IMPROVING AROMATIC QUALITY OF BRRI dhan80 THROUGH MINIMIZATION OF NITROGEN AND SUPPLEMENTATION OF ZINC

SHAPLA AKTER

DEPARTMENT OF AGRONOMY
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

JUNE, 2020

IMPROVING AROMATIC QUALITY OF BRRI dhan80 THROUGH MINIMIZATION OF NITROGEN AND SUPPLEMENTATION OF ZINC

BY

SHAPLA AKTER

REGISTRATION NO. 13-05692

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfilment of the requirements
for the degree
of

MASTER OF SCIENCE (MS)

IN

AGRONOMY

SEMESTER: JANUARY-JUNE, 2020

Approved by:

Prof. Dr. Tuhin Suvra Roy	**Prof. Dr. A. K. M. Ruhul Amin**
Supervisor	**Co-supervisor**

Prof. Dr. Md. Shahidul Islam
Chairman
Examination Committee

DEPARTMENT OF AGRONOMY

Sher-e-Bangla Agricultural University

Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

*This is to certify that the thesis entitled '**Improving Aromatic Quality of BRRI dhan80 through Minimization of Nitrogen and Supplementation of Zinc**' 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 **SHAPLA AKTER**, Registration No. **13-05692** 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.

Date:
Dhaka, Bangladesh

Prof. Dr. Tuhin Suvra Roy
Department of Agronomy
Sher-e-Bangla Agricultural University
Dhaka-1207

DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENTS

All praises to the Almightly and Kindful trust on to the "Almighty Allah" for His never-ending blessing, the author deems it a great pleasure to express her profound gratefulness to her respected parents, who entitled much hardship and inspiring for prosecuting her studies and as well as receiving proper education.

*The author feels proud to express her heartiest sense of gratitude, sincere appreciation and immense indebtedness to her Supervisor **Prof. Dr. Tuhin Suvra Roy**, Department of Agronomy, Sher-e-Bangla Agricultural University (SAU), Dhaka, for his continuous scholastic and intellectual guidance, cooperation, constructive criticism and suggestions in carrying out the research work and preparation of thesis, without his intense co-operation this work would not have been possible.*

*The author feels proud to express her deepest respect, sincere appreciation and immense gratitude to her Co-supervisor **Dr. A. K. M. Ruhul Amin**, Professor, Department of Agronomy, Sher-e-Bangla Agricultural University (SAU), Dhaka, for his scholastic and continuous guidance, constructive criticism and valuable suggestions during the entire period of course and research work and preparation of this thesis.*

*The author expresses her sincere respect and sense of gratitude to **Prof. Dr. Md. Shahidul Islam**, Honorable Chairman, Departement of Agronomy, SAU, Dhaka for valuable suggestions and cooperation during the study period. The author also expresses her heartfelt thanks to all the teachers of the Department of Agronomy, SAU, for their valuable teaching, suggestions and encouragement during the period of study.*

*The author expresses her gratefulness to **'Ministry of Science & Technology'** for funding the research as a fellow of 'National Science and Technology (NST) fellowship' progam that supported her to conduct the study smoothly.*

*The author expresses her special thanks to her fellow mates and friends **Akhi Badrunnesa, Hasan Mahmud and Chaity Dey Puja.** The whole journey might be very difficult without their encouragement and co-operation.*

The author also expresses her sincere appreciation to her relatives, well wishers and friends for their inspiration, help and encouragement throughout the study.

The Author

IMPROVING AROMATIC QUALITY OF BRRI dhan80 THROUGH MINIMIZATION OF NITROGEN AND SUPPLEMENTATION OF ZINC

ABSTRACT

The experiment was conducted during the period of June to November, 2018 in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka for improving aromatic quality of BRRI dhan80 through minimization of nitrogen and supplementation of zinc. The experiment consisted of two factors: Factor A: Levels of N (4) as - N_1: 35 kg N ha^{-1}; N_2: 37 kg N ha^{-1}; N_3: 39 kg N ha^{-1}; N_4: 41 kg N ha^{-1} and Factor B: Levels of Zn (4) as -Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}; Zn_3: 5.0 kg Zn ha^{-1}; Zn_4: 5.5 kg Zn ha^{-1}. The experiment was laid out in split-plot design with three replications. The levels of N were assigned to main plot and levels of zinc to sub-plot. Result revealed that plant height, effective tillers, filled grains, weight of 1000-grains, grain yield, milled rice, protein content increased with increasing nitrogen level but amylose, proline and grain 2-Acetyl-1-pyrroline (2-AP) content decreased with increasing its levels. Zn had no significant effect on 1000 grain weight, grain yield and size of grain whereas, protein, Zn, proline and grain 2-AP content increased with increasing its levels. Among the 16 treatment combinations, the highest grain yield (4.23 t ha^{-1}) was observed from N_3Zn_4 treatment combination which was statistically similar with N_2Zn_1, N_2Zn_4, N_3Zn_3, N_4Zn_2, and N_4Zn_3. Significantly the highest protein content (8.58%-8.95%) was recorded from N_4Zn_4, N_4Zn_3 and N_2Zn_3 and the maximum Zn content (0.159 mg g^{-1} DW) was obtained from N_3Zn_4 which was statistically similar with N_4Zn_3, N_3Zn_3 and N_2Zn_4 respectively while the maximum amylose (25.59%), proline (22.17 mg g^{-1} DW) and 2-AP content (0.87µg g^{-1} DW) was obtained from N_1Zn_4 combination. From the present study it may be concluded that the rice growers may use 35- 37 kg N ha^{-1} and 4-5.5 kg Zn ha^{-1} along with other recommended fertilizers for producing good quality aromatic rice.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

LIST OF APPENDICES

Chapter I

Introduction

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.), belonging to the family Poaceae, is the principal staple food for more than 50% of the world's population (Jahan *et al.,* 2017). Scented rice is globally appreciated among rice consumers and have high demand because of its potent aromatic flavor and also for good quality (Hashemi *et al*., 2013; Ashraf *et al*., 2017). Scented rice, such as Basmati and Jasmine, has a characteristic fragrance and good grain quality (Ashraf *et al*., 2017) and the grains valued is also at a higher in the market price than the non-aromatic rice varieties (Zhang *et al*., 2008). Despite a huge market demand at present area of scented rice cultivation is less than 2% of the national rice coverage of Bangladesh (Ashrafuzzaman *et al*., 2009). The production of scented rice in Bangladesh during 2013 is approximately 0.30 million tons from 0.16 million ha of land which is far below the national average, and hence the yield needs to be increased by 53.3% (Mahamud *et al*., 2013).

Most of the well-off people preferred long, slender scented fine grain rice (Mannan *et al*., 2012; Sarkar *et al*., 2014). The demand for scented fine grain rice has been increased in Bangladesh due to the economic development of the people (Ali *et al*., 2016). On the other hand, the population in Bangladesh swelling progressively and fulfilling the food demand it will demand additional more than 48 million tons of food grains by 2030 (Bhuiyan *et al*., 2014). As per the report of FAO (2018) it was found that the average rice yield of Bangladesh is about 3.12 t ha^{-1} which is very low compared to other rice growing countries of the world, like China (6.30 t ha^{-1}), Japan (6.60 t ha^{-1}) and South Korea (6.30 t ha^{-1}). The low yield of rice in Bangladesh however is not an indication of low yielding potentiality of rice varieties of our country, but may be attributed to a number of reasons. The major reason of low yield of rice in Bangladesh may be attributed to prevalence of local varieties instead of high yielding varieties and without practicing proper management and fertilization (Mandira *et al*., 2016).

Among the essential nutrient's nitrogen (N) is the main nutrient that determines rice yield, due to its role in the photosynthesis and dry matter accumulation in plant (Yoshida *et al.,* 2006) and also different metabolic processes of rice plant (Ghoneim and Ebid, 2015). Efficient management of N fertilizer in high yielding rice varieties is crucial for attaining potential yield benefit (Mahajan *et al.*, 2010; Jahan *et al.*, 2020). Before making recommendations for the nitrogen fertilizer dose, it should be evaluated the efficiency and optimum rate of N fertilizers for better growth and yield performance of rice (Hameed *et al*., 2019). Generally, nitrogenous fertilizer recommendations in many rice-growing regions follow a prescriptive approach based on generic models, without considering site-specific differences for crop N requirements, soil series, cropping seasons, application of others organic and inorganic fertilizers etc. (Fan *et al*., 2012; Murthy *et al*., 2015). Efficient use of N fertilizers can be attained through cultural and agronomic practices. Most importantly by breeding varieties having maximum nitrogen use efficiency (NUE), thereby reducing risks of environmental and soil water pollution (Sachiko *et al*., 2009; Gewaily *et al*., 2018).

Significant improvement in crop yields is attributed to the increase in fertilizer use, especially nitrogen fertilizer (Cassman *et al*., 2003). At farmer's level, the rate of applied N fertilizer is usually greater than the recommendation for maximum crop growth and maximum yields (Fan *et al*., 2012). However, excessive N input could increase the rice production cost and reduce paddy yield (Peng *et al*., 2009; Guo *et al*., 2010; Fan *et al*., 2012). Imbalanced using nitrogen fertilizer applied rate in soils is the most important variable that limits the quality and yields in rice (Wang *et al*., 2008). N level at 80 kg ha^{-1} improved grain quality and soil fertility (Sikdar *et al*., 2008). However, high nitrogen can lead to lodging in rice (Mahajan *et al*., 2010). High aroma content in rice grains associated with the presence of optimum level of nitrogen in the soil (Yang *et al*., 2012) and 2-AP content in rice grains was decreased with increasing nitrogenous application (Zhong and Tang, 2014). The 2-AP content in brown rice was maximum when the N supply was 60 kg ha^{-1} (Li *et al*., 2014).

Zinc (Zn) is the fourth most deficient nutrient element in soils and its deficiency causes severe yield reduction in rice (Alam *et al*., 2012; Suman and Sheeja, 2018). 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).

Nitrogen and zinc are the two major yield-limiting factors of flooded fine rice cultivation systems (Ali *et al*., 2014). Management of nutrition in fine rice is primarily concomitant with the judicious application of nitrogen and zinc fertilizers (Arif *et al*., 2018). Tang and Wu (2006) found that N and Zn application could improve the growth and quality of aromatic rice. Except growth and yield, N and Zn could also improve rice aroma of grains by enhancing the biosynthesis of 2-Acetyl-1-pyrroline (2-AP) in rice plants (Lie *et al*., 2017). The 2-AP is produced in the rice grain while they are growing in the fields. So, it is quite important to preserve the content and maintain its flavor characteristics during preservation of aromatic rice through proper fertilizer management. From the above discussion the experiment was conducted to study the improving aromatic quality of BRRI dhan80 through minimization of nitrogen and supplementation of zinc with the following objective-

1. To find out the optimum level of nitrogen and zinc for improving aromatic quality without sacrificing yield.

Chapter II

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Rice is one of the most important field crops after wheat in the world and providing staple food to the millions. Bangladesh produces different high yielding coarse and fine rice and most of them have excellent production with the proper management of nutrients. Nutritious management in fine rice is primarily concomitant with the application of nitrogen (N) and zinc (Zn) fertilizers. Application of nitrogen (N) and zinc (Zn) caused significant improvement in growth, yield attributes, yield and quality of rice. There are a significant number of research works on the effect of nitrogen and zinc on yield and yield attributes but there are a limitation in respect of quality of rice. In this chapter some of the important and informative research findings related to the yield contributing characters, yield and quality of aromatic and non-aromatic rice in respect to the effect of nitrogen and Zn so far been done at home and abroad, reviewed under the following headings-

2.1 Effect of nitrogen on growth and yield of rice

Angayarkanni and Ravichandran (2001) carried out a field experiment in Tamil Nadu, India to determine the best split application of 150 kg N ha^{-1} for rice cv. IR20 and they observed that applying 16.66% of the recommended N as basal, followed by 33.33% N at 10 DAT, 25% N at 20 DAT and 25% N at 40 DAT recorded the highest grain (6189.4 kg ha^{-1}) and straw (8649.6 kg ha^{-1}) yields, response ratio (23.40) and agronomic efficiency (41.26).

Munnujan *et al*. (2001) treated 4 levels of nitrogen fertilizer (0, 40, 80, and 160 kg ha^{-1}) application at three levels each planting density (20, 40 and 80 hill m^{-1}) and conducted that the highest grain yield (3.8 t ha^{-1}) was obtained with 180 kg N ha^{-1}, which was similar to the yield obtained at 80 kg N ha^{-1} (3.81 t ha^{-1}).

Sidhu *et al*. (2004) reported that nitrogen fertilizers substantially increased the mean grain yield of Basmati up to 40 kg ha^{-1} N in the fallow Basmati-wheat sequence, while 60 kg ha^{-1} N reduced Basmati yield. Compared to 0 kg N ha^{-1}, the mean grain yield of Basmati was increased by 0.31, 0.40 t ha^{-1} at doses of 20 and 40 kg N ha^{-1}.

Hossain *et al.* (2005) carried out an experiment to assess the effects of nitrogen (30, 60, 90 and 120 kg ha^{-1} N) and phosphorus on the growth and yield of rice and reported that application of nitrogen up to 90 kg ha^{-1} enhanced the growth and yield of rice crop.

Amin *et al.* (2006) found significant variation on growth, tillering and yield of three traditional rice varieties due to variable doses of N fertilizer compared with that of a modern variety at BSMRAU, Salna, Gazipur and reported that application of 60 kg ha^{-1} N produced more TDM and lesser ineffective tillers. Application of 30 kg ha^{-1} N produced the highest yield (4451 kg ha^{-1}).

Manzoor *et al.* (2006) evaluated the nine different nitrogen levels i.e. 0, 50, 75, 100, 125, 150, 175, 200 and 225 kg ha^{-1} for observing the field performance of rice. Plant height, productive tillers $hill^{-1}$, panicle length, grains $panicle^{-1}$, 1000 grain weight and paddy yield showed increasing trend from 0 kg ha^{-1} N up to 175 kg ha^{-1} N. The yield parameters including rice yield, grains $panicle^{-1}$ and 1000 grain weight started declining at 200 kg N ha^{-1} level and above. Maximum rice yield (4.24 t ha^{-1}) was obtained from 175 kg ha^{-1} nitrogen application treatment which also produced highest values of grains $panicle^{-1}$ (130.2) along with a maximum 1000 grain weight (22.92 gm). The plant height (139.8 cm) along with productive tillers $hill^{-1}$ (23.42) and panicle length (29.75 cm) was the maximum at 225 kg N ha^{-1}.

Hossain *et al.* (2007) carried out an experiment and reported that the N levels also exerted significant effect on all the yield parameters, except for panicle length and 1000 grain weight. The highest grain yield was obtained from the application of 75 kg ha^{-1} of the recommended dose of N and the lowest from the control treatment (0 kg ha^{-1}) of rice cv. BRRI dhan32. The greatest plant height and highest number of tillers hill^{-1} were observed with the application of 69 kg ha^{-1} N, which was significantly followed by 51.75, 34.5 and 17.25 kg ha^{-1} N, respectively and the lowest was observed in control treatment (0 kg ha^{-1} N).

Hossain *et al*. (2008) reported that different nitrogen rates also significantly affected the aromatic rice cultivars. All the yield components were significantly increased up to 90 kg ha^{-1} N. Nonetheless, maximum grain yield (3.62 t ha^{-1}) was observed from 60 kg ha^{-1} N.

Islam *et al*. (2008) conducted a field experiment at Bangladesh Agricultural University, Mymensingh to evaluate the effect of nitrogen (N) level on the quality of aromatic rice and fertility status of the post-harvest soil. The experiment comprised of three varieties viz., Kalizira, Badshabhog and Tulshimala and three levels of nitrogen viz., 40, 60 and 80 kg ha^{-1}. Among three N levels, 80 kg ha^{-1} performs the best to quality of aromatic rice.

Nori *et al*. (2008) studied to assess the grain yield and straw nutritive quality of MR 211 and MR 219 rice varieties due to five nitrogen rates (0, 120, 160, 200 and 240 kg ha^{-1} N). Increases in nitrogen application was found increase ($P<0.01$) the grain yield, total spikelets m^{-2}, spikelets panicle^{-1} and straw crude protein from 4.56% to a maximum level of 8.45%.

Salahuddin *et al*. (2009) found gradual increase in panicle length (24.50 cm), grains panicle^{-1} (110) and grain yield (4.91 t ha^{-1}) due to the increase in nitrogen levels up to 150 kg ha^{-1} and declined thereafter. 1000 grain weight was not significantly influenced by application of different levels of nitrogen.

Islam *et al*. (2009) found significant variation on morpho-physiological attributes of BINA dhan5, Tainan 3 and BINA dhan6 due to four N levels. Plant height, tillers hill^{-1}, leaf area hill^{-1} (cm^2) were increased with the split application of N. Among the treatments, T_4 (full doze of urea at three equal splits, 1/3 at 15 DAT + 1/3 at 30 DAT + 1/3 at 55 DAT showed the best performance and grain yield (45.25 g hill^{-1}) compared to control (30.61 g hill^{-1}). Full dose of urea (215 kg ha^{-1}

urea) applied at three equal split at 15, 30 and 55 DAT was found to be the most beneficial one for the all the rice genotypes.

Kandil *et al*. (2010) found that the increasing nitrogen fertilizer levels up to 80 kg ha^{-1} N resulted in marked increases in number of tillers m^{-2}, panicle length, panicle weight, filled grains $panicles^{-1}$, 1000 grain weight, grain and straw yields ha^{-2} and harvest index in both seasons. The addition of 144 or 192 kg ha^{-1} N recorded the tallest plants and the highest number of panicles m^{-2} without significant differences.

Karim (2011) studied on the effect of nitrogen fertilizer (0, 20, 40, 60, 80.100 120 kg ha^{-1} N) in respect to high yield and better seed quality. Growth parameters like plant height (114.37 cm) and tillers $hill^{-1}$ (15.1) had higher at higher level of nitrogen. However, plants with moderate level of applied nitrogen showed better yield component of the variety where the highest panicle $hill^{-1}$ (11.8), grains $panicle^{-1}$ (140.5) and filled grains $panicle^{-1}$ (130.33) were observed with 60 kg N ha^{-1}. Better yield components of the variety obtained at 60 kg N ha^{-1} attributed to the highest yield (4.43 t ha^{-1}) of the variety.

Khorshidi *et al*. (2011) reported that the effect of nitrogen fertilizer had no significant difference on 1000 seeds weight and number of grains $panicle^{-1}$. The effect of fertilizers on rice yield showed that application of 100 kg of nitrogen had the highest yield of 5733 kg ha^{-1}. Data also indicated that yield had the highest positive correlation with panicle and harvest index.

Azarpour *et al*. (2014) studied on yield and physiological traits of three rice cultivars due to the effect of N fertilizer (0, 30, 60, and 90 Kg N ha^{-1}). Results of growth analysis indicated that, nitrogen increasing rates of fertilizer caused the increment of growth indexes and yield of rice.

Zhaowen *et al*. (2018) carried out and experiment the South China Agricultural University in Guangzhou, China with three N levels (N_0: 0 kg ha^{-1}, N_1: 30 kg ha^{-1}, and N_2: 60 kg ha^{-1}) at the booting stage were applied to a popular aromatic rice cv. Yungengyou 14, to assess the accumulation pattern of 2-AP, proline, and N as well as relationships among the investigated indices regarding 2-AP accumulation. Among all other plant parts, the highest 2AP contents were found in ear axes and flag leaves, *i.e*., 17.04%-18.26% and 14.37%- 15.05% at 17 as well as 18.41%-22.74% and 14.38%-15.75% at 30 DAF under all N-levels.

Hossain *et al*. (2018) conducted an experiment at Patuakhali Science and Technology University, Dumki, Patuakhali under AEZ-13 to optimize the nitrogen rate for three aromatic rice varieties in Aman season. The experiment was consisted of three aromatic rice varieties *viz*., V_1 = BRRI dhan34, V_2 = BRRI dhan38 and V_3 = Sakkorkhora and four fertilizer treatments viz., N_0 = 0 kg ha^{-1} nitrogen (control), N_1 = 30 kg ha^{-1} nitrogen, N_2 = 45 kg ha^{-1} nitrogen and N_3 = 60 kg ha^{-1} nitrogen. Result revealed that number of effective tillers hill^{-1} (12.00), 1000-grain weight (16.69 g), grain yield (3.44 t ha^{-1}), biological yield (8.05 t ha^{-1}), panicle length (29.44 cm) and harvest index (42.76%) were found highest with 45 kg N ha^{-1} but the highest plant height (152.43 cm) and straw yield (4.64 t ha^{-1}) were found from 60 kg N ha^{-1} and all the characters showed the lowest value in control condition.

2.2 Effect of zinc on yield and yield attributes of rice

Ullah *et al*. (2001) conducted a field experiment 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}.

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 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 i.e. 38.19 and 18.27 mg Zn kg^{-1}, respectively in Zn at 1.0 kg ha^{-1} as Zn-EDTA.

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}.

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.

Sudha and Stalin (2015) conducted an experiment to study the effect of zinc application on yield, quality and grain zinc content of different rice genotypes. The main plots were two levels of Zn (no Zn and 100 kg ha^{-1} $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 per cent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice) and sub-plots were 18 of rice genotypes. The application of zinc significantly increased the plant height, number of productive tillers, filled grains per panicle, panicle length and 1000-grain weight as compared to NPK fertilization alone. The yield of grain (4623 to 7434 kg ha^{-1}) and straw (6657 to 10041 kg ha^{-1}) of different rice genotypes significantly increased with the application of zinc in which the grain and straw yields were increased by 14 and 16 percent, respectively. Further the quality parameters like starch, amylase, crude protein and zinc content in processed rice grains increased markedly by the application of Zn as compared to NPK alone.

Shahane *et al*. (2018) conducted a pot experiment at New Delhi, to study the interaction effects of two levels each of nitrogen (N) (0 and 120 kg ha^{-1}), phosphorus (P; 0 and 25.8 kg ha^{-1}), and zinc (Zn; 0 and 5 kg ha^{-1}) in two aromatic rice varieties, viz. Pusa Rice Hybrid 10 and Pusa Basmati 1121. Application of N, P, and Zn resulted in increase of dry matter (0.91, 0.32, and 0.24 g $plant^{-1}$, respectively) 60 days after sowing (DAS) and grain yield of rice (3.68, 1.67, and 1.17 g $plant^{-1}$). The increase in yield of rice owing to N application was relatively higher by 0.98, 0.22, and 1.05 g $plant^{-1}$, respectively, when either P or Zn or both were applied with N than alone application of N, indicating synergetic effect of P and Zn application with N.

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

Khatun *et al*. (2018) conducted a field experiment 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 cowdung 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.

Luo *et al*. (2019) conduceted a study to assess the physio-biochemical responses involved in biosynthesis of 2-acety-1-pyrroline (2-AP), which is a key compound in the aroma of fragrant rice, in four different fragrant rice varieties, i.e., *Meixiangzhan-2*, *Xiangyaxiangzhan*, *Ruanhuayou-134* and *Yunjingyou*. Four concentrations (0, 0.50, 1.00 and 2.00 g L^{-1}) of zinc chloride were applied to fragrant rice foliage at the heading stage and named CK, Zn_1, Zn_2 and Zn_3, respectively. Results showed that compared with CK, the Zn_1, Zn_2 and Zn_3 treatments significantly increased the 2-AP concentration in mature grains of the four fragrant rice genotypes. In addition, compared to the CK treatment, the Zn_2 treatment markedly increased the net photosynthetic rate of fragrant rice during the grain filling stage and increased the seed-setting rate, 1000-grain weight and grain yield in all fragrant rice genotypes. In general, 1.00 g L^{-1} seemed to be the most suitable application concentration because the highest 2-AP content and grain weight were recorded with this treatment.

The above cited review revealed that application of nitrogen and zinc nutrients greatly influences the growth, yield attributes, yield and quality of rice. The literature also indicated that the effects of nitrogen and zinc on the growth, yield attributes, yield and quality of different aromatic rice variety have not well articulated and have no definite conclusion in the agro-climatic condition of Bangladesh especially for aromatic rice.

.

Chapter III
Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted for improving aromatic quality of BRRI dhan80 through minimization of nitrogen and supplementation of zinc. 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 was followed for this experiment has been presented below under the following headings:

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the period of June to November, 2018.

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 (FAO, 1988). During the experimental period the maximum temperature (36.4^{0}C), highest relative humidity (88%) and highest rainfall (591 mm) was recorded for the month of July, 2019, whereas the minimum temperature (16.4^{0}C), minimum relative humidity (74%) and rainfall (12 mm) was recorded for the month of November, 2018. 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 yellow 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 BRRI dhan80 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 N (4 levels) as

i. N_1: 35 kg N ha^{-1}

ii. N_2: 37 kg N ha^{-1}

iii. N_3: 39 kg N ha^{-1}

iv. N_4: 41 kg N ha^{-1} (Recommended dose)

Factor B: Levels of Zn (4 levels) as

i. Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

ii. Zn_2: 4.5 kg Zn ha^{-1}

iii. Zn_3: 5.0 kg Zn ha^{-1}

iv. Zn_4: 5.5 kg Zn ha^{-1}

There were total 16 (4×4) treatment combination as a whole *viz*., N_1Zn_1, N_1Zn_2, N_1Zn_3, N_1Zn_4, N_2Zn_1, N_2Zn_2, N_2Zn_3, N_2Zn_4, N_3Zn_1, N_3Zn_2, N_3Zn_3, N_3Zn_4, N_4Zn_1, N_4Zn_2, N_4Zn_3 and N_4Zn_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 330.40 m^2 (28.0 m × 11.8 m) was divided into 3 blocks. The four levels of N were assigned in the main plot and four levels of Zn in the sub-plot. The size of the each plot was 2.5 m × 1.05 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

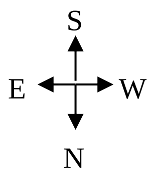
Seeds of different aromatic rice varieties were collected from BRRI (Bangladesh Rice Research Institute), Gazipur and local market just 20 days ahead of the sowing of seeds in seed bed. For seedlings clean seeds were immersed in water in a bucket for 24 hours. The imbibed seeds were then taken out of 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 7th June, 2018. 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 9th July, 2018 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 10th July, 2018. Organic and inorganic manures as indicated 3.3.4 were mixed with the soil of each unit plot.



Plot size = 2.5 m × 1.05 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 N (4 levels) as
i. N_1: 35 kg N ha^{-1}
ii. N_2: 37 kg N ha^{-1}
iii. N_3: 39 kg N ha^{-1}
iv. N_4: 41 kg N ha^{-1} (Recommended dose)

Factor B: Levels of Zn (4 levels) as
i. Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)
ii. Zn_2: 4.5 kg Zn ha^{-1}
iii. Zn_3: 5.0 kg Zn ha^{-1}
iv. Zn_4: 5.5 kg Zn ha^{-1}

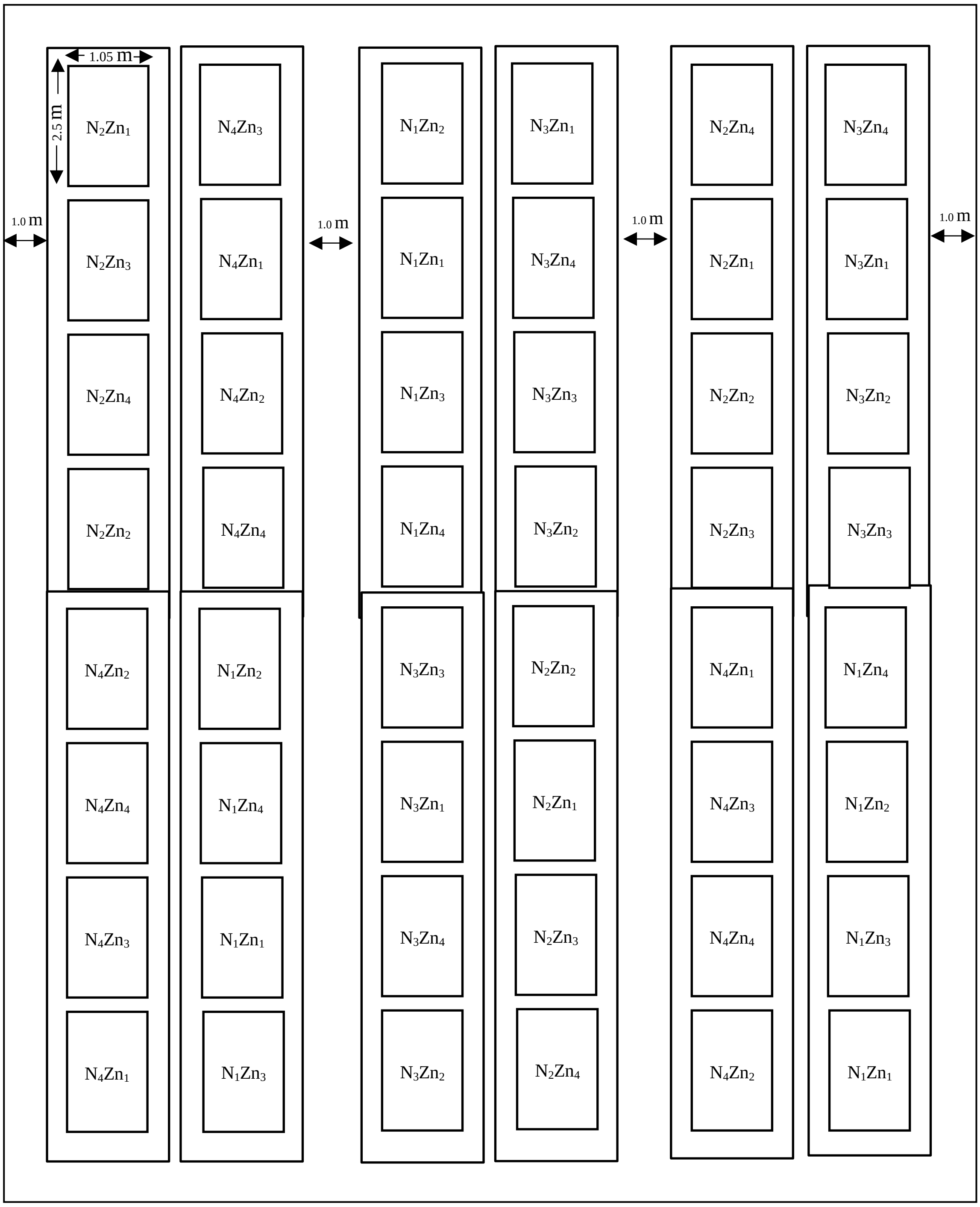


Figure 1. Layout of the experimental plot

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. TSP, MoP, Gypsum and borax were applied @ 80, 60, 90, 12 and 10 kg ha^{-1} (BRRI, 2018). Urea and Zn were applied as per treatment. The entire amount of 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 also panicle initiation stages.

3.3.5 Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 12^{th} July, 2018 in well puddled plot with spacing of 20 × 15 cm. Two seedlings was transplanted in each hill.

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 up to 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.

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 30, 45, 60, 75 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} were recorded at 30, 45, 60, 75 DAT and at harvest as the average of randomly selected 5 plants from the inner rows of each plot.

3.5.3 Effective tillers hill^{-1}

The total number of effective tillers hill^{-1} were 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.

3.5.4 Non-effective tillers hill^{-1}

The total number of non-effective tillers hill^{-1} were 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.

3.5.5 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.

3.5.6 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.

3.5.7 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.

3.5.8 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.

3.5.9 Weight of 1000-grains

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

3.5.10 Grain yield

Grains obtained from each unit plot were sun-dried (13-14%) and weighed carefully. Dry weight of grains of each plot were taken and converted to ton hectare^{-1} (t ha^{-1}).

3.5.11 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}).

3.5.12 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.

3.5.13 Harvest index

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

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

3.5.14 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 and expressed in millimeter (mm).

3.5.15 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 and expressed in millimeter (mm).

3.5.16 Milled rice

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

3.5.17 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) and expressed in percentage (%).

3.5.18 Husk of 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) and expressed in percentage (%).

3.5.19 Protein content

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

3.5.20 Zn content

The samples of rice grains were grind 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 content was estimated with the help of atomic absorption spectrophotometer (Perkin Elmer; Model-A. Analyst 100) as described by Prasad *et al*. (2006).

3.5.21 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 rice amylose and expressed in per cent basis.

3.5.22 Proline content

The proline content of rice grains were measured according to the method that was 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 of proline content was expressed as mg g^{-1}.

3.5.23 Grain 2-AP content

The 2-AP content in rice 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 IV

Results and Discussion

CHAPTER IV

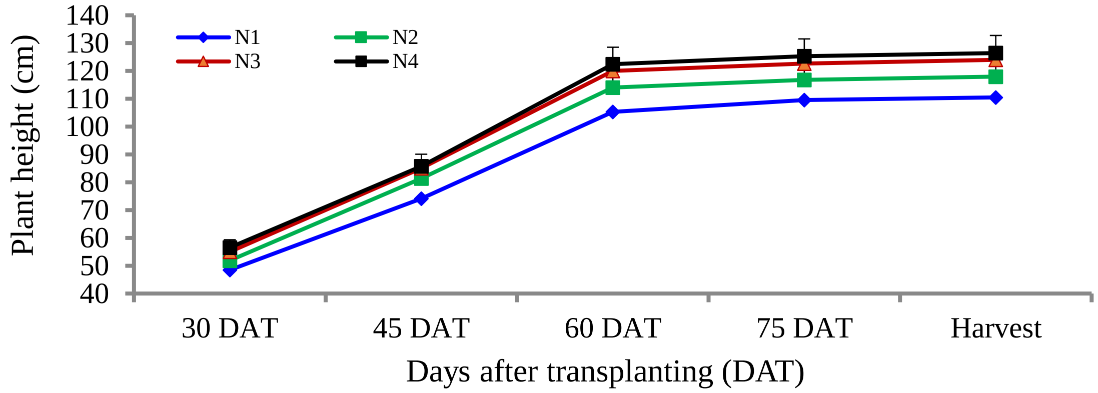
RESULTS AND DISCUSSION

The experiment was carried out for improving aromatic quality of BRRI dhan80 through minimization of nitrogen and supplementation of zinc. The analyses of variance (ANOVA) of the data on yield contributing characters, yield and quality BRRI dhan80 are presented in Appendix IV-IX. The findings have been presented and discusses under the following headings and sub-headings:

4.1 Growth

4.1.1 Plant height

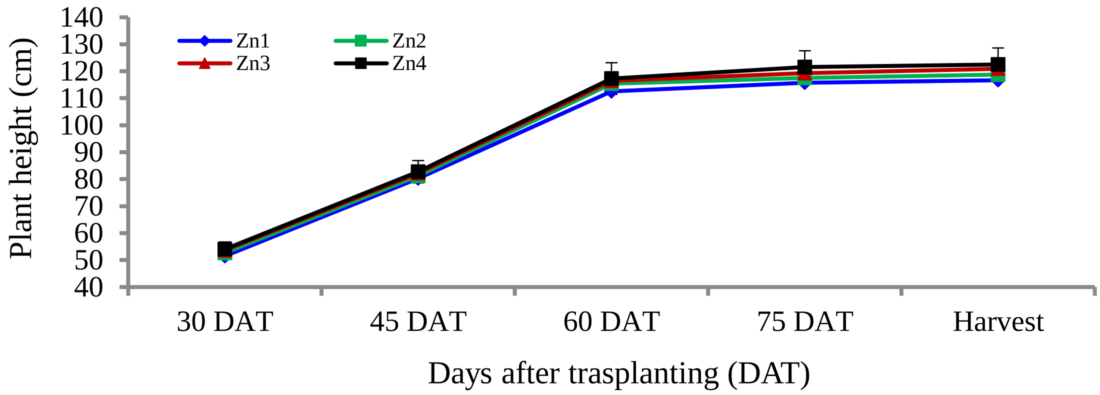
Different levels of nitrogen showed statistically significant differences in terms of plant height of BRRI dhan80 at 30, 45, 60 and 75 DAT (days after transplanting) and at harvest (Figure 2). At 30, 45, 60, 75 DAT and at harvest, the tallest plant (56.50, 85.77, 122.39, 125.24 and 126.41 cm, respectively) was observed from N_4 (41 kg N ha^{-1}) which was statistically similar (54.98, 85.08, 119.96, 122.60 and 123.98 cm, respectively) to N_3 (39 kg N ha^{-1}) and followed (51.86, 81.37, 114.07, 116.75 and 117.95 cm, respectively) by N_2 (37 kg N ha^{-1}), whereas the shortest plant (48.44, 74.16, 105.29, 109.57 and 110.48 cm, respectively) was found from N_1 (35 kg N ha^{-1}). Karim (2011) observed plant height (114.37 cm) at higher level of N. Similar results also reported by Haque *et al*., 2015; Rajesh *et al*., 2017.



N_1: 35 kg N ha^{-1}; N_2: 37 kg N ha^{-1}
N_3: 39 kg N ha^{-1}; N_4: 41 kg N ha^{-1}

Figure 2. Effect of different levels of nitrogen on plant height of BRRI dhan80. Vertical bars represent Sx value.

Plant height of BRRI dhan80 at 30, 45, 60 and 75 DAT and at harvest varied non-significantly due to different levels of zinc (Figure 3). At 30, 45, 60 and 75 DAT and at harvest, the tallest plant (54.02, 82.76, 117.30, 121.51 and 122.50 cm, respectively) was recorded from Zn_4 (5.5 kg Zn ha^{-1}), while the shortest plant (51.48, 80.22, 112.54, 115.74 and 116.66 cm, respectively) was observed from Zn_1 (4.0 kg Zn ha^{-1}). Zn is one of the vital nutrients which is required for various biochemical and metabolic process in rice. Singh *et al.* (2012) observed the tallest plant with the application of 4 kg Zn ha^{-1}. But Ghasal *et al*. (2018) reported the tallest plant with 1.25 kg Zn ha^{-1} as Zn-EDTA + 0.5% foliar spray.



Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}; Zn_4: 5.5 kg Zn ha^{-1}

Figure 3. Effect of different levels of zinc on plant height of BRRI dhan80. Vertical bars represent Sx value.

Combined effect of different levels of nitrogen and zinc showed statistically significant differences on plant height of BRRI dhan80 at 30, 45, 60 and 75 DAT and at harvest (Table 1). At 30, 45, 60 and 75 DAT and at harvest, the tallest plant (60.75, 88.49, 127.08, 129.89 and 130.91 cm, respectively) was observed from N_4Zn_4 (41 kg N ha^{-1} and 5.5 kg Zn ha^{-1}) and the shortest plant (46.96, 70.38, 100.83, 105.70 and 106.75 cm, respectively) was recorded from N_1Zn_1 (35 kg N ha^{-1} and 4.0 kg Zn ha^{-1}) treatment combination. Arif *et al*. (2018) reported that management of nutritious in fine rice is primarily concomitant with the judicious application of nitrogen and zinc fertilizers and their optimum doses produced the desirable growth characters especially plant height of rice.

Table 1. Combined effect of different levels of nitrogen and zinc on plant height of cv. BRRI dhan80 at different days after transplanting (DAT) and at harvest

Treatments	Plant height (cm) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
N_1Zn_1	46.96 g	70.38 i	100.83 g	105.70 f	106.75 f
N_1Zn_2	48.70 fg	72.97 hi	104.83 fg	106.80 ef	107.85 ef
N_1Zn_3	50.31 efg	76.91 fgh	106.40 e-g	110.55 def	111.27 def
N_1Zn_4	47.77 g	76.37 gh	109.10 d-g	115.21 c-f	116.05 c-f
N_2Zn_1	53.56 b-f	80.88 d-g	116.12 bcd	119.20 a-d	119.53 a-d
N_2Zn_2	52.10 c-g	83.81 a-e	117.04 bcd	118.33 bcd	119.66 a-d
N_2Zn_3	50.55 e-g	79.63 e-g	110.78 def	114.77 c-f	116.77 c-f
N_2Zn_4	51.22 d-g	81.14 d-g	112.32 c-f	114.70 c-f	115.84 c-f
N_3Zn_1	54.30 b-e	87.38 ab	117.75 a-d	120.41 a-d	121.86 a-d
N_3Zn_2	53.18 b-f	81.34 c-g	117.39 bcd	115.19 c-f	116.64 c-f
N_3Zn_3	56.08 a-d	86.57 a-d	124.01 ab	127.11 ab	128.90 ab
N_3Zn_4	56.35 abc	85.03 a-e	120.68 abc	127.68 ab	128.53 ab
N_4Zn_1	51.08 d-g	82.22 b-f	115.46 b-e	117.65 b-e	118.51 b-e
N_4Zn_2	56.61 abc	86.92 abc	122.46 ab	128.44 ab	129.59 ab
N_4Zn_3	57.55 ab	85.43 a-d	124.56 ab	124.97 abc	126.66 abc
N_4Zn_4	60.75 a	88.49 a	127.08 a	129.89 a	130.91 a
Sx	1.537	1.725	2.863	3.433	3.407
Level of significance	*	*	*	*	*
CV(%)	5.03	3.66	4.30	5.02	4.93

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

N_1: 35 kg N ha^{-1}
N_2: 37 kg N ha^{-1}
N_3: 39 kg N ha^{-1}
N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)
Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}
Zn_4: 5.5 kg Zn ha^{-1}

* = Significant at 5% level

4.1.2 Tillers hill^{-1}

Statistically significant variation was recorded in terms of tillers hill^{-1} of BRRI dhan80 at 30, 45, 60 and 75 DAT and at harvest due to different levels of nitrogen (Figure 4). At 30, 45, 60, 75 DAT and at harvest, the maximum number of tillers hill^{-1} (6.97, 9.13, 14.80, 17.30 and 17.72, respectively) was recorded from N_4 which was statistically similar (6.92, 9.00, 14.50, 17.10 and 17.47, respectively) to N_3 and followed (6.48, 8.42, 13.67, 16.28 and 16.63, respectively) by N_2, while the minimum number (5.63, 7.50, 12.50, 14.50 and 14.88, respectively) was found from N_1. Rajesh *et al.* (2017) observed the highest number of tillers hill^{-1} with the application of 120 kg N ha^{-1}.

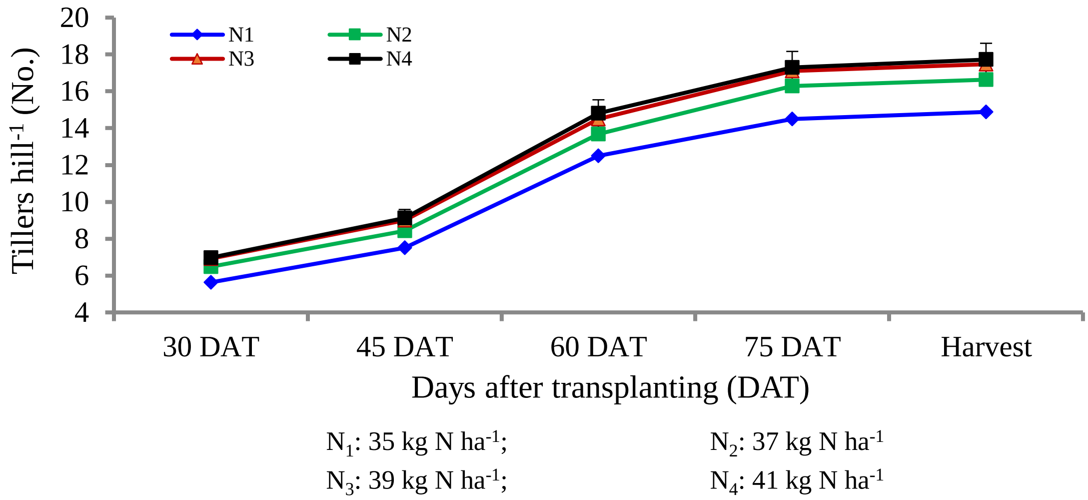
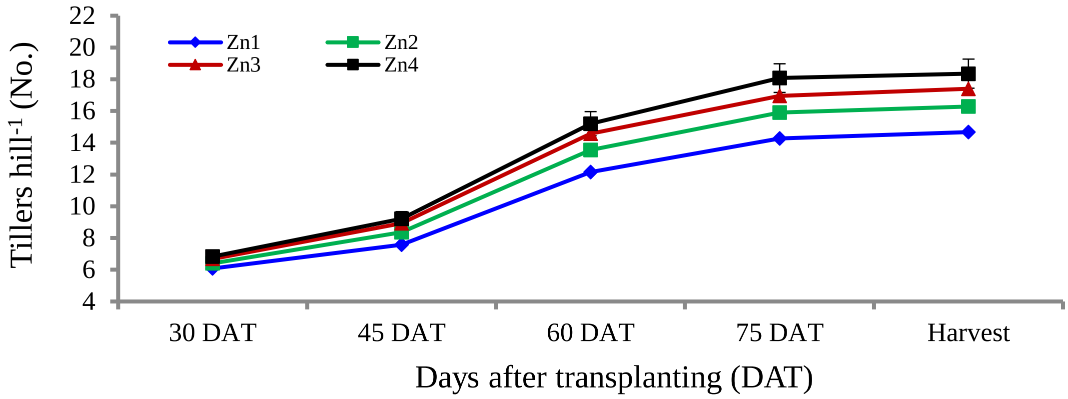


Figure 4. Effect of different levels of nitrogen on number of tillers hill^{-1} of BRRI dhan80. Vertical bars represent Sx value.

Different levels of zinc varied significantly in terms of tillers hill^{-1} of BRRI dhan80 at 30, 45, 60 and 75 DAT and at harvest (Figure 5). At 30, 45, 60 and 75 DAT and at harvest, the maximum number of tillers hill^{-1} (6.83, 9.20, 15.20, 18.07 and 18.35, respectively) was found from Zn_4 which was statistically similar (6.68, 8.92, 14.57, 16.95 and 17.40, respectively) to Zn_3 and followed (6.40, 8.37, 13.55, 15.90 and 16.28, respectively) by Zn_2 and the minimum number (6.08, 7.57, 12.15, 14.27 and 14.67, respectively) was recorded from Zn_1. Sudha and Stalin (2015) also recorded the maximum number of tillers hill^{-1} at earlier with the highest level of zinc application.



Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}; Zn_4: 5.5 kg Zn ha^{-1}

Figure 5. Effect of different levels of zinc on number of tillers hill^{-1} of BRRI dhan80. Vertical bars represent Sx value.

Tillers hill^{-1} of BRRI dhan80 at 30, 45, 60 and 75 DAT and at harvest varied significantly due to the combined effect of different levels of nitrogen and zinc (Table 2). At 30, 45, 60 and 75 DAT and at harvest, the maximum number of tillers hill^{-1} (7.53, 9.80, 16.87, 19.73 and 19.93, respectively) was observed from N_4Zn_4, whereas the minimum number (5.07, 7.07, 11.33. 13.33 and 13.67, respectively) was found from N_1Zn_1 treatment combination.

4.2 Yield attributes

4.2.1 Effective tillers hill^{-1}

Effective tillers hill^{-1} of BRRI dhan80 showed statistically significant differences due to different levels of nitrogen (Table 3). The maximum number of effective tillers hill^{-1} (15.60) was found from N_3 which was followed (14.20 and 14.10, respectively) by N_2 and N_4 and they were statistically similar and the minimum (11.63) was recorded from N_1. Hossain *et al*. (2018) were found highest number of effective tillers hill^{-1} (12.00) with 45 kg N ha^{-1}.

Statistically significant variation was recorded in terms of effective tillers hill^{-1} of BRRI dhan80 due to different levels of zinc (Table 3). The maximum number of effective tillers hill^{-1} (15.43) was recorded from Zn_4 which was statistically similar (15.13) to Zn_3 and followed (13.57) by Zn_2, while the minimum number (11.40) was found from Zn_1. Similar observations also reported by Ghasal *et al*. (2018).

Table 2. Combined effect of different levels of nitrogen and zinc on number of tillers hill^{-1} of cv. BRRI dhan80 at different days after transplanting (DAT) and at harvest

Treatments	Tillers hill^{-1} (No.) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
N_1Zn_1	5.07 g	7.07 g	11.33 i	13.33 j	13.67 j
N_1Zn_2	5.40 g	7.20 fg	12.00 hi	13.40 j	13.87 ij
N_1Zn_3	6.00 f	7.53 efg	13.40 ef	15.40 f-i	15.73 fgh
N_1Zn_4	6.07 f	8.20 cde	13.27 efg	15.93 e-h	16.27 e-g
N_2Zn_1	6.20 ef	7.27 fg	12.60 fgh	14.53 h-j	14.80 hij
N_2Zn_2	6.60 cde	8.60 bcd	13.47 ef	16.80 c-f	17.27 cde
N_2Zn_3	6.47 d-f	8.67 bcd	13.87 de	16.07 e-g	16.47 efg
N_2Zn_4	6.67 c-e	9.13 ab	14.73 cd	17.73 bcd	18.00 bcd
N_3Zn_1	6.60 c-e	7.87 d-g	12.53 fgh	14.87 g-i	15.20 ghi
N_3Zn_2	6.93 bcd	8.73 bcd	14.00 de	16.40 def	16.87 def
N_3Zn_3	7.07 bc	9.73 a	15.53 bc	18.27 bc	18.60 abc
N_3Zn_4	7.07 bc	9.67 a	15.93 ab	18.87 ab	19.20 ab
N_4Zn_1	6.47 def	8.07 c-f	12.13 ghi	14.33 ij	14.80 hij
N_4Zn_2	6.67 cde	8.93 abc	14.73 cd	17.07 cde	17.33 cde
N_4Zn_3	7.20 ab	9.73 a	15.47 bc	18.07 bc	18.80 ab
N_4Zn_4	7.53 a	9.80 a	16.87 a	19.73 a	19.93 a
Sx	0.148	0.269	0.359	0.461	0.445
Level of significance	*	*	*	**	**
CV(%)	3.95	5.48	4.48	4.90	4.62

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

N_1: 35 kg N ha^{-1} — Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

N_2: 37 kg N ha^{-1} — Zn_2: 4.5 kg Zn ha^{-1}

N_3: 39 kg N ha^{-1} — Zn_3: 5.0 kg Zn ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose) — Zn_4: 5.5 kg Zn ha^{-1}

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

Table 3. Effect of different levels of nitrogen and zinc on effective, non-effective tillers hills^{-1}, panicle length, filled and unfilled grains panicle^{-1} of cv.BRRI dhan80

Treatments	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)
Levels of Nitrogen					
N_1	11.63 c	3.25 b	26.88 b	156.43 b	26.55 a
N_2	14.20 b	2.43 c	28.39 a	168.70 a	22.08 bc
N_3	15.60 a	1.87 d	29.33 a	174.05 a	20.13 c
N_4	14.10 b	3.62 a	28.12 ab	167.83 a	23.00 b
Sx	0.266	0.063	0.0.391	2.344	0.643
Level of significance	**	**	*	**	**
CV(%)	6.64	7.85	4.80	4.87	9.71
Levels of Zinc					
Zn_1	11.40 c	3.27 a	25.65 c	155.63 c	27.22 a
Zn_2	13.57 b	2.72 b	27.81 b	165.45 b	23.57 b
Zn_3	15.13 a	2.27 c	29.45 a	172.55 a	20.80 c
Zn_4	15.43 a	2.92 b	29.80 a	173.38 a	20.18 c
Sx	0.238	0.087	0.400	2.057	0.499
Level of significance	**	**	**	**	**
CV(%)	5.95	10.73	4.92	4.27	7.54

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

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

Different levels of nitrogen and zinc varied significantly due to their combined effect on effective tillers $hill^{-1}$ of BRRI dhan80 (Table 4). The maximum number of effective tillers $hill^{-1}$ (17.73) was observed from N_3Zn_4, whereas the minimum number (10.33) was recorded from N_1Zn_2 treatment combination.

4.2.2 Non-effective tillers $hill^{-1}$

Different levels of nitrogen showed statistically significant differences in terms of non-effective tillers $hill^{-1}$ of BRRI dhan80 (Table 3). The minimum number of non-effective tillers $hill^{-1}$ (1.87) was recorded from N_3 which was followed (2.43) by N_2, whereas the maximum number (3.62) was observed from N_4 which was followed (3.25) by N_1. Hossain *et al*. (2008) reported that number of non-effective tillers $hill^{-1}$ were significantly increased up to 90 kg ha^{-1} N.

Non-effective tillers $hill^{-1}$ of BRRI dhan80 varied significantly due to different levels of zinc (Table 3). The minimum number of non-effective tillers $hill^{-1}$ (2.27) was found from Zn_3 which was followed (2.72 and 2.92, respectively) by Zn_2 and Zn_4 and they were statistically similar and the maximum number (3.27) was recorded from Zn_1.

Combined effect of different levels of nitrogen and zinc showed statistically significant differences on non-effective tillers $hill^{-1}$ of BRRI dhan80 (Table 4). The minimum number of non-effective tillers $hill^{-1}$ (1.47) was observed from N_3Zn_4, while the maximum number (5.00) from N_4Zn_4 treatment combination.

4.2.3 Panicle length

Panicle length of BRRI dhan80 showed statistically significant differences in terms of panicle length of BRRI dhan80 due to different levels of nitrogen (Table 3). The longest panicle (29.33 cm) was recorded from N_3 which was statistically similar (28.39 and 28.12 cm, respectively) to N_2 and N_4, while the shortest panicle (26.88 cm) was found from N_1. Salahuddin *et al*. (2009) found gradual increase in panicle length (24.50 cm) with the increase in nitrogen levels up to 150 kg ha^{-1} and declined thereafter.

Table 4. Combined effect of different levels of nitrogen and zinc on effective, non-effective tillers hills^{-1}, panicle length, filled and unfilled grains panicle^{-1} of cv.BRRI dhan80

Treatments	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)
N_1Zn_1	10.47 j	3.40 bc	24.79 hi	144.07 f	31.93 a
N_1Zn_2	10.33 j	3.33 bc	25.92 ghi	153.47 ef	26.27 bc
N_1Zn_3	12.67 fgh	3.07 cd	27.13 d-h	160.47 de	24.20 b-e
N_1Zn_4	13.07 fg	3.20 bcd	29.68 a-d	167.73 cd	23.80 b-e
N_2Zn_1	11.53 hij	3.27 bcd	26.49 f-i	162.73 de	26.60 b
N_2Zn_2	14.73 de	2.53 e	28.82 b-f	171.40 bcd	25.80 bc
N_2Zn_3	14.53 de	1.93 g	29.03 b-f	167.73 cd	18.00 g
N_2Zn_4	16.00 bcd	2.00 fg	29.21 b-e	172.93 bcd	17.93 g
N_3Zn_1	12.47 ghi	2.73 de	26.83 e-i	162.33 de	25.53 bcd
N_3Zn_2	15.20 cde	1.67 g	27.33 d-h	163.73 de	19.07 fg
N_3Zn_3	17.00 ab	1.60 g	31.27 ab	182.73 ab	19.40 fg
N_3Zn_4	17.73 a	1.47 g	31.89 a	187.40 a	16.53 g
N_4Zn_1	11.13 ij	3.67 b	24.48 i	153.40 ef	24.80 b-e
N_4Zn_2	14.00 ef	3.33 bc	29.18 b-e	173.20 bcd	23.13 cde
N_4Zn_3	16.33 abc	2.47 ef	30.37 abc	179.27 abc	21.60 ef
N_4Zn_4	14.93 cde	5.00 a	28.44 c-g	165.47 de	22.47 de
Sx	0.477	0.173	0.800	4.114	0.998
Level of significance	**	**	*	*	**
CV(%)	5.95	10.73	4.92	4.27	7.54

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

N_1: 35 kg N ha^{-1}
N_2: 37 kg N ha^{-1}
N_3: 39 kg N ha^{-1}
N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)
Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}
Zn_4: 5.5 kg Zn ha^{-1}

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

Statistically significant variation was recorded in terms of panicle length of BRRI dhan80 due to different levels of zinc (Table 3). The longest panicle (29.80 cm) was observed from Zn_4 which was statistically similar (29.45 cm) to Zn_3 and followed (27.81 cm) by Zn_2, whereas the shortest panicle (25.65 cm) from Zn_1.

Panicle length of BRRI dhan80 showed statistically significant differences due to the combined effect of different levels of nitrogen and zinc (Table 4). The longest panicle (31.89 cm) was observed from N_3Zn_4, while the shortest panicle (24.48 cm) was recorded from N_4Zn_1 treatment combination.

4.2.4 Filled grains panicle^{-1}

Statistically significant differences was observed due to different levels of nitrogen in terms of filled grains panicle^{-1} of BRRI dhan80 (Table 3). The maximum number of filled grains panicle^{-1} (174.05) was found from N_3 which was statistically similar (168.70 and 167.83, respectively) to N_2 and N_4, whereas the minimum number (156.43) was observed from N_1. Abbasi *et al*. (2007) reported that triple split application of 80 kg ha^{-1} N could be best for the production of highest filled grains panicle^{-1}.

Filled grains panicle^{-1} of BRRI dhan80 varied significantly due to different levels of zinc (Table 3). The maximum number of filled grains panicle^{-1} (173.38) was found from Zn_4 which was statistically similar (172.55) to Zn_3 and followed (165.45) by Zn_2, while the minimum number (155.63) was recorded from Zn_1. In earlier Lei *et al*. (2017) reported that the exogenous application of mixed micro-nutrient Zn significantly increased filled grains.

Different levels of nitrogen and zinc varied significantly on filled grains panicle^{-1} of BRRI dhan80 due to combined effect (Table 4). The maximum number of filled grains panicle^{-1} (187.40) was recorded from N_3Zn_4 and the minimum number (144.07) was observed from N_1Zn_1 treatment combination.

4.2.5 Unfilled grains panicle^{-1}

Different levels of nitrogen showed statistically significant differences in terms of unfilled grains panicle^{-1} of BRRI dhan80 (Table 3). The minimum number of unfilled grains panicle^{-1} (20.13) was found from N_3 which was statistically similar (22.08) to N_2 and the maximum number (26.55) from N_1. Mannan *et al*. (2010) found that the highest N level increased the unfilled grains panicle^{-1}.

Unfilled grains panicle^{-1} of BRRI dhan80 varied significantly due to different levels of zinc (Table 3). The minimum number of unfilled grains panicle^{-1} (20.18) was observed from Zn_4 which was statistically similar (20.80) to Zn_3, while the maximum number (27.22) was obtained from Zn_1. Similar findings reported by Sudha and Stalin (2015) at earlier with the minimum level of zinc application.

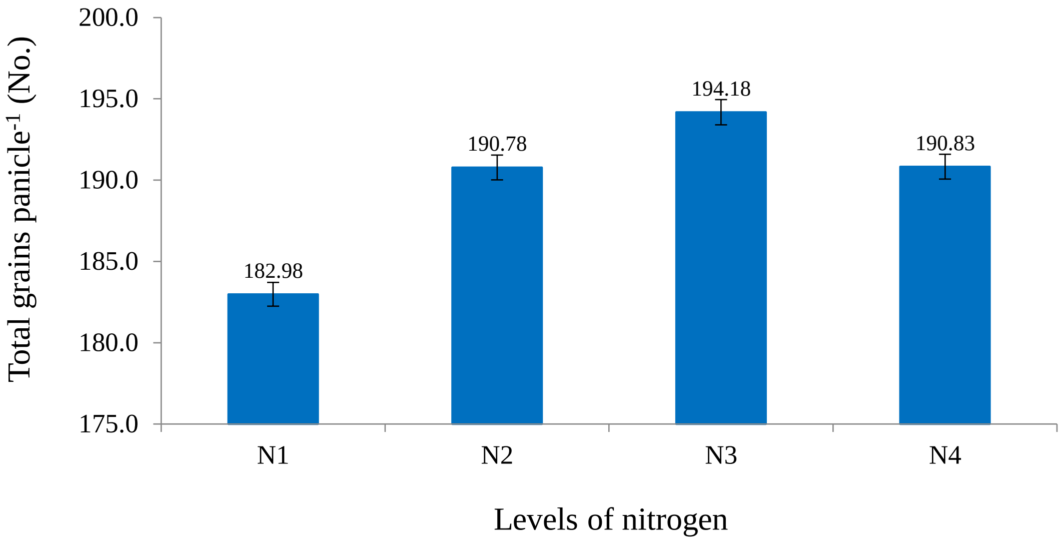
Combined effect of different levels of nitrogen and zinc varied significantly on unfilled grains panicle^{-1} of BRRI dhan80 (Table 4). The minimum number of unfilled grains panicle^{-1} (16.53) was observed from N_3Zn_4, whereas the maximum number (31.93) was found from N_1Zn_1 treatment combination.

42.6 Total grains panicle^{-1}

Statistically significant differences was recorded due to different levels of nitrogen in terms of total grains panicle^{-1} of BRRI dhan80 (Figure 7). The maximum number of total grains panicle^{-1} (194.18) was observed from N_3 which was statistically similar (190.83 and 190.78, respectively) to N_4 and N_2, whereas the minimum number (182.98) was found from N_1. Karim (2011) recorded the total grains panicle^{-1} (140.5) with 60 kg N ha^{-1}.

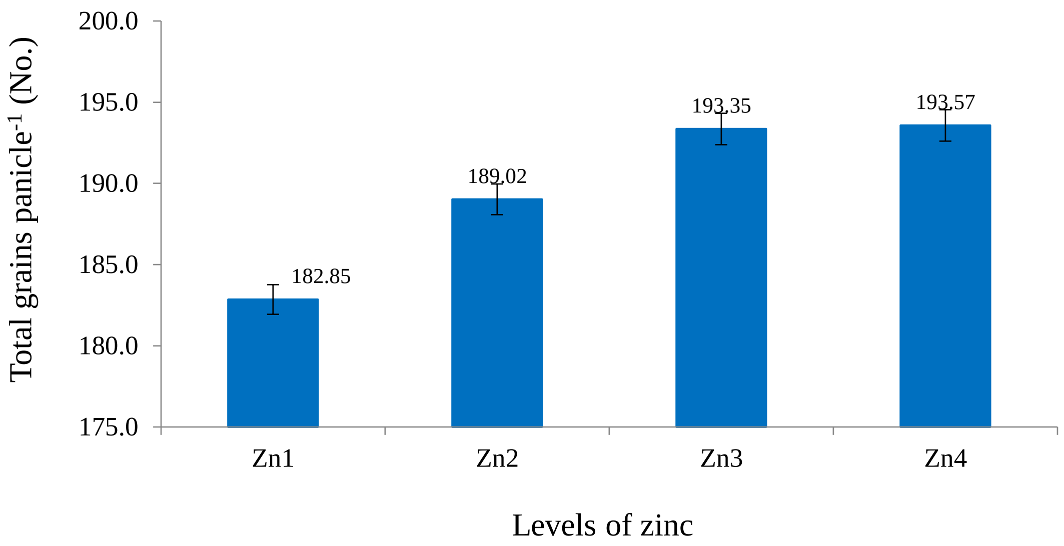
Different levels of zinc varied significantly in terms of total grains panicle^{-1} of BRRI dhan80 (Figure 8). The maximum number of total grains panicle^{-1} (193.57) was recorded from Zn_4 which was statistically similar (193.35 and 189.02, respectively) to Zn_3 and Zn_2, while the minimum number (182.85) from Zn_1. Lei *et al*. (2017) reported that Zn significantly increased total grains panicle^{-1}.

Total grains panicle^{-1} of BRRI dhan80 showed statistically significant differences due to the combined effect of different levels of nitrogen and zinc (Figure 9). The maximum number of total grains panicle^{-1} (203.93) was obtained from N_3Zn_4 and the minimum number (176.00) was found from N_1Zn_1 treatment combination.



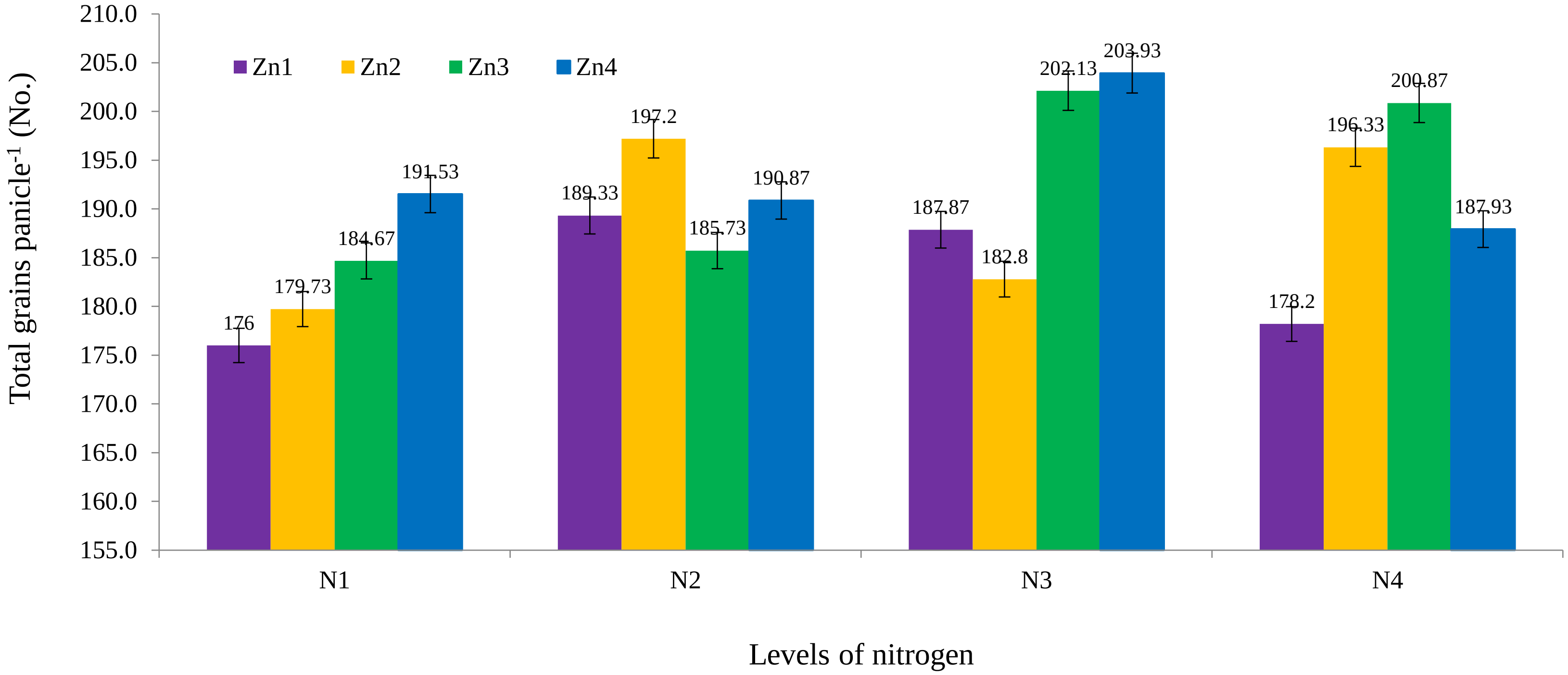
N_1: 35 kg N ha^{-1}; N_2: 37 kg N ha^{-1}
N_3: 39 kg N ha^{-1}; N_4: 41 kg N ha^{-1}

Figure 6. Effect of different levels of nitrogen on number of total grains $panicle^{-1}$ of BRRI dhan80. Vertical bars represent Sx value.



Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}; Zn_4: 5.5 kg Zn ha^{-1}

Figure 7. Effect of different levels of zinc on number of total grains $panicle^{-1}$ of BRRI dhan80. Vertical bars represent Sx value.



N_1: 35 kg N ha^{-1}; N_2: 37 kg N ha^{-1} Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}

N_3: 39 kg N ha^{-1}; N_4: 41 kg N ha^{-1} Zn_3: 5.0 kg Zn ha^{-1}; Zn_4: 5.5 kg Zn ha^{-1}

Figure 8. Combined effect of different levels of nitrogen and zinc on number of total grains panicle^{-1} of BRRI dhan80. Vertical bars represent Sx value.

4.2.7 Weight of 1000-grains

Weight of 1000-grains of BRRI dhan80 showed statistically significant differences due to different levels of nitrogen (Table 5). The highest weight of 1000-grains (26.96 g) was found from N_4 which was statistically similar (26.40 and 26.21 g, respectively) to N_3 and N_2, while the lowest weight (25.12 g) was recorded from N_1. Hossain *et al*. (2018) were found highest 1000-grain weight (16.69 g) with 45 kg N ha^{-1}. Salahuddin *et al*. (2009) reported that 1000 grain weight was not significantly influenced by application of different levels of nitrogen.

Different levels of zinc showed non-significant differences in terms of weight of 1000-grains of BRRI dhan80 (Table 5). The highest weight of 1000-grains (26.69 g) was found from Zn_4 and the lowest weight (25.53 g) was recorded from Zn_1. Sudha and Stalin (2015) also recorded the highest weight of 1000-grains at earlier with the minimum level of zinc application.

Statistically significant variation was observed due to the combined effect of different levels of nitrogen and zinc on weight of 1000-grains of BRRI dhan80 (Table 6). The highest weight of 1000-grains (27.75 g) was observed from N_4Zn_4, while the lowest weight (24.15 g) was found from N_1Zn_2 treatment combination.

4.3 Yield

4.3.1 Grain yield

Different levels of nitrogen showed statistically significant differences in terms of grain yield of BRRI dhan80 (Table 5). The highest grain yield (4.33 t ha^{-1}) was found from N_3 which was statistically similar (4.17 and 4.13 t ha^{-1}, respectively) to N_2 and N_4, whereas the lowest grain yield (3.56 t ha^{-1}) was observed from N_1. Data revealed that optimum levels of nitrogen ensured the suitable yield contributing characters and subsequently yield of rice. Maqsood *et al*. (2013) reported that the nitrogen application at 100 kg ha^{-1} N provided a maximum paddy yield (4.39 and 4.67 t ha^{-1}) in two successive year.

Table 5. Effect of different levels of nitrogen and zinc on weight of 1000-grains, grain, straw, biological yield and harvest index of cv. BRRI dhan80

Treatments	Weight of 1000-grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Levels of Nitrogen					
N_1	25.12 b	3.56 b	4.72 b	8.28 b	42.97
N_2	26.21 ab	4.17 a	4.98 a	9.14 a	45.56
N_3	26.40 a	4.33 a	5.04 a	9.38 a	46.13
N_4	26.96 a	4.13 a	4.95 a	9.07 a	45.45
Sx	0.329	0.110	0.059	0.103	0.824
Level of significance	*	**	**	**	NS
CV(%)	4.35	9.41	4.11	3.99	6.34
Levels of Zinc					
Zn_1	25.53	3.85	4.71 b	8.56 b	44.86
Zn_2	26.00	4.04	4.92 a	8.97 a	45.03
Zn_3	26.47	4.13	5.02 a	9.15 a	45.02
Zn_4	26.69	4.17	5.03 a	9.20 a	45.20
Sx	0.349	0.090	0.069	0.114	0.640
Level of significance	NS	NS	**	**	NS
CV(%)	4.62	7.74	4.89	4.42	4.93

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

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

Table 6. Combined effect of different levels of nitrogen and zinc on weight of 1000-grains, grain, straw, biological yield and harvest index of cv. BRRI dhan80

Treatments	Weight of 1000-grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
N_1Zn_1	24.57 cd	3.40 f	4.55 ef	7.95 f	42.71
N_1Zn_2	24.15 d	3.46 ef	4.53 f	7.99 f	43.34
N_1Zn_3	25.51 a-d	3.62 def	4.79 b-f	8.40 ef	43.07
N_1Zn_4	26.27 a-d	3.77 c-f	5.01 a-e	8.78 cde	42.74
N_2Zn_1	25.39 a-d	4.23 abc	4.72 cdf	8.95 b-e	47.28
N_2Zn_2	27.05 ab	4.19 a-d	5.13 a-d	9.32 a-d	44.91
N_2Zn_3	27.04 ab	3.97 b-f	4.90 a-f	8.87 b-e	44.76
N_2Zn_4	25.34 bcd	4.27 abc	5.15 a-d	9.42 abc	45.29
N_3Zn_1	25.47 a-d	4.03 b-e	4.89 a-f	8.92 b-e	45.11
N_3Zn_2	26.89 abc	4.06 b-e	4.80 a-f	8.86 b-e	45.76
N_3Zn_3	25.85 a-d	4.51 ab	5.22 ab	9.73 a	46.28
N_3Zn_4	27.39 ab	4.73 a	5.26 a	9.99 a	47.37
N_4Zn_1	26.68 abc	3.73 c-f	4.69 def	8.41 ef	44.32
N_4Zn_2	25.92 a-d	4.46 ab	5.23 ab	9.69 a	46.08
N_4Zn_3	27.50 ab	4.41 ab	5.18 abc	9.59 ab	45.96
N_4Zn_4	27.75 a	3.91 b-f	4.69 def	8.60 def	45.42
Sx	0.698	0.181	0.139	0.229	1.280
Level of significance	*	*	**	**	NS
CV(%)	4.62	7.74	4.89	4.42	4.93

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

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

Statistically non-significant variation was observed in terms of grain yield of BRRI dhan80 due to different levels of zinc (Table 5). The highest grain yield (4.17 t ha^{-1}) was found from Zn_4 and the lowest grain yield (3.85 t ha^{-1}) was recorded from Zn_1. Cheema *et al*. (2006) reported that paddy yield have positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Combined effect of different levels of nitrogen and zinc showed significant differences on grain yield of BRRI dhan80 (Table 6). The highest grain yield (4.73 t ha^{-1}) was observed from N_3Zn_4 which was statistically similar with N_2Zn_1, N_2Zn_4, N_3Zn_3, N_4Zn_2, and N_4Zn_3, while the lowest grain yield (3.40 t ha^{-1}) was recorded from N_1Zn_1 treatment combination.

4.3.2 Straw yield

Straw yield of BRRI dhan80 showed statistically significant differences due to different levels of nitrogen (Table 5). The highest straw yield (5.04 t ha^{-1}) was obtained from N_3 which was statistically similar (4.98 and 4.95 t ha^{-1}, respectively) to N_2 and N_4, while the lowest straw yield (4.72 t ha^{-1}) was found from N_1. Hoshain (2010) observed that straw yield were significantly increased with the increasing rates of N 120 Kg ha^{-1}.

Different levels of zinc varied significantly in terms of straw yield of BRRI dhan80 (Table 5). The highest straw yield (5.03 t ha^{-1}) was found from Zn_4 which was statistically similar (5.02 and 4.92 t ha^{-1}, respectively) to Zn_3 and Zn_2, whereas the lowest straw yield (4.71 t ha^{-1}) was recorded from Zn_1.

Statistically significant variation was recorded due to the combined effect of different levels of nitrogen and zinc in terms of straw yield of BRRI dhan80 (Table 6). The highest straw yield (5.26 t ha^{-1}) was found from N_3Zn_4 and the lowest straw yield (4.53 t ha^{-1}) was attained from N_1Zn_2 treatment combination.

4.3.3 Biological yield

Different levels of nitrogen showed statistically significant differences in terms of biological yield of BRRI dhan80 (Table 5). The highest biological yield (9.38 t ha^{-1}) was observed from N_3 which was statistically similar (9.14 and 9.07 t ha^{-1}, respectively) to N_2 and N_4, while the lowest biological yield (8.56 t ha^{-1}) was recorded from N_1. Hossain *et al*. (2018) were found highest biological yield (8.05 t ha^{-1}) with 45 kg N ha^{-1}.

Biological yield of BRRI dhan80 varied significantly due to different levels of zinc (Table 5). The highest biological yield (9.20 t ha^{-1}) was found from Zn_4 which was statistically similar (9.15 and 8.97 t ha^{-1}, respectively) to Zn_3 and Zn_2, whereas the lowest biological yield (8.56 t ha^{-1}) was obtained from Zn_1. Lei *et al*. (2017) reported earlier that the exogenous application of mixed micro-nutrient Zn significantly increased biological yield of BRRI dhan80.

Combined effect of different levels of nitrogen and zinc showed significant differences on biological yield of BRRI dhan80 (Table 6). The highest biological yield (9.99 t ha^{-1}) was recorded from N_3Zn_4, while the lowest biological yield (7.95 t ha^{-1}) was observed from N_1Zn_1 treatment combination.

4.3.4 Harvest index

Harvest index of BRRI dhan80 showed statistically non-significant differences due to different levels of nitrogen (Table 5). The highest harvest index (46.13%) was found from N_3 and the lowest harvest index (42.97%) was observed from N_1. Hossain *et al*. (2018) were found the highest harvest index (42.76%) with 45 kg N ha^{-1}.

Different levels of zinc varied non-significantly in terms of harvest index of BRRI dhan80 (Table 5). The highest harvest index (45.20%) was found from Zn, whereas the lowest harvest index (44.86%) was observed from Zn_1.

Statistically non-significant variation was observed in terms of harvest index of BRRI dhan80 due to the combined effect of different levels of nitrogen and zinc (Table 6). The highest harvest index (47.37%) was observed from N_3Zn_4, while the lowest harvest index (42.71%) was recorded from N_1Zn_1 treatment combination.

4.4 Grain quality of BRRI dhan80

4.4.1 Length of rice grain

Different levels of nitrogen showed statistically non-significant differences in terms of length of grain rice of BRRI dhan80 (Table 7). The highest length of grain rice (5.32 mm) was found from N_4, while the lowest length (5.19 mm) was recorded from N_1.

Length of grain rice of BRRI dhan80 varied non-significantly due to different levels of zinc (Table 7). The highest length of grain rice (5.41 mm) was obtained from Zn_4 and the lowest length (5.10 mm) was found from Zn_1.

Statistically non-significant differences was recorded in terms of length of grain rice of BRRI dhan80 due to the combined effect of different levels of nitrogen and zinc (Table 8). The highest length of grain rice (5.66 mm) was obtained from N_3Zn_4, while the lowest length (5.01 mm) was recorded from N_1Zn_1 treatment combination.

4.4.2 Breadth of rice grain

Different levels of nitrogen showed statistically non-significant differences in terms of breadth of grain rice of BRRI dhan80 (Table 7). The highest breadth of grain rice (2.37 mm) was recorded from N_3, whereas the lowest breadth (2.28 mm) was observed from N_1.

Breadth of grain rice of BRRI dhan80 varied non-significantly due to different levels of zinc (Table 7). The highest breadth of grain rice (2.39 mm) was found from Zn_4, while the lowest breadth (2.25 mm) was recorded from Zn_1.

Combined effect of different levels of nitrogen and zinc showed non-significant differences on breadth of grain rice of BRRI dhan80 (Table 8). The highest breadth of grain rice (2.49 mm) was observed from N_3Zn_4 and the lowest breadth (2.16 mm) was found from N_1Zn_2 treatment combination.

Table 7. Effect of different levels of nitrogen and zinc on length, breadth, milled, broken and husk of cv. BRRI dhan80

Treatments	Length of grain rice (mm)	Breadth of grain rice (mm)	Milled rice (%)	Broken rice (%)	Husk of rice (%)
Levels of Nitrogen					
N_1	5.19	2.28	68.56 b	2.89 c	28.55 a
N_2	5.27	2.35	72.07 a	3.38 b	24.55 b
N_3	5.31	2.37	73.88 a	3.63 a	22.49 b
N_4	5.32	2.35	71.93 a	3.36 b	24.71 b
Sx	0.055	0.049	0.843	0.058	0.865
Level of significance	NS	NS	*	**	**
CV(%)	3.65	7.30	4.08	6.04	11.95
Levels of Zinc					
Zn_1	5.10	2.25	69.08 b	2.88 c	28.04 a
Zn_2	5.24	2.33	71.60 a	3.26 b	25.14 b
Zn_3	5.33	2.37	72.70 a	3.53 a	23.76 b
Zn_4	5.41	2.39	73.06 a	3.58 a	23.36 b
Sx	0.090	0.053	0.750	0.039	0.774
Level of significance	NS	NS	**	**	**
CV(%)	5.90	7.84	3.63	4.09	10.69

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

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

Table 8. Combined effect of different levels of nitrogen and zinc on length, breadth, milled, broken and husk of cv. BRRI dhan80

Treatments	Length of grain rice (mm)	Breadth of grain rice (mm)	Milled rice (%)	Broken rice (%)	Husk of rice (%)
N_1Zn_1	5.01	2.22	65.79 f	2.64 h	31.56 a
N_1Zn_2	5.07	2.16	67.88 ef	2.65 h	29.48 ab
N_1Zn_3	5.13	2.32	69.60 def	3.08 f	27.32 abc
N_1Zn_4	5.53	2.42	70.97 b-e	3.18 ef	25.85 bcd
N_2Zn_1	5.28	2.20	72.32 b-e	2.95 fg	24.73 b-e
N_2Zn_2	5.37	2.44	73.12 bcd	3.47 cd	23.41 cde
N_2Zn_3	5.18	2.29	69.61 def	3.41 de	26.99 a-d
N_2Zn_4	5.26	2.46	73.24 bcd	3.69 bc	23.07 cde
N_3Zn_1	5.15	2.29	70.58 def	3.10 f	26.32 bcd
N_3Zn_2	4.94	2.24	70.81 c-f	3.53 cd	25.66 bcd
N_3Zn_3	5.49	2.44	75.84 ab	3.88 ab	20.29 ef
N_3Zn_4	5.66	2.49	78.28 a	4.02 a	17.70 f
N_4Zn_1	4.97	2.30	67.63 ef	2.83 gh	29.54 ab
N_4Zn_2	5.59	2.47	74.57 a-d	3.40 de	22.03 def
N_4Zn_3	5.53	2.44	75.77 abc	3.77 b	20.45 ef
N_4Zn_4	5.21	2.18	69.74 def	3.44 d	26.82 a-d
Sx	0.180	0.106	1.501	0.078	1.547
Level of significance	NS	NS	**	**	**
CV(%)	5.90	7.84	3.63	4.09	10.69

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

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

4.4.3 Milled grain

Milled rice of BRRI dhan80 showed statistically significant differences due to different levels of nitrogen (Table 7). The highest milled rice (73.88%) was found from N_3, which was statistically similar (72.07% and 71.93%, respectively) to N_2 and N_4, while the lowest (68.56%) was obtained from N_1.

Different levels of zinc varied significantly in terms of milled rice of BRRI dhan80 (Table 7). The highest milled rice (73.06%) was observed from Zn_4 which was statistically similar (72.70% and 71.60%, respectively) to Zn_3 and Zn_2, whereas the lowest (69.08%) was found from Zn_1.

Statistically significant variation was observed in terms of milled rice of BRRI dhan80 recorded due to the combined effect of different levels of nitrogen and zinc (Table 8). The highest milled rice (78.28%) was recorded from N_3Zn_4, whereas the lowest (65.79%) was observed from N_1Zn_1 treatment combination.

4.4.4 Broken grain

Different levels of nitrogen showed statistically significant differences in terms of broken rice of BRRI dhan80 (Table 7). The highest broken rice (3.63%) was recorded from N_3, which was followed (3.38% and 3.36%, respectively) to N_2 and N_4, whereas the lowest (2.89%) was observed from N_1.

Broken rice of BRRI dhan80 varied significantly due to different levels of zinc (Table 7). The highest broken rice (3.58%) was found from Zn_4 which was statistically similar (3.53%) to Zn_3 and followed (3.26%) by Zn_2, while the lowest (2.88%) was recorded from Zn_1.

Combined effect of different levels of nitrogen and zinc showed significant differences on broken rice of BRRI dhan80 (Table 8). The highest broken rice (4.02%) was observed from N_3Zn_4 and the lowest (2.64%) was found from N_1Zn_1 treatment combination.

4.4.5 Husk of rice

Statistically significant differences was recorded in terms of husk of rice of BRRI dhan80 due to different levels of nitrogen (Table 7). The highest husk of rice (28.55%) was found from N_1, which was followed by other levels of nitrogen and the lowest (22.49%) was recorded from N_3.

Different levels of zinc varied significantly in terms of husk of rice of BRRI dhan80 (Table 7). The highest husk of rice (28.04%) was observed from Zn_1 which was statistically similar with other levels of zinc, while the lowest (23.36%) was found from Zn_4.

Husk of rice of BRRI dhan80 showed significant differences due to the combined effect of different levels of nitrogen and zinc (Table 8). The highest husk of rice (31.56%) was attained from N_1Zn_1, whereas the lowest (17.70%) was observed from N_3Zn_2 treatment combination.

4.4.6 Protein content in rice grain

Protein content in rice grain of BRRI dhan80 showed statistically significant differences due to different levels of nitrogen (Table 9). The highest protein content in rice grain (8.28%) was recorded from N_4, which statistically similar (7.99%) to N_3 and followed (7.95%) by N_2, while the lowest (7.54%) from N_1.

Different levels of zinc varied significantly in terms of protein content in rice grain of BRRI dhan80 (Table 9). The highest protein content of rice grain (8.38%) was found from Zn_4 which was statistically similar (3.28%) to Zn_3 and followed (7.84%) by Zn_2, whereas the lowest (7.26%) was recorded from Zn_1. Sudha and Stalin (2015) reported that crude protein content in rice grains increased markedly by the application of Zn.

Statistically significant variation was observed in terms protein content in rice grain of BRRI dhan80 due to the combined effect of different levels of nitrogen and zinc (Table 10). The highest protein content in rice (8.95%) was observed from N_4Zn_4 and the lowest (6.97%) was found from N_1Zn_1 treatment combination.

Table 9. Effect of different levels of nitrogen and zinc on protein, Zn, amylose, proline and grain 2-AP content in cv. BRRI dhan80

Treatments	Protein content (%)	Zn content (mg g^{-1}) on dry weight basis	Amylose content (%)	Proline content in grains (mg g^{-1}) on dry weight basis	Grain 2-AP (µg g^{-1}) on dry weight basis
Levels of Nitrogen					
N_1	7.54 c	0.129 b	23.83 a	20.84 a	0.84 a
N_2	7.95 b	0.143 a	22.87 b	20.29 ab	0.78 b
N_3	7.99 ab	0.148 a	21.67 c	20.15 b	0.75 c
N_4	8.28 a	0.142 a	23.04 b	19.14 c	0.73 d
Sx	0.086	0.001	0.181	0.159	0.005
Level of significance	**	**	**	**	**
CV(%)	3.74	7.14	2.74	2.74	3.23
Levels of Zinc					
Zn_1	7.26 c	0.130 b	21.19 c	18.95 c	0.74 c
Zn_2	7.84 b	0.139 a	22.61 b	19.93 b	0.77 b
Zn_3	8.28 a	0.145 a	23.69 a	20.66 a	0.79 a
Zn_4	8.38 a	0.147 a	23.92 a	20.88 a	0.79 a
Sx	0.097	0.002	0.208	0.201	0.005
Level of significance	**	**	**	**	**
CV(%)	4.21	4.45	3.15	3.46	2.39

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

N_1: 35 kg N ha^{-1}

N_2: 37 kg N ha^{-1}

N_3: 39 kg N ha^{-1}

N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)

Zn_2: 4.5 kg Zn ha^{-1}

Zn_3: 5.0 kg Zn ha^{-1}

Zn_4: 5.5 kg Zn ha^{-1}

** = Significant at 1% level

Table 10. Combined effect of different levels of nitrogen and zinc on protein, Zn, amylose, proline and grain 2-AP content in cv. BRRI dhan80

Treatments	Protein content (%)	Zn content (mg g^{-1}) on dry weight basis	Amylose content (%)	Proline content in grains (mg g^{-1}) on dry weight basis	Grain 2-AP (µg g^{-1}) on dry weight basis
N_1Zn_1	6.97 h	0.123 e	22.17 fg	19.79 def	0.81 cd
N_1Zn_2	7.24 gh	0.124 e	22.49 efg	19.63 efg	0.82 c
N_1Zn_3	7.65 d-g	0.130 de	25.09 ab	21.77 ab	0.85 b
N_1Zn_4	8.28 bcd	0.138 b-e	25.59 a	22.17 a	0.87 a
N_2Zn_1	6.98 h	0.132 de	20.57 hi	19.37 fgh	0.77 fg
N_2Zn_2	8.21 b-e	0.145 a-d	23.82 b-e	20.66 b-f	0.79 de
N_2Zn_3	8.58 abc	0.142 a-e	24.43 abc	20.21 c-f	0.77 fg
N_2Zn_4	8.02 c-f	0.152 abc	22.67 d-g	20.93 a-e	0.80 de
N_3Zn_1	7.47 fgh	0.136 cde	20.32 i	18.46 gh	0.72 h
N_3Zn_2	8.12 cde	0.142 a-e	20.78 hi	21.01 a-d	0.72 h
N_3Zn_3	8.14 b-e	0.156 ab	22.17 fg	21.32 abc	0.77 f
N_3Zn_4	8.25 bcd	0.159 a	23.40 c-f	19.80 def	0.79 e
N_4Zn_1	7.60 efg	0.130 de	21.69 gh	18.18 h	0.68 i
N_4Zn_2	7.80 d-g	0.146 a-d	23.34 c-f	18.42 gh	0.75 g
N_4Zn_3	8.76 ab	0.153 abc	23.09 c-f	19.36 fgh	0.76 fg
N_4Zn_4	8.95 a	0.138 b-e	24.03 bcd	20.62 b-f	0.71 h
Sx	0.193	0.004	0.416	0.401	0.011
Level of significance	*	**	**	**	**
CV(%)	4.21	4.45	3.15	3.46	2.39

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

N_1: 35 kg N ha^{-1}
N_2: 37 kg N ha^{-1}
N_3: 39 kg N ha^{-1}
N_4: 41 kg N ha^{-1} (Recommended dose)

Zn_1: 4.0 kg Zn ha^{-1} (Recommended dose)
Zn_2: 4.5 kg Zn ha^{-1}
Zn_3: 5.0 kg Zn ha^{-1}
Zn_4: 5.5 kg Zn ha^{-1}

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

4.4.7 Zn content in rice grain

Different levels of nitrogen showed statistically significant differences in terms of Zn content in rice grain of BRRI dhan80 (Table 9). The highest Zn content in rice grain (0.148 mg g^{-1}) was observed from N_3, which statistically similar (0.143 and 0.142 mg g^{-1}, respectively) to N_2 and N_4, whereas the lowest (0.129 mg g^{-1}) was recorded from N_1.

Zn content in rice grain of BRRI dhan80 varied significantly due to different levels of zinc (Table 9). The highest Zn content of rice grain (0.147 mg g^{-1}) was observed from Zn_4 which was statistically similar (0.145 and 0.139 mg g^{-1}, respectively) to Zn_3 and Zn_2, while the lowest (0.130 mg g^{-1}) was found from Zn_1. Singh *et al.* (2012) reported the highest zinc content in grain with 4 kg Zn ha^{-1}.

Combined effect of different levels of nitrogen and zinc showed significant differences on Zn content in rice grain of BRRI dhan80 (Table 10). The highest Zn content in rice (0.159 mg g^{-1}) was recorded from N_3Zn_4, whereas the lowest (0.123 mg g^{-1}) was obtained from N_1Zn_1 treatment combination.

4.4.8 Amylose content in rice grain

Amylose content in rice grain of BRRI dhan80 varied significantly due to different levels of nitrogen (Table 9). The highest amylose content in rice grain (23.83%) was recorded from N_1, which was followed (23.04% and 22.87%, respectively) to N_4 and N_2 and they were statistically similar, while the lowest (21.67%) was observed from N_3.

Different levels of zinc showed statistically significant differences in terms of amylose content in rice grain of BRRI dhan80 (Table 9). The highest amylose content of rice grain (23.92%) was found from Zn_4 which was statistically similar (23.69%) to Zn_3 and followed (22.61%) by Zn_2, whereas the lowest (21.19%) was recorded from Zn_1. Sudha and Stalin (2015) reported that amylase content in rice grains increased markedly by the application of Zn.

Statistically significant variation was recorded in terms of amylose content in rice grain of BRRI dhan80 due to the combined effect of different levels of nitrogen and zinc (Table 10). The highest amylose content in rice (25.59%) was observed from N_1Zn_4 and the lowest (20.32%) was found from N_3Zn_1 treatment combination.

4.4.9 Proline content in grains

Different levels of nitrogen showed statistically significant differences in terms of proline content in grains of BRRI dhan80 (Table 9). The highest proline content in grains (20.84 mg g^{-1} DW) was found from N_1, which statistically similar (20.29 mg g^{-1} DW) to N_2 and followed (20.15 mg g^{-1} DW) by N_3, whereas the lowest (19.14 mg g^{-1} DW) was recorded from N_4. Zhaowen *et al*. (2018) N application at the booting stage also maintained higher proline in different plant tissues during the early grain filling stage.

Proline content in grains of BRRI dhan80 varied significantly due to different levels of zinc (Table 9). The highest proline content in grains (20.88 mg g^{-1} DW) was recorded from Zn_4 which was statistically similar (20.66 mg g^{-1} DW) to Zn_3 and followed (19.93 mg g^{-1} DW) by Zn_2 and the lowest (18.95 mg g^{-1} DW) was found from Zn_1.

Combined effect of different levels of nitrogen and zinc showed significant differences on proline content in grains of BRRI dhan80 (Table 10). The highest proline content in grains (22.17 mg g^{-1} DW) was observed from N_1Zn_4, while the lowest (18.18 mg g^{-1} DW) was found from N_4Zn_1 treatment combination.

4.4.10 Grain 2-AP content in rice grain

Statistically significant variation was recorded differences in terms of grain 2-AP content in rice grain of BRRI dhan80 due to different levels of nitrogen (Table 9). The highest grain 2-AP content in rice grain (0.84 µg g^{-1} DW) was observed from N_1, which was followed (0.78 µg g^{-1} DW) by N_2 and the lowest (0.73 µg g^{-1} DW) was found from N_4 which was followed (0.75 µg g^{-1} DW) by N_3. Islam *et al*. (2008) reported that 80 kg ha^{-1} performs the best to quality of aromatic rice.

Different levels of zinc showed statistically significant differences in terms of grain 2-AP content in rice grain of BRRI dhan80 (Table 9). The highest grain 2-AP content of rice grain (0.79 µg g^{-1} DW) was recorded from Zn_3 and Zn_4 which was followed (0.77 µg g^{-1} DW) by Zn_2, while the lowest (0.74 µg g^{-1} DW) was found from Zn_1.

Grain 2-AP content in rice grain of BRRI dhan80 showed significant differences due to the combined effect of different levels of nitrogen and zinc (Table 10). The highest grain 2-AP content in rice (0.87 µg g^{-1} DW) was recorded from N_1Zn_4, whereas the lowest (0.68 µg g^{-1} DW) was observed from N_4Zn_1 treatment combination.

Chapter V
Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted during the period of June to November, 2018 in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka for improving aromatic quality of BRRI dhan80 through minimization of nitrogen and supplementation of zinc. The experiment consisted of two factors: Factor A: Levels of N (4 levels) as - N_1: 35 kg N ha^{-1}; N_2: 37 kg N ha^{-1}; N_3: 39 kg N ha^{-1}; N_4: 41 kg N ha^{-1} and Factor B: Levels of Zn (4 levels) as - Zn_1: 4.0 kg Zn ha^{-1}; Zn_2: 4.5 kg Zn ha^{-1}; Zn_3: 5.0 kg Zn ha^{-1}, Zn_4: 5.5 kg Zn ha^{-1}. The two factors experiment was laid out in split-plot design with three replications. Data were recorded on different yield attributes, yield and quality of grain rice and observed statistically significant different for different characters that studies due to different levels of nitrogen and zinc.

In case of different levels of nitrogen, at 30, 45, 60, 75 DAT and harvest, the tallest plant (56.50, 85.77, 122.39, 125.24 and 126.41 cm, respectively) was observed from N_4, whereas the shortest plant (48.44, 74.16, 105.29, 109.57 and 110.48 cm, respectively) from N_1. At 30, 45, 60, 75 DAT and harvest, the maximum number of tillers hill^{-1} (6.97, 9.13, 14.80, 17.30 and 17.72, respectively) was recorded from N_4, while the minimum number (5.63, 7.50, 12.50, 14.50 and 14.88, respectively) from N_1. The maximum number of effective tillers hill^{-1} (15.60) was found from N_3 and the minimum number (11.63) from N_1. The minimum number of non-effective tillers hill^{-1} (1.87) was recorded from N_3, whereas the maximum number (3.62) from N_4. The longest panicle (29.33 cm) was recorded from N_3, while the shortest panicle (26.88 cm) from N_1. The maximum number of filled grains panicle^{-1} (174.05) was found from N_3, whereas the minimum number (156.43) from N_1. The minimum number of unfilled grains panicle^{-1} (20.13) was found from N_3 and the maximum number (26.55) from N_1. The maximum number of total grains panicle^{-1} (194.18) was observed from N_3, whereas the minimum number (182.98) from N_1. The highest weight of 1000-grains (26.96 g) was found from N_4, while the lowest weight (25.12 g) from N_1. The highest grain yield (4.33 t ha^{-1}) was found from N_3, whereas the lowest (3.56 t ha^{-1}) from N_1. The highest straw yield (5.04 t ha^{-1}) was obtained from N_3, while the lowest (4.72 t ha^{-1}) from N_1. The highest biological yield (9.38 t ha^{-1}) was observed from N_3, while the lowest (8.56 t ha^{-1}) from N_1. The highest harvest index (46.13%) was found from N_3 and the lowest (42.97%) from N_1.

The highest length of grain rice (5.32 mm) was found from N_4, while the lowest length (5.19 mm) from N_1. The highest breadth of grain rice (2.37 mm) was recorded from N_3, whereas the lowest breadth (2.28 mm) from N_1. The highest milled rice (73.88%) was found from N_3, while the lowest (68.56%) from N_1. The highest broken rice (3.63%) was recorded from N_3, whereas the lowest (2.89%) from N_1. The highest husk of rice (28.55%) was found from N_1, and the lowest (22.49%) from N_3. The highest protein content in rice grain (8.28%) was recorded from N_4, while the lowest (7.54%) from N_1. The highest Zn content in rice grain (0.148 mg g^{-1}) was observed from N_3, whereas the lowest (0.129 mg g^{-1}) from N_1. The highest amylose content in rice grain (23.83%) was recorded from N_1, while the lowest (21.67%) from N_3. The highest proline content in leaves (20.84 mg g^{-1}) was found from N_1, whereas the lowest (19.14 mg g^{-1}) from N_4. The highest grain-2AP content in rice grain (0.84 μg g^{-1}) was observed from N_1, and the lowest (0.73 μg g^{-1}) was found from N_4.

For different levels of zinc, at 30, 45, 60 and 75 DAT and harvest, the tallest plant (54.02, 82.76, 117.30, 121.51 and 122.50 cm, respectively) was recorded from Zn_4, while the shortest plant (51.48, 80.22, 112.54, 115.74 and 116.66 cm, respectively) from Zn_1. At 30, 45, 60 and 75 DAT and harvest, the maximum number of tillers $hill^{-1}$ (6.83, 9.20, 15.20, 18.07 and 18.35, respectively) was found from Zn_4 and the minimum number (6.08, 7.57, 12.15, 14.27 and 14.67, respectively) from Zn_1. The maximum number of effective tillers $hill^{-1}$ (15.43) was recorded from Zn_4, while the minimum number (11.40) from Zn_1. The minimum number of non-effective tillers $hill^{-1}$ (2.27) was found from Zn_3 and the maximum number (3.27) from Zn_1. The longest panicle (29.80 cm) was observed from Zn_4, whereas the shortest panicle (25.65 cm) from Zn_1. The maximum number of filled grains panicle^{-1} (173.38) was found from Zn_4, while the minimum number (155.63) from Zn_1. The minimum number of unfilled grains panicle^{-1} (20.18) was observed from Zn_4, while the maximum number (27.22) from Zn_1. The maximum number of total grains panicle^{-1} (193.57) was recorded from Zn_4, while the minimum number (182.85) from Zn_1. The highest weight of 1000-grains (26.69 g) was found from Zn_4 and the lowest weight (25.53 g) from Zn_1. The highest grain yield (4.17 t ha^{-1}) was found from Zn_4 and the lowest (3.85 t ha^{-1}) from Zn_1. The highest straw yield (5.03 t ha^{-1}) was found from Zn_4, whereas the lowest (4.71 t ha^{-1}) from Zn_1. The highest biological yield (9.20 t ha^{-1}) was found from Zn_4, whereas the lowest (8.56 t ha^{-1}) from Zn_1. The highest harvest index (45.20%) was found from Zn, whereas the lowest (44.86%) from Zn_1.

The highest length of grain rice (5.41 mm) was obtained from Zn_4 and the lowest length (5.10 mm) from Zn_1. The highest breadth of grain rice (2.39 mm) was found from Zn_4, while the lowest breadth (2.25 mm) from Zn_1. The highest milled rice (73.06%) was observed from Zn_4, whereas the lowest (69.08%) from Zn_1. The highest broken rice (3.58%) was found from Zn_4, while the lowest (2.88%) from Zn_1. The highest husk of rice (28.04%) was observed from Zn_1, while the lowest (23.36%) from Zn_4. The highest protein content of rice grain (8.38%) was found from Zn_4, whereas the lowest (7.26%) from Zn_1. The highest Zn content of rice grain (0.147 mg g^{-1}) was observed from Zn_4, while the lowest (0.130 mg g^{-1}) from Zn_1. The highest amylose content of rice grain (23.92%) was found from Zn_4, whereas the lowest (21.19%) from Zn_1. The highest proline content in leaves (20.88 mg g^{-1}) was recorded from Zn_4 and the lowest (18.95 mg g^{-1}) was found from Zn_1. The highest grain-2AP content of rice grain (0.79 µg g^{-1}) was recorded from Zn_3 and Zn_4, while the lowest (0.74 µg g^{-1}) from Zn_1.

Due to the combined effect of different levels of nitrogen and zinc, at 30, 45, 60 and 75 DAT and harvest, the tallest plant (60.75, 88.49, 127.08, 129.89 and 130.91

cm, respectively) was observed from N_4Zn_4 and the shortest plant (46.96, 70.38, 100.83, 105.70 and 106.75 cm, respectively) was recorded from N_1Zn_1 treatment combination. At 30, 45, 60 and 75 DAT and harvest, the maximum number of tillers hill^{-1} (7.53, 9.80, 16.87, 19.73 and 19.93, respectively) was observed from N_4Zn_4, whereas the minimum number (5.07, 7.07, 11.33. 13.33 and 13.67, respectively) from N_1Zn_1 treatment combination. The maximum number of effective tillers hill^{-1} (17.73) was observed from N_3Zn_4, whereas the minimum number (10.33) from N_1Zn_2 treatment combination. The minimum number of non-effective tillers hill^{-1} (1.47) was observed from N_3Zn_4, while the maximum number (5.00) from N_4Zn_4 treatment combination. The longest panicle (31.89 cm) was observed from N_3Zn_4, while the shortest panicle (24.48 cm) from N_4Zn_1 treatment combination. The maximum number of filled grains panicle^{-1} (187.40) was recorded from N_3Zn_4 and the minimum number (144.07) from N_1Zn_1 treatment combination. The minimum number of unfilled grains panicle^{-1} (16.53) was observed from N_3Zn_4, whereas the maximum number (31.93) from N_1Zn_1 treatment combination. The maximum number of total grains panicle^{-1} (203.93) was obtained from N_3Zn_4 and the minimum number (176.00) from N_1Zn_1 treatment combination. The highest weight of 1000-grains (27.75 g) was observed from N_4Zn_4, while the lowest weight (24.15 g) from N_1Zn_2 treatment combination. The highest grain yield (4.73 t ha^{-1}) was observed from N_3Zn_4 which was statistically similar with N_2Zn_1, N_2Zn_4, N_3Zn_3, N_4Zn_2, and N_4Zn_3, while the lowest (3.40 t ha^{-1}) from N_1Zn_1 treatment combination. The highest straw yield (5.26 t ha^{-1}) was found from N_3Zn_4 and the lowest (4.53 t ha^{-1}) from N_1Zn_2 treatment combination. The highest biological yield (9.99 t ha^{-1}) was recorded from N_3Zn_4, while the lowest (7.95 t ha^{-1}) from N_1Zn_1 treatment combination. The highest harvest index (47.37%) was observed from N_3Zn_4, while the lowest (42.71%) from N_1Zn_1 treatment combination.

The highest length of grain rice (5.66 mm) was obtained from N_3Zn_4, while the lowest length (5.01 mm) from N_1Zn_1 treatment combination. The highest breadth of grain rice (2.49 mm) was observed from N_3Zn_4 and the lowest breadth (2.16

mm) from N_1Zn_2 treatment combination. The highest milled rice (78.28%) was recorded from N_3Zn_4, whereas the lowest (65.79%) from N_1Zn_1 treatment combination. The highest broken rice (4.02%) was observed from N_3Zn_4 and the lowest (2.64%) from N_1Zn_1 treatment combination. The highest husk of rice (31.56%) was attained from N_1Zn_1, whereas the lowest (17.70%) from N_3Zn_2 treatment combination. The highest protein content in rice (8.95%) was observed from N_4Zn_4 and the lowest (6.97%) from N_1Zn_1 treatment combination. The highest Zn content in rice (0.159 mg g^{-1}) was recorded from N_3Zn_4, whereas the lowest (0.123 mg g^{-1}) from N_1Zn_1. The highest amylose content in rice (25.59%) was observed from N_1Zn_4 and the lowest (20.32%) from N_3Zn_1 treatment combination. The highest proline content in leaves (22.17 mg g^{-1}) was observed from N_1Zn_4, while the lowest (18.18 mg g^{-1}) from N_4Zn_1 treatment combination. The highest grain-2AP content in rice (0.87 µg g^{-1}) was recorded from N_1Zn_4, whereas the lowest (0.68 µg g^{-1}) from N_4Zn_1 treatment combination.

Application of 35- 37 kg N ha^{-1} and 4-5.5 kg Zn ha^{-1} along with other recommended fertilizers for producing good quality aromatic rice.

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

- Such study is needed to be repeated in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of regional adaptability,
- Other combination of organic manures such as vermicompost, cow dung, poultry manure and chemicals fertilizer may be used for further study to specify the specific combination.
- Promising aromatic cultivars may be studied.

References

REFERENCES

Abbasi, H.R.A., Esfahani, M., Rabiei, B. and Kavousi, M. (2007). Effect of nitrogen fertilizing management on rice (cv. Khazar) yield and its components in a paddy soil of Guilan Province. *J. Sci. Tech. Agric. Res.* **104**(8): 293-307.

Abou-Khalifa, A.A.B. (2012). Evaluation of some rice varieties under different nitrogen levels. *Adv. Appl. Sci. Res.* **3**(2): 1144-1149.

Alam, M.S., Biswas, B.K., Gaffer, M.A. and Hossain, M.K. (2012). Efficiency of weeding at different stages of seedling emergence in direct-seeded aus rice. *Bangladesh J. Sci. Ind. Res*. **30**(4): 155-167.

Ali, H., Hasnain, Z., Shahzad, A.N., Sarwar, N., Qureshi, M.K., Khaliq, S. and Qayyum. M.F. (2014). Nitrogen and zinc interaction improves yield and quality of submerged basmati rice (*Oryza sativa* L.). *No Bot Horti Agrobo,* **42**(2): 372-379.

Ali, H., Sawar, N., Hasnain, Z., Ahmad, S. and Hussain, A. (2016). Zinc fertilization under optimum soil moisture condition improved the aromatic rice productivity. *Philippine J. Crop Sci*. **41**(2): 71-78.

Amin, M.R., Hamid, A., Choudhury, R.U., Raquibullah, S.M. and Asaduzzaman M. (2006). Nitrogen fertilizer on tillering, dry matter production and yield of traditional varieties of rice. *Intl. J. Suatain. Crop Prod*. **1**(1): 17-20.

Angayarkanni, A. and Ravichandran, M. (2001). Judicious fertilizer N split for higher use efficiency in transplanted rice. *Indian J. Agril. Res.* **35**(4):278-280.

AOAC-Association of official Analytical Chemist. (1990). Official methods of analysis. Association of official Analytical Chemist (15th edn.), AOAC, Washington, DC, USA.

Arif, M., Zahid, M., Tasneem, M., Bashir, F., Shafiq, M., Akhtar, N., Yaseen, G., Anwar, A and Iqra Tariq, I. (2018). Exogenously Applied Nitrogen and Zinc Fertilizers Improved the Rice Productivity. *Curr. Inves. Agri. Curr. Res*. **4**(2): 503-507.

Ashraf, U., Kanu, A.S., Deng, Q., Mo, Z., Pan, S., Tian, H. and Tang, X. (2017). Lead (Pb) toxicity; physio-biochemical mechanisms, grain yield, quality, and pb distribution proportions in scented rice. *Fron. Plant Sci*. **8**: 1-17.

Ashrafuzzaman, M., Islam, M.R., Ismail, M.R., Shahidullah, S.M. and Hanafi, M. (2009). Evaluation of six aromatic rice varieties for yield and yield contributing characters. *Intl. J. Agril. Biol.* **11**: 616-620.

Azarpour, E., Moraditochaee, M. and Bozorgi, H.R. (2014). Effect of nitrogen fertilizer management on growth analysis of rice cultivars. *Intl. J. Biosci.* **4**(5): 35-47.

Bates, L., Waldren, R. and Teare, I. (1973). Rapid determination of free proline for water-stress studies. *Plant Soil*. **39**(1): 205-207.

Bhuiyan, M.S.H., Zahan, A., Khatun, H., Iqbal, M., Alam, F. and Manir, M.R. (2014). Yield performance of newly developed test crossed hybrid rice variety. *Intl. J. Agron. Agril. Res*. **5**(4): 48-54.

Broadley, M.R., White, P.J., Hammond, J.P., Zelko, I. and Lux, A. (2007). Zinc in plants. *New Phytol*. **173**: 677-702.

BRRI (Bangladesh Rice Research Institute). (2018). Adhunik Dhaner Chash. Joydebpur, Dhaka.

Cakmak. I., Kalayci, M., Ekiz, H., Braun, H. and Kiline, J. (2002). Effect of foliar spray and sources of zinc on yield, zinc content and uptake by rice grown in a vertisol of central India. *Intl. J. Chem. Stud*. **5**(2): 35-38.

Cassman, K.G., Dobermann, A.D., Walters, D. and Yang, H. (2003). Meeting cereal demand while protecting natural resources and improving environmental quality. *Ann. Rev. Environ. Res*. **28**: 315-358.

Chaudhary, S.K., Thakur, S.K. and Pandey, A.K. (2007). Response of wet land rice to nitrogen and zinc. *Oryza*. **44**(1): 31-34.

Cheema, N.M., Ullah, N. and Khan, N.U. (2006). Effect of zinc on the panicle structure and yield of coarse Rice IR-6. *Pak. J. Agril. Res*. **19**(4): 34-37.

Coffin, M.D. and Slaton, N.A. (2019). Effect of low-use-rate zinc fertilization on rice growth and grain yield. *Agrosyst Geosci Environ*. **3**: 1-10.

Djaman, K., Bado, B.V. and Mel, V.C. (2016). Effect of nitrogen fertilizer on yield and nitrogen use efficiency of four aromatic rice varieties. *Emirates J. Food Agric*. **28**(2): 126-135.

Duhan, B.S. and Singh, M. (2002). Effect of green manuring and nitrogen on the yield and nutrient uptake of micronutrient by rice. *J. Indian Soc. Soil Sci*. **50**(2): 178-180.

Dwivedi, A.P., Dixit, R.S. and Singh, G.R. (2006). Effect of nitrogen, phosphorus and potassium levels on growth, yield and quality of hybrid rice (*Oryza sativa* L.). *Oryza*. **43**: 64-66.

Fageria, N.K., Moreira, A. and Coelho, A. M. (2011). Yield and yield components of upland rice as influenced by nitrogen sources. *J. Plant Nutr*. **34**(3): 361-370.

Fan, M., Shen, J., Yuan, L., Jiang, R., Chen, X. and Davies, W.J. (2012). Food security. Improving crop productivity and resource efficiency to ensure food security and environmental quality in China. *J. Exp. Bot*. **63**: 13-24.

FAO (Food and Agriculture Organization). (1988). Production Yearbook for 1998. FAO, UN. Rome, Italy. p. 118.

FAO (Food and Agriculture Organization). (2018). FAOSTAT Production Statistics. Food and Agriculture Organization. Rome, Italy.

Gewaily, E.E., Ghoneim, A.M. and Osman, M.M. (2018). Effects of nitrogen levels on growth, yield and nitrogen use efficiency of some newly released Egyptian rice genotypes. *Open Agrice*, **3**(1): 310-318.

Ghasal, P.C., Shivay, Y.S., Pooniya, V., Choudhary, M. and Verma, R.K. (2018). Zinc partitioning in basmati rice varieties as influenced by Zn fertilization. *Crop J*. **6**: 136-147.

Ghoneim, A.M. and Ebid, A.I. (2015). Combined Effects of Soil Water Regimes and Rice Straw Incorporation into the Soil on 15N, P, K Uptake, Rice Yield and Selected Soil Properties. *Intl. J. Plant Soil Sci*. **5**(6): 339-349.

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

Guo, C.H., Gao, Z.Q. and Miao, G.Y. (2010). Effect of shading at post flowering on photosynthetic characteristics of flag leaf and response of grain yield and quality to shading in wheat. *Acta Agron. Sci*. **36**: 673-679.

Hameed, F., Xu, J., Rahim, S.F., Wei, Q., Khalil, A.R and Liao, Q. (2019). Optimizing Nitrogen Options for Improving Nitrogen Use Efficiency of Rice under Different Water Regimes. *Agron*, **9**(39): 1-18.

Haque, M.M., Pramanik, H.R., Biswas, J.K., Iftekharuddaula, K.M. and Mirza Hasanuzzaman, M. (2015). Comparative performance of hybrid and elite inbred rice varieties with respect to their source-sink relationship. *Sci World J*. **15**: 1-11.

Hashemi, F.G., Rafii, M.Y., Ismail, M.R., Mahmud, T.M.M., Rahim, H.A. and Asfaliza, R. (2013). Biochemical, genetic and molecular advances of fragrance characteristics in rice. *Crit Rev Plant Sci*. **32**(6):445-457.

Hossain, M.B., Islam, M.O. and Hasanuzzaman, M. (2008). Influence of different nitrogen levels on the performance of four aromatic rice varieties. *Intl. J. Agril. Biol.* **5**: 1560-1570.

Hossain, M.E., Ahmed, S., Islam, M.T., Riaj, M.M.R. Haque, K.A. and Hassan, S.M.Z. (2018). Optimization of nitrogen rate for three aromatic rice varieties in Patuakhali region. *Intl. J. Natural and Social Sci*. **5**(4): 65-70.

Hossain, M.F., Bhuiya, M.S.U. and Ahmed, M. (2005). Morphological and agronomic attributes of some local and modern aromatic rice varieties of Bangladesh. *Asian J. Plant. Sci*. **4**(6): 664-666.

Hossain, M.S., Mosaddeque, H.Q.M., Alam, M.A., Moniruzzaman, S.M. and Ahmed, I. (2007). Effect of different organic manures and nitrogen levels on yield and yield attributes of T. aman rice. *Intl. J. Susta. Agri. Tech.* **3**(1): 21-26.

Huang, Z.L., Tang, X.R., Wang, Y.L., Chen, M.J., Zhao, Z.K. and Duan, M.Y. (2012). Effects of increasing aroma cultivation on aroma and grain yield of aromatic rice and their mechanism. *Sci. Agril. Res*. **45**(6): 1054-1065.

IRRI ([International Rice Research Institute). (2000). Nutritional disorders and nutrient management in rice. International Rice Research Institute, Manila, Philippines.

Islam, M.S., Akhter, M.M., Rahman, M.S., Banu, M.B. and Khalequzzaman, K.M. (2008). Effect of nitrogen and number of seedlings per hill on the yield and yield components of transplant aman rice (BRRI dhan33). *Intl. J. Sustain. Crop Prod.* **3**(3): 61-65.

Islam, M.S.H., Bhuiyan, M.S.U., Gomosta, A.R., Sarkar, A.R. and Hussain, M.M. (2009). Evaluation of growth and yield of selected hybrid and inbred rice varieties grown in net house during transplanted aman season. *Bangladesh J. Agril. Res*. **34**(1): 67-73.

Jahan, A., Islam, A., Sarkar, M.I.U., Iqbal, M., Ahmed, M.N. and Islam, M.R. (2020). Nitrogen response of two high yielding rice varieties as influenced by nitrogen levels and growing seasons. *J. Geol., Ecol. Landscapes*. **10**: 1-8.

Jahan, S., Sarkar, M.A.R. and Paul, S.K. (2017). Variations of growth parameters in transplanted Aman rice (cv. BRRI dhan39) in response to plant spacing and fertilizer management. *Archives Agril. Env. Sci*. **2**(1): 1-5.

Juliano. (1971). A simplified assay for milled rice amylose. *Cereal Sci. Today*. **16**: 334-338.

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

Kandil, A.A., El-Kalla, S.E., Badawi, A.T. and El-Shayb O.M. (2010). Effect of hill spacing, nitrogen levels and harvest date on rice productivity and grain quality. *Crop Environ*. **1**(1): 22-26.

Karim, M.R. (2011). Effect of nitrogen on growth, productivity and seed quality of long grain rice. MS Thesis, Dept. of Agronomy, BSMRAU, Salna, Gazipur. p. 83.

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

Khorshidi, Y.R., Ardakani, M.R., Ramezanpour, M.R., Khavazi, K. and Zargari, K. (2011). Response of yield and yield components of rice (*Oryza sativa* L.) to *Pseudomonas flouresence* and *Azospirillum lipoferum* under different nitrogen levels. *American-Eurasian J. Agric. & Env. Sci*. **10**(3): 387-395.

Lei, S., Wang, C.C., Ashraf, U., Mo, Z.W., Nawaz, M., Ashraf, I., Muzaffar, W., Liu, S.J. and Tang, X.R. (2017). Exogenous application of mixed micro-nutrients improves yield, quality, and 2-Acetyl-1-Pyrroline contents in fragrant rice. *Appl. Ecol. Env. Res*. **15**(3): 1097-1109.

Li, Y.H., Tang, X.R., Pan, S.G. and Yang, X.J. (2014). Effect of water-nitrogen interaction at tillering stage on aroma, grain yield and quality of aromatic rice. *Acta Agril. Boreali Sci.* **29**(1): 159-164.

Lukman, S., Audu, A.M., Dikko, A.U., Ahmed, H.G., Sauwa, M. M., Haliru, M., Noma, S.S., Yusif1, S.A., Salisu, A. and Hayatu, N.G. (2016). Effects of NPK and Cowdung on the performance of rice (*Oryza sativa*) in the Sudan Savanna Agro-ecological Zone of Nigeria. *Asian Res. J. Agric.* **1**(4): 1-9.

Luo, H., Du, B., He, L., He, J., Hu, L., Pan, S. and Tang, X. (2019). Exogenous application of zinc (Zn) at the heading stage regulates 2-acetyl-1-pyrroline (2-AP) biosynthesis in different fragrant rice genotypes. *Sci Rep.* **9: 1-10.**

Mahajan, G., Sekhon, N., Singh, N., Kaur, R. and Sidhu, A. (2010). Yield and nitrogen-use efficiency of aromatic rice cultivars in response to nitrogen fertilizer. *J. New Seeds*, **11**(4): 356-368.

Mahamud J.A., Haque, M.M. and Hasanuzzaman, M. (2013). Growth, dry matter production and yield performance of transplanted aman rice varieties influenced by seedling densities per hill. *Intl. J. Sustain. Agric*. **5**(1): 16-24.

Mandira, B., Kumar, S., Chakraborty, D., Kapil, A.C. and Nath, D.J. (2016). Performance of rice variety Gomati in front line demonstration under rainfed condition of south Tripura district. *Intl. J. Agric. Sci*. **8**(63): 3555-3556.

Mannan, M.A., Bhuiya, M.S.U., Akand, M.M. and Rana, M.M. (2012). Influence of date of planting on the growth and yield of locally popular traditional aromatic rice varieties in *Boro* season. *J. Sci. Foundation*. **10**(1): 20-28.

Mannan, M.A., Bhuiya, M.S.U., Hossain, H.M.A. and Akhand, M.I.M. (2010). Optimization of nitrogen rate for aromatic basmati rice (*Oryza sativa* L). *Bangladesh J. Agril. Res.* **35**: 157-165.

Manzoor, Z., Awan, T.H., Zahid, M.A. and Faiz, F.A. (2006). Response of rice crop (super basmati) to different nitrogen levels. *J. Anim. Plant. Sci.* **16**(1-2): 52-55.

Maqsood, M., Shehzad, M.A., Ali, S.N.A. and Iqbal, M. (2013). Rice cultures and nitrogen rate effects on yield and quality of rice (*Oryza sativa* L.). *Turkish J. Agric. Forest*. **37**: 665–673.

Metwally, T.F., Gewaily, E.E. and Naeem, S.S. (2011). Nitrogen response curve and nitrogen use efficiency of Egyptian hybrid rice. *J. Agric. Res. Kafer El-Sheikh Univ*. **37**(1): 73-81.

Mohaddesi, A., Abbasian, A., Bakhshipour, S. and Aminpanah, H. (2011). Effect of different levels of nitrogen and plant spacing on yield, yield components and physiological indices in high–yield rice (number 843). *American-Eurasian J. Agric. Environ. Sci*. **10**(5): 893-900.

Munnujan, K., Hamaid, A., Hashem, A., Hirota, O. and Khanam, M. (2001). Effect of nitrogen fertilizer levels and planting density on growth and yield of long grain rice. *Bull. Inst. Tropic. Agril. Kyushu Univ.* **24**: 1-10.

Murthy, K.M.D., Rao, A.U., Vijay, D. and Sridhar, T.V. (2015). Effect of levels of nitrogen, phosphorus and potassium on performance of rice. *Indian J. Agric. Res*. **49**(1): 83-87.

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

Muthukumararaja, T.M. and Sriramachandrasekharan, M.V. (2012). Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. *J. Agril. Technol*. **8**(2): 551-561.

Naik, K.R. and Paryani, A.K. (2005). Response of rice hybrids to nitrogen and number of seedlings. *Crop Res.* **29**(3): 379-381.

Naik, S.K. and Das, D.K. (2007). Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an inceptisol. *Arch. Agron. Soil Sci*. **53**: 305-313.

Namai, Sachiko, N., Toriyama, K. and Fukuta, Y. (2009). Genetic variation in dry matter production and physiological nitrogen use efficiency in rice (*Oryza sativa* L.) varieties. *Breeding Sci*. **59**: 269-276.

Naznin, A., Afroz, H., Hoque, T.S. and Mian, M.H. (2013). Effects of PU, USG and NPK briquette on nitrogen use efficiency and yield of BR22 rice under reduced water condition. *J. Bangladesh Agril. Univ*. **11**(2): 215-220.

Nori, H., Halim, R.A. and Ramlan, M.F. (2008). Effects of nitrogen fertilization management practice on the yield and straw nutritional quality of commercial rice varieties. *Malaysian J. Math. Sci*. **2**(2): 61-71.

Peng, S., Tang, Q. and Zou, Y. (2009). Current status and challenges of rice production in China. *Plant Prod. Sci*. **12**: 3-8.

Prasad, R. (2006). Zinc in soils and in plants, human & animal nutrition. *Indian J Fertil*. **2**(9): 103-119.

Rajesh, K., Thatikunta, R., Naik, D.S. and Arunakumari, J. (2017). Effect of different nitrogen levels on morpho-physiological and yield parameters in rice (*Oryza sativa* L.). *Intl. J. Curr. Microbiol. App. Sci*. **6**(8): 2227-2240.

Rehman, H., Tariq, A., Muhammad, F.W. and Rengel, A. (2012). Zinc nutrition in rice production systems: a review. *Plant and Soil*. p. 65.

Salahuddin, K.M., Chowhdury, S.H., Munira, S., Islam, M.M. and Parvin, S. (2009). Response of nitrogen and plant spacing of transplanted *Aman* rice. *Bangladesh J. Agril. Res.* **34**(2): 279-285.

Salem, A.K.M., ElKhoby, W.M., Abou-Khalifa, A.B. and Ceesay, M. (2011). Effect of nitrogen fertilizer and seedling age on inbred and hybrid rice varieties. *American-Eurasian J. Agric. Environ. Sci.* **11**(5): 640-646.

Sarkar, S.K., Sarkar, M.A.R., Islam, N. and Paul, S.K. (2014). Yield and quality of aromatic fine rice as affected by variety and nutrient management. *J. Bangladesh Agril. Univ*. **12**(2): 279-284.

Sharma, P., Abrol, V. and Kumar, R. (2012). Effect of water regimes and nitrogen levels on rice crop performance and nitrogen uptake. *Indian J. Soil Conser*. **40**(2): 122-128.

Sidhu, M.S., Sikka, R. and Singh, T. (2004). Performance of transplanted Basmati rice in different cropping systems as affected by N application. *Intl. Rice Res. Notes.* **29**(1): 63-65.

Sikdar, M.S.I., Rahman, M.M., Islam, M.S., Yeasmin, M.S. and Akhter, M.M. (2008). Effect of nitrogen level on aromatic rice varieties and soil fertility status. *Intl. J. Sus. Crop Prod*. **3**(3): 49-54.

Singh, A.K., Manibhushan. K., Meena, M.K. and Upadhyaya, A. (2012). Effect of sulphur and zinc on rice performance and nutrient dynamics in plants and soils of Indo gangetic plains. *J. Agril. Sci*. **4**(11): 162-169.

Singh, V., Singh, V. Singh S. and Khanna, R. (2020). Effect of zinc and silicon on growth and yield of aromatic rice (*Oryza Sativa*) in North-Western plains of India. *J. Rice Res. Dev.* **3**(1): 82-86.

Sudha, S. and Stalin, P. (2015). Effect of zinc on yield, quality and grain zinc content of rice genotypes. *Intl. J. Farm Sci*. **5**(3): 17-27.

Suman, B.M. and Sheeja, K.R. (2018). A review on zinc and boron nutrition in rice. *J. Appl. Natural Sci*. **10**(4): 1180 -1186.

Tang, X.R. and Wu, L. (2006). Effect of application of Zinc, Iron and Lanthanum on contents of aroma in brown rice and proline in flag leaf of aromatic rice. *Hybrid Rice.* **21**(6): 69-72.

Tian, H., Li, G.X., Yuan, H.M., Zhong, K.Y., Duan, M.Y., Wu, L. and Tang, X.R. (2009). Studies on the cultivation techniques characterized by enhancing source, activating sink and improving quality for double-cropping super rice II. Effects of a rice quality promoter on source, sink and grain quality. *Hybrid Rice*. **24**(1): 78-81.

Ullah, K.M.I.I., Sarken, A.K. and Faruk-E-Alam. A.K.M. (2001). Zinc sulphate on the yield and quality of *aman* rice (BRRI dhan11). *Bangladesh J. Agril. Dev*. **14**(1-2): 25-30.

Wang, Y.Y., Zhu, B., Shi. Y. and Hu, C.S. (2008). Effect of nitrogen fertilization on upland rice based on pot experiments. *Commun. Soil Sci*. **39**(11-12): 1733-1749.

Yang, S., Zou, Y., Liang, Y., Xia, B., Liu, S. and Ibrahim, M. (2012). Role of soil total nitrogen in aroma synthesis of traditional regional aromatic rice in China. *Field Crops Res.* **125**: 151-160.

Yoseftabar, S., Fallah. A. and Daneshian, J. (2012). Comparing of yield and yield components of hybrid rice (GRH1) in different application of nitrogen fertilizer. *Intl. J. Biol.* **4**(4): 60-65.

Yoshida, H., Horie, T. and Shiraiwa T. (2006). A model explaining genotypic and environmental variation of rice spikelet number per unit area measured by cross-locational experiments in Asia. *Field Crops Res*. **97**: 337-343.

Zhang, T., Zheng, J., Xu, J., Jiang, K., Wu, X. and Wang, X. (2008). Genetic diversity of aromatic rice varieties based on markers of functional genes and SSR. *Agril. Sci*. **41**(3): 625-635.

Zhaowen, M, Ashraf, U., Tang, Y., Li, W., Pan, S., Duan, M., Tian, H. and Tang, X. (2018). Nitrogen application at the booting stage affects 2-acetyl-1-pyrroline, proline, and total nitrogen contents in aromatic rice. *Chilean J. Agril. Res*. **78**(2): 165-172.

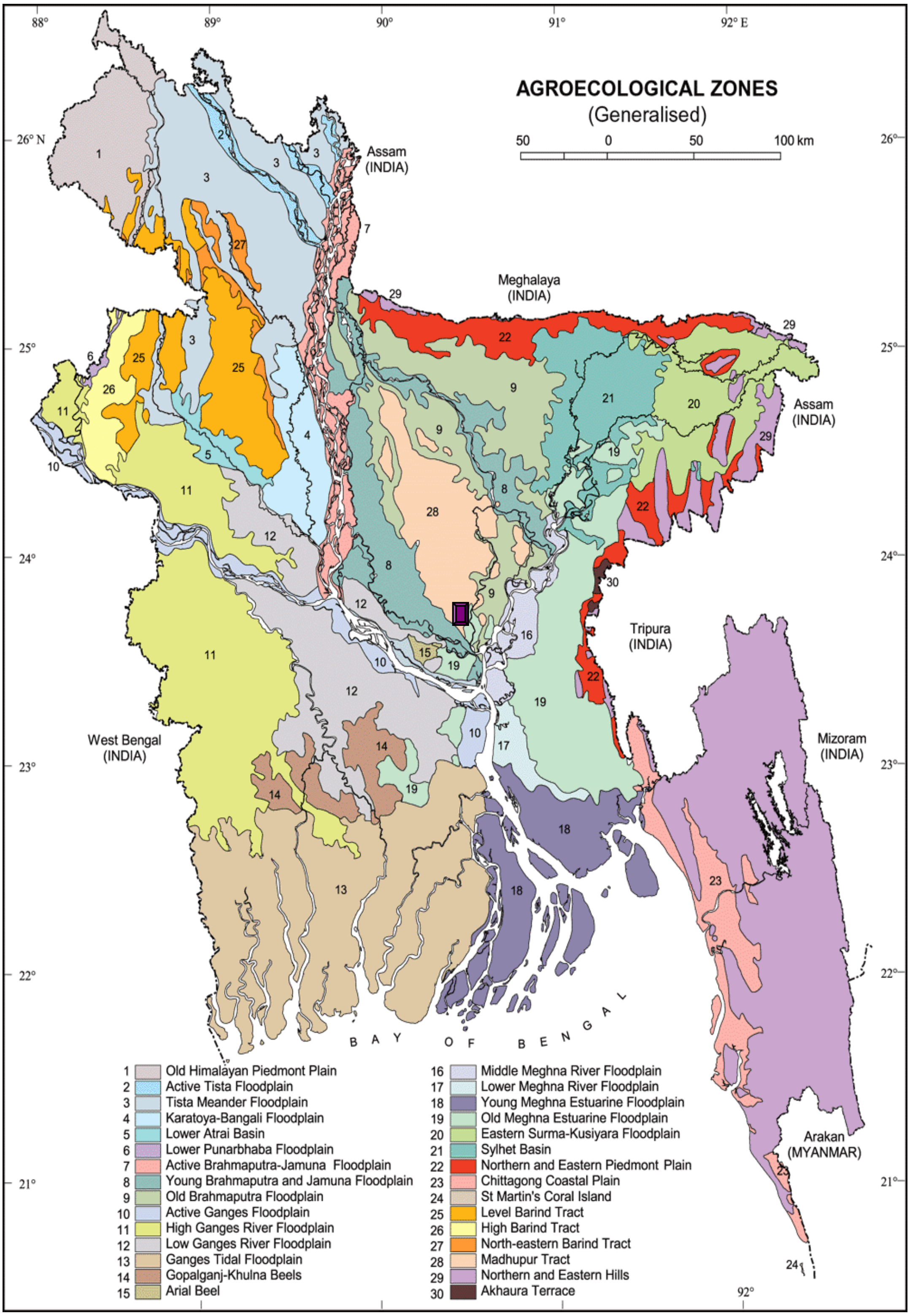
Zheng, Y., Han, X., Yuying Li, Y., Liu, S., Ji, J. and Tong. Y. (2020). Effects of Mixed Controlled Release Nitrogen Fertilizer with Rice Straw Biochar on Rice Yield and Nitrogen Balance in Northeast China. *Sci Reports*. **10**: 1-10.

Zhong, Q. and Tang, X.R. (2014). Effects of nitrogen application on aroma of aromatic rice and their mechanism. *Guangdong Agric. Sci*. **41**(4) 85-87.

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 November 2019

Month (2019)	Air temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)	Sunshine (hr)
	Maximum	Minimum			
June	32.6	25.8	84	245	5.9
July	36.4	24.6	88	591	5.8
August	35.1	23.6	83	275	6.4
September	33.3	22.1	81	193	6.9
October	26.4	19.7	77	45	6.3
November	24.8	16.4	74	12	6.8

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 at harvest BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm) at				
		30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Replication	2	0.075	2.109	16.281	3.811	6.358
Levels of Nitrogen (A)	3	153.082**	339.618**	694.647**	580.095**	606.204**
Error	6	8.107	5.648	36.956	31.358	33.188
Level of Zinc (B)	3	15.463	14.634	51.432	73.100	77.595
Interaction (A×B)	9	17.041*	21.878*	60.385*	98.093*	94.093*
Error	24	7.090	8.925	24.586	35.359	34.821

**: 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 at harvest BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square				
		Tillers hill^{-1} (No.) at				
		30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Replication	2	0.017	0.047	0.011	0.301	0.727
Levels of Nitrogen (A)	3	4.571**	6.630**	12.720**	19.521**	19.694**
Error	6	0.042	0.473	0.211	0.877	0.769
Level of Zinc (B)	3	1.313**	6.208**	21.260**	31.352**	30.072**
Interaction (A×B)	9	0.347*	0.716*	1.059*	1.679**	1.754**
Error	24	0.066	0.218	0.386	0.637	0.594

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

Appendix VI. Analysis of variance of the data on effective, non-effective tillers hills^{-1}, panicle length, filled, unfilled and total grains panicle^{-1} of BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square					
		Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)
Replication	2	0.626	0.006	0.996	16.526	2.813	29.986
Levels of Nitrogen (A)	3	32.627**	7.499**	12.247*	658.800**	86.588**	270.688**
Error	6	0.849	0.048	1.831	65.924	4.958	54.986
Level of Zinc (B)	3	40.929**	2.090**	43.196**	811.646**	123.446**	302.652**
Interaction (A×B)	9	2.324**	1.153**	4.994*	142.192*	12.036**	176.025**
Error	24	0.682	0.090	1.921	50.772	2.988	55.921

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

Appendix VII. Analysis of variance of the data on weight of 1000-grains, grain, straw, biological yield and harvest index of BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square				
		Weight of 1000-grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.325	0.015	0.017	0.014	1.761
Levels of Nitrogen (A)	3	7.109*	1.345**	0.240**	2.720**	23.693
Error	6	1.298	0.145	0.041	0.128	8.148
Level of Zinc (B)	3	3.205	0.246	0.262**	1.014**	0.241
Interaction (A×B)	9	2.265*	0.218*	0.147**	0.650**	2.929
Error	24	1.460	0.098	0.058	0.157	4.918

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

Appendix VIII. Analysis of variance of the data on length, breadth, milled, broken and husk of BRRI dhan80 of BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square				
		Length of grain rice (mm)	Breadth of grain rice (mm)	Milled rice (%)	Broken rice (%)	Husk of rice (%)
Replication	2	0.002	0.005	3.834	0.009	4.192
Levels of Nitrogen (A)	3	0.045	0.017	59.071*	1.151**	76.711**
Error	6	0.037	0.029	8.530	0.040	8.978
Level of Zinc (B)	3	0.215	0.042	38.757**	1.248**	53.839**
Interaction (A×B)	9	0.182	0.045	24.455**	0.084**	26.668**
Error	24	0.097	0.033	6.756	0.018	7.183

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

Appendix IX. Analysis of variance of the data on protein, Zn, amylose, proline and grain-2AP content in BRRI dhan80 as influenced by different levels of nitrogen and zinc

Source of variation	Degrees of freedom	Mean square				
		Protein content (%)	Zn content (mg g^{-1}) on dry weight basis	Amylose content (%)	Proline content in leaves (mg g^{-1}) on dry weight basis	Grain-2AP (µg g^{-1}) on dry weight basis
Replication	2	0.029	0.0001	0.058	0.068	0.0001
Levels of Nitrogen (A)	3	1.119**	0.001**	9.594**	5.990**	0.028**
Error	6	0.088	0.0001	0.393	0.303	0.0001
Level of Zinc (B)	3	3.143**	0.001**	18.705**	9.104**	0.006**
Interaction (A×B)	9	0.331*	0.0001**	2.641**	2.075**	0.002**
Error	24	0.112	0.0001	0.519	0.483	0.0001

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

Appendix X. Photographs of the experiment

Plate 1. Experimental plot during transplanting of seedlings

Plate 2. Experimental plot during intercultural operation

Plate 3. Experimental plot during intercultural operation

Plate 4. Experimental plot during ripening stage