IMPROVEMENT OF GROWTH, YIELD AND YIELD ATTRIBUTES OF AROMATIC RICE BY THE EXOGENOUS APPLICATION OF ZINC

A THESIS

BY

REZWANA SULTANA
Student No. 1701374
Session: 2023-2024
Semester: January-June 2024

MASTER OF SCIENCE (M.S.)

IN

AGRONOMY

DEPARTMENT OF AGRONOMY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY

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DINAJPUR-5200

JUNE 2024

Dedicated to

My

Beloved Parents

ACKNOWLEDGEMENT

First and foremost, all praises are putting forward to Allah (SWT) Who is the Supreme Planner and has blessed the author to complete this piece of study as required for the degree Master of Science.

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June 2024 *The authoress*

ABSTRACT

The experiment was conducted at the Agronomy Research Field, Hajee Mohammad Danesh Science and Technology University in Dinajpur from July to December 2023 to assess the effect of different levels of zinc fertilizer at different growth stages on yield performance of aromatic rice cv. Tulsimala. The experiment consisted of two factors, namely factor-A consisted of four doses of zinc, viz. Zn_1 (control), Zn_2 (5 kg ha^{-1}), Zn_3 (10 kg ha^{-1}), and Zn_4 (15 kg ha^{-1}), and factor-B consisted of three application times of zinc, such as T_1 (application of zinc at the tillering stage at 25 DAT), T_2 (application of zinc at the panicle stage at 50 DAT), and T_3 (application of zinc at the dough stage at 75 DAT). The experiment was laid out in a randomized complete block design with 12 treatment combinations with three replications. The treatments were randomly distributed to the plots within a block. Each plot was fertilized with urea, TSP, MoP, and those doses were recommended by BRRI. During the study period, various growth, yield and yield contributing parameters were recorded, including plant height (cm), number of effective tillers $hill^{-1}$, panicle length (cm), filled grains $panicle^{-1}$, sterile grains $panicle^{-1}$, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}), and harvest index (%). The study result showed that Zn_4 have the tallest plant (162.58 cm at harvest) in all cases while Zn_3 produced the highest number of effective tillers $hill^{-1}$ (18.34), longest panicle length (26.63 cm), the maximum filled grains $panicle^{-1}$ (186.52), the 1000-grain weight (10.35 g), the highest grain yield (1.67 t ha^{-1}), the biological yield (5.08 t ha^{-1}), and the harvest index (32.78%). Moreover, the T_2 treatment recorded the maximum plant height (162.59 cm at harvest), number of effective tillers $hill^{-1}$ (17.92), longest panicle length (25.34 cm), top grain yield (1.63 t ha^{-1}), biological yield (5.08 t ha^{-1}), and harvest index (32.05%). Considering interactions, Zn_4T_2 combination gave the best result for plant height (142.13 and 172.26 cm respectively) whereas the Zn_3T_2 had the highest number of effective tillers $hill^{-1}$ (19.80), the longest panicle length (27.37 cm), the most filled grains $panicle^{-1}$ (196.18), the highest grain yield (1.90 t ha^{-1}), the highest straw yield (4.45 t ha^{-1}), the highest biological yield (5.34 t ha^{-1}) and the highest harvest index (35.42%). The results indicate that the best-performing Tulsimala aromatic rice variety in Bangladesh would benefit economically from applying 10 kg ha^{-1} of zinc at the panicle initiation stage.

CONTENTS

CONTENTS (Contd.)

CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variances
BINA	Bangladesh Institute of Nuclear Agriculture
BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
cm	Centimeter
DAS	Days After Sowing
DAT	Days After Transplanting
cv.	Cultivar (s)
CV	Coefficient of variance
et al.	And others
g	Gram(s)
HSTU	Hajee Mohammad Danesh Science and Technology University
IRRI	International Rice Research Institute
K	Potassium
K_2O	Potassium Oxide
Kg	Kilogram (s)
LS	Level of significance
LSD	Least Significant Difference
m^2	Meter Squares
mm	Millimeter
MoP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Non Significant
P_2O_5	Phosphorus Penta Oxide
RCBD	Randomized Complete Block Design
S	Sulphur
TSP	Triple Super Phosphate
var.	Variety
Wt.	Weight
t ha^{-1}	Ton per hectare
°C	Degree Centigrade
%	Percentage

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple grain that is crucial for ensuring food security for more than half of the global population (Fukagawa *et al.,* 2019). It provides more than 21% of the total caloric needs of humans and can provide up to 76% of the caloric intake of people living in Southeast Asia (Zhao *et al.,* 2020). Aromatic rice varieties command a greater premium on the rice market compared to non-aromatic ones. In recent years, the cultivation of high-quality and fragrant rice has become increasingly popular in Bangladesh due to its significant demand for both domestic consumption and export purposes (Sarkar *et al.,* 2023). Although the agro-climatic conditions are generally good, the cultivation area of aromatic rice in Bangladesh is less than 2% of the total national rice acreage (Akter *et al.,* 2020).

Bangladeshi farmers grow a diverse range of high-quality rice varieties. Certain ones are very attractive because of their fragrance. Chinisagar, Badshabhog, Kataribhog, Kalizira, Tulsimala, Dulabhog, Basmati, Banglamoti (BRRI dhan50), BRRI dhan34, BRRI dhan37, BRRI dhan38, and Binadhan-13 are some of the most prevalent rice types. Most fine rice varieties are from Bangladesh, although the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Institute of Nuclear Agriculture (BINA) have introduced a few new aromatic fine rice types. Most aromatic rice varieties have modest yields, but their higher price and low cultivation costs lead to a larger profit margin compared to other types (Saha, 2021).

Rice cultivation in Bangladesh spans over 17963 thousand acres of land, with a total production of around 39095 thousand metric tons (BBS, 2023). The population growth in Bangladesh necessitates a consistent rise in rice production, which has been given the utmost importance (Islam *et al.,* 2020). The growing demand for food is posing a challenge to global food security. It is anticipated that by 2035, an additional 114 million tonnes of rice would be required, representing a 26% increase over the following 25 years (Shamim *et al.,* 2024). In order to meet the growing demand for food from the expanding population, rice production must be boosted by at least 60% by 2020 (Hemathilake and Gunathilake, 2022). Therefore, the population is projected to increase steadily to 223 million by the year 2030, resulting in a need for an additional 48 million tons of food grains (Kuczuk and Widera, 2021). Rice yields in the post green revolution era are either remaining at the same level or decreasing, primarily due to several issues associated with crop production (Harwood, 2019). The primary cause of low rice productivity can be linked to the prevalence of local varieties rather than high yielding types, as well as the lack of suitable management and fertilization practices (Fahad *et al.*, 2019). Despite a significant growth in crop production in Bangladesh during the past 50 years. There is still a need to enhance crop yields in order to meet the food demands of the growing population. In addition to the global agricultural sector, Bangladesh also confronts the task of cultivating crops within its restricted land resources in order to satisfy the substantial demand from its people. The scope is restricted to the expansion of cultivated land. Furthermore, each year, arable land is diminishing as a result of human habitation and the swift processes of urbanization and industrialization. Consequently, global rice output will persistently fall short of demand. In response to the evolving circumstances, rice breeders have prioritized the creation of cultivars with enhanced productivity and stability, as well as heightened resistance to both living organisms and non-living factors (Qamar *et al.,* 2023). Simultaneously, implementing enhanced agronomic methods and integrated nutrition management can significantly contribute to increasing rice yield while minimizing costs.

The excessive application of inorganic fertilizers and pesticides, without the use of organic fertilizers, has resulted in the degradation of soil health and a decline in crop yields, which is now a matter of worry (Urmi *et al.,* 2022). The increased reliance on chemical fertilizers and the use of uneven nutrient management practices has negatively impacted soil production in several Asian countries, including Bangladesh. The intensified cropping and continuous cultivation of high-yielding rice varieties in Bangladesh have led to an increasing depletion of nitrogen (N), phosphorous (P), potassium (K), and other essential macro and micro-nutrients from the soils (Yadav *et al.,* 2019). There is a growing focus on micronutrient insufficiency in regions where intensive agriculture is being carried out, as highlighted by recent studies (Fatematuz-Zohora *et al.*, 2023; Islam *et al.*, 2021). The depletion of micronutrients in soil has been expedited by the intensification of cultivation, which involves a greater reliance on chemical fertilizers and high-yielding crop types, as well as a reduced emphasis on the use of organic manures. Zinc deficiency is a significant agricultural problem worldwide, particularly in rice cultivation which may cause yield loss of about 10-18% in certain regions of the country (Khan *et al.*, 2022). It is an essential nutrient that plays a crucial role in various biochemical and metabolic processes in rice. These processes include the synthesis of cytochromes and nucleotides, auxin metabolism, chlorophyll production, activation of enzymes, maintenance of membrane integrity, carbohydrate metabolism, cell wall development, gene expression, and respiration (Tariq *et al.*, 2023).

Zinc (Zn) is a crucial nutrient that significantly influences the growth and development of rice (Prathap *et al.*, 2022). Zinc insufficiency is recognized as the primary nutritional stress that hampers rice production in Asia (Liu *et al.*, 2022). Zinc deficiency has a negative impact on tillering, leading to an increase in spikelet sterility and a delay in crop maturity (Kaznina *et al.,* 2022). The signs of zinc deficiency include leaf chlorosis, reduced internode length, inhibited development, and small leaves (Fariduddin *et al.,* 2022). In their study, Tang and Wu (2006) discovered that the application of Zn had a positive impact on both the growth and quality of aromatic rice. In addition to promoting growth and yield, zinc (Zn) can also enhance the manufacture of 2 Acetyl-1-pyrroline (2-AP) in rice plants, hence improving rice scent (Lie *et al.*, 2017).

Aromatic rice is highly valued for its distinctive fragrance, exceptional taste, and superior quality (Roy *et al.,* 2020). Thai 'jasmine' and Pak-Indian 'basmati' kinds are highly esteemed by customers worldwide and are becoming increasingly popular in foreign marketplaces (Huang *et al.,* 2012). Additionally, aromatic rice commands a higher sale price compared to non-aromatic rice (Sharma *et al.,* 2020). In 2013, Bangladesh produced around 0.30 million tons of aromatic rice from 0.16 million hectares of land. This production is far below the national average, indicating the need to raise the yield by 53.3% (Mahamud *et al.,* 2013). The economic prosperity of the people of Bangladesh has led to a growing demand for scented fine grain rice (Saha *et al.,* 2021). The majority of affluent individuals favored fragrant, thin, and high-quality rice (Ahmed *et al.,* 2020). Although there is now a high demand for fragrant rice in Bangladesh, the area of land dedicated to its cultivation is less than 2% of the total rice production in the country (Al Mamun *et al.,* 2024).

Enhancing the production of aromatic rice can be achieved by the careful selection of suitable rice varieties and effective nutrient management strategies. The substance 2-Acetyl-1-pyrroline (2-AP) is responsible for the popcorn-like flavor found in aromatic rice. This compound has been identified as a key active flavor component by Huang *et al.*, 2024. Sensory evaluation has shown a high link between the characteristics of this compound and its contents, as demonstrated by Hu *et al.*, (2020). Preserving the substance and retaining the flavour of fragrant rice is crucial.

From the above content the experiment was conducted with the following objectives-

- To determine the optimum dose of Zinc for maximum yield and quality of aromatic rice.
- To know the suitable time for application of Zinc for higher yield and quality.
- To find out the interaction effect of dose and application time of Zinc.

CHAPTER II

REVIEW OF LITERATURE

Rice serves as the primary food source for over three billion individuals worldwide, with around 90% of rice production and consumption concentrated in the densely populated regions of South and Southeast Asia. Bangladesh cultivates various high-yielding rice cultivars, many of which exhibit exceptional productivity. The majority of rice cultivars in Bangladesh have been developed by IRRI, BRRI, and BINA. The genetic factor of variety has a significant role in determining the yield and yield components of rice. It may be categorized into aromatic and non-aromatic rice based on its aroma. Various researchers have documented the impact of different rice types on the components that contribute to yield, as well as on the overall grain yield, for both aromatic and non-aromatic rice. The treatment of zinc, either as a foliar spray or through soil application, resulted in a substantial enhancement in the growth and production characteristics of rice. This chapter provides a review of significant and instructive research findings on the morpho-physiological characteristics, yield-contributing traits, and yield of aromatic and non-aromatic rice. It also examines the impact of zinc on rice production. The works and studies discussed in this chapter have been conducted both domestically and internationally.

2.1 Effect of zinc on plant height of aromatic rice

Rasel *et al.* (2023) conducted a field experiment to observe the effect of zinc and poultry manure-based fertilization on the yield of aromatic fine rice, BRRI dhan34. Four levels of zinc and three levels of poultry manure (PM) were tested as treatment including control. Application of zinc significantly influenced the growth and yield of rice that result the tallest plant (131.33 cm) according to their findings of the experiment.

Hasnain *et al.* (2022) performed a field study to assess the yield response and quality attributes of aromatic rice to three levels of zinc (Zn) and nitrogen (N) under three irrigation regimes (8-, 12-, and 16-acre inches) in the Sheikhupura and Sargodha districts of Pakistan. They reported that, application of Zn at 10 kg ha^{-1} was observed to be more responsive to improving the plant height of aromatic rice crops among the studied traits.

Farzana *et al.* (2021) conducted an experiment on how water management and Zn application rates affect the growth and yield of rice. Their treatments consisted of two factors, a) water management, like 1) Continuous flooding (CF) and 2) Alternate wetting and drying (AWD) system and b) Zn application like 1) Control (0% Zn), 2) 75% Zn, 3) 100% Zn, 4) 125% Zn, and 5) 150% Zn of the recommended dose. They recorded that the application of 150% Zn increased the plant height in both AWD and CF system.

Bharti *et al.* (2020) conducted a field experiment during kharif, 2019 at the Research Farm, Bihar Agricultural University, Sabour, Bhagalpur, India with treatments comprising of soil and foliar application of Fe and Zn from organic and inorganic sources. They found that soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} along with RDF recorded significantly higher plant height compared to control.

Singh *et al.* (2020) carried out an experiment to know the effect of Zinc and silicon on growth and yield of aromatic rice in north western plain zone of India was carried out during kharif 2018 at Student Instructional Cum-Research Farm, IFTM University, Moradabad, India. The results revealed that the application of zinc significantly influenced the plant height (from 104 cm to 132 cm) of aromatic rice compared to control.

2.2 Effect of zinc on tillering characters of aromatic rice

Chattha *et al.* (2023) performed a study to determine the impact of different rates of foliar applied Zn at different growth stages on the growth, yield, quality, and Zn bio-fortification of fine rice. Their study comprised foliar application of distilled water (control), foliar applied Zn @ 0.5% at stem elongation stage + booting stage, foliar applied Zn @ 1.0% at stem elongation stage + booting stage, foliar applied Zn @ 0.5% at booting stage and milking stage, foliar applied Zn @ 1.0% at booting stage and milking stage, foliar applied Zn @ 0.5% at milking stage + dough stage and applied Zn @ 1.0% at milking stage + dough stage. They indicated Zn applied different growth stages significantly improved, productivity and Zn bio-fortification of rice crop. The maximum fertile tillers were observed by them with foliar applied Zn (0.5%) at booting and milking stage and lowest values of all these traits were observed in control.

Meher *et al.* (2023) researched the effects of zinc treatment on rice (*Oryza sativa* L.) growth and yield. Their treatments s included the verities MTU-7029, BPT -5204, and RNR15048, as well as zinc concentrations of 0.2%, 0.3%, and 0.4%. They got the greater number of tillers per hill (13.64) at 0.4% Zn application.

Rasel *et al.* (2023) conducted a field experiment was conducted to observe the effect of zinc and poultry manure-based fertilization on the yield of aromatic fine rice, BRRI dhan34. They used four levels of zinc and three levels of poultry manure (PM) as treatment including control. They found Application of zinc significantly influenced the growth and yield of rice that result the maximum number of effective tillers/hill (13.89) where 4 kg Zn ha^{-1} were applied.

Paul *et al.* (2021) conducted an experiment to study the effect of Zn on growth performance of aromatic Boro rice (cv. BRRI dhan50) in response to nitrogen and potassium fertilization. The experiment consisted of four levels of zinc viz., 0, 5, 10 and 15 kg ha^{-1}, and four levels of potassium viz., 0, 30, 60 and 90 kg ha^{-1}. Application of 10 kg Zn ha^{-1} produced the tallest plant (82.17 cm) heading stage.

Khatun *et al.* (2018) carried out a field experiment at the Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh to assess the growth, yield, and yield characteristics of aromatic rice (cv. Tulsimala) when fertilized with cow dung (organic manure) and zinc (micronutrient) during the Aman season. They recorded that the utilization of varying levels of cow dung and zinc fertilizers significantly enhanced the quantities of total tillers per hill, productive tillers per hill.

2.3 Effect of zinc on panicle characters of aromatic rice

In a field study conducted by Hasnain *et al.* (2022), evaluated the impact of three levels of zinc (Zn) and nitrogen (N) on the yield response and quality attributes of aromatic rice. The study was carried out in the Sheikhupura and Sargodha areas of Pakistan, and three different irrigation regimes (8-, 12-, and 16-acre inches) were implemented. The researchers found that applying 10 kg ha^{-1} of Zn resulted in a significant improvement in the panicle length of aromatic rice crops, compared to other attributes that were evaluated

Kandil *et al.* (2022) performed two field experiments to evaluate the response of some rice cultivars to various foliar zinc (Zn) concentrations based on different measurements, such as agronomic, yield, yield compounds, and grain technological parameters. They used five rice cultivars (Skaha 101, Giza178, Yasmeen, Fourate, and Amber 33) with the four foliar applications of Zn (1,500, 2,000, 2,500 mg/L besides spray water. They found that foliar application of Zn at the rate of 2,500 mg/L achieved the highest mean values of panicle length, in both seasons irrespective of varieties.

Khatun *et al.* (2018) carried out a field experiment at the Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh to assess the growth, yield, and yield characteristics of aromatic rice (cv. Tulsimala) when fertilized with cow dung (organic manure) and zinc (micronutrient) during the Aman season. They recorded that the utilization of varying levels zinc fertilizers significantly enhanced the panicle length compared to the control group.

Özcan and Taban (2018) conducted a field experiment in a random block design with 3 replications in Osmancık, Çorum by using 6 rice genotypes (Osmancık 97, KA-080, KA-081, Lotto, Akçeltik, GA-721). They applied Zinc to the soil at the rates of 0, 5 and 10 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ form. They recorded that the rice genotypes of KA-081, Lotto, Akçeltik, GA-7721 were positively affected by zinc application and their biological yield increased. According to the zinc application, the number of panicles, panicle length, and grain number in the panicle increased in all the genotypes.

Dore *et al.* (2018) conducted field experiments during kharif 2013 and 2014 at Agricultural Research Station, Mugad, University of Agricultural Sciences (UAS), Dharwad (Karnataka), to determine the response of zinc application on growth, zinc content and grain yield of rice genotypes and also studied correlation between yield and zinc content. Their experiment was comprised of 20 genotypes and three treatments viz., T_1: Control (no zinc); T_2: Soil application of $ZnSO_4$ (20 kg ha^{-1}) T_3– Foliar Spray of $ZnSO_4$ @ 0.5% at 50% flowering. They revealed that application of $ZnSO_4$ recorded significantly higher panicle weight (15.3 g $plant^{-1}$), number of panicles (81.6 m^{-1}) over the foliar application of Zn and control. They classified the genotypes based on correlation studies as high seed zinc content (> 21 ppm) and low seed zinc content genotypes (less than 21 ppm). High and low seed zinc content genotypes showed negative correlation with yield and yield attributes, reported by them.

2.4 Effect of zinc on yield and yield contributing characters of aromatic rice

Chattha *et al.* (2023) performed a study to determine the impact of different rates of foliar applied Zn at different growth stages on the growth, yield, quality, and Zn bio-fortification of fine rice. Their study comprised foliar application of distilled water (control), foliar applied Zn @ 0.5% at stem elongation stage + booting stage, foliar applied Zn @ 1.0% at stem elongation stage + booting stage, foliar applied Zn @ 0.5% at booting stage and milking stage, foliar applied Zn @ 1.0% at booting stage and milking stage, foliar applied Zn @ 0.5% at milking stage + dough stage and applied Zn @ 1.0% at milking stage + dough stage. They indicated Zn applied different growth stages significantly improved, productivity and Zn bio-fortification of rice crop. The maximum LAI, LAD, CGR, fertile tillers, 1000 KW, kernel yield, biomass yield, HI, chlorophyll concentration, relative water content (RWC), and antioxidant activities were observed by them with foliar applied Zn (0.5%) at booting and milking stage and lowest values of all these traits were observed in control. Likewise, the maximum kernel protein, amylose, kernel length and width, and grain Zn concentration was Zn (0.5%) at the booting and milking stage, and minimum kernel protein, amylose, kernel length, and width, and grain Zn concentration was noted in control. They suggested that foliar-applied Zn (0.5%) at the booting and milking stage could be an important practice to get better productivity, quality, and grain Zn bio-fortification of rice in semi-arid conditions.

Meher *et al.* (2023) researched the effects of zinc treatment on rice (*Oryza sativa* L.) growth and yield. Their treatments s included the verities MTU-7029, BPT -5204, and RNR15048, as well as zinc concentrations of 0.2%, 0.3%, and 0.4%. They got the larger plant height (117.68 cm), greater number of tillers per hill (13.64), Application of RNR-15048 + $ZnSO_4$ - 0.4% significantly increased plant dry weight (55.47 g/plant), number of panicles/hill (10.01), number of grains/panicle (141.37), 1000 seed weight (22.27 gm), grain yield (6.43 t/ha), and stove yield (12.11 t/ha). Higher B:C ratio (2.37) and higher gross return (INR 1,52,860/ha), net return (INR 1,07,531/ha), and net return (INR 1,07,531/ha) were also found in treatment-9 (RNR-15048 + $ZnSO_4$ - 0.4%).

Rasel *et al.* (2023) conducted a field experiment was conducted to observe the effect of zinc and poultry manure-based fertilization on the yield of aromatic fine rice, BRRI dhan34. They used four levels of zinc and three levels of poultry manure (PM) as treatment including control. They found Application of zinc significantly influenced the growth and yield of rice that result the tallest plant (131.33 cm), maximum number of effective tillers/hill (13.89), grains/panicle (128.54), 1000-grain weight (12.09 g) and highest grain yield (3.21 t/ha) where 4 kg Zn/ha were applied.

Soltani *et al.* (2023) conducted a field experiment to assess the impact of applying Zn and Fe glycine amino acid chelates, as well as $ZnSO_4$, at rates of 0.5, 1, and 1.5 kg ha^{-1} on the yield of rice grains, protein content, and the levels of Zn and Fe in the head rice (specifically the Hashemi cultivar). The experiment was conducted using both the recommended dose of NPK and half of the recommended dose. It was documented that applying Zn to the leaves of rice plants improves the yield of rice, as well as the protein, Zn, and Fe content of the rice grains. This effect was observed in plots that received both the recommended dose of NPK fertilizer and half of the recommended dose.

Hanifuzzaman *et al.* (2022) carried out a field experiment to study the effect of different levels of Zn and B fertilizers on the yield of Aus rice (cv. BRRI dhan48). The experiment included four levels of Zn fertilizer management ($ZnSO_4.7H_2O$) (0 kg ha^{-1}; control, basal application @ 10 kg ha^{-1}, basal application @ 5 kg ha^{-1} + soil application during active tillering stage @ 5 kg ha^{-1}, and foliar application; 0.5% solution of $ZnSO_4.7H_2O$ during flag leaf stage) and three levels of boron fertilizer (boric acid) management (0 kg ha^{-1} ; control, 1.5 kg ha^{-1} basal application, and foliar application of 2% solution of H_3BO_3 during flag leaf stage). Zn and B boosted all studied parameters of rice in comparison to their controls, i.e., no fertilization. The highest number of filled grains panicle^{-1} and grain yield was obtained from foliar 12 application of $ZnSO_4.7H_2O$. The results also showed that grain yield of rice increased with increasing levels of Zn up to 4.39 t ha^{-1}.

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

Paul *et al.* (2021) conducted an experiment to study the effect of Zn on growth performance of aromatic Boro rice (cv. BRRI dhan50) in response to nitrogen and potassium fertilization. The experiment consisted of four levels of zinc viz., 0, 5, 10 and 15 kg ha^{-1}, and four levels of potassium viz., 0, 30, 60 and 90 kg ha^{-1}. Application of 10 kg Zn ha^{-1} produced the tallest plant (82.17 cm), the highest number of tillers hill^{-1} (10.08) and chlorophyll content (52.21) at heading stage. In case of interaction, the tallest plant (85.33 cm), the highest number of tillers hill^{-1} (10.83) and chlorophyll content (58.28) were obtained from 10 kg Zn ha^{-1} along with 90 kg Kha^{-1} at heading stage with the application of 120:80:40 kg ha^{-1} NPK + @ 0.5% Zn spray at 30 and 45 DAT. They also found that the grain yield and harvest index also influenced significantly with the application of zinc and silicon and maximum grain yield was recorded with the application of 150:80:40 NPK + two Zn spray 0.5% (65.88 q ha^{-1}) followed by treatment 150:80:40 NPK + Two Si spray @ 0.3% (63.46 q ha^{-1}) and lowest in T_1 control (30.12 q ha^{-1}). Harvest index was recorded non-significant.

The study conducted by Bao *et al.* (2021) showed that the regulation of 2-acetyl-1-pyrroline (2AP) of two different rice cultivars under foliar Zn application. Their results showed that the 2AP and Zn contents in leaves and grains were improved substantially under foliar Zn application. The 2AP content was positively related to the expression $P5CS_2$ gene, contents of proline, 1-pyrroline, and Δ1-pyrroline-5-carboxylate (P5C), and the activity of pyrroline-5-carboxylate synthase (P5CS) under Zn application in fragrant rice. Furthermore, their study showed that the optimal foliar Zn application at a concentration of 30 mg L^{-1} could increase the 2AP content of aromatic rice and keep the yield stable or increase the yield.

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

Hoque (2021) reported insufficient zinc (Zn) and water are key concerns in agricultural production, resulting in lower yields and nutritional qualities. The goal of the study was to figure out how water management and Zn application rates affect the growth and yield of rice. The experiment was carried out in a split-plot design with three replications. The treatments consisted of two factors, a) water management, like 1) Continuous flooding (CF) and 2) Alternate wetting and drying (AWD) system and b) Zn application like 1) Control (0% Zn), 2) 75% Zn, 3) 100% Zn, 4) 125%Zn, and 5) 150% Zn of the recommended dose. All the plots received an equal amount of NPKS fertilizers. The application of Zn in both AWD and CF systems had a significant effect on a number of grains panicle^{-1}, 1000 grain weight and grain yield. The highest value for both yield contributing traits and yield was obtained by the application of 150% Zn in the AWD system. However, the lowest value was found in the control treatment of the CF system for both the yield components and yield. It is also evident that the growth rate of yield components and yield was increased with increased doses of Zn in both AWD and CF systems. In Bangladesh, farmers involved in rice cultivation maybe benefited following the treatment of 150% Zn and AWD irrigation systems.

Alwahibi *et al.* (2020) reported continuous cropping of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) deplete soil fertility and reduce crop productivity as well as zinc (Zn) concentrations in rice grains and straw. Low Zn concentrations in rice grains have a negative impact on human health, while low Zn concentration in rice straw creates a nutritional problem for animals. The current high yielding rice varieties and hybrids remove large quantities of Zn from the soils, lowering the residual concentrations of soil Zn for the subsequent crop (e.g., wheat). Field experiments were conducted on farmers field in Malakand with the objective to evaluate the impact of various combinations of phosphorus (0, 40, 80, and 120 kg ha^{-1}) and Zn levels (0, 5, 10, and 15 kg ha^{-1}) on bio-fortification of Zn in grains and straw of rice genotypes (Bamati-385) vs. coarse (Fakhre-e-Malakand and Pukhraj). The results revealed that Zn bio-fortification in rice genotypes increased with the integrated use of both nutrients (P + Zn) when applied at higher rates (80 and 120 kg P ha^{-1}, and 10 and 15 kg Zn ha^{-1}, respectively). The bio-fortification of Zn in both grains and straw was higher in the coarse than fine rice genotypes (Pukhraj>Fakhre-e-Malakand>Basmati-385). It was concluded from this study that the application of higher P and Zn levels increased Zn contents in rice parts (grains and straw) under the rice-wheat system. We also concluded from this study that Zn concentrations in rice grains and straw are influenced by plant genetic factors and Zn management practices.

Bharti *et al.* (2020) conducted a field experiment during kharif, 2019 at the Research Farm, Bihar Agricultural University, Sabour, Bhagalpur, India with treatments comprising of soil and foliar application of Fe and Zn from organic and inorganic sources. They found that soil application of $ZnSO_4$ and FeSO4 each @ 25 kg ha^{-1} along with RDF recorded significantly higher plant height, number of tillers $hill^{-1}$, leaf area index and dry matter accumulation, highest grain yield (41.30 q ha^{-1}), straw yield (59.05 q ha^{-1}), net return (65698 Rs. ha^{-1}) compared to control. RDF along with foliar application of $ZnSO_4$ and $FeSO_4$ each @ 0.5% at 25 DAT and 1 week after flowering showed similar results as that with soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} along with RDF with respect to growth, yield and economics of aromatic rice. Foliar application of Zinc & Iron through inorganic sources resulted into better biofortification. T_4 (RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering) recorded higher Zn content in grain (35.74 mg kg^{-1}) and straw (37.93 mg kg^{-1}) while T_6 (RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering) recorded higher Fe content in grain (74.26 mg kg^{-1}) and straw (193.52 mg kg^{-1}) followed by T_8 (RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering.

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

Khatun *et al.* (2018) carried out a field experiment at the Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh to assess the growth, yield, and yield characteristics of aromatic rice (cv. Tulsimala) when fertilized with cow dung (organic manure) and zinc (micronutrient) during the Aman season. They recorded that the utilization of varying levels of cow dung and zinc fertilizers significantly enhanced the quantities of total tillers per hill, productive tillers per hill, panicle length, test weight (in grams), grain yield per hill (in grams), straw yield per hill (in grams), grain yield per hectare (in metric tons), straw yield per hectare (in metric tons), and overall biological yields compared to the control group.

Ghasal *et al.* (2018) conducted a two-year field experiment to evaluate the impact of Zn application on the levels and absorption of Zn in several components of the rice kernel, including the hull, bran, and the white rice kernel, at various stages of growth. The variety 'PB 1509' achieved the highest zinc content in the hull, bran, and white rice kernel when treated with 1.25 kg of zinc per hectare as Zn-EDTA and a 0.5% foliar spray at the maximum tillering (MT) and panicle initiation (PI) stages. The cultivar 'PB 1401' had the greatest zinc absorption in rice straw, but 'PB 1509' demonstrated the maximum zinc absorption in both the hull and white rice kernel. The application of 1.25 kilogram of Zn ha^{-1} in the form of Zn-EDTA, along with a 0.5% foliar application at MT and PI, as well as the application of 2.5 kg of Zn ha^{-1} in the form of $ZnSO_4.7H_2O$, along with a 0.5% foliar application at MT and PI, resulted in a greater uptake of Zn compared to the other treatments. The use of Zn-EDTA in combination with 0.5% FS resulted in the highest Zn mobilization efficiency index and Zn-induced nitrogen recovery efficiency, while using a lower amount of Zn. This treatment also led to the maximum kernel yield.

Roy (2018) conducted an experiment to find out the influence of zinc on yield and quality of aromatic rice. The experiment consisted of four levels of zinc (Zn) such AsZn_1: 2.5 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 3.5 kg Zn ha^{-1}, Zn_4: 4.0 kg Zn ha^{-1}; with four cultivars of aromatic rice such as - V_1: Dulhabhog, V_2: Chinigura, V_3: Khoisanne and V_4: Chiniatab. The result revealed that zinc level had no significant effect on grain yield. Their results revealed that supplementation of zinc and/or different varieties had significant effect on most of the yield and quality contributing parameters. Effective tillers, filled grains, weight of milled rice increased with increasing zinc level. But Zn level had no significant effect on 1000-grains weight, grain yield, harvest index among the four aromatic rice varieties.

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

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

Amanullah and Inamullah (2016) reported Phosphorus (P) and zinc (Zn) deficiencies are the major problems that decrease crop productivity under rice-wheat cropping system. Field experiments were conducted to investigate impacts of P (0, 40, 80 and 120 kg ha^{-1}) and Zn levels (0, 5, 10 and 15 kg ha^{-1}) on dry matter (DM) accumulation and partitioning, and harvest index of three rice genotypes ‘fine (Bamati-385) vs. coarse (F-Malakand and Pukhraj)’ at various growth stages (tillering, heading and physiological maturity). The experiments were conducted at farmers’ field at Batkhela in Northwestern Pakistan for two years in summer 2011 and 2012. The two year pooled data revealed that there were no differences in percent of DM partitioning into leaves and culms with application of different P and Zn levels, and genotypes at tillering. The highest P level (120 kg ha^{-1}) partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The highest Zn level (15 kg ha^{-1}) accumulated more DM and partitioned more DM into panicles than leaves and culms at heading and physiological maturity stages. The hybrid rice (Pukhraj) produced and partitioned more DM into panicles than F-Malak and Basmati-385 at heading and physiological maturity stages. Higher DM accumulation and greater amounts of partitioning into panicles at heading and physiological maturity stages was noticed with increase in P and Zn levels, and the increase was significantly higher in the coarse rice genotypes than fine. We concluded that the growing hybrid rice with application of 120 kg ha^{-1} P and 15 kg ha^{-1} Zn not only increases total DM accumulation and partitioned greater amounts into the reproductive plant parts (panicles) but also results in higher harvest index.

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

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

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

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

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

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

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

Sudha and Stalin (2015) conducted a field experiment during Thaladi (Rabi) season 2013–14 to study the effect of zinc application on yield, quality and grain zinc content of different rice genotypes in a split plot design. The main plots were two levels of Zn (no Zn and 100 kg ha^{-1} $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 percent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice) and sub-plots were 18 of rice genotypes. The application of zinc significantly increased the plant height, number of productive tillers, filled grains per panicle, panicle length and 1000-grain weight as compared to NPK fertilization alone. The yield of grain (4623 to 7434 kg ha^{-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 per cent respectively. Further the quality parameters like starch, amylase, crude protein and zinc content in processed rice grains increased markedly by the application of Zn as compared to NPK alone. Thus the present study indicated that the application of 100 kg ha^{-1} $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 percent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice along with 100 percent NPK to rice genotypes enhanced considerably the productivity, quality and zinc content of rice grains.

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

Oahiduzzaman (2013) conducted an experiment to study the effect of zinc and cow dung on growth, yield and nutrient content of transplanted aman rice. BRRI dhan33 was used as the test crop in this experiment. The experiment consisted of 4 levels of zinc (Zn_0: 0 kg Zn ha^{-1} (control), Zn_1: 2.0 kg Zn ha^{-1}, Zn_2: 3.0 kg Zn ha^{-1}, Zn_3: 4.0 kg Zn ha^{-1}) and 4 levels of cow dung (Co: 0-ton cow dung ha^{-1} (control). C1: 4.50-ton cow dung ha^{-1}, C2: 5.0-ton cow dung ha^{-1} and C3: 5.5-ton cow dung ha^{-1}). For 4.0 kg Zn ha^{-1} (Zn_3), the tallest plant (25.12, 41.09, 58.90, 75.03 and 88.34 cm) were recorded at 30, 50, 70, 90 days after transplanting (DAT) and at harvest, respectively. On the other hand, the shortest plant (19.95, 33.52, 51.08, 65.25 and 80.50 cm) were found from control treatment (Zn_0) at 30, 50, 70, 90 DAT and at harvest, respectively. The maximum number of effective tillers $hill^{-1}$ (13.30) was observed from Zn_3 and the minimum number (10.18) from Zn_0. The highest grain yield ha^{-1} (5.11 ton) was found from Zn_3 and the lowest grain yield ha^{-1} (3.28 ton) from Zn_0.

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

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

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

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

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

Singh *et al.* (2012) reported rice is the staple food of more than three billion people in the world, most of who live in Asia. Rice is important crop of Indo Gangetic Plains of Bihar, productivity of system is stagnate and somewhere going down, to ascertain the role of sulphur and zinc an experiment was conducted at main campus of ICAR Research Complex of Eastern Region Patna with four levels of both nutrients i.e. sulphur and zinc, total 16 treatments were tested in Randomized Block Design. Both the nutrients were applied to rice and their direct and residual response was ascertained to rice and lentil in sequence. Based on three years of experimentation, results revealed that rice plant height is significantly affected by sulphur and zinc. Tallest plant (101.7cm) was recorded at maturity with 6kg Zn application Zn. With the advance of stage dry matter accumulation was increased, it was not like the LAI which was decreased after Panicle initiation stage. Highest LAI (4.29) at anthesis was produced in the plots treated with Zn at 6 kg ha^{-1}. Dry matter share of root was in general less than 15% across the levels of sulphur and zinc during all the phenological stages. Maximum rice yield (7.63 t/ha) was recorded with combined application of 30kg sulphur and 6kg zinc, whereas corresponding minimum rice yield (7.09 t/ha) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period. Maximum (281.2 kg ha^{-1}) nitrogen uptake was recorded with 6kg zinc treatment. However highest uptake of P (91.4 kg ha^{-1}) 1 kg ha^{-1}) and K (150was recorded in the plot supplemented with no Zn and sulphur at 40 kg ha^{-1}, respectively. Soil parameters viz., pH, EC and organic carbon content did not influenced with the S and Zn. N, P, K, S and Zn were affected significantly due to sulphur and zinc nutrition.

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

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

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

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

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

Tahura (2011) conducted a field experiment with the objective of evaluating the effect of S and Zn on the yield performance and nutrient content of T-Aman Rice. The experiment composed of four different individual and combined treatment (sixteen) of sulphur viz. S_0 (control). S_8 (8 kg ha^{-1}), S_{12} (12 kg ha^{-1}) and S_{16} (16 kg ha^{-1}) and zinc viz. Zn_0 (0 kg ha^{-1}), Zn_1.0 (1.0 kg ha^{-1}), $Zn_{1.5}$ (1.5 kg ha^{-1}) and Zn_2.0 (2.0 kg ha^{-1}). The tallest plant (124.0 cm), highest grain yield (5.663 t ha^{-1}) and straw yield (8.163 t ha^{-1}) of T-Aman Rice was recorded in $S_{12}Zn_{1.5}$ (12 kg S ha^{-1} + 1.5 kg Zn ha^{-1}). Overall results indicate that the treatment combination of $S_{12}Zn_{1.5}$ (12 kg S ha^{-1} and 1.5 kg Zn ha^{-1}) alone or combinedly was more effective to produce higher yield of T-Arran rice supported with recommended doses of N, P and K.

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

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

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

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

Rahman (2007) conducted a field experiment with an objective of evaluating the effect of S and Zn on the yield, yield components and nutrient uptake by T-Aman (BRRI dhan31). There were twelve treatments taking various doses of Sulphur and Zinc viz. S_0Zn_0 (control), S_0Zn_1, S_0Zn_2, $S_{12}Zn_0$, $S_{12}Zn_1$, $S_{12}Zn_2$, $S_{16}Zn_0$, $S_{16}Zn_1$, $S_{16}Zn_2$, $S_{20}Zn_0$, $S_{20}Zn_1$ and $S_{20}Zn_2$. The subscripts represent doses in kg ha^{-1}. The application of Sulphur and Zinc had a positive significant effect on tillers $hill^{-1}$, plant height, panicle length and number of grains $panicle^{-1}$. The highest grain yield (4.20 t ha^{-1}) and straw yield (5.62 t ha^{-1}) of BRRI dhan31 was recorded in $S_{20}Zn_2$ treatment. The S_0Zn_0 treatment (control) had the lowest grain (3.01 t ha^{-1}) and straw yield (4.50 t ha^{-1}). Overall results indicate that the application of S and Zn at a rate of 20 kg S and 2 kg Zn ha^{-1} along with recommended dose of N, P, and K is necessary for obtaining maximum grain yield as well as straw yield of T-Aman rice.

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

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

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

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

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

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

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

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

Khan *et al.* (2003) conducted a field experiment where comparative effect of three different methods of zinc application was studied, aimed at alleviating Zn deficiency in transplanted flood rice (cv. IRRI 6) grown in alkaline soil. Three methods were tried i.e.

nursery root dipping in 1.0% $ZnSO_4$, 0.20% $ZnSO_4$ solution spray after transplanting and 10 kg Zn ha^{-1} by field broadcast method. The yield and yield parameters increased significantly from the application of Zn by any method. Among the methods, the effect of Zn was non-significant on yield components like tiller m^{-2}, spikelet's $panicle^{-1}$, % filled grains, 1000-grain weight and straw yield. However, soil application of Zn @ 10 kg ha^{-1} was rated superior because it produced significantly higher paddy yield. The maximum number of tillers m^{-2} (415.67) in rice field was recorded where zinc was applied @ 10 kg ha^{-1} by soil dressing which did not differ significantly from that of foliar spray of 0.20% $ZnSO_4$ and root dipping of 1.0% $ZnSO_4$ on silt loam soils.

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

2.5 Effect of zinc on aroma content of aromatic rice

Shuochen *et al.* (2023) conducted field experiments in the rice season (May-September) in 2019 to 2021. Two light i.e., normal light (NL) and low light (LL) and four Zn levels i.e., 0 kg Zn ha^{-1} (N0), 1 kg Zn ha^{-1} (Zn_1), 2 kg Zn ha^{-1} (Zn_2), and 3 kg Zn ha^{-1} (Zn_3), were applied at booting stage by them. They investigated grain yield, 2AP contents, Zn content in polished rice, photosynthesis related indicators, MDA content, antioxidant enzyme activity and the biochemical parameters related to 2AP formation. They found both increasing Zn application increased the 2AP content by promoting the biosynthesis of 2AP irrespective of light.

The research carried out by Bao *et al.* (2021) demonstrated how foliar Zn application regulated the levels of 2-acetyl-1-pyrroline (2AP) in two distinct rice varieties. Their findings demonstrated a significant enhancement in the levels of 2AP and Zn in both leaves and grains as a result of foliar Zn treatment. The content of 2AP exhibited a positive correlation with the expression of the $P5CS_2$ gene, as well as the levels of proline, 1-pyrroline, and Δ1-pyrroline-5-carboxylate (P5C), and the activity of pyrroline-5-carboxylate synthase (P5CS) when fragrant rice was treated with Zn. In addition, their research shown that applying zinc to the leaves at a concentration of 30 mg L^{-1} might enhance the 2AP content of aromatic rice and maintain or perhaps improve the yield.

Luo *et al.* (2019) assessed the physio-biochemical responses involved in biosynthesis of 2-acety-1-pyrroline (2-AP), in four different fragrant rice varieties, i.e., Meixiangzhan-2, Xiangyaxiangzhan, Ruanhuayou-134, and Yunjingyou under four concentrations (0, 0.50, 1.00 and 2.00 g L^{-1}) of zinc chloride at the heading stage and named CK, Zn_1, Zn_2 and Zn_3, respectively. They found that the exogenous zinc application at heading stage increased 2-acetyl-1-pyrroline (2-AP) content, a key aroma compound, in fragrant rice genotypes, enhancing aroma quality.

Mo *et al.* (2019) conducted field experiments in the early season (March–July) and repeated in the late season (July–November) to conform that zinc application and different water regimes at booting stage improved yield and 2-acetyl-1-pyrroline (2AP) formation in fragrant rice. Three Zn levels i.e., 0 kg Zn ha^{-1} (Zn_1), 3kg Zn ha^{-1} (Zn_2), and 6 kg Zn ha^{-1} (Zn_3) and three water levels i.e., W1 treatment (water layer of 2–4 cm), W2 treatment (soil water potential 15 ± 5 kPa), and W3 treatment (soil water potential 25±5 kPa) at booting stage was set up for three rice varieties i.e., Nongxiang 18, Yungengyou 14 and Basmati. The Zn_2 and Zn_3 treatment significantly increased the 2AP contents in brown rice by 9.54% and 11.95%; 8.88% and 32.54% in the early and the late season, respectively; improved grain yield and head milled rice yield. This study also revealed that the 6 kg Zn ha^{-1} coupled with 25±5 kPa water treatment showed the best positive effects on yield and aroma in fragrant rice.

Lei *et al.* (2017) examined the effects of externally applied mixed micro-nutrients on the quality of yield, accumulation of 2-acetyle-1-pyrroline (2-AP), and mineral content in the grains of two aromatic rice cultivars, namely Xiangyaxiangzhan and Guixiangzhan. Two mixtures with different proportions of micro-nutrients were applied externally during the full heading stage. Mixture-1 contained 40% zinc sulfate, 6% manganese sulfate, 1% ferric chloride, 50% proline, and 3% sodium selenite. Mixture-II contained 1% gibberellic acid, 8% zinc sulfate, 76% potassium di-hydrogen phosphate, 8% manganese sulfate, and 7% copper sulfate. The application rates were 1.5 kg ha-2 for T_1 and 3 kg ha-2 for T_2, diluted in 750 L of water. Plots that received only water were used as the control (CK). The results showed that the external application of a combination of micronutrients significantly increased the yield by improving the number of grains per panicle, the percentage of filled grains, the weight of 1000 grains, the overall grain yield, and the levels of grain 2-AP and zinc (Zn) content.

CHAPTER III

MATERIALS AND METHODS

The materials and methods used for conducting this experiment has been presented in this section. It includes short description of various information as for example location of the experimental site, soil, climatic condition of the experimental area, materials that are used in the experiments, design of the experiments, treatments, data collection parameters and analysis procedure of collected data. The experiments were carried out during the period from July 2023 to December, 2023 at the research field of Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200.

3.1 Description of experimental site

3.1.1 Geographical location

The experimental field (research field of HSTU) was located at 25.56^o N latitude and 88.5^o E longitude at an altitude of 37 m above from the mean sea level. This area is situated at the AEZ-1 which is Old Himalayan Piedmont Plain (Appendix I).

3.1.2 Agro Ecological Zone

The soil of the experimental field belongs to the Agro-ecological zone of "Old Himalayan Piedmont Plain. This was a region of complex relief and soil developed over the Dinajpur is sandy loam. The experimental site was shown in the map of AEZ of Bangladesh.

3.1.3 Climate

The experimental area is under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in kharif season (April-September) and less rainfall associated with moderately low temperature during the Rabi season (October-March). The average annual precipitation of the site was around 167 mm. The average maximum temperature in summer was 28^{o}C and average minimum temperature was 18^{o}C. Sometimes it goes nearly 10^{o}C. The average mean temperature was 23^{o}C (Appendix II).

3.1.4 Soil

The experimental field is medium high with sandy loam type soil with a pH value 6.5, low in organic matter and fertile. The soil was well drained and morphological characteristics of soil of the experimental site have been presented in the appendix III.

3.2 Experimental details

3.2.1 Planting material

The experiment was conducted with local variety ‘Tulsimala’ of aromatic rice as test crops.

3.3 Experimental Treatments

The experiment consisted of two types of treatments.

Factor A: amount of zinc

i. Zn_1 =0.0kg
ii. Zn_2=5kg ha^{-1}
iii. Zn_3=10 kg ha^{-1}
iv. Zn_4=15 kg ha^{-1}

B. Factor B: time of application

i. T_1 = Tillering stage at 25 days after transplanting (DAT)
ii. T_2 = Panicle initiation stage at 50 DAT
iii. T_3= Dough stage at 75 DAT

Treatments were replicated three times

Rice Variety:

Tulsimala was used as test variety.

Total 12 treatment combinations were as follows:

Zn_1T_1= 0 kg ha^{-1} of Zinc (control) at 25 DAT
Zn_1T_2= 0 kg ha^{-1} of Zinc (control) at 50 DAT
Zn_1T_3= 0 kg ha^{-1} of Zinc (control) at 75 DAT
Zn_2T_1= 5 kg ha^{-1} of Zinc at 25 DAT
Zn_2T_2= 5 kg ha^{-1} of Zinc at 50 DAT
Zn_2T_3= 5 kg ha^{-1} of Zinc at 75 DAT
Zn_3T_1= 10 kg ha^{-1} of Zinc at 25 DAT
Zn_3T_2= 10 kg ha^{-1} of Zinc at 50 DAT
Zn_3T_3= 10 kg ha^{-1} of Zinc at 75 DAT
Zn_4T_1= 15 kg ha^{-1} of Zinc at 25 DAT
Zn_4T_2= 15 kg ha^{-1} of Zinc at 50 DAT
Zn_4T_3= 15 kg ha^{-1} of Zinc at 75 DAT

3.4 Experimental layout

The experiment was laid out in a randomized complete block design (RCBD). There were 12 treatment combinations, each treatment replicated three times. The treatments were randomly distributed to the plots within a block. Thus, the number of plots was 3 × 12 = 36. The unit plot size was 12 m^2 (4m × 3 m). Irrigation and drainage channel were made with maintaining 50 wide and 30 cm between blocks and 25 cm wide and 25 cm depth between plots.

Block-1		**Block-2**		**Block-3**	
Zn_2T_1	Zn_4T_3	Zn_1T_1	Zn_2T_3	Zn_4T_3	Zn_1T_2
Zn_3T_1	Zn_1T_2	Zn_2T_2	Zn_3T_2	Zn_2T_1	Zn_4T_2
Zn_4T_1	Zn_4T_2	Zn_4T_2	Zn_1T_3	Zn_3T_1	Zn_2T_2
Zn_3T_3	Zn_2T_2	Zn_1T_2	Zn_3T_3	Zn_4T_1	Zn_1T_1
Zn_1T_3	Zn_1T_1	Zn_4T_3	Zn_4T_1	Zn_3T_3	Zn_2T_3
Zn_3T_2	Zn_2T_3	Zn_2T_1	Zn_3T_1	Zn_1T_3	Zn_3T_2

Replication:

Block-1, Block-2 and Block-3

Unit plot size: 4.0 m × 3 m

Block to block distance: 75 cm

Plot to plot distance: 50 cm

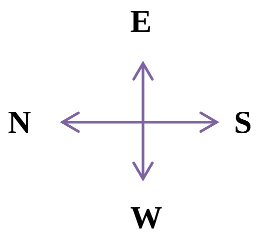

Figure 1: Layout of the experimental field

3.4.1 Collection of seeds of Tulsimala

Seeds were immersed in water in a bucket for 24 hours. The immersed seeds were taken out from water and kept in gunny bags. The seeds started sprouting after 48 hours. These seeds were suitable for sowing in the seed bed in 72 hours.

3.4.2 Preparation of seedbed

The seed bed was made by puddling with 3-4 ploughing followed by laddering. Gently irrigation was provided, and weeds were removed from the bed as and when necessary and no fertilizer was used in the nursery bed.

3.4.3 Seed sowing

The sprouted seeds were sown in the seedbeds on 23 June 2023. The beds were irrigated to a depth of 2-3 cm after establishing the roots. Excess water was occasionally drained off to attain water depth of 5 cm that partially controlled weeds.

3.4.4 Preparation of experimental land

The plot selected for the experiment was opened with a power tiller, and left exposed to the sun for a week. For obtaining good puddle condition, the land was harrowed, ploughed and cross-ploughed several times after one week followed by laddering. Weeds and stubbles were removed from the field. The experimental plot was partitioned into unit plots in accordance with the experimental design.

3.4.5 Fertilizer dose and methods of application

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MP, DAP, gypsum, zinc sulphate and borax, respectively were applied. The entire amount of TSP, MP, gypsum, and borax were applied during the final preparation of land. The mixture of cowdung and compost was applied during 15 days before transplanting. Urea was applied in three equal instalments at seedling establishment, tillering and before panicle initiation.

3.4.6 Uprooting of seedlings

The seedbed was wetted by application water in the morning to make the soil soft so that uprooting became easy. Then uprooting was done in the evening on the previous day of transplanting. Seedlings were uprooted carefully without causing any injury to the roots and stem and kept in water for the whole night.

3.4.7 Transplanting of seedlings

Twenty-eight days old seedlings of the fine rice cultivars were transplanted in the main field on 20 July in 2023 with a spacing 20 cm from row to row and 15 cm from hill to hill.

3.4.8 Intercultural operations

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

3.4.8.1 Weeding

Weeding was done during the first two top dressings of urea to break the soil crust, to keep the plots free from weeds and to incorporate the urea properly into the soil which reduced the loss of urea through de-nitrification and leaching.

3.4.8.2 Application of irrigation water

Irrigation water was added to each plot as and when necessary. All the plots were kept irrigated maintaining 3-5 cm stagnant water throughout the entire period up to 15 days before harvesting. Irrigation had applied before the water level was fell down to the root of the crop plants.

3.4.8.3 Plant protection measures

There were some incidences of insects specially stem borer which was controlled by Furadan 5G @ 10 kg ha^{-1} at 30 days after transplanting. Brown spot of rice was controlled by spraying tilth. Rifit was used as herbicide @ 1.0 L. ha^{-1}. And ripcord was used as insecticide @ 200 ml ha^{-1}. Batir was applied as insecticides @ 12.54 g ha^{-1}.

3.5 General observation of the experimental field

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

3.6 Harvesting, threshing and cleaning

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

3.7 Recording of data

The following data was recorded during the experiment.

A. Crop growth parameters

1. Plant height (cm)
2. Panicle length (cm)

B. Yield and yield contributing parameters

1. Number of effective tillers hill^{-1}
2. Number of filled grains panicle^{-1}
3. Number of unfilled grains panicle^{-1}
4. Weight of 1000 grain (g)
5. Grain yield (t ha^{-1})
6. Straw yield (t ha^{-1})
7. Biological yield (t ha^{-1})
8. Harvest index (%)

3.8 Description of the recorded data

A. Crop growth parameters

1. Plant height (cm)

The height of plant was recorded in centimetres (cm) at the time of 25, 50, 75 DAT and at harvest. The height was measured from the ground level to the tip of the plant. Plant height of 5 hills were measured and averaged for each plot.

2. Panicle length (cm)

The length of the panicle was measured with a meter scale from 10 selected panicles and the average value was recorded. The length of the panicle was measured from basal node of the rachis to apex of each panicle.

B. Yield and yield contributing parameters

1. Number of effective tillers hill^{-1}

The total number of effective tillers per hill was counted from five selected hills and finally average for counting effective tillers number per hill.

2. No. of filled grains panicle^{-1}

If any kernel was present in grain, the grain was considered to be filled. The total number of filled grains were recorded on ten panicles and finally averaged.

3. No. of unfilled grains panicle^{-1}

Unfilled grains mean the absence of any kernel inside the grain and such grains present on each of ten panicles were counted and finally averaged for each plot.

4. Weight of 1000 grain (g)

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

5. Grain yield (t ha^{-1})

Grain from each plot area was thoroughly sun dried till constant weight was attained. Then yield per hectare was determined based on net plot area. Weight of grains of each plot was converted into t ha^{-1}.

6. Straw yield (t ha^{-1})

After separation of grains from plants of each plot the straw was sun dried till a constant weight is obtained and expressed as ton ha^{-1}.

7. Biological yield (t ha^{-1})

Grain yield together with straw yield was calculated as biological yield with the following formula:

Biological yield (t ha^{-1}) = Grain yield (t ha^{-1}) + Straw yield (t ha^{-1})

8. Harvest index (%)

It denotes the ratio of grain yield to biological yield and was calculated with the following formula.

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

3.9 Statistical Analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique and the mean difference were adjudged by LSD test using the statistical computer package program, Statistix-10. The significant difference among treatment means were estimated by Duncan's Multiple Test Range at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter comprises of the presentation and discussions of the research obtained due to different application of Zinc on growth and yield contributing characters of aromatic rice (Tulsimala). The data on different growth, yield and yield contributing characters of rice were recorded. The results have been presented and discussed in different tables and graphs as far as available with the results of the researchers.

4.1 Plant height (cm)

4.1.1 Effect of dose

The plant height at different days after sowing showed significant difference among the different level of zinc application ($p < 0.01$). The plant height at 25 DAT showed insignificant variation among them. However, the maximum plant height was recorded from Zn_4 (15 kg Zn ha^{-1}) 40.96 cm while minimum from Zn_2 (5 kg Zn ha^{-1}) (39.44 cm). At 50, 75 DAT, and harvest the highest plant height was recorded from Zn_4 (91.45, 131.41 and 162.58 cm respectively). On the other hand, the control treatment gave the dwarf plant at the 50, 75 DAT, and harvest (82.58, 116.30 and 151.22 cm, respectively) (Table 1). Maximum zinc application likely resulted in higher plant height compared to the control due to zinc's role in promoting enzyme activity and protein synthesis, which are essential for plant growth. Zinc also aids in the production of growth hormones such as auxins, which directly influence cell elongation and division. The absence or low levels of zinc in the control could limit these physiological processes, resulting in shorter plants. Ghoneim *et al.* (2016) stated that the Zn application significantly affected the plant height. He recorded the maximum plant height (100 cm) was recorded from the treatment with 15 kg Zn ha^{-1}.

Table 1: Effect of different dose of zinc fertilizer on plant height (cm) at different days after transplanting

Dose of Zinc	Plant height (cm)			
	25 DAT	50DAT	75DAT	At harvest
Zn_1	40.66	82.58 c	116.30 c	151.22 c
Zn_2	39.44	86.51 b	127.01 b	158.77 b
Zn_3	40.28	88.30 b	128.14 b	160.96 a
Zn_4	40.96	91.45 a	131.41 a	162.58 a
CV (%)	8.40	3.22	4.82	3.36
LSD	3.31	2.74	2.23	2.09
LS	NS	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
Zn_1=control
Zn_2=5 kg ha^{-1}
Zn_3=10 kg ha^{-1}
Zn_4=15 kg ha^{-1}

4.1.2 Effect of application time

The plant height showed significant different among the time of zinc application at different days after transplanting except 25 DAT ($p<0.01$). The plant height at 25 DAS showed insignificant variation among the treatments. However, the maximum plant height was recorded from T_1 (control) (41.30cm) while minimum from T_2 (39.72 cm). At 50 DAT the top plant height was recorded from T_1 (94.171 cm) and lowest from T_2 (83.69 cm). At 75 DAT, and harvest the highest plant height was recorded from T_2 (133.79 and 162.59 cm respectively) (Table 2). A similar outcome was observed by Singh *et al.* (2022). Zinc application is particularly effective for plant height in rice, as it enhances essential processes such as cell division and growth, thereby improving grain formation and yield.

Table 2: Effect of different application time of zinc fertilizer on plant height (cm) at different days after transplanting

Time of Application	Plant height (cm)			
	25 DAT	50 DAT	75 DAT	At harvest
T_1	41.30	94.17 a	124.66 b	154.48 c
T_2	39.72	83.69 b	133.79 a	162.59 a
T_3	39.99	83.77 b	118.70 c	158.07 b
CV (%)	8.40	3.22	4.82	3.36
LSD	2.86	2.37	1.93	1.81
LS	NS	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
T_1 = application of zinc at the tillering stage at 25 DAT
T_2 = application of zinc at the panicle stage at 50 DAT
T_3 = application of zinc at the dough stage at 75 DAT

4.1.3 Combined effect of dose and time

The interaction of the different amount of zinc fertilizer and application time of zinc displayed the significant difference among the treatment combinations for plant height ($p < 0.01$). At 25 DAT, all treatment combinations gave the statistically alike performance among them. At 50 DAT, Zn_4T_1 gave the maximum plant height (100.14 cm) statistically alike to Zn_3T_1. However, Zn_4T_2 gave the best result (142.13 and 172.26 cm respectively) while lowest value was recorded from control treatment combinations (40.08, 84.59, 115.40 and 150.61 cm, respectively) at 25, 50, 75 and harvest time.

Table 3: Combined effect of different dose and different application time of zinc fertilizer on plant height (cm) at different days after transplanting

Interaction of Zinc and Application Time		Plant height (cm)			
		25 DAT	50 DAT	75 DAT	At harvest
	T_1	40.08	84.59 cd	115.40 f	150.61 f
Zn_1	**T_2**	41.30	81.66 d	116.43 ef	151.76 ef
	T_3	40.61	81.51 d	117.08 ef	151.28 f
	T_1	39.57	92.81 b	124.22 d	154.99 de
Zn_2	**T_2**	39.87	83.07 cd	137.13 b	162.72 b
	T_3	38.90	83.66 cd	119.67 e	158.61 cd
	T_1	42.43	99.14 a	126.89 d	158.25 cd
Zn_3	**T_2**	38.02	83.03 cd	139.46 ab	163.62 b
	T_3	40.40	82.73 cd	118.07 ef	161.02 bc
	T_1	43.11	100.14 a	132.13 c	154.09 ef
Zn_4	**T_2**	39.71	87.03 c	142.13 a	172.26 a
	T_3	40.07	87.18 c	119.96 e	161.39 bc
CV (%)		8.40	3.22	4.82	3.36
LSD		5.73	4.74	3.87	3.63
LS		NS	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.

Legend:

**= Significant at 1% level of significance

*= Significant at 5% level of significance

NS=Not Significant

LS= Level of significance

CV-Co-efficient of variance

LSD=Least Significant Difference

Here,

Zn_1T_1= 0 kg ha^{-1} of Zinc (control) at 25 DAT

Zn_1T_2= 0 kg ha^{-1} of Zinc (control) at 50 DAT

Zn_1T_3= 0 kg ha^{-1} of Zinc (control) at 75 DAT

Zn_2T_1= 5 kg ha^{-1} of Zinc at 25 DAT

Zn_2T_2= 5 kg ha^{-1} of Zinc at 50 DAT

Zn_2T_3= 5 kg ha^{-1} of Zinc at 75 DAT

Zn_3T_1= 10 kg ha^{-1} of Zinc at 25 DAT

Zn_3T_2= 10 kg ha^{-1} of Zinc at 50 DAT

Zn_3T_3= 10 kg ha^{-1} of Zinc at 75 DAT

Zn_4T_1= 15 kg ha^{-1} of Zinc at 25 DAT

Zn_4T_2= 15 kg ha^{-1} of Zinc at 50 DAT

Zn_4T_3= 15 kg ha^{-1} of Zinc at 75 DAT

4.2 Number of effective tillers hill^{-1}

4.2.1 Effect of dose

The numbers of tiller per hill showed significant difference among the different level of zinc application ($p < 0.01$). The highest effective tillers was found (18.34) was recorded from Zn_3 (10 kg Zn ha^{-1}) followed by Zn_4 (15 kg Zn ha^{-1}) (18.00 respectively). The lowest effective tillers was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (14.31) (Table 4).

Table 4: Effect of various amount of zinc on the number of effective tillers hill^{-1}, panicle length (cm), filled grains panicle^{-1}, sterile grains panicle^{-1} and 1000-grain weight (g) of aromatic rice cv Tulsimala

Dose of Zinc	Effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1}	Sterile grains panicle^{-1}	1000-grain weight (g)
Zn_1	14.31 c	23.51 c	149.63 d	28.44 a	10.01 c
Zn_2	16.86 b	24.43 b	164.54 c	18.56 b	10.15 bc
Zn_3	18.34 a	26.63 a	186.52 a	12.42 c	10.35 a
Zn_4	18.00 ab	24.95 b	178.65 b	21.73 b	10.19 b
CV (%)	7.96	4.20	3.95	16.34	3.48
LSD	1.31	0.53	6.56	3.24	0.14
LS	**	**	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
Zn_1=control Zn_2=5 kg ha^{-1}
Zn_3=10 kg ha^{-1} Zn_4=15 kg ha^{-1}

4.2.2 Effect of application time

The number of effective tillers hill^{-1} showed significant due to different time application of zinc fertilizer. ($p < 0.01$). The highest effective tillers hill^{-1} was recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (17.92) statistically alike to T_3 (application of Zinc at dough stage at 75 DAT) treatment (16.62). The lowest effective tillers was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (16. 09) (Table 5).

Table 5: Effect of various application time of zinc on the number of effective tillers hill^{-1}, panicle length (cm), filled grains panicle^{-1}, sterile grains panicle^{-1} and 1000-grain weight (g) of aromatic rice cv Tulsimala

Time of Application	Effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1}	Sterile grains panicle^{-1}	1000-grain weight (g)
T_1	16.09 b	24.41 b	163.48 b	23.160 a	10.05 c
T_2	17.92 a	25.34 a	175.38 a	17.793 b	10.32 a
T_3	16.62 b	24.89 a	170.65 a	19.918 b	10.15 b
CV (%)	7.96	4.20	3.95	16.34	3.48
LSD	1.13	0.46	5.68	2.80	0.12
LS	**	**	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
T_1 = application of zinc at the tillering stage at 25 DAT
T_2 = application of zinc at the panicle stage at 50 DAT
T_3 = application of zinc at the dough stage at 75 DAT

4.2.3 Combined effect of dose and time

The interaction of the different amount of zinc fertilizer and application time of zinc displayed the significant difference among the treatment combinations for the number of effective tillers hill^{-1} ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg ha^{-1} zinc at panicle initiation stage at 50 DAT) recorded the highest number of effective tillers hill^{-1} (19.80) statistically alike to Zn_4T_2 (19.09) . The lowest number of effective tillers hill^{-1} (13.69) was recorded from Zn_1T_3 treatment (Application of 0 Kg zinc at dough stage at 75 DAT) (Table 6). Sultana, 2021 studied the effect of Zinc on rice verities at different doses and at different application time resulted that application of moderate dose of zinc at panicle initiation stage gave the best result.

Table 6: Combined effect of various amount of zinc and its different application time on the number of effective tillers hill^{-1}, panicle length (cm), filled grains panicle^{-1}, sterile grains panicle^{-1} and 1000-grain weight (g) of aromatic rice cv Tulsimala

Interaction of Zinc and Application Time		Effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1}	Sterile grains panicle^{-1}	1000-grain weight (g)
	T_1	14.22 ef	22.65 g	144.95 i	33.04 a	9.76 c
Zn_1	T_2	15.02 def	24.09 ef	154.15 ghi	25.31 b	10.22 b
	T_3	13.69 f	23.79 f	149.78 hi	26.97 b	10.06 b
	T_1	16.02 cde	24.22 ef	158.78 fgh	21.97 bc	10.05 b
Zn_2	T_2	17.76 abc	24.65 def	169.42 def	15.97 de	10.24 b
	T_3	16.80 cd	24.41 def	165.42 efg	17.74 cde	10.15 b
	T_1	16.98 bcd	26.05 bc	174.65 cde	14.64 def	10.21 b
Zn_3	T_2	19.80 a	27.37 a	196.18 a	10.31 f	10.56 a
	T_3	18.25 abc	26.47 ab	188.74 ab	12.31 ef	10.26 b
	T_1	17.13 bcd	24.72 de	175.55 cde	22.97 bc	10.16 b
Zn_4	T_2	19.09 ab	25.24 cd	181.75 bc	19.57 cd	10.25 b
	T_3	17.77 abc	24.90 de	178.65 bcd	22.64 bc	10.15 b
	CV (%)	7.96	4.20	3.95	16.34	3.48
	LSD	2.27	0.92	11.36	5.61	0.25
	LS	*	*	*	*	*

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.

Legend:

**= Significant at 1% level of significance

*= Significant at 5% level of significance

NS=Not Significant

LS= Level of significance

CV-Co-efficient of variance

LSD=Least Significant Difference

Here,

Zn_1T_1= 0 kg ha^{-1} of Zinc (control) at 25 DAT
Zn_1T_2= 0 kg ha^{-1} of Zinc (control) at 50 DAT
Zn_1T_3= 0 kg ha^{-1} of Zinc (control) at 75 DAT
Zn_2T_1= 5 kg ha^{-1} of Zinc at 25 DAT
Zn_2T_2= 5 kg ha^{-1} of Zinc at 50 DAT
Zn_2T_3= 5 kg ha^{-1} of Zinc at 75 DAT
Zn_3T_1= 10 kg ha^{-1} of Zinc at 25 DAT
Zn_3T_2= 10 kg ha^{-1} of Zinc at 50 DAT
Zn_3T_3= 10 kg ha^{-1} of Zinc at 75 DAT
Zn_4T_1= 15 kg ha^{-1} of Zinc at 25 DAT
Zn_4T_2= 15 kg ha^{-1} of Zinc at 50 DAT
Zn_4T_3= 15 kg ha^{-1} of Zinc at 75 DAT

4.3 Panicle length (cm)

4.3.1 Effect of dose

The panicle length showed significant difference among the different level of zinc application ($p < 0.01$). The longest panicle (26.63 cm) was recorded from Zn_3 (10 kg Zn ha^{-1}) followed by Zn_4 (15 kg Zn ha^{-1}) and Zn_2 (5 kg Zn ha^{-1}) (24.95 and 24.43 cm respectively). The shortest panicle was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (23.51 cm) (Table 4). Cheema *et al.* (2006) observed that plant height showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Zinc likely optimizes the availability of this essential micronutrient, enhancing the plant's physiological processes such as enzyme activation and hormone production, which are crucial for growth and development. At 0 kg ha^{-1}, zinc deficiency may limit these processes, while at 15 kg ha^{-1}, excess zinc could potentially cause toxicity or nutrient imbalance, both of which can negatively impact panicle length (Ganesh *et al.,* 2023). Verma *et al.* (1999) observed that panicle size showed positive correlation with the increase in $ZnSO_4$ levels from 10-40 kg ha^{-1}.

4.3.2 Effect of application time

The panicle length showed significant due to different time application of zinc fertilizer. ($p < 0.01$). The longest panicle was recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (25.34 cm) statistically alike to T_3 (application of Zinc at dough stage at 75 DAT) treatment (24.89 cm). The shortest panicle was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (24.41 cm) (Table 5). Similar result was recorded by Singh *et al.,* 2022. Zinc application is most effective at the panicle initiation stage in rice because it supports crucial processes like cell division and growth, leading to better grain formation and yield. During the tillering and dough stages, the demand for zinc is lower, making its application less impactful on overall plant development and productivity (Verma *et al.,* 2022).

4.3.3 Combined effect of time and dose

The interaction of the different amount of zinc fertilizer and application time of zinc displayed the significant difference among the treatment combinations for panicle length ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg zinc at panicle initiation stage at 50 DAT) recorded the longest panicle (27.37 cm) statistically alike to Zn_3T_3 (26.47 cm) followed by Zn_3T_1 (26.05 cm). The shortest panicle (22.65 cm) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT) (Table 6). Sultana, 2021 studied the effect of Zinc on rice verities at different doses and at different application time resulted that application of moderate dose of zinc at panicle initiation stage gave the best result.

4.4 Filled grain panicle^{-1}

4.4.1 Effect of dose

Significant variation was recorded from the different level of zinc fertilizer application for the filled grain panicle^{-1} of rice (P<0.01). The maximum filled grain panicle^{-1}(186.52) was recorded from Zn_3 (10 kg Zn ha^{-1}) followed by Zn_4 (15 kg Zn ha^{-1}) (178.65) and Zn_2 (5 kg Zn ha^{-1}) (164.54). The minimum filled grain panicle^{-1} was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (149.63) (Table 4). Zinc increases filled grain per panicle because it optimizes the availability of zinc, which is crucial for enzyme activation and chlorophyll production, thereby enhancing grain filling. In contrast, 0 and 5 kg ha^{-1} may be insufficient for optimal plant growth, while 15 kg ha^{-1} might lead to zinc toxicity or nutrient imbalances, reducing overall plant health and grain filling (Dore *et al.,* 2018). Lei *et al.* (2017) reported that exogenous application of mixed micro-nutrients Zn notably increased filled grains.

4.4.2 Effect of application time

Significant differences were seen in the filled grain panicle^{-1} due to the varying timing of zinc fertilizer application ($p < 0.01$). The top most filled grain panicle^{-1} was recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (175.38) statistically alike to T_3 (application of Zinc at dough stage at 75 DAT) treatment (170.65). The lowest filled grain panicle^{-1}was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (163.48) (Table 5). Filled grain panicle^{-1} is higher when zinc is applied during the panicle initiation stage of rice because this stage is crucial for the development of the reproductive organs, which directly influence grain filling. Adequate zinc during this stage enhances enzyme activities and hormonal balances necessary for proper grain formation. In contrast, applications at the tillering and dough stages are less effective because the critical processes for grain development have either not yet begun or are already complete (Kumar *et al.,* 2022).

4.4.3 Combined effect of dose and time

There was a substantial difference in the treatment combinations for filled grain panicle^{-1} due to the varying amounts of zinc fertilizer the variable application time of zinc ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg zinc at panicle initiation stage at 50 DAT) recorded the highest filled grain panicle^{-1} (196.18) statistically alike to Zn_3T_3 (188.74) followed by Zn_3T_1 (26.05 cm). The Zn_1T_1 treatment resulted in the lowest filled grain panicle^{-1} (144.95), which was recorded when 0 Kg of zinc was applied at the tillering stage at 25 DAT (Table 6). Rani, 2021 recorded the alike result in her experiment at Sher-E-Bangla Agricultural University, Dhaka where she mentioned that application of zinc at panicle initiation stage displayed the best performance.

4.5 Sterile grain panicle^{-1}

4.5.1 Effect of dose

The sterile grain panicle^{-1}showed substantial difference among the different level of zinc application ($p < 0.01$). The highest sterile grain panicle^{-1}was recorded from control/Zn_1 (0 Kg K ha^{-1}) treatment (28.44) followed by Zn_4 (15 kg Zn ha^{-1}) and Zn_2 (5 kg Zn ha^{-1}) (21.73 and 18.56 respectively). The lowest sterile grain panicle^{-1}was recorded from Zn_3 (10 kg Zn ha^{-1}) treatment (12.42) (Table 4).

4.5.2 Effect of application time

The sterile grain panicle^{-1} showed significant due to different time application of zinc fertilizer ($p < 0.01$). The highest sterile grain panicle^{-1} was recorded from control/T_1 (application of zinc at tillering stage at 25 DAS) treatment (23.16). The treatment with the lowest sterile grain panicle^{-1} was T_3, where Zinc was applied at the dough stage at 75 DAT, with a recorded value of 19.91. This value was statistically similar to the T_2 treatment, where Zinc was applied at the panicle commencement stage at 50 DAT, with a recorded value of 17.79 (Table 5).

4.5.3 Combined effect of dose and time

There was a significant difference in sterile grain panicle^{-1} among the treatment combinations due to the varying amounts of zinc fertiliser and the timing of its application ($p < 0.05$). The Zn_1T_1 combinations (Application of 0 Kg zinc at tillering stage at 25 DAT) recorded the maximum sterile grain panicle^{-1} (33.043) statistically different from other treatments. The lowest sterile grain panicle^{-1} was seen in the Zn_3T_2 treatment (10.31), followed by Zn_3T_3 (12.31) and Zn_3T_1 (14.64) (Table 6).

4.6 1000-grain weight (g)

4.6.1 Effect of dose

A substantial variation was seen in the 1000-grain weight of the rice variety under varying levels of zinc fertiliser application ($p < 0.01$). The highest 1000-grain weight was observed in the Zn_3 treatment (10 kg Zn ha^{-1}) with a weight of 10.35g, followed by Zn_4 treatment (15 kg Zn ha^{-1}) with a weight of 10.19g, which was statistically similar to the Zn_2 treatment (5 kg Zn ha^{-1}) with a weight of 10.15g. The control/Zn_1 treatment (0 Kg Zn ha^{-1}) had the lowest observed 1000-grain weight, with a value of 10.01 g (Table 4). Application of zinc increases the 1000-grain weight because it provides an optimal level of zinc necessary for enzyme activation and metabolic processes essential for grain development. Lower or higher levels of zinc might result in deficiency or toxicity, respectively, which can hinder these processes and negatively affect grain weight (Talib *et al.,* 2016). Hasan 2021, observed from earlier experiment that 1000 grain weight showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

4.6.2 Effect of application time

The 1000-grain weight exhibited a notable variation as a result of the varying period of zinc fertiliser administration ($p < 0.01$). The maximum 1000-grain weight recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (10.32 g) followed by T_3 (application of Zinc at dough stage at 75 DAT) treatment (10.15 g). The lowest 1000-grain weight was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (10.05 g) (Table 5). The application of zinc at the panicle initiation stage in rice leads to higher 1000-grain weight because this stage is crucial for the development and filling of grains. Zinc plays a key role in enzyme activation and carbohydrate metabolism, which are vital for grain development. Applying zinc at this stage ensures optimal nutrient availability during critical phases of grain formation, unlike the tillering and dough stages where the benefits of zinc on grain weight are less pronounced (Sucharita *et al.,* 2023).

4.6.3 Combined effect of dose and time

The interaction of the different amount of zinc fertilizer and application time of zinc displayed the significant variation among the treatment combinations for 1000-grain weight ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg zinc at panicle initiation stage at 50 DAT) recorded the topmost 1000-grain weight (10.56 g). The lowest 1000-grain weight (9.76 g) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT) (Table 6). The rest of the treatment combination showed the statistically alike performance to each other. Sudha *et al.*, 2015 stated that application of zinc increased the grain and straw yields by 14 and 16 percent (%) respectively.

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

4.7.1 Effect of dose

There was a notable variation in grain production among the various levels of zinc application ($p < 0.01$). The highest grain yield was recorded from Zn_3 (10 kg Zn ha^{-1}) treatment (1.67 t ha^{-1}) statistically similar with Zn_4 (15 kg Zn ha^{-1}) (1.61 t ha^{-1}). Next to it Zn_2 (5 kg Zn ha^{-1}) produced the intermediate result (1.50 t ha^{-1}). The lowest grain yield was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (1.30 t ha^{-1}) (Figure 2). Zinc likely increases grain yield because it provides an optimal balance of this essential micronutrient, enhancing plant growth and development. In contrast, 0 kg ha^{-1} results in a deficiency, while 15 kg ha^{-1} may cause toxicity or nutrient imbalances, both of which can inhibit optimal crop performance (Hussan *et al.*, 2021). Cheema *et al.* (2006) observed that paddy yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

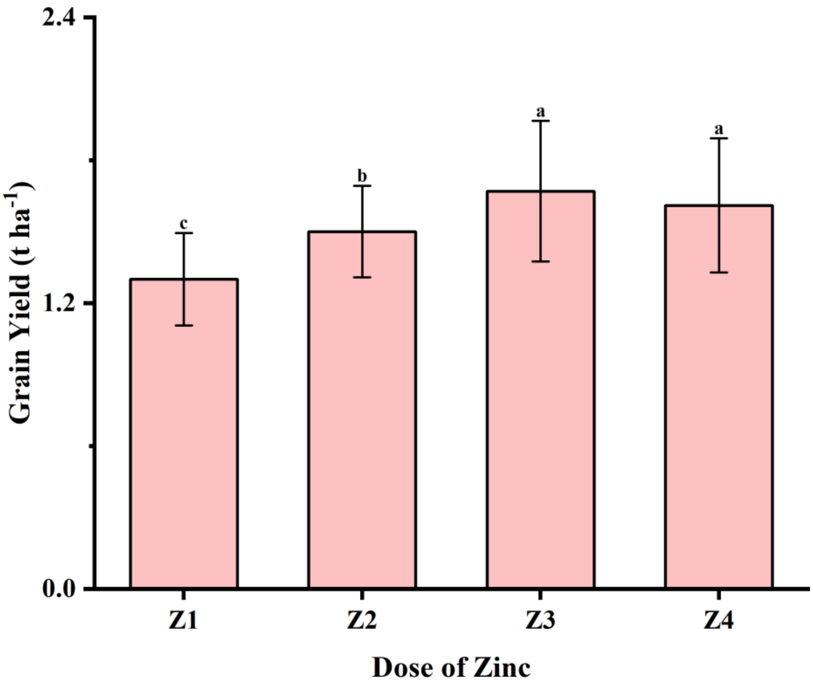

Figure 2: Effect of different doses of zinc on grain yield (t ha^{-1})

4.7.2 Effect of application time

The grain yield exhibited a notable variation as a result of the varying timing of zinc fertiliser application ($p < 0.01$). The top most grain yield recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (1.63 t ha^{-1}) followed by T_3 (application of Zinc at dough stage at 75 DAT) treatment (1.52 t ha^{-1}). The T_1 treatment, which involved applying zinc during the tillering stage at 25 DAS, resulted in the lowest grain yield of 1.40 t ha^{-1} (Figure 3). Grain yield in rice is higher when zinc is applied at the panicle initiation stage because this timing ensures optimal zinc availability during critical periods of reproductive development, enhancing grain formation and filling. Zinc application at the tillering or dough stages is less effective as the nutrient needs during these phases are different, and zinc's role in earlier developmental stages is crucial for maximizing yield potential (Kandil *et al.,* 2022).

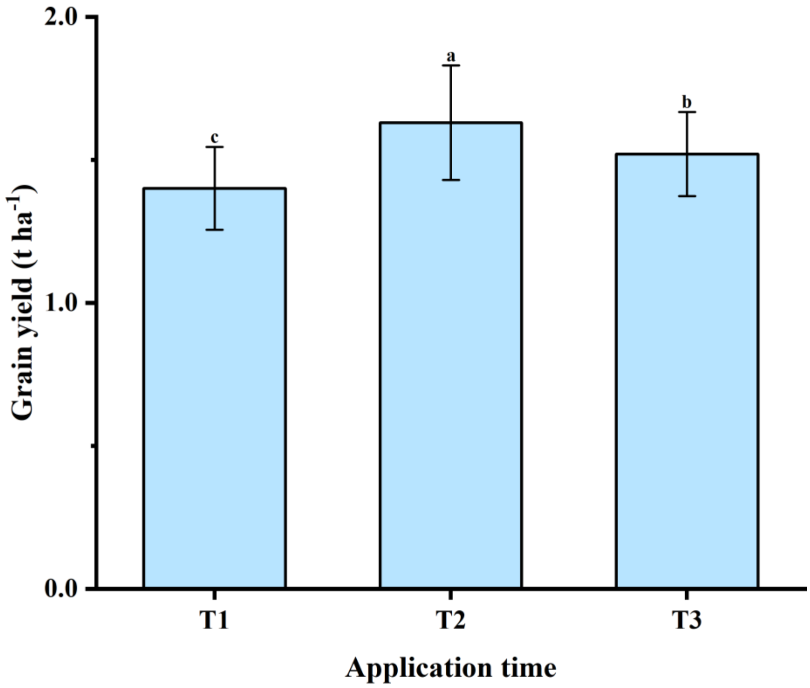

Figure 3: Effect of different application time of zinc on grain yield (t ha^{-1})

4.7.3 Combined effect of dose and time

There was a considerable difference in grain production among the treatment combinations due to the varying amounts of zinc fertiliser and the timing of its application ($p < 0.05$). The combinations of Zn_3T_2, which involved the application of 10 kg ha^{-1} of zinc at the panicle start stage at 50 days after transplanting, resulted in the highest grain yield of 1.90 t ha^{-1}. This was followed by Zn_3T_3 and Zn_4T_2, both of which had a grain yield of 1.66 tonnes per hectare. The lowest grain yield (1.16 t ha^{-1}) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT)

(Figure 4). In a study conducted in 2021, Sultana investigated the impact of several dosages of Zinc on different varieties of rice. The findings revealed that applying a modest amount of Zinc during the panicle start stage yielded the most favourable outcome.

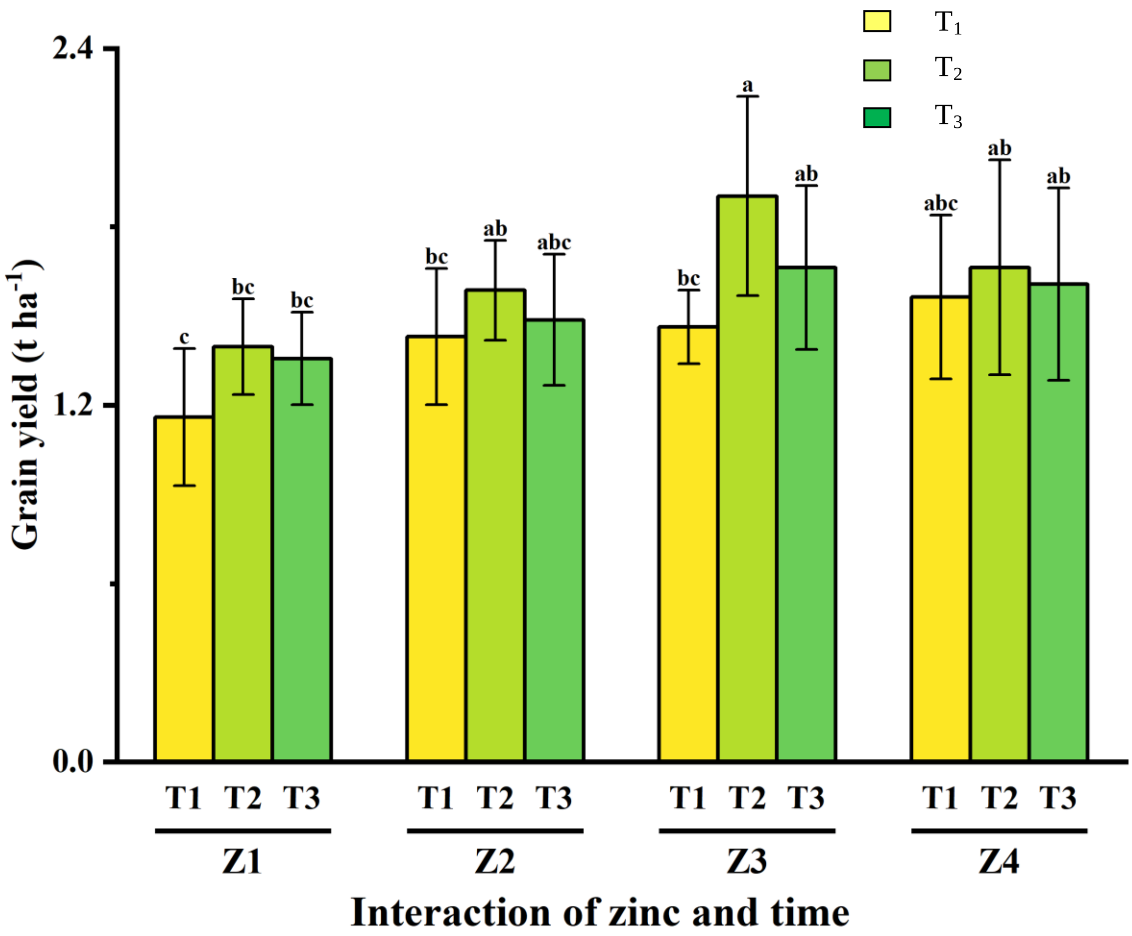

Figure 4: Effect of interaction of different dose and application time of zinc on grain yield (t ha^{-1})

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

4.8.1 Effect of dose

There was a significant variation in straw yield among the varied levels of zinc application ($p < 0.01$). The highest straw yield was recorded from Zn_3 (10 kg Zn ha^{-1}) treatment (4.36 t ha^{-1}) statistically similar with Zn_4 (15 kg Zn ha^{-1}) (4.34 t ha^{-1}) and Zn_2 (5kg Zn ha^{-1}) (4.29 t ha^{-1}). The control treatment, which received 0 Kg Zn ha^{-1}, had the lowest straw yield of 4.21 t ha^{-1}, which was statistically equal to the yield of Zn_2 treatment (Table 7). Application of zinc optimally balances the nutrient needs of the crop, enhancing growth processes such as photosynthesis and enzyme activity, which contribute to higher straw yield. Straw yield showed positive correlation with the increase in $ZnSO_4$ levels upto to 10 kg ha^{-1} (Amanullah *et al.*, 2020).

Table 7: Effect of various amount of zinc on straw yield (t ha^{-1}), biological yield (t ha^{-1}), and harvest index (%) of aromatic rice cv Tulsimala

Dose of Zinc	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Zn_1	4.21 b	4.85 c	26.78 c
Zn_2	4.29 ab	4.93 bc	30.35 b
Zn_3	4.36 a	5.08 a	32.78 a
Zn_4	4.34 a	4.98 ab	32.18 a
CV (%)	4.03	4.20	5.48
LSD	0.08	0.10	1.63
LS	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
Zn_1=control
Zn_2=5 kg ha^{-1}
Zn_3=10 kg ha^{-1}
Zn_4=15 kg ha^{-1}

4.8.2 Effect of application time

The straw yield showed significant due to different time application of zinc fertilizer ($p < 0.01$). The top straw yield recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (4.37 t ha^{-1}) followed by T_3 (application of Zinc at dough stage at 75 DAT) treatment (4.31 t ha^{-1}). The lowest straw yield was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (4.21 t ha^{-1}) (Table 8). Straw yield in rice is higher when zinc is applied during the panicle initiation stage because this stage is crucial for the development of reproductive organs, leading to better nutrient uptake and growth. Zinc application during this period enhances enzyme activity and hormone production, which are essential for vigorous plant growth and increased biomass (Kumar *et al.*, 2022).

Table 8: Effect of various time of zinc application on straw yield (t ha^{-1}), biological yield (t ha^{-1}), and harvest index (%) of aromatic rice cv Tulsimala

Time of Application	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	4.21 b	4.85 c	28.78 b
T_2	4.37 a	5.08 a	32.05 a
T_3	4.31 a	4.95 b	30.74 a
CV (%)	4.03	4.20	5.48
LSD	0.07	0.09	1.41
LS	**	**	**

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,
T_1 = application of zinc at the tillering stage at 25 DAT
T_2 = application of zinc at the panicle stage at 50 DAT
T_3 = application of zinc at the dough stage at 75 DAT

4.8.3 Combined effect of dose and time

The interaction of the different amount of zinc fertilizer and application time of zinc displayed the significant difference among the treatment combinations for straw yield ($p < 0.05$). The Zn_3T_2 combinations, which involved applying 10 Kg ha^{-1} of zinc at the panicle initiation stage at 50 DAT, resulted in the highest grain production of 4.45 t ha^{-1}. This yield was statistically similar to certain other treatment combinations. The lowest straw grain yield (4.00 t ha^{-1}) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT) statistically similar to Zn_1T_2, Zn_1T_3, Zn_2T_2 and Zn_4T_1 (Table 9). In 2021, Rani conducted an experiment at Sher-E-Bangla Agricultural University in Dhaka -1207. She found that applying zinc during the panicle starting stage yielded the most favourable results.

Table 9: Combined effect of various amount of zinc and its different application time on straw yield (t ha^{-1}), biological yield (t ha^{-1}), and harvest index (%) of aromatic rice cv. Tulsimala

Interaction of Zinc and Application Time		Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
	T_1	4.00 c	4.64 c	24.88 f
Zn_1	**T_2**	4.03 c	4.98 b	27.96 e
	T_3	4.06 c	4.92 b	27.49 ef
	T_1	4.26 bc	4.87 b	29.23 de
Zn_2	**T_2**	4.34 ab	5.01 b	31.61 bcd
	T_3	4.34 ab	4.90 b	30.21 cde
	T_1	4.33 b	4.90 b	29.79 cde
Zn_3	**T_2**	4.45 a	5.34 a	35.42 a
	T_3	4.36 ab	5.00 b	33.13 ab
	T_1	4.28 bc	4.98 b	31.22 bcd
Zn_4	**T_2**	4.37 ab	4.98 b	33.20 ab
	T_3	4.34 ab	4.97 b	32.11 bc
CV (%)		4.03	4.20	5.48
LSD		0.14	0.18	2.83
LS		*	*	*

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.

Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
NS=Not Significant
LS= Level of significance
CV-Co-efficient of variance
LSD=Least Significant Difference
Here,

Zn_1T_1= 0 kg ha^{-1} of Zinc (control) at 25 DAT
Zn_1T_2= 0 kg ha^{-1} of Zinc (control) at 50 DAT
Zn_1T_3= 0 kg ha^{-1} of Zinc (control) at 75 DAT
Zn_2T_1= 5 kg ha^{-1} of Zinc at 25 DAT
Zn_2T_2= 5 kg ha^{-1} of Zinc at 50 DAT
Zn_2T_3= 5 kg ha^{-1} of Zinc at 75 DAT
Zn_3T_1= 10 kg ha^{-1} of Zinc at 25 DAT
Zn_3T_2= 10 kg ha^{-1} of Zinc at 50 DAT
Zn_3T_3= 10 kg ha^{-1} of Zinc at 75 DAT
Zn_4T_1= 15 kg ha^{-1} of Zinc at 25 DAT
Zn_4T_2= 15 kg ha^{-1} of Zinc at 50 DAT
Zn_4T_3= 15 kg ha^{-1} of Zinc at 75 DAT

4.9 Biological yield (t ha^{-1})

4.9.1 Effect of dose

There was a notable variation in the biological yield among the various levels of zinc application ($p < 0.01$). The highest biological yield was recorded from Zn_3 (10 kg Zn ha^{-1}) treatment (5.08 t ha^{-1}) statistically similar with Zn_4 (4.98 t ha^{-1}). The lowest biological yield was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (4.85 t ha^{-1}) statistically similar Zn_2 (4.93 t ha^{-1}) (Table 7). A 10 kg ha^{-1} application of zinc may optimize the nutrient balance in the soil, promoting better plant growth and higher biological yield compared to 0 and 5 kg ha^{-1}, where zinc levels might be insufficient. At 15 kg ha^{-1}, however, zinc could reach toxic levels or cause nutrient imbalances, negatively impacting plant health and yield (Hasan, 2021).

4.9.2 Effect of application time

The biological yield showed significant due to different time application of zinc fertilizer ($p < 0.01$). The highest biological yield recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (5.08 t ha^{-1}) followed by T_3 (application of Zinc at dough stage at 75 DAT) treatment (4.95 t ha^{-1}). The T_1 treatment, which involved the administration of zinc during the tillering stage at 25 DAS, resulted in the lowest biological output of 4.85 t ha^{-1} (Table 8). Biological yield is higher when zinc is applied at the panicle initiation stage of rice because this stage is crucial for the development of reproductive structures, leading to better nutrient assimilation and improved grain formation. In contrast, applying zinc at tillering or dough stages is less effective as the critical growth and nutrient uptake phases have already passed, limiting the potential impact on overall yield (Kumar *et al.*, 2022).

4.9.3 Combined effect of dose and time

There was a considerable difference in the biological yield among the treatment combinations due to the varying amounts of zinc fertiliser and the timing of its application ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg zinc at panicle initiation stage at 50 DAT) recorded the topmost biological yield (5.34 t ha^{-1}) statistically dissimilar to other treatments. The minimum biological yield (4.64 t ha^{-1}) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT) statistically also dissimilar to other treatments (Table 9). Rest of the treatments showed statistically alike performance. Sultana did a study in 2021 to examine the effects of various doses of Zinc on different types of rice. The results indicated that the application of a moderate quantity of Zinc during the panicle initiation stage produced the most favorable result.

4.10 Harvest index (%)

4.10.1 Effect of dose

The harvest index showed significant difference among the different level of zinc application ($p < 0.01$). The highest harvest index was recorded from Zn_3 (10 kg Zn ha^{-1}) treatment (32.78%) statistically similar with Zn_4 (15 kg Zn ha^{-1}) (32.18%). Next to it, Zn_2 (5 kg Zn ha^{-1}) (30.35%) recorded the intermediate result. The lowest harvest index was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (26.78) (Table 7). Cheema *et al.*

(2006) observed that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Zinc increases the Harvest Index (HI) by optimizing zinc availability, which enhances crucial physiological processes such as photosynthesis, enzyme activation, and protein synthesis. This balanced zinc application promotes better biomass allocation towards the grain rather than the vegetative parts compared to the suboptimal or excessive applications. Thus, the optimal zinc level at 10 kg ha^{-1} improves the efficiency of resource utilization, leading to a higher proportion of harvested grain mass relative to the total biomass (Baral *et al.*, 2023).

4.10.2 Effect of application time

The harvest index showed significant due to different time application of zinc fertilizer ($p < 0.01$). The maximum harvest index recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (32.05%) followed by T_3 (application of Zinc at dough stage at 75 DAT) treatment (30.74%). The bottommost harvest index was recorded from T_1 (application of zinc at tillering stage at 25 DAS) treatment (28.78%) (Table 8). Harvest index (%) is high when zinc is applied at the panicle initiation stage of rice because this timing optimizes nutrient uptake during the critical phase of reproductive development, enhancing grain filling and overall yield. In contrast, zinc application during the tillering and dough stages does not significantly influence the yield components as effectively, leading to a lower harvest index (Kumar *et al.,* 2022).

4.10.3 Combined effect of dose and time

There was a considerable difference in the harvest index among the treatment combinations due to the varying amounts of zinc fertiliser and the timing of its application ($p < 0.05$). The Zn_3T_2 combinations (Application of 10 Kg zinc at panicle initiation stage at 50 DAT) recorded the topmost harvest index (35.42%) statistically similar to Zn_3T_3, Zn_4T_2. The minimum harvest index (24.88%) was recorded from Zn_1T_1 treatment (Application of 0 Kg zinc at tillering stage at 25 DAT) statistically similar to Zn_1T_3 (27.49 %) (Table 9). In their study, Sudha *et al.* (2015) reported that the use of zinc resulted in a 14% increase in grain yield and a 16% increase in straw output.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at Agronomy Research Field, Hajee Mohammad Danesh Science and Technology, Dinajpur during July 2023 to December 2023 to assess the effect of different levels of zinc fertilizer and different growth stage of aromatic rice cv Tulsimala.

The experiment consisted with two factors namely Factor-A consisted four doses such as Zn_1 (control), Zn_2 (5 kg ha^{-1}), Zn_3 (10 kg ha^{-1}) and Zn_4 (15 kg ha^{-1}) as zinc and factor-B consisted three application time of zinc such as T_1 (application of zinc at tillering stage at 25 DAT), T_2 (application of zinc at panicle stage at 50 DAT), and T_3 (application of zinc at dough stage at 75 DAT). The planting material of the experiment was rice (Tulsimala). The experiment was laid out in a randomized complete block design with 12 treatment combinations, each treatment replicated three times. The treatments were randomly distributed to the plots within a block. The size of each plot was 4m× 3m. During the study period, various growth, yield and yield contributing parameters including plant height, number of effective tillers $hill^{-1}$, panicle length (cm), filled grain $panicle^{-1}$, sterile grain $panicle^{-1}$, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), Biological yield (t ha^{-1}) and Harvest index (%) were recorded. The statistical analysis was conducted using the Least Significant Difference Test (LSD) at a significance level of 5%. The Statistix10 computer package programme was used to determine the significance of the differences among the means of the treatments.

The application of various amount of zinc fertilizer resulted in a notable among the studied parameters of the selected rice variety. The plant height at 25 DAT showed insignificant variation among them. At 50, 75 DAT and harvest the highest plant height was recorded from Zn_4 (91.45, 131.41 and 162.58 cm respectively). On the other hand, the control treatment gave the dwarf plant at the 50, 75 DAT, and harvest (82.58, 116.30 and 151.22 cm, respectively).The highest number of effective tillers $hill^{-1}$ (18.34) was recorded from Zn_3 (10kg Zn ha^{-1}). The lowest number of effective tillers $hill^{-1}$(14.31) was found Z_1 treatment. The longest panicle (26.63 cm) was recorded from Zn_3 (10 kg Zn ha^{-1}) followed by Zn_4 (15 kg Zn ha^{-1}). The shortest panicle was recorded from control/Zn_1 (0 Kg Zn ha^{-1}) treatment (23.51 cm). The maximum filled grain $panicle^{-1}$ (186.52) was recorded from Zn_3 followed by Zn_4 (178.65). The minimum filled grain $panicle^{-1}$ was recorded from Zn_1 (149.63). The highest sterile grain $panicle^{-1}$ was recorded from control treatment (28.44) followed by Zn_4 (15 kg Zn ha^{-1}) and Zn_2 (21.73

and 18.56 respectively). The lowest sterile grain panicle^{-1} was recorded from Zn_3 treatment (12.42). The highest 1000-grain weight was observed in the Zn_3 treatment with a weight of 10.35g, followed by Zn_4 treatment. The control treatment had the lowest observed 1000-grain weight (10.01 g). The highest grain yield was recorded from Zn_3 treatment (1.67 t ha^{-1}) statistically similar with Zn_4 (1.61 t ha^{-1}). The lowest grain yield was recorded from control treatment (1.30 t ha^{-1}). The highest straw yield was recorded from Zn_3 treatment (4.36 t ha^{-1}) statistically similar with Zn_4 (4.34 t ha^{-1}. The Zn_1 treatment had the lowest straw yield of 4.21 t ha^{-1}, which was statistically equal to the yield of Zn_2 treatment. The highest biological yield was recorded from Zn_3 treatment (5.08 t ha^{-1}) statistically similar with Zn_4 (4.98 t ha^{-1}). The lowest biological yield was recorded from control treatment (4.85 t ha^{-1}). The highest harvest index was recorded from Zn_3 treatment (32.78%) statistically similar with Zn_4 (32.18%) while the lowest harvest index was recorded from control treatment (26.78%).

Considering the time of zinc fertilizer application, the plant height at 25 DAS showed insignificant variation among the treatments. At 50 DAT the top plant height was recorded from T_1 (94.171 cm) and lowest from T_2 (83.69 cm). At 75 DAT, and harvest the highest plant height was recorded from T_2 (133.79, and 162.59 cm respectively). The highest number of effective tiller (17.92) was recorded from T_2. The longest panicle was recorded from T_2 (application of Zinc at panicle initiation stage at 50 DAT) treatment (25.34 cm) statistically alike to T_3 (application of Zinc at dough stage at 75 DAT) treatment (24.89 cm). The shortest panicle was recorded from control/T_1 (application of zinc at tillering stage at 25 DAS) treatment (24.41 cm). The top most filled grain panicle^{-1} was recorded from T_2 treatment (175.38) statistically alike to T_3 treatment (170.65). The lowest filled grain panicle^{-1} was recorded from T_1 treatment (163.48). The maximum sterile grain panicle^{-1} was recorded from T_1 treatment (23.16). The treatment with the lowest sterile grain panicle^{-1} was T_2 (17.79). The top most 1000-grain weight recorded from T_2 treatment (10.32 g) followed by T_3 treatment (10.15 g). The lowest 1000-grain weight was recorded from T_1 (treatment (10.05 g). The top grain yield recorded from treatment T_2 (1.63 t ha^{-1}) followed by T_3 treatment (1.52 t ha^{-1}). The T_1 treatment, which involved applying zinc during the tillering stage at 25 DAS, resulted in the lowest grain yield of 1.40 t ha^{-1}. The highest straw yield recorded from T_2 treatment (4.37 t ha^{-1}) followed by T_3 (4.31 t ha^{-1}). The lowest straw yield was recorded from T_1 treatment (4.21 t ha^{-1}). The top most biological yield recorded from T_2 treatment (5.08 t ha^{-1}) followed by T_3 treatment (4.95 t ha^{-1}). The T_1 treatment, which involved the administration of zinc during the tillering stage at 25 DAS, resulted in the lowest biological output of 4.85 t ha^{-1}. The top harvest index recorded from T_2 treatment (32.05%) while the bottommost harvest index was recorded from T_1 treatment (28.78%).

Considering the combined application of zinc at different date, all treatment combinations gave the statistically alike performance among them at 25 DAT. At 50 DAT, Zn_4T_1 gave the maximum plant height (100.14 cm) statistically alike to Zn_3T_1. However, Zn_4T_2 gave the best result (142.13 and 172.26 cm respectively) while lowest value was recorded from control treatment combinations (40.08, 84.59, 115.40 and 150.61 cm, respectively) at 25, 50, 75 and harvest time. However, The Zn_3T_2 combinations (Application of 10 Kg ha^{-1} zinc at panicle initiation stage at 50 DAT) recorded the highest number of tillers $hill^{-1}$ (19.80) followed by Zn_4T_2 (19.09), the longest panicle (27.37 cm) statistically alike to Zn_3T_3 (26.47 cm) followed by Zn_3T_1 (26.05 cm). The shortest panicle (22.65 cm) was recorded from Zn_1T_1 treatment combinations (Application of 0 Kg zinc at tillering stage at 25 DAT). The Zn_3T_2 combinations recorded the highest filled grain $panicle^{-1}$ (196.18) statistically alike to Zn_3T_3 (188.74) while the Zn_1T_1 treatment combinations resulted in the lowest filled grain $panicle^{-1}$ (144.95). The Zn_1T_1 combinations recorded the maximum sterile grain $panicle^{-1}$ (33.04) but the lowest sterile grain $panicle^{-1}$ was found in the Zn_3T_2 treatment (10.31). The Zn_3T_2 combinations recorded the topmost 1000-grain weight (10.56 g) while the lowest 1000-grain weight (9.76 g) was recorded from Zn_1T_1 treatment combinations. The combinations of Zn_3T_2 resulted in the highest grain yield of 1.90 t ha^{-1} but the lowest grain yield (1.16 t ha^{-1}) was recorded from Zn_1T_1 treatment combinations. The Zn_3T_2 combinations gave in the highest grain production of 4.45 t ha^{-1}. The lowest straw grain yield (4.00 t ha^{-1}) was recorded from Zn_1T_1 treatment combinations statistically similar to Zn_1T_2, Zn_1T_3, Zn_2T_2 and Zn_4T_1.The Zn_3T_2 combinations recorded the topmost biological yield (5.34 t ha^{-1}) but the minimum biological yield (4.64 t ha^{-1}) was recorded from Zn_1T_1 treatment combinations. The Zn_3T_2 combinations recorded the topmost harvest index (35.42%) but the minimum harvest index (24.88%) was recorded from Zn_1T_1 treatment combinations statistically similar to Zn_1T_3 (27.49 %).

Conclusion

Considering the above discussions, it can be concluded that the application of 10 kg ha^{-1} zinc at the panicle initiation stage of aromatic rice would be beneficial and economic for the best-performing Tulsimala aromatic rice variety in Bangladesh.

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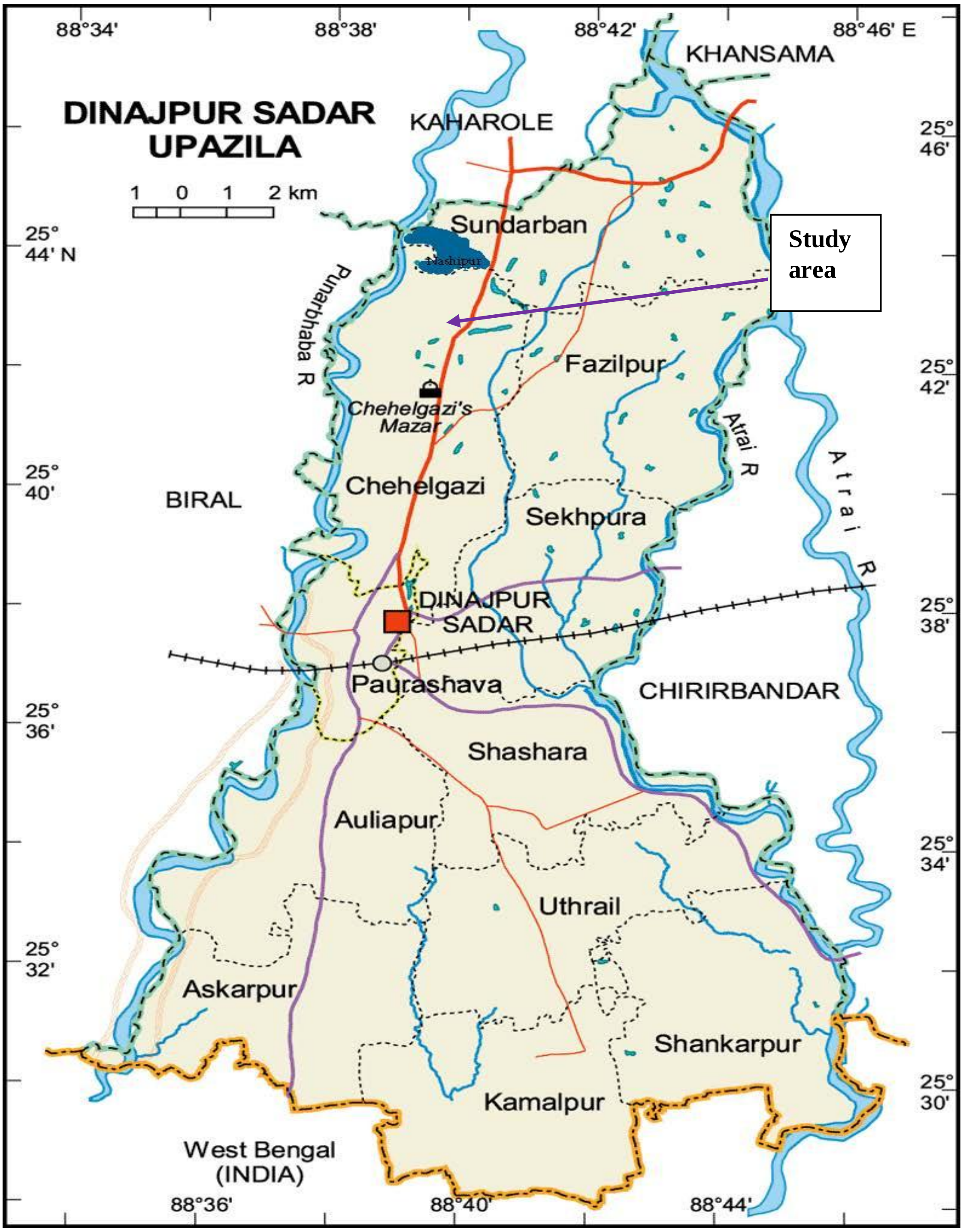
APPENDICES

Appendix I. Location of the experimental site



Appendix II: Mean temperature, rainfall and humidity during research period (June 2023-November 2023)

Months	Temperature (^oc)	Rainfall (mm)	Humidity (%)
June	29	361.9	83
July	29	425.2	84
August	29	372.9	84
September	29	440.0	85
October	26	122.7	82
November	23	9.2	76

Appendix III: Fertilizer used in research, their doses and percentage of active ingredient

Fertilizer	Doses (kg ha^{-1})	Active ingredient (%)
Urea	260	46 (N)
TSP	75	44-46 (P_2O_5)
MOP	90	60 (K_2O)
Gypsum	4	18 (S)

Appendix IV: Morphological, physical and chemical characteristics of soil of experimental field

i. Morphological characteristics of soil

Morphological parameters	characteristics
Location	Agronomy research field, HSTU, Dinajpur
Agro-ecological Zone (AEZ-1)	Old Himalayan Piedmont Plain
Geographical position	25^o38 N latitude and 88^o41 E lonitudes
General soil types	Non-calcareous dark gray floodplain soil
Parent materials	Old Brahmaputrs River borne Deposit
Land type	Medium high land
Elevation	37 meter above the mean sea level
Drainage	Well drained
Cropping Pattern	Rice crop grown year round
Topography	Fairly leveled

ii. Physical characteristics of soil

Characteristics	Value (%)
Sand	58
Silt	28
Clay	14
Soil textural class	Sandy loam

iii. Chemical properties of soil

Characteristics	Value (%)
pH (soil : water = 1: 1.25)	5.41
Organic matter	1.25
Organic Carbon	0.72
Total N	0.08
Available P (ppm)	11.20
Exchangeable P (meq)	0.10
Exchangeable Ca (meq)	2.48
Exchangeable Mg (meq)	2.29
Available S (ppm)	17.29
Available B (ppm)	0.13
Available Zn (ppm)	0.90
Available Fe (ppm)	51.90
Available Mn (ppm)	12.13

Appendix V: Analysis of variance (ANOVA) (Mean Squares) for plant height of aromatic rice

Source of variation	Degree of Freedom	Mean Squares			
		25 DAT	50 DAS	75 DAS	At harvest
Factor A	3	3.88^{NS}	123.21**	385.52**	227.29**
Factor B	2	8.48^{NS}	435.71**	693.24**	197.84**
Factor AB	6	6.14^{NS}	32.42*	90.52*	40.12*
Error	22	11.48	7.86	5.22	4.61
CV (%)		8.40	3.22	4.82	3.36

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV = Co-efficient of variance
Factor A-Dose of Zn fertilizer
Factor B- Application time of Zn fertilizer
Factor AB= Zn, dose and application time

Appendix VI: Analysis of variance (ANOVA) (Mean Squares) for number of effective tillers hill^{-1}, panicle length, filled grains panicle^{-1}, seed yield, thousand grain weight and filled grain panicle^{-1} of aromatic rice

Source of variation	Degree of Freedom	Mean Squares					
		Effective tillers hill^{-1}	Panicle Length	Filled grains panicle^{-1}	Seed yield	Thousand grain weight	Filled grain panicle^{-1}
Factor A	3	29.94**	15.43**	2377.87**	400.35**	0.50**	2377.87**
Factor B	2	10.60**	2.582**	430.17**	87.65**	0.44**	430.17**
Factor AB	6	0.66*	0.287*	35.84*	5.07*	0.16*	35.84*
Error	22	1.80	0.29	45.06	10.99	0.50	45.06
CV (%)		7.96	4.20	3.95	16.34	3.48	3.95

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV = Co-efficient of variance
Factor A-Dose of Zn fertilizer
Factor B- Application time of Zn fertilizer
Factor AB= Zn, dose and application time

Appendix VII: Analysis of variance (ANOVA) (Mean Squares) for grain yield, straw yield, biological yield and harvest index of aromatic rice

Source of variation	Degree of Freedom	Mean Squares			
		Grain yield	Straw yield	Biological yield	Harvest Index
Factor A	3	0.24^{**}	0.04^{**}	0.09^{**}	65.65^{**}
Factor B	2	0.16^{**}	0.08^{**}	0.16^{**}	32.42^{**}
Factor AB	6	0.02^{*}	0.02^{*}	0.04^{*}	2.36^{*}
Error	22	0.01	0.01	0.09	2.80
CV (%)		7.17	4.03	4.20	5.48

In a column, figure having common letter(s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV = Co-efficient of variance
Factor A-Dose of Zn fertilizer
Factor B- Application time of Zn fertilizer
Factor AB= Zn, dose and application time

Appendix VIII: Some photos of my research work

Transplanting of Tulshimala rice seedlings in my research plot

During Data Collection

Determining 1000-grain weight