zn_3V_1	197.07 a	22.13 c-e	219.20 ab	14.09 ab
Zn_3V_2	177.07 b-d	22.00 c-e	199.07 c-e	12.65 d
Zn_3V_3	166.60 d-f	24.40 b-d	191.00 de	13.59 bc
Zn_3V_4	187.93 a-c	23.27 c-e	211.20 a-c	13.30 b-d
Zn_4V_1	202.13 a	20.60 e	222.73 a	14.40 a
Zn_4V_2	194.07 ab	23.13 c-e	217.20 a-c	13.65 bc
Zn_4V_3	158.27 ef	22.73 c-e	181.00 e	13.07 cd
Zn_4V_4	187.60 a-c	22.93 c-e	210.53 a-c	13.01 cd
SE value	5.518	0.886	5.758	0.239
Level of significance	**	**	**	*
CV(%)	5.43	6.32	4.97	3.11

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

Combined effect of different levels of zinc and rice varieties showed significant differences on unfilled grains panicle^{-1} (Table 7). The lowest number of unfilled grains panicle^{-1} (20.60) was observed from Zn_4V_1 treatment combination and the highest number (30.80) was found from Zn_1V_3 treatment combination.

4.1.9 Total grains panicle^{-1}

Total grains panicle^{-1} of aromatic rice showed statistically significant differences due to different levels of zinc (Table 6). The highest number of total grains panicle^{-1} (207.87) was found from Zn_4 which was statistically similar (205.12 and 199.22) to Zn_3 and Zn_2 while the lowest number (189.65) was recorded from Zn_1. Lei *et al*. (2017) reported that exogenous application of mixed micro-nutrients Zn notably increased yield in terms of improved grain numbers panic.

Statistically significant variation was recorded in terms of total grains panicle^{-1} for different rice varieties (Table 6). The highest number of total grains panicle^{-1} (207.12) was observed from V_1 which was statistically similar (203.02 and 200.43) to V_4 and V_2, whereas the lowest number (191.28) was recorded from V_3.

Combined effect of different levels of zinc and rice varieties showed significant differences on total grains panicle^{-1} (Table 7). The highest number of total grains panicle^{-1} (222.73) was recorded from Zn_4V_1 treatment combination and the lowest number (181.00) was observed from Zn_4V_3 treatment combination.

4.1.10 Weight of 1000-grains

Weight of 1000-grains of aromatic rice showed statistically non-significant differences due to different levels of zinc (Table 6). The highest weight of 1000-grains (13.53 g) was recorded from Zn_4, whereas the lowest weight (13.16 g) was observed from Zn_1. Cheema *et al*. (2006) observed from earlier experiment that 1000 grain weight showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of weight of 1000-grains for different rice varieties (Table 6). The highest weight of 1000-grains (13.87 g) was found from V_1, while the lowest weight (13.06 g) was recorded from V_2 which was statistically similar (13.16 g and 13.24 g) to V_3 and V_4. Sumon *et al*. (2018) sated that 'BRRI dhan34' gave the highest 1,000-grain weight (17.22 g).

Combined effect of different levels of zinc and rice varieties showed significant differences on weight of 1000-grains (Table 7). The highest weight of 1000-grains (14.40 g) was observed from Zn_4V_1 treatment combination, whereas the lowest weight (12.74 g) was found from Zn_1V_2 treatment combination.

4.1.11 Grain yield

Grain yield of aromatic rice showed statistically non-significant differences due to different levels of zinc (Table 8). The highest grain yield (2.56 t ha^{-1}) was found from Zn_4 and the lowest (2.35 t ha^{-1}) was recorded from Zn_1. Mustafa *et al*. (2011) reported maximum paddy yield (5.21 t ha^{-1}) from basal application at the rate of 25 kg ha^{-1} of $ZnSO_4.7H_2O$ and minimum paddy yield (4.17 t ha^{-1}) @ 0.5% Zn solution. Cheema *et al*. (2006) observed that paddy yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of grain yield for different rice varieties (Table 8). The highest grain yield (2.73 t ha^{-1}) was observed from V_1 which was followed (2.52 t ha^{-1} and 2.46 t ha^{-1}) to V_4 and V_2 and they were statistically similar, whereas the lowest (2.18 t ha^{-1}) was found from V_3. Chowdhury *et al*. (2016) obtained the highest grain yield (3.33 t ha^{-1}) from Binadhan-13 followed by BRRI dhan34 (3.16 t ha^{-1}) and the lowest grain yield in Kalizira (2.11 t ha^{-1}).

Combined effect of different levels of zinc and rice varieties showed significant differences on grain yield (Table 9). The highest grain yield (2.94 t ha^{-1}) was found from Zn_4V_1 treatment combination, while the lowest (2.05 t ha^{-1}) was recorded from Zn_1V_3 treatment combination.

Table 8. Effect of supplementation of zinc and different aromatic rice varieties on grain, straw and biological yield and harvest index

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
Levels of Zn				
Zn_1	2.35	3.53 c	5.88 c	39.87
Zn_2	2.44	3.79 b	6.24 b	39.12
Zn_3	2.53	3.94 ab	6.47 ab	38.93
Zn_4	2.56	4.01 a	6.57 a	38.78
SE value	0.047	0.046	0.084	0.383
Level of significance	NS	**	**	NS
CV(%)	6.66	4.14	4.61	3.39
Rice varieties				
V_1	2.73 a	4.00 a	6.73 a	40.45 a
V_2	2.46 b	3.79 bc	6.24 b	39.30 a
V_3	2.18 c	3.65 c	5.82 c	37.37 b
V_4	2.52 b	3.84 ab	6.36 b	39.58 a
SE value	0.063	0.061	0.116	0.409
Level of significance	**	**	**	**
CV(%)	8.74	5.54	6.35	3.62

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

** = Significant at 1% level and NS = Non significant

Table 9. Combined effect of supplementation of zinc and different aromatic rice varieties on grain, straw and biological yield and harvest index

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
Zn_1V_1	2.44 c-f	3.61 d-f	6.05 b-f	40.17 ab
Zn_1V_2	2.38 c-f	3.49 ef	5.87 d-f	40.46 ab
Zn_1V_3	2.05 f	3.32 f	5.37 f	38.28 bc
Zn_1V_4	2.53 b-d	3.70 c-f	6.23 b-e	40.57 ab
Zn_2V_1	2.61 a-c	3.95 a-d	6.56 a-d	39.80 ab
Zn_2V_2	2.36 c-f	3.78 b-e	6.14 b-e	38.29 bc
Zn_2V_3	2.47 c-e	3.80 b-e	6.28 b-e	39.40 ab
Zn_2V_4	2.33 c-f	3.65 d-f	5.98 c-f	38.99 ab
Zn_3V_1	2.92 ab	4.15 ab	7.07 a	41.21 a
Zn_3V_2	2.38 c-f	3.78 b-e	6.16 b-f	38.59 a-c
Zn_3V_3	2.12 d-f	3.83 b-e	5.95 c-f	35.63 d
Zn_3V_4	2.70 a-c	4.01 a-d	6.71 a-c	40.29 ab
Zn_4V_1	2.94 a	4.30 a	7.24 a	40.62 ab
Zn_4V_2	2.72 a-c	4.09 a-c	6.81 ab	39.87 ab
Zn_4V_3	2.06 ef	3.64 d-f	5.70 ef	36.17 cd
Zn_4V_4	2.51 b-d	4.01 a-d	6.51 a-d	38.46 a-c
SE value	0.125	0.123	0.231	0.818
Level of significance	*	**	*	*
CV(%)	8.74	5.54	6.35	3.62

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

4.1.12 Straw yield

Straw yield of aromatic rice showed statistically significant differences due to different levels of zinc (Table 8). The highest straw yield (4.01 t ha^{-1}) was recorded from Zn_4 which was statistically similar (3.94 t ha^{-1}) to Zn_3 and closely followed (3.79 t ha^{-1}) by Zn_2 whereas the lowest (3.53 t ha^{-1}) was observed from Zn_1. Cheema *et al*. (2006) observed that straw yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of straw yield for different rice varieties (Table 8). The highest straw yield (4.00 t ha^{-1}) was found from V_1 which was statistically similar (3.84 ha^{-1}) to V_4 and followed (3.79 t ha^{-1}) by V_2, while the lowest (3.65 t ha^{-1}) was recorded from V_3.

Combined effect of different levels of zinc and rice varieties showed significant differences on straw yield (Table 9). The highest straw yield (4.30 ha^{-1}) was observed from Zn_4V_1 treatment combination, whereas the lowest (3.32 t ha^{-1}) was found from Zn_1V_3 treatment combination.

4.1.13 Biological yield

Biological yield of aromatic rice showed statistically significant differences due to different levels of zinc (Table 8). The highest biological yield (6.57 t ha^{-1}) was found from Zn_4 which was statistically similar (6.47 t ha^{-1}) to Zn_3 and closely followed (6.24 t ha^{-1}) by Zn_2, while the lowest biological yield (5.88 t ha^{-1}) was observed from Zn_1.

Statistically significant variation was recorded in terms of biological yield for different rice varieties (Table 8). The highest biological yield (6.73 t ha^{-1}) was found from V_1 which was closely followed (6.36 ha^{-1} and 6.24 t ha^{-1}) by V_4 and V_2 and they were statistically similar, whereas the lowest (5.82 t ha^{-1}) was observed from V_3. Sumon *et al*. (2018) revealed that 'Raniselute' variety produced the highest biological yield (9.05 t ha^{-1}).

Combined effect of different levels of zinc and rice varieties showed significant differences on biological yield (Table 9). The highest biological yield (7.24 ha^{-1}) was recorded from Zn_4V_1 treatment combination and the lowest (5.37 t ha^{-1}) was observed from Zn_1V_3 treatment combination.

4.1.14 Harvest index

Harvest index of aromatic rice showed statistically non-significant differences due to different levels of zinc (Table 8). The highest harvest index (39.87%) was recorded from Zn_1 and the lowest (38.78%) was observed from Zn_4. Cheema *et al*. (2006) observed that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of harvest index for different rice varieties (Table 8). The highest harvest index (40.45%) was found from V_1 which was statistically similar (39.58% and 39.30%) to V_4 and V_2, while the lowest (37.37%) was recorded from V_3.

Combined effect of different levels of zinc and rice varieties showed significant differences on harvest index (Table 9). The highest harvest index (41.21%) was recorded from Zn_3V_1 treatment combination and the lowest (35.63%) was found from Zn_3V_3 treatment combination.

4.2 Grain quality of aromatic rice

4.2.1 Length of grain rice

Length of grain rice showed statistically non-significant differences due to different levels of zinc (Table 10). The highest length of grain (5.28 mm) was found from Zn_4 and the lowest length (5.12 mm) was recorded from Zn_1.

Statistically significant variation was recorded in terms of length of grain rice for different rice varieties (Table 10). The highest length of grain (6.18 mm) was observed from V_3 which was followed (5.03 mm) by V_2. On the other hnad, the lowest length (4.76 mm) was found from V_1 which was statistically similar (4.88 mm) to V_4.

Table 10. Effect of supplementation of zinc and different aromatic rice varieties on length of grain rice, weight of milled and broken rice and rice and husk ratio

Treatments	Length of grain rice (mm)	Weight of milled rice (%)	Weight of broken rice (%)	Rice and husk ratio
Levels of Zn				
Zn_1	5.12	70.10 b	3.76 a	3.60
Zn_2	5.20	70.74 ab	3.17 b	3.69
Zn_3	5.25	71.24 ab	3.08 b	3.85
Zn_4	5.28	71.66 a	3.12 b	4.13
SE value	0.052	0.390	0.107	0.189
Level of significance	NS	**	**	NS
CV(%)	3.49	1.91	11.23	17.18
Rice varieties				
V_1	4.76 c	69.42 b	2.69 c	3.37 b
V_2	5.03 b	69.71 b	2.24 c	3.48 b
V_3	6.18 a	71.55 a	4.67 a	4.02 a
V_4	4.88 c	73.06 a	3.54 b	4.40 a
SE value	0.047	0.563	0.205	0.174
Level of significance	**	**	**	**
CV(%)	3.09	2.75	11.62	15.77

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

Zn_1: 2.5 kg Zn ha^{-1} | V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} | V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} | V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} | V_4: Chiniatab

* = Significant at 5% level; ** = Significant at 1% level and NS = Non significant

Table 11. Combined effect of supplementation of zinc and different aromatic rice varieties on length of grain rice, weight of milled and broken rice and rice and husk ratio

Treatments	Length of grain rice (mm)	Weight of milled rice (%)	Weight of broken rice (%)	Rice and husk ratio
Zn_1V_1	4.59 d	67.78 ef	2.60 de	2.98 de
Zn_1V_2	4.94 bc	71.59 b-d	3.14 cd	3.76 b-e
Zn_1V_3	6.06 a	71.01 b-e	4.97 a	4.16 a-d
Zn_1V_4	4.88 b-d	70.02 b-e	4.35 a-c	3.48 b-e
Zn_2V_1	4.63 d	69.28 c-e	2.59 de	3.34 c-e
Zn_2V_2	5.02 bc	69.57 c-e	2.15 de	3.38 c-e
Zn_2V_3	6.17 a	71.18 b-e	4.52 ab	3.77 b-e
Zn_2V_4	4.96 bc	72.92 a-c	3.44 b-d	4.25 a-c
Zn_3V_1	4.85 b-d	68.68 d-f	3.43 b-d	3.23 c-e
Zn_3V_2	5.02 bc	72.24 a-d	1.58 e	4.04 b-d
Zn_3V_3	6.19 a	70.30 b-e	4.18 a-c	3.56 b-e
Zn_3V_4	4.94 bc	73.76 ab	3.14 cd	4.58 ab
Zn_4V_1	4.95 bc	71.95 a-d	2.13 de	3.93 b-d
Zn_4V_2	5.14 b	65.45 f	2.11 de	2.73 e
Zn_4V_3	6.30 a	73.70 ab	5.03 a	4.60 ab
Zn_4V_4	4.73 cd	75.55 a	3.22 b-d	5.27 a
SE value	0.093	1.126	0.410	0.347
Level of significance	**	**	**	*
CV(%)	3.09	2.75	11.62	15.77

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

Combined effect of different levels of zinc and rice varieties showed significant differences on length of grain rice (Table 11). The highest length of grain rice (6.30 mm) was recorded from Zn_4V_3 treatment combination, while the lowest length (4.59 mm) was observed from Zn_1V_1 treatment combination.

4.2.2 Breadth of grain rice

Breadth of grain rice showed statistically non-significant differences due to different levels of zinc (Figure 4). The highest breadth of grain (2.30 mm) was recorded from Zn_4, while the lowest breadth (2.20 mm) was observed from Zn_1.

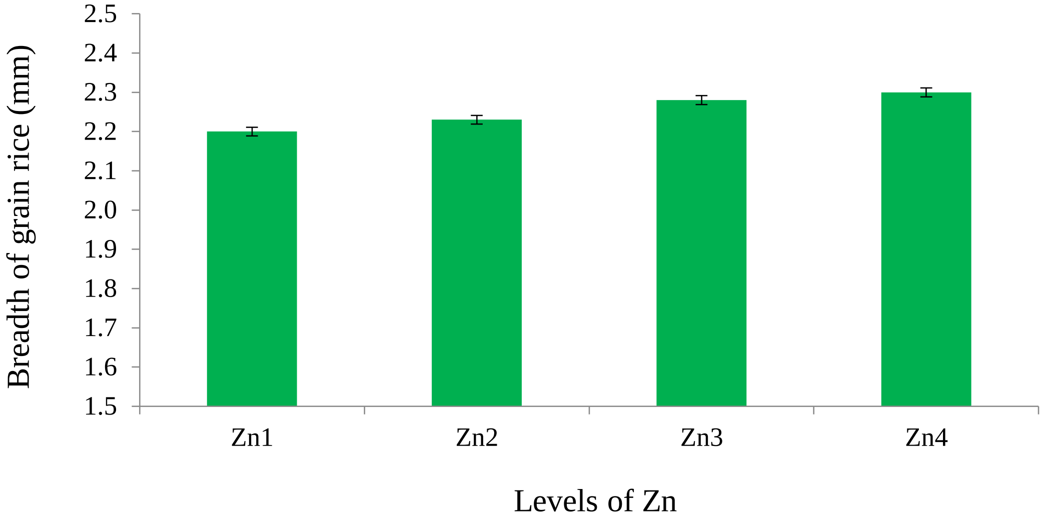
Statistically significant variation was recorded in terms of breadth of grain rice for different rice varieties (Figure 5). The highest breadth of grain (2.42 mm) was found from V_3 which was followed (2.29 mm) by V_1, whereas the lowest breadth (2.14 mm) was recorded from V_4 which was statistically similar (2.15 mm) to V_2.

Combined effect of different levels of zinc and rice varieties showed significant differences on breadth of grain rice (Figure 6). The highest breadth of grain rice (2.42 mm) was observed from Zn_2V_3 treatment combination, while the lowest breadth (2.03 mm) was found from Zn_1V_2 treatment combination.

4.2.3 Weight of milled rice

Weight of milled rice showed statistically significant differences due to different levels of zinc (Table 10). The highest weight of milled rice (71.66%) was recorded from Zn_4 which was statistically similar (71.24% and 70.74%) to Zn_3 and Zn_2, while the lowest weight (70.10%) was found from Zn_1.

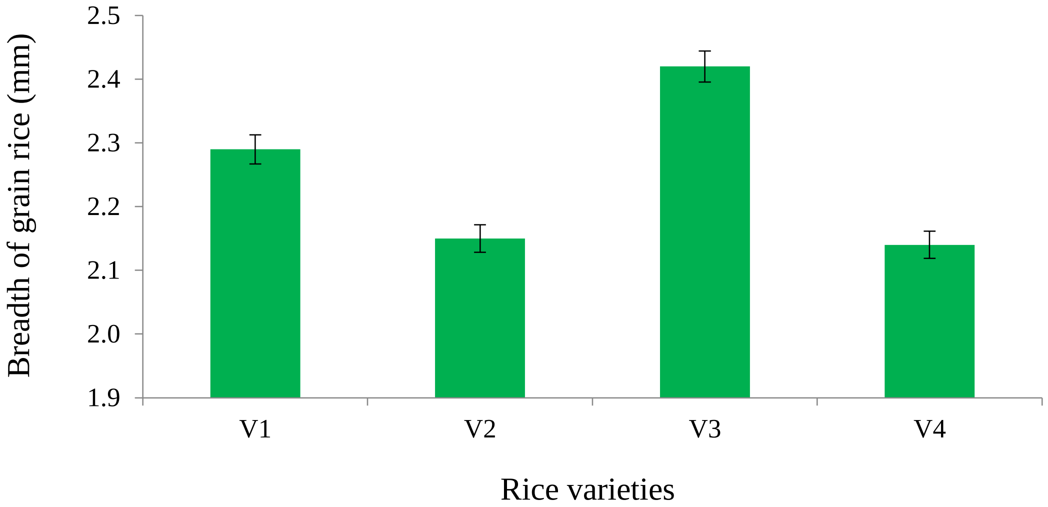
Statistically significant variation was recorded in terms of weight of milled rice for different rice varieties (Table 10). The highest weight of milled rice (73.06%) was observed from V_4 which was statistically similar (71.55%) to V_3. On the other hand, the lowest weight (69.42%) was found from V_1 which was statistically similar (69.71%) to V_2.



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}

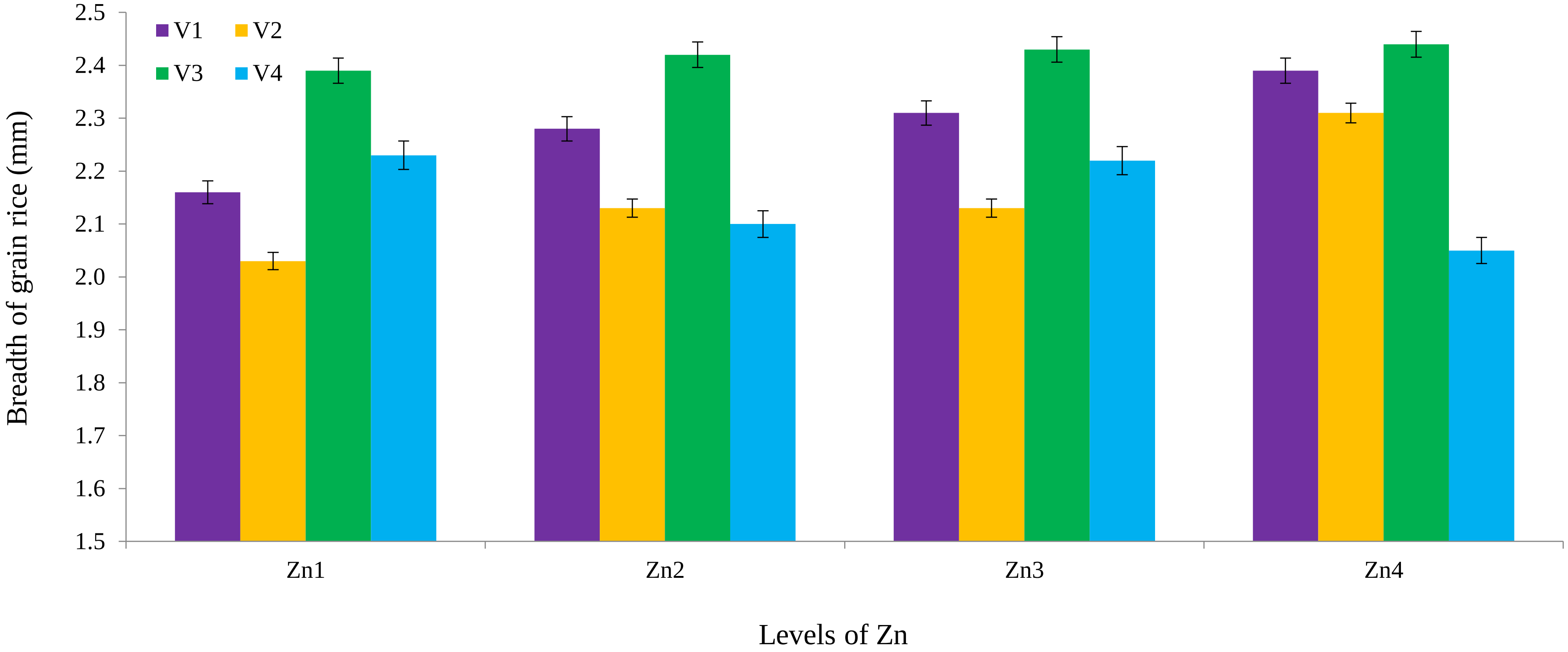
Figure 4. Effect of different levels of Zn on breadth of grain rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability)



V_1: Dulhabhog V_2: Chinigura

V_3: Khoisanne V_4: Chiniatab

Figure 5. Effect of different variety on breadth of grain rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability)



Zn_1: 2.5 kg Zn ha^{-1} Zn_2: 3.0 kg Zn ha^{-1} V_1: Dulhabhog V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} Zn_4: 4.0 kg Zn ha^{-1} V_3: Khoisanne V_4: Chiniatab

Figure 6. Combined effect of different levels of Zn and variety on breadth of grain rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability

Combined effect of different levels of zinc and rice varieties showed significant differences on weight of milled rice (Table 11). The highest weight of milled rice (75.55%) was recorded from Zn_4V_4 treatment combination and the lowest weight (65.45%) was observed from Zn_4V_2 treatment combination.

4.2.4 Weight of head rice

Weight of head rice showed statistically significant differences due to different levels of zinc (Figure 7). The highest weight of head rice (68.54%) was recorded from Zn_4 which was statistically similar (68.16% and 67.58%) to Zn_3 and Zn_2, whereas the lowest weight (66.34%) was observed from Zn_1.

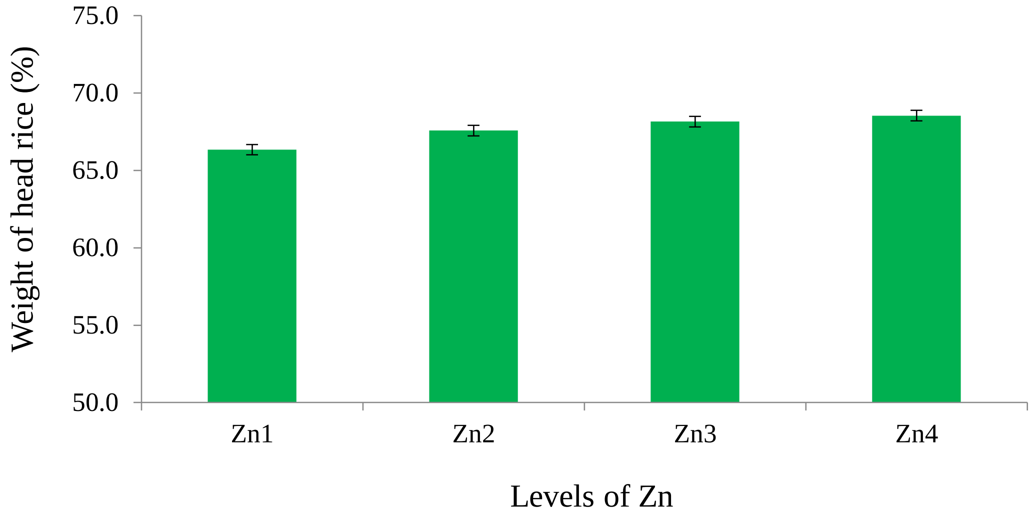
Statistically significant variation was recorded in terms of weight of head rice for different rice varieties (Figure 8). The highest weight of head rice (69.53%) was found from V_4, while the lowest weight (66.74%) was recorded from V_1 which was statistically similar (66.88% and 67.47%) to V_3 and V_2.

Combined effect of different levels of zinc and rice varieties showed significant differences on weight of head rice (Figure 9). The highest weight of head rice (72.33%) was recorded from Zn_4V_4 treatment combination, whereas the lowest weight (63.34%) was found from Zn_4V_2 treatment combination.

4.2.5 Weight of broken rice

Weight of broken rice showed statistically significant differences due to different levels of zinc (Table 10). The highest weight of broken rice (3.76%) was observed from Zn_1, while the lowest weight (3.08%) was found from Zn_3 which was statistically similar (3.12% and 3.17%) to Zn_4 and Zn_2.

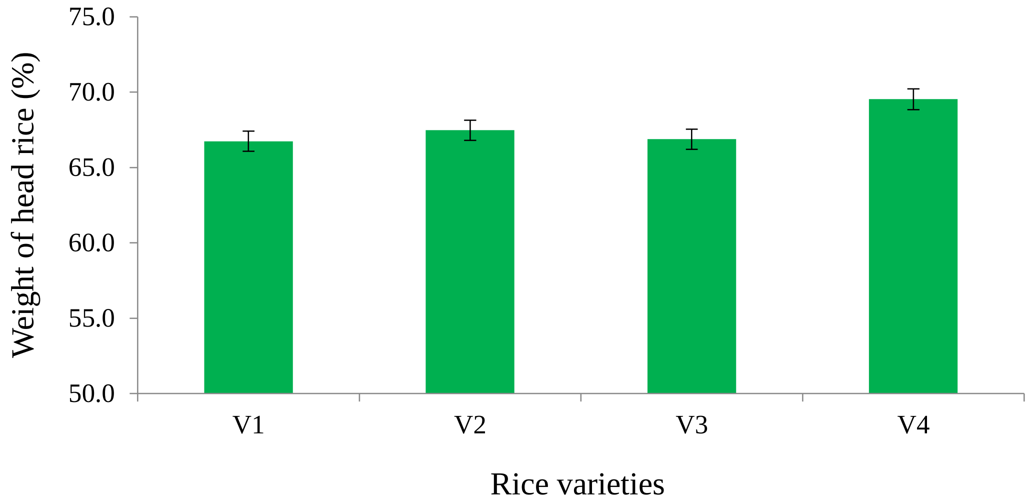
Statistically significant variation was recorded in terms of weight of broken rice for different rice varieties under the present study (Table 10). The highest weight of broken rice (4.67%) was recorded from V_3 which was followed (3.54%) by V_4, whereas the lowest weight (2.24%) was found from V_2 which was statistically similar (2.69%) to V_1.



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}

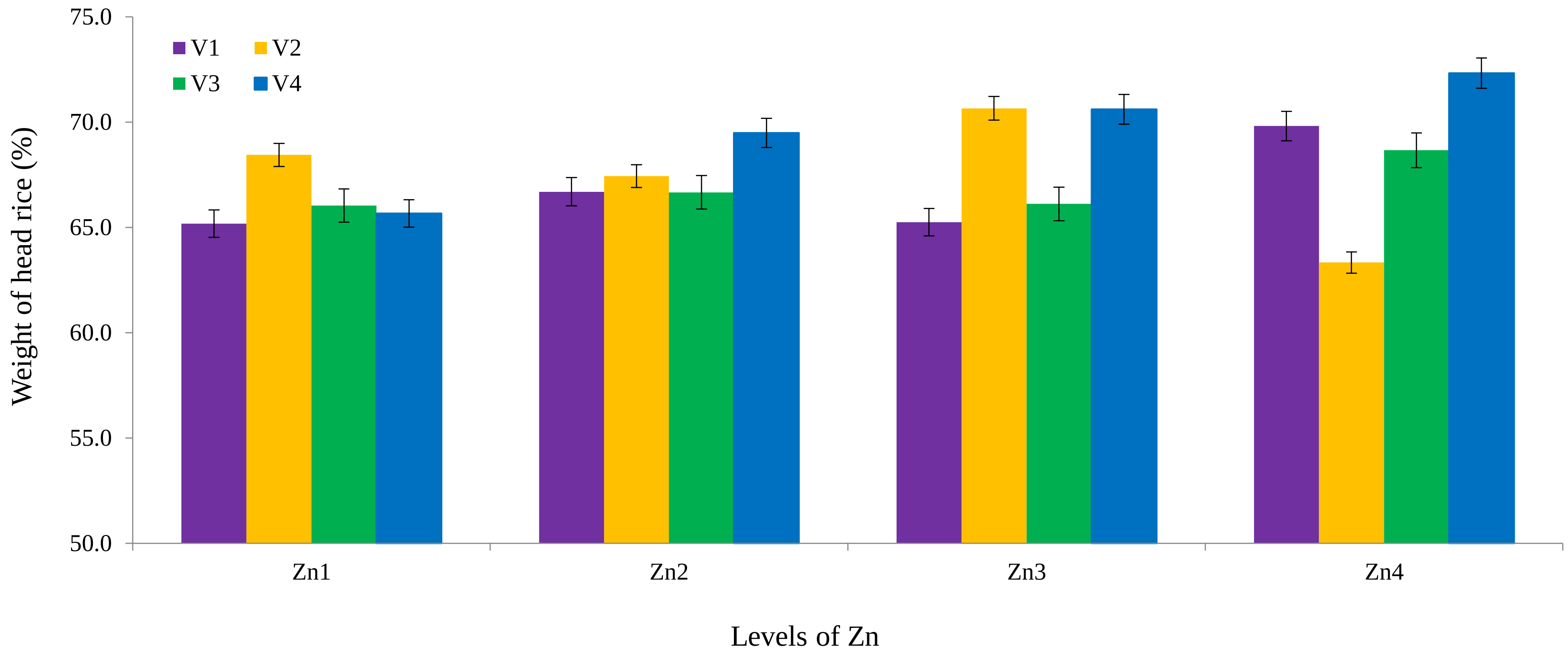
Figure 7. Effect of different levels of Zn on weight of head rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability)



V_1: Dulhabhog V_2: Chinigura

V_3: Khoisanne V_4: Chiniatab

Figure 8. Effect of different variety on weight of head rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability)



Zn_1: 2.5 kg Zn ha^{-1} Zn_2: 3.0 kg Zn ha^{-1} V_1: Dulhabhog V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} Zn_4: 4.0 kg Zn ha^{-1} V_3: Khoisanne V_4: Chiniatab

Figure 9. Combined effect of different levels of Zn and variety on weight of head rice of aromatic rice. (Vertical bars represent SE value at 5% level of probability

Weight of broken rice varied significantly due to combined effect of different levels of zinc and rice varieties (Table 11). The highest weight (5.03%) was found from Zn_4V_3 and the lowest (1.58%) from Zn_3V_2 treatment combination.

4.2.6 Rice and husk ratio

Rice and husk ratio showed statistically non-significant differences due to different levels of zinc (Table 10). The highest rice and husk ratio (4.13) was recorded from Zn_4 and the lowest (3.60) was observed from Zn_1.

Statistically significant variation was recorded in terms of rice and husk ratio for different rice varieties (Table 10). The highest rice and husk ratio (4.40) was found from V_4 which was statistically similar (4.02) to V_3, while the lowest (3.37) was recorded from V_1 which was statistically similar (3.48) to V_2.

Combined effect of different levels of zinc and rice varieties showed significant differences on rice and husk ratio (Table 11). The highest rice and husk ratio (5.27) was observed from Zn_4V_4 treatment combination, whereas the lowest (2.73) was found from Zn_4V_3 treatment combination.

4.2.7 Protein content in rice

Protein content in rice showed statistically significant differences due to different levels of zinc (Table 12). The highest protein content (8.94%) was recorded from Zn_4 which was statistically similar (8.89% and 8.83%) to Zn_3 and Zn_2, while the lowest (8.72%) was found from Zn_1.

Statistically significant variation was recorded in terms of protein content in different rice varieties (Table 12). The highest protein content (9.12%) was found from V_3 which was statistically similar (8.91%) to V_2, whereas the lowest (8.61%) was observed from V_4 which was statistically similar (8.74%) to V_1.

Combined effect of different levels of zinc and rice varieties showed significant differences on protein content in rice (Table 13). The highest protein content (9.25%) was observed from Zn_1V_3 treatment combination, while the lowest (8.37%) was found from Zn_1V_4 treatment combination.

Table 12. Effect of supplementation of zinc and different aromatic rice varieties on protein, amylose, Zn, proline and 2-AP content in grain

Treatments	Protein content (%)	Amylose content (%)	Zn content (mg g^{-1}) on dry weight basis	Proline content (mg g^{-1}) on dry weight basis	Grain-2AP (µg g^{-1}) on dry weight basis
Levels of Zn					
Zn_1	8.72 b	22.18	0.107 c	18.62 b	0.65 c
Zn_2	8.83 ab	22.62	0.151 a	19.66 a	0.67 bc
Zn_3	8.89 a	23.02	0.132 b	19.88 a	0.69 ab
Zn_4	8.94 a	23.35	0.136 b	20.31 a	0.72 a
SE value	0.043	0.482	0.003	0.182	0.009
Level of significance	*	NS	**	**	*
CV(%)	1.68	7.32	7.63	3.22	4.64
Rice varieties					
V_1	8.74 bc	21.93 b	0.114 c	15.35 d	0.54 d
V_2	8.91 ab	22.28 b	0.129 b	23.31 a	0.57 c
V_3	9.12 a	24.99 a	0.142 a	21.59 b	0.94 a
V_4	8.61 c	21.97 b	0.141 a	18.22 c	0.69 b
SE value	0.095	0.281	0.003	0.327	0.009
Level of significance	**	**	**	**	**
CV(%)	3.73	4.26	4.76	5.76	4.70

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level; ** = Significant at 1% level and NS = Non significant

Table 13. Combined effect of supplementation of zinc and different aromatic rice varieties on protein, amylose, Zn, proline and 2-AP content in grain

Treatments	Protein content (%)	Amylose content (%)	Zn content (mg g^{-1}) on dry weight basis	Proline content (mg g^{-1}) on dry weight basis	Grain-2AP (µg g^{-1}) on dry weight basis
Zn_1V_1	8.75 a-d	21.26 f	0.095 g	11.71 h	0.52 f
Zn_1V_2	8.50 cd	20.86 f	0.103 fg	24.70 b	0.62 e
Zn_1V_3	9.25 a	25.71 ab	0.112 e-g	23.13 b-d	0.63 e
Zn_1V_4	8.37 d	20.91 f	0.117 ef	14.93 g	0.82 d
Zn_2V_1	8.75 a-d	21.93 ef	0.141 b-d	16.05 g	0.36 g
Zn_2V_2	8.92 a-d	22.28 d-f	0.144 a-c	21.73 de	0.48 f
Zn_2V_3	9.01 a-d	24.32 bc	0.161 a	21.12 de	0.92 c
Zn_2V_4	8.63 a-d	21.96 ef	0.157 ab	19.75 ef	0.93 c
Zn_3V_1	8.90 a-d	22.35 d-f	0.096 g	18.91 f	1.01 b
Zn_3V_2	9.00 a-d	22.60 c-f	0.141 b-d	20.07 ef	0.38 g
Zn_3V_3	9.10 a-c	23.90 cd	0.146 ab	18.03 f	0.78 d
Zn_3V_4	8.55 b-d	23.25 c-e	0.145 a-c	22.50 cd	0.61 e
Zn_4V_1	8.55 b-d	22.20 d-f	0.123 de	14.72 g	0.25 h
Zn_4V_2	9.20 ab	23.40 c-e	0.127 c-f	26.74 a	0.80 d
Zn_4V_3	9.10 a-c	26.05 a	0.148 ab	24.10 bc	1.41 a
Zn_4V_4	8.90 a-d	21.75 ef	0.147 ab	15.69 g	0.40 g
SE value	0.191	0.561	0.006	0.653	0.018
Level of significance	**	*	**	**	**
CV(%)	3.73	4.26	4.76	5.76	4.70

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

Zn_1: 2.5 kg Zn ha^{-1} — V_1: Dulhabhog

Zn_2: 3.0 kg Zn ha^{-1} — V_2: Chinigura

Zn_3: 3.5 kg Zn ha^{-1} — V_3: Khoisanne

Zn_4: 4.0 kg Zn ha^{-1} — V_4: Chiniatab

* = Significant at 5% level and ** = Significant at 1% level

4.2.8 Amylose content in rice

Amylose content in rice showed statistically non-significant differences due to different levels of zinc (Table 12). The highest amylose content (23.35%) was recorded from Zn_4 and the lowest (22.18%) was observed from Zn_1.

Statistically significant variation was recorded in terms of amylose content in different rice varieties (Table 12). The highest amylose content (24.99%) was observed from V_3, while the lowest (21.93%) was found from V_1 which was statistically similar (21.97% and 22.28%) to V_4 and V_2.

Combined effect of different levels of zinc and rice varieties showed significant differences on amylose content in rice (Table 13). The highest amylose content (26.05%) was recorded from Zn_4V_3 treatment combination, whereas the lowest (20.86%) was observed from Zn_1V_2 treatment combination.

4.2.9 Zn content in rice

Zn content in rice showed statistically non-significant differences due to different levels of zinc (Table 12). The highest Zn content (0.151 mg g^{-1}) was found from Zn_2 which was statistically similar (0.136 mg g^{-1} and 0.132 mg g^{-1}) to Zn_4 and Zn_3, while the lowest (0.107 mg g^{-1}) was observed from Zn_1. Kabeya and Shankar (2013) reported that high zinc groups showed better uptake ability in zinc content.

Statistically significant variation was recorded in terms of Zn content in different rice varieties (Table 12). The highest Zn content (0.142 mg g^{-1}) was observed from V_3 which was statistically similar (0.141 mg g^{-1}) to V_4 and followed (0.129 mg g^{-1}) by V_2, whereas the lowest (0.114 mg g^{-1}) was found from V_1.

Combined effect of different levels of zinc and rice varieties showed significant differences on Zn content in rice (Table 13). The highest Zn content (0.161 mg g^{-1}) was observed from Zn_2V_3 treatment combination and the lowest (0.095 mg g^{-1}) was found from Zn_1V_1 treatment combination.

4.2.10 Proline content in rice

Proline content in rice showed statistically non-significant differences due to different levels of zinc (Table 12). The highest proline content (20.31 mg g^{-1}) was found from Zn_4 which was statistically similar (19.36 mg g^{-1} and 19.66 mg g^{-1}) to Zn_3 and Zn_2, while the lowest (18.62 mg g^{-1}) was recorded from Zn_1.

Statistically significant variation was recorded in terms of proline content in different rice varieties (Table 12). The highest proline content (23.31 mg g^{-1}) was found from V_2 which was followed (21.59 mg g^{-1}) by V_3, whereas the lowest (15.35 mg g^{-1}) was observed from V_1 which was followed (18.22 mg g^{-1}) by V_4.

Combined effect of different levels of zinc and rice varieties showed significant differences on proline content in rice (Table 13). The highest proline content (26.74 mg g^{-1}) was recorded from Zn_4V_2 treatment combination and the lowest (11.71 mg g^{-1}) was observed from Zn_1V_1 treatment combination.

4.2.11 Grain-2AP content in rice

Grain 2-AP content in rice showed statistically non-significant differences due to different levels of zinc (Table 12). The highest grain-2AP content (0.72 µg g^{-1}) was observed from Zn_4 which was statistically similar (0.69 µg g^{-1}) to Zn_3, whereas the lowest (0.65 µg g^{-1}) was recorded from Zn_1 which was statistically similar (0.67 µg g^{-1}) to Zn_2.

Statistically significant variation was recorded in terms of grain-2AP content in different rice varieties (Table 12). The highest grain-2AP content (0.94 µg g^{-1}) was found from V_3 which was followed (0.69 µg g^{-1}) by V_4, while the lowest (0.54 µg g^{-1}) was recorded from V_1 which was followed (0.57 µg g^{-1}) by V_4.

Combined effect of different levels of zinc and rice varieties showed significant differences on grain-2AP content in rice (Table 13). The highest grain-2AP content (1.41 µg g^{-1}) was recorded from Zn_4V_3 treatment combination, whereas the lowest (0.36 µg g^{-1}) was observed from Zn_2V_1 treatment combination.

Chapter 5

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period of June to December 2017 to find out the influence of zinc on yield and quality of aromatic rice. Aromatic rice cultivars Dulhabhog, Chinigura, Khoisanne and Chiniatab were used as the test crops in this experiment. The experiment consisted of two factors: Factor A: Levels of Zn (4 levels) as- Zn_1: 2.5 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 3.5 kg Zn ha^{-1}, Zn_4: 4.0 kg Zn ha^{-1}; and Factor B: Aromatic rice variety (4 varieties) as-V_1: Dulhabhog, V_2: Chinigura, V_3: Khoisanne and V_4: Chiniatab. The two factors experiment was laid out in split-plot design with three replications. Data were recorded on yield attributes, yield and quality of aromatic rice and significant variation was observed for most of the studied characters.

In case of different levels of zinc, at 20, 40, 60, 80 DAT and harvest, the tallest plant (50.27, 81.00, 110.59, 116.54 and 119.42 cm, respectively) was recorded from Zn_4, whereas the shortest plant (41.97, 70.29, 97.59, 102.35 and 105.67 cm, respectively) was observed from Zn_1. At 20, 40, 60, 80 DAT and harvest, the highest number of tillers $hill^{-1}$ (4.60, 8.12, 13.65, 14.57 and 15.17, respectively) was found from Zn_4, while the lowest number (4.02, 6.52, 11.57, 12.58 and 13.23, respectively) was recorded from Zn_1. The highest chlorophyll content in flag leaf (42.22 mg g^{-1}) was found from Zn_4 and the lowest (39.33 mg g^{-1}) was recorded from Zn_1. The highest number of effective tillers $hill^{-1}$ (12.37) was found from Zn_4, while the lowest number (9.88) was recorded from Zn_1. The lowest number of non-effective tillers $hill^{-1}$ (2.80) was recorded from Zn_4 and the highest number (3.35) was observed from Zn_1. The longest panicle (24.30 cm) was found from Zn_4, whereas the shortest panicle (22.00 cm) was recorded from Zn_1. The highest number of filled grains $panicle^{-1}$ (185.52) was found from Zn_4, while the lowest number (163.37) was recorded from Zn_1. The lowest number of unfilled grains panicle^{-1} (22.35) was recorded from Zn_4 and the highest number (26.28) was observed from Zn_1. The highest number of total grains panicle^{-1} (207.87) was found from Zn_4, while the lowest number (189.65) was recorded from Zn_1. The highest weight of 1000-grains (13.53 g) was recorded from Zn_4, whereas the lowest weight (13.16 g) was observed from Zn_1. The highest grain yield (2.56 t ha^{-1}) was found from Zn_4 and the lowest (2.35 t ha^{-1}) from Zn_1. The highest straw yield (4.01 t ha^{-1}) was recorded from Zn_4, whereas the lowest (3.53 t ha^{-1}) was observed from Zn_1. The highest biological yield (6.57 t ha^{-1}) was found from Zn_4, while the lowest (5.88 t ha^{-1}) from Zn_1. The highest harvest index (39.87%) was recorded from Zn_1 and the lowest (38.78%) was observed from Zn_4.

The highest length of grain (5.28 mm) was found from Zn_4 and the lowest length (5.12 mm) was recorded from Zn_1. The highest breadth of grain (2.30 mm) was recorded from Zn_4, while the lowest breadth (2.20 mm) was observed from Zn_1. The highest weight of milled rice (71.66%) was recorded from Zn_4, while the lowest weight (70.10%) was found from Zn_1. The highest weight of head rice (68.54%) was recorded from Zn_4, whereas the lowest weight (66.34%) was observed from Zn_1. The highest weight of broken rice (3.76%) was observed from Zn_1, while the lowest weight (3.08%) from Zn_3. The highest rice and husk ratio (4.13) was recorded from Zn_4 and the lowest (3.60) was observed from Zn_1. The highest protein content (8.94%) was recorded from Zn_4, while the lowest (8.72%) from Zn_1. The highest amylose content (23.35%) was recorded from Zn_4 and the lowest (22.18%) was observed from Zn_1. The highest Zn content (0.151 mg g^{-1}) was found from Zn_2, while the lowest (0.107 mg g^{-1}) was observed from Zn_1. The highest proline content (20.31 mg g^{-1}) was found from Zn_4, while the lowest (18.62 mg g^{-1}) was recorded from Zn_1. The highest grain-2AP content (0.72 µg g^{-1}) was observed from Zn_4 whereas the lowest (0.65 µg g^{-1}) from Zn_1.

For different rice varieties, at 20, 40, 60, 80 DAT and harvest, the tallest plant (49.44, 81.64, 110.34, 117.37 and 121.05 cm, respectively) was found from V_1, while the shortest plant (44.09, 71.61, 99.32, 106.04 and 109.22 cm, respectively) was recorded from V_3. At 20, 40, 60, 80 DAT and harvest, the highest number of tillers hill^{-1} (4.58, 7.85, 13.68, 14.98 and 15.87, respectively) was observed from V_1, whereas the lowest number (4.10, 7.08, 11.33, 12.30 and 12.68, respectively) was found from V_3. The highest chlorophyll content in flag leaf (42.54 mg g^{-1}) was observed from V_1, while the lowest (39.40 mg g^{-1}) was recorded from V_3. The highest number of effective tillers hill^{-1} (13.10) was recorded from V_1, whereas the lowest number (9.18) was found from V_3. The lowest number of non-effective tillers hill^{-1} (2.77) was found from V_1, whereas the highest number (3.50) was recorded from V_3. The longest panicle (25.43 cm) was observed from V_1, while the shortest panicle (21.84 cm) was found from V_3. The highest number of filled grains panicle^{-1} (185.30) was observed from V_1, whereas the lowest number (163.62) was found from V_3. The lowest number of unfilled grains panicle^{-1} (21.82) was found from V_1, whereas the highest number (27.67) was recorded from V_3. The highest number of total grains panicle^{-1} (207.12) was observed from V_1, whereas the lowest number (191.28) was recorded from V_3. The highest weight of 1000-grains (13.87 g) was found from V_1, while the lowest weight (13.06 g) was recorded from V_2. The highest grain yield (2.73 t ha^{-1}) was observed from V_1, whereas the lowest (2.18 t ha^{-1}) was found from V_3. The highest straw yield (4.00 t ha^{-1}) was found from V_1, while the lowest (3.65 t ha^{-1}) was recorded from V_3. The highest biological yield (6.73 t ha^{-1}) was found from V_1, whereas the lowest (5.82 t ha^{-1}) was observed from V_3. The highest harvest index (40.45%) was found from V_1, while the lowest (37.37%) was recorded from V_3.

The highest length of grain (6.18 mm) was observed from V_3, the lowest length (4.76 mm) was found from V_1. The highest breadth of grain (2.42 mm) was found from V_3, whereas the lowest breadth (2.14 mm) was recorded from V_4. The highest weight of milled rice (73.06%) was observed from V_4 and the lowest weight (69.42%) was found from V_1. The highest weight of head rice (69.53%) was found from V_4, while the lowest weight (66.74%) was recorded from V_1. The highest weight of broken rice (4.67%) was recorded from V_3, whereas the lowest weight (2.24%) was observed from V_2. The highest rice and husk ratio (4.40) was found from V_4, while the lowest (3.37) was recorded from V_1. The highest protein content (9.12%) was found from V_3, whereas the lowest (8.61%) was observed from V_4. The highest amylose content (24.99%) was observed from V_3, while the lowest (21.93%) was found from V_1. The highest Zn content (0.142 mg g^{-1}) was observed from V_3, whereas the lowest (0.114 mg g^{-1}) was found from V_1. The highest proline content (23.31 mg g^{-1}) was found from V_2, whereas the lowest (15.35 mg g^{-1}) was observed from V_1. The highest grain-2AP content (0.94 µg g^{-1}) was found from V_3, while the lowest (0.54 µg g^{-1}) was recorded from V_1.

Due to the combined effect of different levels of zinc and rice varieties, at 20, 40, 60, 80 DAT and harvest, the tallest plant (54.77, 87.76, 120.78, 127.49 and 130.79 cm, respectively) was observed from Zn_4V_1, whereas the shortest plant (41.50, 63.35, 94.11, 100.47 and 101.13 cm, respectively) was found from Zn_1V_3 treatment combination. At 20, 40, 60, 80 DAT and harvest, the highest number of tillers $hill^{-1}$ (5.00, 8.60, 15.13, 16.53 and 17.33, respectively) was recorded from Zn_4V_1 treatment combination, while the lowest number (3.67, 6.13, 11.07, 11.80 and 12.13, respectively) was observed from Zn_1V_3 treatment combination. The highest chlorophyll content in flag leaf (47.30 mg g^{-1}) was found from Zn_3V_1 treatment combination and the lowest (35.88 mg g^{-1}) was recorded from Zn_1V_3 treatment combination. The highest number of effective tillers $hill^{-1}$ (14.67) was recorded from Zn_4V_1 treatment combination, while the lowest number (8.40) was observed from Zn_1V_3 treatment combination. The lowest number of non-effective tillers $hill^{-1}$ (2.47) was observed from Zn_4V_4 treatment combination, while the highest number (3.73) was found from Zn_1V_3 treatment combination. The longest panicle (27.39 cm) was recorded from Zn_4V_1 treatment combination, whereas the shortest panicle (20.33 cm) was observed from Zn_1V_3

treatment combination. The highest number of filled grains panicle^{-1} (202.13) was recorded from Zn_4V_1 treatment combination and the lowest number (152.00) was observed from Zn_1V_3 treatment combination. The lowest number of unfilled grains panicle^{-1} (20.60) was observed from Zn_4V_1 treatment combination and the highest number (30.80) was found from Zn_1V_3 treatment combination. The highest number of total grains panicle^{-1} (222.73) was recorded from Zn_4V_1 treatment combination and the lowest number (181.00) was observed from Zn_4V_3 treatment combination. The highest weight of 1000-grains (14.40 g) was observed from Zn_4V_1 treatment combination, whereas the lowest weight (12.74 g) was found from Zn_1V_2 treatment combination. The highest grain yield (2.94 ha^{-1}) was found from Zn_4V_1 treatment combination, while the lowest (2.05 t ha^{-1}) was recorded from Zn_1V_3 treatment combination. The highest straw yield (4.30 ha^{-1}) was observed from Zn_4V_1 treatment combination, whereas the lowest (3.32 t ha^{-1}) was found from Zn_1V_3 treatment combination. The highest biological yield (7.24 ha^{-1}) was recorded from Zn_4V_1 treatment combination and the lowest (5.37 t ha^{-1}) was observed from Zn_1V_3 treatment combination. The highest harvest index (41.21%) was recorded from Zn_3V_1 treatment combination and the lowest (35.63%) was found from Zn_3V_3 treatment combination.

The highest length of grain rice (6.30 mm) was recorded from Zn_4V_3 treatment combination, while the lowest length (4.59 mm) was observed from Zn_1V_1 treatment combination. The highest breadth of grain rice (2.42 mm) was observed from Zn_2V_3 treatment combination, while the lowest breadth (2.03 mm) was found from Zn_1V_2 treatment combination. The highest weight of milled rice (75.55%) was recorded from Zn_4V_4 treatment combination and the lowest weight (65.45%) was observed from Zn_4V_2 treatment combination. The highest weight of head rice (72.33%) was recorded from Zn_4V_4 treatment combination, whereas the lowest weight (63.34%) was found from Zn_4V_2 treatment combination. The highest weight of broken rice (5.03%) was observed from Zn_4V_3 treatment combination, while the lowest weight (1.58%) was found from Zn_3V_2 treatment combination. The highest rice and husk ratio (5.27) was observed from Zn_4V_4 treatment combination, whereas the lowest (2.73) was found from Zn_4V_3 treatment combination. The highest protein content (9.25%) was observed from Zn_1V_3 treatment combination, while the lowest (8.37%) was found from Zn_1V_4 treatment combination. The highest amylose content (26.05%) was recorded from Zn_4V_3 treatment combination, whereas the lowest (20.86%) was observed from Zn_1V_2 treatment combination. The highest Zn content (0.161 mg g^{-1}) was observed from Zn_2V_3 treatment combination and the lowest (0.095 mg g^{-1}) was found from Zn_1V_1 treatment combination. The highest proline content (26.74 mg g^{-1}) was recorded from Zn_4V_2 treatment combination and the lowest (11.71 mg g^{-1}) was observed from Zn_1V_1 treatment combination. The highest grain-2AP content (1.41 µg g^{-1}) was recorded from Zn_4V_3 treatment combination, whereas the lowest (0.36 µg g^{-1}) was observed from Zn_2V_1 treatment combination.

But 4.0 kg Zn ha^{-1} and aromatic rice variety Khoisanne showed best performance when considered yield with protein, amylose, zinc and 2-AP content but not on proline.

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

1. Such study is needed to be repeated in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of regional adaptability,
2. Other management practices may be used for further study, and
3. Other combination of organic manures and chemicals fertilizer may be used for further study to specify the specific combination.

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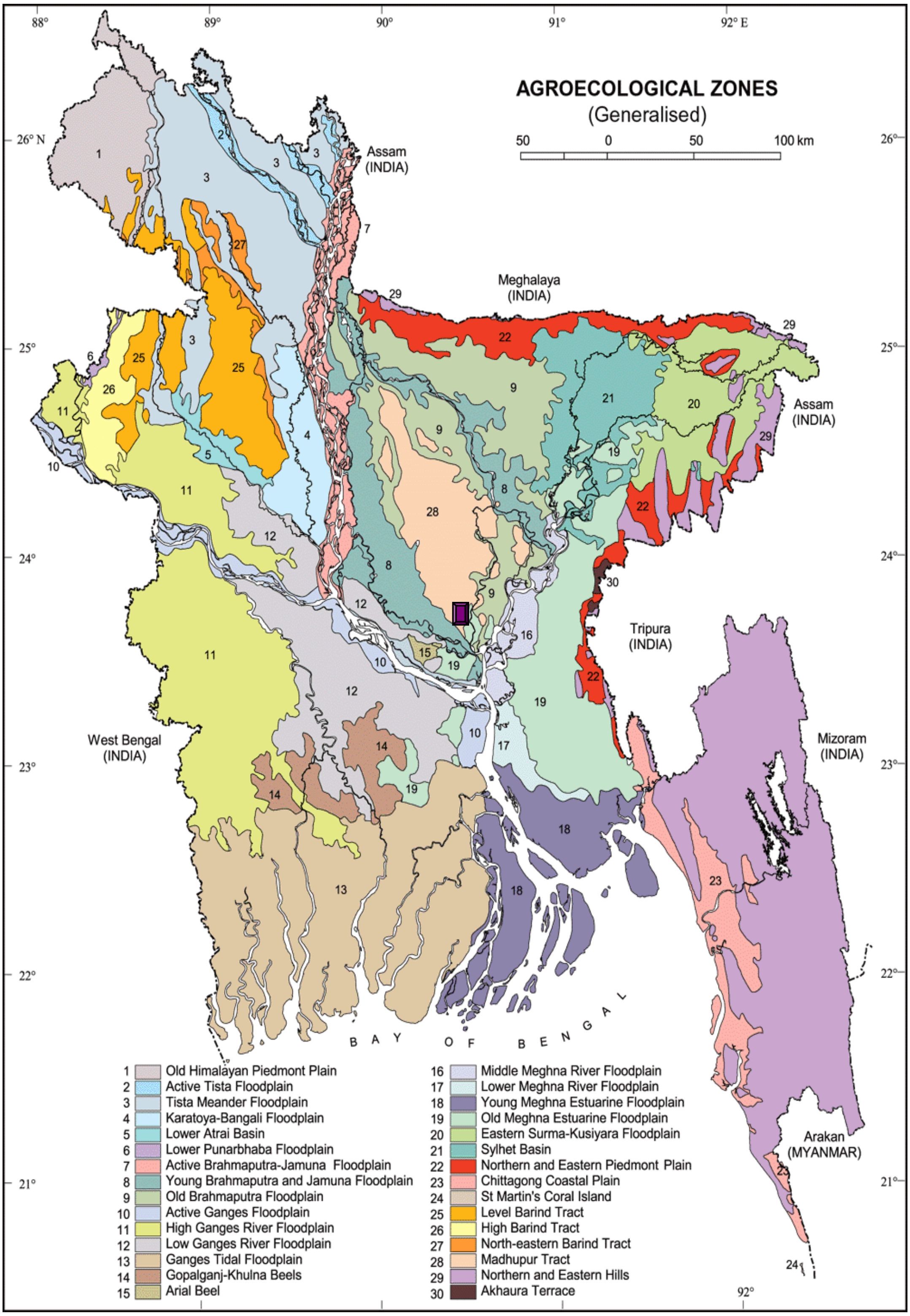
Appendices

APPENDICES

Appendix I. The Map of the experimental site



Appendix II. Monthly record of air temperature, relative humidity, rainfall, and sunshine (average) of the experimental site during the period from June to December 2017

Month (2017)	Air temperature (^0C)		Relative humidity (%)	Rainfall (mm)	Sunshine (hr)
	Maximum	Minimum			
June	32.4	25.5	81	228	5.7
July	36.8	24.9	87	573	5.5
August	35.2	23.3	85	303	6.2
September	33.7	22.6	82	234	6.8
October	26.6	19.5	79	34	6.5
November	25.1	16.2	77	07	6.7
December	22.6	13.4	74	00	6.6

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka–1207

Appendix III. Soil characteristics of experimental field as analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	26
% Silt	43
% clay	31
Textural class	Sandy loam
pH	5.9
Catayan exchange capacity	2.64 meq 100 g/soil
Organic matter (%)	1.15
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Appendix IV. Analysis of variance of the data on plant height at different days after transplanting (DAT) and harvest as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm) at				
		20 DAT	40 DAT	60 DAT	80 DAT	Harvest
Replication	2	0.156	1.275	4.769	4.829	7.787
Levels of Zn (A)	3	167.248**	291.056**	412.479**	505.266**	476.296**
Error	6	5.136	7.113	47.263	19.446	21.246
Rice varieties (B)	3	58.102**	203.951**	257.409**	264.612**	291.415**
Interaction (A×B)	9	21.708*	27.934*	134.223*	163.694**	172.980**
Error	24	8.840	11.219	50.046	39.952	27.243

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix V. Analysis of variance of the data on number of tillers hill^{-1} at different days after transplanting (DAT) and harvest as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square				
		Tillers hill^{-1} (No.) at				
		20 DAT	40 DAT	60 DAT	80 DAT	Harvest
Replication	2	0.006	0.026	0.092	0.413	0.676
Levels of Zn (A)	3	0.838**	6.562**	10.585**	9.350**	9.130**
Error	6	0.007	0.145	0.391	0.576	0.819
Rice varieties (B)	3	0.522**	1.224**	12.329**	14.903**	20.957**
Interaction (A×B)	9	0.156*	2.408**	1.694*	2.199**	2.320**
Error	24	0.056	0.257	0.617	0.401	0.471

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VI. Analysis of variance of the data on chlorophyll content in flag leaf, effective and non-effective tillers hill^{-1} and panicle length as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square			
		Chlorophyll content in flag leaf (mg g^{-1})	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)
Replication	2	0.322	0.646	0.001	0.445
Levels of Zn (A)	3	19.360**	14.789**	0.699**	13.397*
Error	6	0.438	0.757	0.025	2.003
Rice varieties (B)	3	21.222**	32.151**	1.226**	27.724**
Interaction (A×B)	9	45.280**	2.101**	0.072*	8.420**
Error	24	4.324	0.404	0.027	1.598

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VII. Analysis of variance of the data on filled, unfilled and total grains panicle^{-1} and weight of 1000-grains as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square			
		Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)	Weight of 1000-grains (g)
Replication	2	2.526	0.606	5.072	0.003
Levels of Zn (A)	3	1174.046**	44.480*	779.779*	0.350^{NS}
Error	6	86.692	6.653	117.562	0.155
Rice varieties (B)	3	1007.349**	72.411**	540.238**	1.585**
Interaction (A×B)	9	321.492**	17.630**	469.373**	0.436*
Error	24	91.353	2.353	99.453	0.171

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VIII. Analysis of variance of the data on grain, straw and biological yield and harvest index as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square			
		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.003	0.017	0.027	0.378
Levels of Zn (A)	3	0.108^{NS}	0.538**	1.127**	2.801^{NS}
Error	6	0.027	0.025	0.084	1.761
Rice varieties (B)	3	0.617**	0.256**	1.661**	20.264**
Interaction (A×B)	9	0.118*	0.395**	0.326*	4.685*
Error	24	0.047	0.045	0.160	2.006

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance; NS: Non significant

Appendix IX. Analysis of variance of the data on length and breadth of grain rice, weight of milled, head and broken rice and rice and husk ratio as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square					
		Length of grain rice (mm)	Breadth of grain rice (mm)	Weight of milled rice (%)	Weight of head rice (%)	Weight of broken rice (%)	Rice and husk ratio
Replication	2	0.013	0.0001	0.169	3.208	2.972	0.014
Levels of Zn (A)	3	0.062^{NS}	0.022**	5.449**	11.149*	1.238**	0.662^{NS}
Error	6	0.033	0.010	1.829	1.867	0.136	0.430
Rice varieties (B)	3	5.163**	0.197**	34.767**	19.980**	13.740**	2.762**
Interaction (A×B)	9	0.371**	0.025*	18.279**	19.874**	6.328**	1.018*
Error	24	0.026	0.009	3.805	4.092	0.504	0.362

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance; NS: Non significant

Appendix X. Analysis of variance of the data on protein, amylose, Zn, proline and 2-AP content as influenced by supplementation of zinc and different aromatic rice varieties

Source of variation	Degrees of freedom	Mean square				
		Protein content (%)	Amylose content (%)	Zn content (mg g^{-1}) on dry weight basis	Proline content (mg g^{-1}) on dry weight basis	Grain-2AP (µg g^{-1}) on dry weight basis
Replication	2	0.006	1.469	0.0001	0.020	0.0001
Levels of Zn (A)	3	0.108*	3.053^{NS}	0.004**	6.211**	0.010*
Error	6	0.022	2.785	0.0001	0.399	0.001
Rice varieties (B)	3	0.573**	26.107**	0.002**	150.952**	0.393**
Interaction (A×B)	9	1.019**	2.369*	0.0001**	35.580**	0.312**
Error	24	0.109	0.945	0.0001	1.279	0.001

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance; NS: Non significant

Appendix XI. Photographs of the experiment

Plate 1. Experimental plot at tillering stage

Plate 2. Experimental Plot at Panicle Initiation Stage

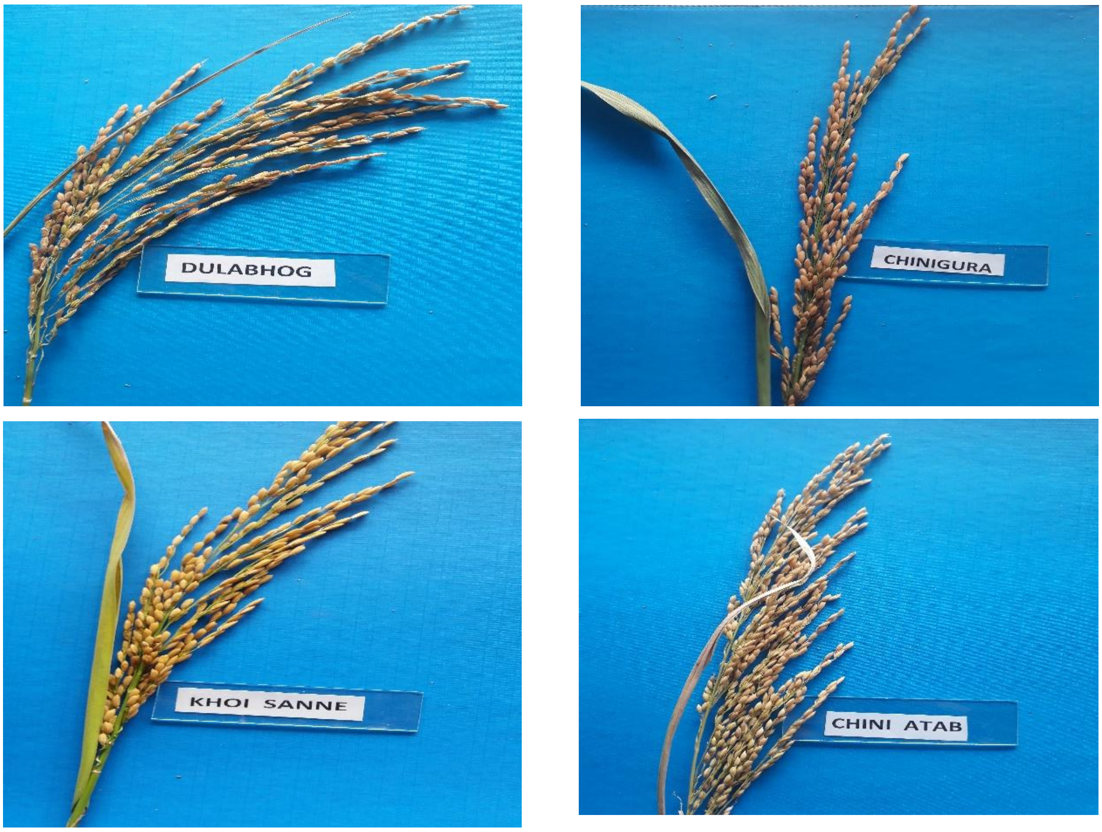


Plate 3. Length of panicle of different aromatic rice variety

Plate 4. Length of grain of different aromatic rice variety