EXOGENOUS APPLICATION OF LANTHANUM ON THE YIELD AND QUALITY OF AROMATIC RICE

A THESIS

BY

NISHAT TASNIM
Student No. 1701373
Session: 2023-2024
Semester: January-June 2024

MASTER OF SCIENCE
IN
AGRONOMY

DEPARTMENT OF AGRONOMY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR-5200

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DEDICATED TO

MY

BELOVED PARENTS

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The Author *June 2024*

EXOGENOUS APPLICATION OF LANTHANUM ON THE YIELD AND QUALITY OF AROMATIC RICE

ABSTRACT

The experiment was carried out at the Agronomy Research Field, Department of Agronomy, HSTU, Dinajpur during July to December 2023 to evaluate the effect of different levels of Lanthanum dose and different growth stages of aromatic rice cv. Kataribhog. The experiment consisted of two factors, namely factor A and factor B. Factor-A consisted of four doses of Lanthanum, such as L_1 (control), L_2 (100ppm), L_3 (200ppm), and L_4 (300ppm), and factor-B consisted of three application times of Lanthanum, such as T_1 (at 25 DAT i.e., tillering stage), T_2 (at 50 DAT i.e., panicle initiation stage), and T_3 (at 75 DAT i.e., dough stage). 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. During the study period, various yield and yield contributing parameters were recorded, including plant height (cm), effective tiller hill^{-1} (no.), 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 (%). The study result showed that L_4 had the tallest plant (148.08 cm at harvest) in all cases while L_3 produced the highest number of effective tiller hill^{-1} (19.94), the longest panicle (26.40 cm), the maximum total grain (184.99), the maximum filled grain panicle^{-1} (174.87), the highest 1000-grain weight (10.35 g), the highest grain yield (1.98 t ha^{-1}), biological yield (6.37 t ha^{-1}), and harvest index (30.99%). Moreover, the T_2 treatment recorded the maximum plant height (146.43 cm at harvest), the highest number of effective tiller hill^{-1} (19.14) the longest panicle length (25.11 cm), the maximum filled grain panicle^{-1} (163.72), the highest 1000-grain weight (10.32 g), grain yield (1.91 t ha^{-1}), biological yield (6.25 t ha^{-1}), and harvest index (30.38%). As combined effect of treatments, L_4T_2 combination gave the best result for plant height (153.38cm at harvest) whereas the L_3T_2 had the highest number of effective tiller hill^{-1} (21.82), the longest panicle (27.14 cm), the maximum total grain (192.53), the most filled grain panicle^{-1} (184.53), the most grain yield (2.08 t ha^{-1}), the most biological yield (6.25 t ha^{-1}) and the highest harvest index (30.38%). The experiment's results indicate that all of the important growth parameters and yield contributing characters were improved due to application of Lanthanum @ 200 ppm when applied at panicle initiation stage resulting higher yield of Kataribhog rice.

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ABBREVIATIONS AND ACRONYMS

2-AP	= 2-acetyl-1-pyrroline
AEZ	= Agro Ecological Zone
BADH2	= Betaine aldehyde dehydrogenase 2
BBS	= Bangladesh Bureau of Statistics
BINA	= Bangladesh Institute of Nuclear Agriculture
BRRI	= Bangladesh Rice Research Institute
CK	= Control
CV	= Coefficient of variation
DAC	= Days after culture
DAT	= Days after transplanting
DM	= Dry matter
DMRT	= Duncan's Multiple Range Test
EDTA	= Ethylenediamine tetraacetic acid
FAO	= Food and Agriculture Organization Statistics
FPMU	= Food Planning and Monitoring Unit
g	= Gram
GABA	= γ- Aminobutyric acid
GABald	= γ-aminobutyl aldehyde
HSTU	= Hajee Mohammad Danesh Science and Technology University
K	= Potassium
Kg	= kilogram
kg ha^{-1}	= Kilograms per hectare
La	= Lanthanum
$Lacl_3$	= Lanthanum chloride
LS	= Level of significance
LSD	= Least significant difference
m	= Meter
mmol L^{-1}	= Millimoles per liter
MoP	= Muriate of Potash
N	=Nitrogen
NS	= Non-significant
O_2	= Oxygen Gas

P	= Phosphorus
PDH	= Proline dehydrogenase
PN	= Net photosynthetic rate
ppm	= Parts Per Million
qP	= Photochemical quenching
RCBD	= Randomized complete block design
$t\ ha^{-1}$	= Tonnes per hectare
TSP	= Triple Superphosphate
USDA	= United States Department of Agriculture
UV	= ultraviolet
μM	= Micromole
$\mu mol\ L^{-1}$	= Micromoles per liter

CHAPTER I

INTRODUCTION

Aromatic rice (*Oryza sativa* L.) is well known worldwide for its unique aroma characteristic and is also highly desired by consumers, attracting premium prices in many international markets (Liu *et al.,* 2020; Luo *et al.,* 2020). Rice is a fundamental cereal crop that plays a vital role in sustaining food security for almost 50% of the world's population (Mohidem *et al.,* 2022). It supplies over nearly one fifth of the overall caloric requirements for humans and can account for up to three fourth of the caloric consumption for individuals residing in Southeast Asia (Zhao *et al.,* 2020). Bangladesh is the third largest rice-producing country in the world (FPMU, 2023), and is rich in aromatic rice cultivars. Rice is a significant provider of calories and proteins, including albumin, globulins, prolamins and glutelin (Jayaprakash *et al.*, 2022). Rice is a source of energy and contains important nutrients such as vitamin E, zinc, and iron (Rezvi *et al.,* 2022). Global consumer preferences for rice grain quality exhibit variation across different regions (Kaewmungkun *et al.*, 2022; Ndikuryayo *et al.,* 2022; Sultana *et al.,* 2022). Aroma is the primary grain quality factor that significantly affects the price of rice in both domestic and global markets (Hui *et al.,* 2022). The primary chemical constituents responsible for the taste of rice include sucrose, glucose, fructose, umami amino acids, sweet amino acids and bitter amino acids (Tanimoto *et al.* 2020). Besides representing a staple food, rice has the potential to become a source of various essential nutrients or bioactive compounds through appropriate genetic improvements to benefit human health and prevent certain chronic diseases (Zhao *et al.*, 2020)

According to Bangladesh Bureau of Statistics (BBS, 2024), the total rice cultivated area was 28755000 acres and production was 39095000 metric ton per hectare in the fiscal year 2022-23. This yield rate is comparatively lower than the other aromatic rice growing countries in the world. The increasing need for food is presenting a difficulty to worldwide food security. Consumers highly like aromatic rice by creating a strong demand for it (Ndikuryayo *et al.,* 2022). However, farmers face significant challenges from climate change as well as a decrease in available agricultural land, labor and water for farming, along with increased costs of all inputs. The primary challenge for food security is to enhance global food production while minimizing negative effects on resources and the environment (Barrett *et al.,* 2021). Despite the challenges, there are significant opportunities for promoting GAPs adoption and enhancing the sustainability of aromatic rice production in Bangladesh (Hoque *et al.*, 2024).

Post-green revolution rice yields are stagnant or declining due to challenges in crop production, including local variety preference and inadequate management and fertilization procedures (Mamun *et al.*, 2021). Bangladesh's farmers cultivate various high-quality rice varieties, including Chinisagar, Badshabhog, Kataribhog, Kalizira, Tulsimla, Dulabhog, Basmati, Banglamoti and Binadhan-13. Aromatic rice varieties often have moderate yields, but their higher market value and low cultivation expenses result in a wider profit margin compared to other types (Alibu *et al.*, 2022). The primary factors that impact the level of customer acceptability of rice are the quality of the rice grain in terms of milling, storage, cooking, eating, and nutritional content (Sultana *et al.*, 2022). Due to the change of the consumer's preference for better quality rice, the demand for aromatic rice varieties has increased globally to a great extent over the past few years (Bairagi *et al.*, 2020). But the productivity of the scented rice cultivars is rather low compared to coarse and medium rice varieties (Sinha *et al.*, 2018). In general, farmers prefer rice varieties that are high yielding, have high market value and are of short duration (Bishwas *et al.*, 2023).

The overuse of inorganic fertilizers and pesticides, without including organic fertilizers, has led to the deterioration of soil quality and a decrease in agricultural productivity (Baweja *et al.*, 2020). In Bangladesh, the practice of increased cropping and ongoing cultivation of high-yielding rice varieties has resulted in the gradual reduction of nitrogen (N), phosphorous (P), potassium (K) and other important macro and micro-nutrients from the soils (Urmi *et al.*, 2022). There are increasing concerns regarding micronutrient inadequacy in locations where intensive agriculture is practiced (Shukla *et al.*, 2022). Chemical fertilizers are crucial for rice production in modern farming. However, excessive and incorrect application of these fertilizers in the soil has been observed to initially boost yields for a limited period, but ultimately leads to significant soil deterioration in the long term (Tripathi *et al.*, 2020).

Lanthanum (La) is classified as one of the rare earth elements, which is a group consisting of 17 elements that share comparable physical and chemical properties (Si *et al.*, 2018). Kastori *et al.*, (2023) stated that Lanthanum at lower concentrations, can favorably influence certain physiological processes of plants (enzyme activity, hormone content, photosynthesis, seed germination, plant growth etc.). Luo *et al.,* (2021a) demonstrated that La improved the growth, yield formation and 2-AP content of aromatic rice and enhanced 2-AP biosynthesis by increasing the conversion of proline to 2-AP and decreasing the conversion of GABald to GABA. A previous study demonstrated that the addition of exogenous La effectively improved the harmful effects of copper on rice plants by lowering oxidative stress and enhancing the chlorophyll content (Zhong and Chen, 2020). Liang *et al.,* (2018) found that the application of La significantly increased the activity of plasma membrane H^+-ATPase in rice plants subjected to acid rain stress. Liu *et al.,* (2016) demonstrated that the addition of La^{3+} from an external source caused changes in the antioxidant system and influenced the levels of hydrogen peroxide, superoxide anion, and malondialdehyde in the roots of rice plants in their study. Mo *et al.,* (2016) demonstrated that adding La to a basic culture medium improved the performance of PDH and raised the 2-AP concentration in detached fragrant rice panicles in a laboratory setting. La possesses the capacity to augment 2-AP biosynthesis and has the potential to be employed in aromatic rice cultivation for the purpose of producing extremely aromatic rice.

However, aromatic rice is highly esteemed for its unique aroma, great flavor, and superior caliber (Roy *et al.,* 2020). The production of this particular item is significantly lower than the average production rate in the entire country. Most of the aromatic rice cultivars have low yields, are susceptible to multiple diseases and pests, and are lodged during maturity. This suggests that there is a requirement to increase the yield (Prodha and Qingyao, 2020). The increasing affluence of the population in Bangladesh has resulted in a rising need for fragrant high-quality rice (Ishfaq *et al.,* 2020). To improve the production of aromatic rice, it is necessary to carefully choose appropriate rice types and implement effective nutrient management procedures, especially micronutrients. It is essential to maintain the essence and preserve the taste of aromatic rice.

So, the experiment was undertaken with the purpose of examining

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

CHAPTER II

REVIEW OF LITERATURE

Rice is the staple food and around 90% of the rice grown and consumed in south and southeast asia, the highly populated area. Bangladesh produces several fine aromatic rice varieties and most of them have excellent eating qualities for regular consumption. Research on this crop is going on various aspects in increasing its potential yield including management practices like application of different heavy materials on growth and yield of aromatic rice. The treatment of Lanthanum, 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 Lanthanum on rice production. Some of the important and informative works and research findings related to the variety done at home and abroad have been reviewed under the following headings:

2.1 Effect of Lanthanum on plant growth and yield

Kastori *et al.,* (2023) stated that Lanthanum at lower concentrations, can favorably influence certain physiological processes of plants (enzyme activity, hormone content, photosynthesis, seed germination, plant growth etc.). They may induce an increase in some antioxidant systems and thereby increase the tolerance of plants to environmental stressors caused by high concentrations of heavy metals, herbicides, lack of water and essential nutrients, UV radiation and oxidative stress. Thus, their favorable effect was documented regarding the yield of cultivated species as well as the effect of their chemical composition on the content of vitamin C, soluble sugars and essential elements, and reduction of the concentration of toxic heavy metals.

Luo *et al.,* (2021a) investigated the effects of Lanthanum on growth, photosynthesis, yield formation and 2-AP biosynthesis in aromatic rice through three experiments they did two pot experiments and a two-year field trial with different rates of La application (20-120 $LaCl_3$ mg kg^{-1} and 12 kg ha^{-1} $LaCl_3$), and treatments without La application were used as controls. Their results showed that the application of $LaCl_3$ at 80 and 100 mg kg^{-1} and at 12 kg ha^{-1} greatly increased the 2-AP content by 6.45-43.03 % in aromatic rice seedlings and mature grains compared with the control. The La treatments also increased the chlorophyll content, net photosynthetic rate and total above ground biomass of rice seedlings. Higher antioxidant enzyme (superoxide, peroxidase and catalase) activity was detected in the La treatments than in the control. The La treatments also increased the grain yield, grain number per panicle and seed-setting rate of aromatic rice relative to the control. Moreover, the grain proline and γ-aminobutyric acid contents and the activity of betaine aldehyde dehydrogenase significantly decreased under the La treatment reported by them.

Luo *et al.,* (2021b) conducted a study, with a new organic-inorganic compound fertilizer made with organic matter, urea, superphosphate, potassium chloride, zinc sulfate and Lanthanum chloride. A four-year field experiment was conducted by them to investigate its effects on fragrant rice growth, yield formation and 2-acetyl-1-pyrroline biosynthesis. Across four experimental years, their results showed that the grain yield in Lanthanum contained treatment ranged between 5.86-8.29 t ha^{-1} and was significantly ($p < 0.05$) higher than other treatments. The improvement in grain yield due to this treatment was by increased effective panicle number per m^{-2} and seed-setting rate. The highest or equally highest chlorophyll content and the net photosynthetic rate at 20, 40, 60, and 80 days after transplanting were recorded in new formulation treatment among three treatments. Lanthanum contained treatment also increased the aboveground biomass of fragrant rice compared with other treatments. Moreover, compared with other treatments, Lanthanum contained treatment significantly ($p < 0.05$) increased grain 2-AP content by 30-38 % and 10-21 %, respectively. The contents of 2-AP related precursors, including proline and 1-pyrroline, also increased due to Lanthanum-containing treatment.

Zhong and Chen, (2020) performed a study to compared the effects of $La(NO_3)_3$ and $La(NO_3)_3$-amino acid chelates, La^{3+}-AA on growth, oxidative stress, ultrastructure, bioaccumulation and gene expression in rice. Results demonstrated that 20 mg L^{-1} La(III)-AA can effectively ameliorate $CuSO_4$ (50 mg L^{-1}) stress in rice by reducing oxidative stress and increasing chlorophyll content, thus promoting growth. Exogenous La(III)-AA decreased Cu(II) content in rice leaves, stems and roots by 55.56%, 59.46% and 26.29%, and ameliorated Cu(II) damage by maintaining the ultrastructure of mesophyll cells.

A study was conducted by (Si *et al.*, 2018) to evaluate the effects of Lanthanum and acid rain stress on the bio-sequestration of Lanthanum in phytoliths in germinated rice seeds. In this study, a high-silicon accumulation crop, rice (*Oryza sativa* L.), was selected as a representative of plants, and orthogonal experiments were conducted under various levels of La(III) and pH. The results showed that various La(III) concentrations could significantly improve the efficiency and sequestration of phytolith La(III) in germinated rice seeds. A pH of 4.5 promoted phytolith La(III) sequestration, while a pH of 3.5 inhibited sequestration. Compared with the single treatment with La(III), the combination of La(III) and acid rain inhibited the efficiency and sequestration of phytolith La(III). Correlation analysis showed that the efficiency of phytolith La(III) sequestration had no correlation with the production of phytolith but was closely correlated with the sequestration of phytolith La(III) and the physiological changes of germinated rice seeds. This study demonstrated that the formation of the phytolith and La(III) complex could be affected by exogenous La(III) and acid rain in germinated rice seeds.

Duarte *et al.,* (2018) carried out a field experiment to evaluate the effects of La on maize growth, La content, photosynthetic rate and chlorophyll content in maize plants in response to La treatment (0, 25, 50, 100, 150, 300 and 600 μ M) in nutrient solution for three weeks. The plants were placed in geminated pots using a split-root technique. One of the pots in the geminated set was filled with a complete nutrient solution without La, while another was filled with a nutrient solution without phosphorus but containing different concentrations of La. It was verified that roots of maize plants can accumulate approximately sixty percent more Lanthanum than shoots. Moreover, low La concentrations stimulated an increase in chlorophyll index, resulting in a slight increase in shoot biomass. At higher levels, La didn't reduce growth but caused a decrease in both photosynthetic rate and chlorophyll index.

Cui *et al.,* (2019) carried out an experiment to examine the possible potential benefits of Lanthanum chloride ($LaCl_3$) on the senescence and grain yield responses of maize. In their study, maize seeds were pre-treated by soaking with $LaCl_3$ at the concentrations of 0 (CK), 400 (LC_1), 800 (LC_2) and 1200 (LC_3) μmol L^{-1}, to evaluate its effect on the green leaf area, chlorophyll contents, photosynthesis, antioxidants, endogenous hormones in the later crop growth stages. Their results showed that LC_1 and LC_2 treatments evidently increase green leaf area, above ground dry biomass, accompanied by a distinct increase in the chlorophyll contents and photosynthetic capacity, which promote the ear characteristics and grain yield of maize. In addition, LC_1 and LC_2 treatments simultaneously increase the activities of antioxidants, including superoxide dismutases, catalases, peroxidases, soluble protein and enhanced levels of auxin, gibberellin and zeatin, following a dose-response tendency also reported by them. Finally, they suggested that seed priming with $LaCl_3$ at a suitable concentration range (400-800 μmol L^{-1}) can prolong the functional periods of leaves, increase photosynthetic capacity, enhance antioxidant activity and alter endogenous hormone levels at reproductive stages, resulting in delaying leaf senescence rate and increasing yield. The moderate concentration of $LaCl_3$ (800 μmol L^{-1}) for maize also can be effectively used to improve grain yield of maize.

Liang *et al.,* (2018) conducted a study to examine the effects of Lanthanum (La^{3+}) (0.06 and 0.12 mmol L^{-1}) on plasma membrane H^+ -ATPase in rice seedlings under acid rain stress (pH 3.5 and 2.5) to alleviate acid rain damage. Relative growth rate, intracellular H^+ , ATP content, the activity and gene expression of plasma membrane H^+ -ATPase were measured to validate the association of La^{3+} and plasma membrane H^+ -ATPase. They found that 0.06 mmol L^{-1} La^{3+} increased the plasma membrane H^+ -ATPase activity in rice treated with acid rain (pH 3.5). Thus, the decrease in relative growth rate was alleviated because of the application of 0.06 mmol L^{-1} La^{3+}, showing an antagonistic interaction of acid rain and La^{3+} (0.06 mmol L^{-1}). Contrarily, the application of 0.12 mmol L^{-1} La^{3+} aggravated the decrease in relative growth rate of rice under acid rain by decreasing the activity and expression of plasma membrane H^+ -ATPase, showing a synergistic interaction of acid rain and La^{3+} (0.12 mmol L^{-1}). These results indicate that La^{3+} at the proper concentration can enhance the tolerance of rice seedlings to acid rain stress by increasing the activity of plasma membrane H^+ -ATPase, whereas La^{3+} at a higher concentration can aggravate the damage caused by acid rain.

Liu *et al.,* (2016) conducted a study in which the effects of Lanthanum were investigated on contents of pigments, chlorophyll (Chl) fluorescence, antioxidative enzymes and biomass of maize seedlings under salt stress. The results showed that salt stress significantly decreased the contents of Chl and carotenoids, maximum photochemical efficiency of PSII (Fv/Fm), photochemical quenching (qP), quantum efficiency of PSII photochemistry (ΦPSII), net photosynthetic rate (PN), and biomass. Salt stress increased non photochemical quenching (qN), the activities of ascorbate peroxidase, catalase, superoxide dismutase, glutathione peroxidase and the contents of malondialdehyde and hydrogen peroxide compared with control. Pretreatment with Lanthanum prior to salt stress significantly enhanced the contents of Chl and carotenoids, Fv/Fm, qP, qN, ΦPSII, PN, biomass and activities of the above antioxidant enzymes compared with the salt-stressed plants. Pretreatment with Lanthanum also significantly reduced the contents of malondialdehyde and hydrogen peroxide induced by salt stress. In summary, Lanthanum can improve salt tolerance of maize seedlings by enhancing the function of photosynthetic apparatus and antioxidant capacity.

Huang *et al.,* (2015) conducted a study to examine the combined effects of Lanthanum(III) and elevated UV-B radiation on nitrate reduction and ammonia assimilation in soybean (*Glycine max* L.) roots. Treatment with 0.08 mmol L^{-1} La(III) did not change the effects of elevated UV-B radiation on nitrate reductase (NR), nitrite reductase (NiR), glutamine synthetase (GS), glutamate synthase (GOGAT), glutamate dehydrogenase (GDH), nitrate, ammonium, amino acids or soluble protein in the roots. Treatment with 0.24 mmol L^{-1} La(III) and elevated UV-B radiation synergistically decreased the NR, NiR, GS and GOGAT activities as well as the nitrate, amino acid and soluble protein levels, except for the GDH activity and ammonium content. Combined treatment with 1.20 mmol L^{-1} La(III) and elevated UV-B radiation produced severely deleterious effects on all test indices, and these effects were stronger than those induced by La(III) or elevated UV-B radiation treatment alone. Following the withdrawal of La(III) and elevated UV-B radiation, all test indices for the combined treatments with 0.08 mmol L^{-1} La(III), 0.24 mmol L^{-1} La(III) and elevated UV-B radiation recovered to a certain extent, but this experiment could not recover for treatments with 1.20 mmol L^{-1} La(III) and elevated UV-B radiation. In summary, combined treatment with La(III) and elevated UV-B radiation seriously affected nitrogen nutrition in soybean roots through the inhibition of nitrate reduction and ammonia assimilation.

Wang *et al.* (2014) showed that the addition of both $LaCl_3$ and acid rain had a significant positive impact on various physiological processes in rice plants. These included an increase in the net photosynthetic rate, stomatal conductance, hill reaction activity, and carboxylation efficiency. Therefore, it can be inferred that La has various impacts on the growth and development of rice.

Chaturvedi *et al.*, (2014) studied Corn (*Zea mays*), green gram (*Vigna radiata*) and black gram (*Vigna mungo*) seeds where they were grown in Hoagland half strength solution containing 5, 10, 15 up to 50 μM La in order to assess the effect of La on growth and physiological activities of these plants they observed increase in germination percentage, root length, shoot length, fresh and dry weight of all the three plants with increase in Lanthanum proportion in the growth medium. However, the magnitude of effect varied in different species. La did enhance the growth of *V. radiata*, *V. mungo* as well as *Z. mays* but it was *Z. mays* which showed best results among the three plants. An increase in Chlorophyll a, b and total content further indicated the stimulating effect of La on physiological activities of the selected plants.

Liu *et al.*, (2013) studied the hormetic effects on the growth of the roots of rice (*Oryza sativa* L. cv. Shengdao16) in an increasing concentration of La^{3+} (0.05, 0.1, 0.5, 1.0, and 1.5 mmol L^{-1}). They indicated that La^{3+} promoted the growth of rice roots at 0.05 mmol L^{-1}, but inhibited the growth at 1.0 and 1.5 mmol L^{-1} La^{3+} after 13 days of exposure. Transmission electron microscope showed that La^{3+} was mainly deposited in the cell walls of the roots. In addition, the accumulation of K, Mg, Ca, Na, Fe, Mn, Zn, Cu and Mo in the roots was also affected with the exposure of different La^{3+} treatments according to them. They also showed that La^{3+} affected the nutritional status of roots and further regulated the growth of rice.

Liu *et al*., (2012) investigated the effects of increasing amounts of Lanthanum (La) in solution on growth, nutrient metal accumulation, and the expression of oxidative stress in rice seedlings. The La concentration in shoots increased with La^{3+} supply and differentially affected the uptake of nutrient elements. Hormetic effects were observed on seed germination and biomass accumulation with increasing trends up to 0.1 mM La^{3+}. Higher La concentrations were associated with an increase in malondialdehyde and H_2O_2 and a decline in chlorophyll, soluble proteins and photosynthetic activity. So, it may be concluded that La supply at low rates may be beneficial to rice, while at higher rates, La induces oxidative stress.

Di *et al.*, (2010) researched the effects of different applications of $LaCl_3$ as base fertilizer on yield and aroma contents of aromatic rice in pots by using one conventional aromatic rice cultivar. Their results showed that applications of 80, 100 mg kg^{-1} $LaCl_3$ improved the yield and increased aroma contents of aromatic rice. The application of 180 mg kg^{-1}

$LaCl_3$ had the highest aroma content and the application of 100 mg kg^{-1} $LaCl_3$ had the second-high aroma content. They found the optimum application coordinating high yield and aroma contents of aromatic rice was 100 mg kg^{-1} $LaCl_3$.

Zhang *et al.,* (2004) conducted a study in which chemical behavior of Lanthanum in root tips excised from wheat seedlings growing at both promotional and inhibitory levels of $LaCl_3$ in culture solutions was investigated by a sequential leaching procedure combined with instrumental neutron activation analysis. The results indicate that most of La exists in non-exchangeable species and the binding of La^{3+} to the root tips is extremely stable. The root tips during growing at the inhibitory level of $LaCl_3$ absorb much more La than those at the promotional level. However, the La proportion in each fraction is similar for both groups.

Xie *et al.,* (2003) studied the effects of Lanthanum on rice growth, phosphorus uptake and phosphorus chemical fractions. Their results showed that low concentration of La (0.05 similar to 1.5 mg L^{-1}) significantly in-creases rice yield while high La concentration (9 similar to 30 mg L^{-1}) markedly decreases rice yield. When La concentration is 0.05 similar to 0.75 mg L^{-1}, La increases stem and root dry weight, but the difference is not statistically significant. La significantly increases EDTA-P and inorganic-P content in the stem and root. They found that more than 80% of the increase of phosphors content in roots attributing to increase of EDTA-P and inorganic-P. Low La concentration (0.05 similar to 0.75 mg L^{-1}) increases nucleic-P content in root, but high La concentration (30 mg L^{-1}) decreases nucleic-P and ester-P content in root. The residue-P content increases in the root and stem. Also, the relationship between the chemical fractions of phosphorus and its uptake by rice was discussed, according to their reports.

Xie *et al.,* (2002) carried out a split root solution culture experiment to study the effects of the rare earth element Lanthanum (La) on rice (*Oryza sativa*) growth, nutrient uptake and distribution. Their Results showed that low concentrations of La could promote rice growth including yield (0.05 mg L^{-1} to 1.5 mg L^{-1}), dry root weight (0.05 mg L^{-1} to 0.75 mg L^{-1}) and grain numbers (0.05 mg L^{-1} to 6 mg L^{-1}). High concentrations depress grain formation (9 mg L^{-1} to 30 mg L^{-1}) and root elongation (1.5 mg L^{-1} to 30 mg L^{-1}). No significant influence on straw dry weight was found by them over the whole concentration range except for the 0.05 mg L^{-1} treatment. In the pot and field experiments, the addition of La had no significant influence on rice growth. Lanthanum had variable influence on nutrient uptake in different parts of rice. Low concentrations (0.05 mg L^{-1} to 0.75 mg L^{-1}) increased the root copper (Cu), iron (Fe) and magnesium (Mg), and grain Cu, calcium (Ca), phosphorus (P), manganese (Mn) and Mg uptake. High concentrations (9 to 30 mg L^{-1}) decreased the grain Ca, Zn, P, Mn, Fe and Mg, and straw Ca, Mn and Mg uptake. With increasing La concentration, root Zn, P, Mn, Cu and Ca concentrations increased, and grain Ca and Fe, and straw Mn, Mg and Ca concentrations decreased.

Hong *et al.,* (2000) promoted germination of natural aged rice seeds by treating them with Lanthanum nitrate. They found Lanthanum significantly increased the germination rate, germination index and vigor index of natural aged rice seeds. The Lanthanum nitrate also enhanced the respiratory rate and activities of superoxide dismutase, catalase and peroxidase, and decreased superoxide O_2* and malondialdehyde contents, and therefore reduced plasma membrane permeability. In fine they suggested that Lanthanum may be used to pretreat seed before sowing.

2.2 Effect of Lanthanum on grain quality and 2-AP synthesis

Two pot experiments and a two-year field trial were conducted by (Luo *et al.,* 2021a) with different rates of La application (20-120 $LaCl_3$ mg kg^{-1} and 12 kg ha^{-1} $LaCl_3$), and treatments without La application were used as controls. Their results showed that the application of $LaCl_3$ at 80 and 100 mg kg^{-1} and at 12 kg ha^{-1} greatly increased the 2-AP content (by 6.45-43.03%) in aromatic rice seedlings and mature grains compared with the control.

Luo *et al.,* (2021b) conducted a study with a new organic-inorganic compound fertilizer made with organic matter, urea, superphosphate, potassium chloride, zinc sulfate, and Lanthanum chloride. A four-year field experiment was conducted by them to investigate its effects on fragrant rice growth, yield formation, and 2-acetyl-1-pyrroline biosynthesis. Across four experimental years, their results showed that Lanthanum contained treatment significantly ($p < 0.05$) increased grain 2-AP content by 30–38% and 10–21%, respectively. The contents of 2-AP related precursors, including proline and 1-pyrroline, also increased due to Lanthanum-containing treatment.

Mo *et al.,* (2016) demonstrated the effects of 2-AP, zinc (Zn) and Lanthanum (La) on the 2-AP concentration of detached aromatic rice panicles in vitro. Detached panicles from three well-known aromatic cultivars, Guixiangzhan, Pin14 and Pin 15, were cultured separately by them in basic culture medium supplemented with 2-AP, Zn and La, and 2-AP concentrations were assessed at 7 and 14 days after culture (DAC). Their results showed that supplementation of 2-AP, Zn and La in the basic culture medium significantly increased the accumulation of proline. 2-AP concentration and the activity of proline dehydrogenase (ProDH) were also increased in rice grains according to their findings. Zn concentrations were also found higher when zinc was added to the basic culture medium, and La concentrations in grains were too low. Additionally, grain 2-AP concentrations were significantly and positively correlated with proline concentrations, ProDH activities in grains and 2-AP in culture medium.

Yoshihashi *et al.,* (2002) revealed that proline is the nitrogen source for 2-AP through an isotope tracing test. Chen *et al.,* (2008) demonstrated that 2-AP biosynthesis in aromatic rice is inhibited by the expression of the BADH2 gene; this gene encodes betaine aldehyde dehydrogenase (BADH) which catalyzes the conversion of γ-aminobutyl aldehyde (GABald) into GABA instead of 2-AP. Furthermore, the study of (Mo *et al.,* 2016) indicated that the 2-AP in aromatic rice was transformed mainly from proline catalyzed by proline dehydrogenase (PDH).

2.3 Variety effect on growth and yield parameters

A field experiment was conducted by (Chakma, 2021) at the Research Farm of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, during the period from November 2019 to May 2020 to evaluate the growth and yield performance of local and modern aromatic rice in Boro season. The tested varieties were as follows: i) BRRI dhan5 (Dulabhog), ii) BRRI dhan34, iii) BRRI dhan37, iv) BRRI dhan38, v) BRRI dhan70, vi) BRRI dhan75, vii) BRRI dhan80, viii) BRRI dhan50 and ix) Kataribhog. Significant differences existed among different aromatic rice varieties with respect to yield and yield attributing parameters. The result revealed that BRRI dhan80 exhibited its superiority to other tested varieties in terms of seed yield (4.63 t ha^{-1}). The higher amount of yield from BRRI dhan80 was possibly aided by the highest number of leaves $hill^{-1}$ at harvest (57.00), the lowest number of non-effective tillers $hill^{-1}$ at harvest (1.09), the highest weight of 1000-grain (26.13 g), the highest biological yield (9.76 t ha^{-1}) and harvest index (47.40%) than other tested varieties in this experiment. On the other hand, the variety BRRI dhan5 (Dulabhog) returned with significantly the lowest grain yield (2.29 t ha^{-1}) among all the varieties under study. The highest yield advantage was recorded from BRRI dhan80 over the check variety Kataribhog which was 47.92%. In the case of BRRI dhan75, yield advantage over check variety Kataribhog was 38.34% and BRRI dhan70 showed 34.50% higher yield over the check variety. BRRI dhan37 showed a 3.19% yield advantage. These four varieties showed positive yield advantage over the check variety under study. BRRI dhan5 (Dulabhog), BRRI dhan34, BRRI dhan38 and BRRI dhan50 did not have a positive yield advantage over check variety Kataribhog, according to their reports.

An experiment was conducted by (Rashid *et al.*, 2017) at RDRS Bangladesh farm, Monthana, Rangpur, Bangladesh during July to December 2016 to evaluate the yield performance of seven aromatic rice varieties of Bangladesh viz. Jirakatari, Chiniatab, Chinigura, Kataribhog, Kalizara, Badshabhog and BRRI dhan34. They found that the entire yield contributing attributes and quality parameters varied significantly among the aromatic rice varieties. In the variety Kataribhog number of filled grains panicle-1 was found highest (255.6) and the lowest (130.7) was recorded in the variety Badshabhog. Badshabhog produced the highest 1000-grain weight (18.3g) and the lowest (11.4 g) was recorded from the variety Kataribhog. The highest grain yield (2.54 t ha^{-1}) was obtained from Kataribhog and the lowest grain yield (1.83 t ha^{-1}) was obtained from Kalizara. Among the seven aromatic rice varieties under North-west condition Kataribhog and BRRI dhan34 are suitable in respect of yield potential.

An experiment was conducted by (Mishu *et al.*, 2015) to evaluate correlation between some traits and yield components of six aromatic rice varieties and also to determine the most effective factors on its yield. Among six varieties Badshabhog was the topmost yielder followed by Kataribhog, Chinigura, and Radhunipagal, Begunbichi and Kalozira. The spikelets $panicle^{-1}$ and 1000-grain weight showed high heritability and effective tillers $hill^{-1}$ showed low heritability. Yield has positive significant correlation with days to maturity, spikelet length and 1000-grain weight. Negative significant correlation found with plant height and sterility percentage and non-significant correlation with other characters.

A field experiment was conducted by (Islam *et al.,* 2014) at the Bangladesh Institute of Nuclear Agriculture (BINA) farm, Mymensingh, Bangladesh, during the rainfed season in June to December, 2011, with a view to study the performance of aromatic fine rice under different dates of transplanting. The experiment was carried out with four aromatic fine rice varieties (V_1- BRRI dhan34, V_2- Ukunimadhu, V_3- Basmati and V_4- Kataribhog and three different dates of transplanting. Experimental results showed that aromatic fine rice varieties and dates of transplanting individually had significant effect on the agronomic parameters. The combined effect differed significantly for all the agronomic characters. The highest grain yield (3.11 t ha^{-1}) was obtained in Kataribhog, which was similar to Basmati (2.75 t ha^{-1}) followed by Ukunimadhu.

Mannan *et al.,* (2012) reported that the Badshabhog and Kalijira showed taller plants and Chinigura was shorter while Chinigura produced the greatest tillers at early, mid and at later growth stages and the lower tillers were observed in Badshabhog. Chinigura produced the highest amount of DM and the least amount of DM was observed in Kataribhog. Chinigura produced significantly the highest panicles but it was statistically identical with Kalijira, while Kataribhog exhibited lower number of panicles but number of grains $panicle^{-1}$ was found more in Badshabhog. The heaviest grain was found in Kataribhog while the light grain was observed in Badshabhog. The grain yield of Chinigura and Kalijira was almost identical. Lower grain yield was found in Kataribhog which may be attributed to the lower number of panicles and grain $panicle^{-1}$.

Ashrafuzzaman *et al.* (2009) reported that the Kalizira was the tallest (107.90 cm) while it was shortest (93.40 cm) in Chiniatop and was identical to Kataribhog (95.30 cm) due to genetic makeup of the cultivar, but the environmental factors also influence it. There was also a significant difference in 1000-grains weight among the cultivars whereas the highest 1000-grains weight was recorded in BR38 (20.13 g) and the lowest was recorded in BR34 (12.17 g). BR34 produced the maximum grain yield and Basmati produced the lowest. The highest harvest index was recorded from BR34 (34.94%) and the lowest harvest index was obtained from Basmati (31.51%).

A field experiment was conducted by (Hossain and Sikdar, 2009) to determine the optimum transplanting date to get maximum yield and quality of three local and two modern aromatic rice varieties of Bangladesh at the Hajee Mohammad Danesh Science and Technology University farm, Dinajpur, Bangladesh during aman season of 2005.

The varieties Kataribhog, Radhunipagal, Badshabhog, BRRI dhan34 and BRRI dhan38 were transplanted by them from 15 July to 14 August with 10-day intervals. According to their findings, all the varieties gave the maximum grain yield when transplanted on 15 July. Among the aromatic rice varieties, the highest grain yield was obtained from BRRI dhan34 followed by Kataribhog and the lowest grain yield was obtained from Radhunipagal.

Hossain *et al.,* (2008) conducted the study to observe the yield and quality of ten popular aromatic rice varieties of Bangladesh. The varieties were Kataribhog (Philippines), Kataribhog (Deshi), Badshabhog, Chinigura, Radhunipagal, Kalizera, Zirabhog, Madhumala, Chiniatab and Shakhorkora. All the yield contributing attributes and quality parameters varied significantly among thearomatic rice varieties. The highest grain yield was obtained from Kataribhog (Philippines) which was followed by Badshabhog. In respect of quality, Zirabhog gave the highest head rice outturn that was statistically similar to Badshabhog and Chiniatab. All the tested varieties had bold type shapes. Grain protein content ranged from 6.6-7.0 % in brown rice. The cooking time of tested varieties varied from 12 to 16 minutes. Aroma intensity differed due to variety. Kalizera, Badshabhog, Chiniatab contained high levels of aroma while, rests of the varieties had moderate type aroma.

A study was conducted by (Hossain *et al.,* 2005) in order to investigation the relationship between grain yield with the morphological parameters of five local and three modern aromatic rice varieties (Kataribhog, Radhunipagal, Chinigura, Badshabhog, Kalizera, BRRI dhan34, BRRI dhan37 and BRRI dhan38). They found all the parameters varied significantly in different aromatic rice varieties. Among the aromatic rice varieties the highest grain yield was obtained from BRRI dhan34 which identically followed by Kataribhog. The highest plant height was observed in Chinigura which is statistically similar to Kataribhog. The highest number of fertile tillers hill^{-1} was observed in BRRI dhan37 and it was identically followed by Radhunipagal, Badshabhog, Chinigura, BRRI dhan38 and the lowest fertile tillers hill^{-1} was obtained from Kalizera which was statistically similar to Kataribhog. The highest number of grains panicle^{-1} was found in BRRI dhan34 and that was the lowest in BRRI dhan38. Maximum 1000-grain weight was observed in BRRI dhan38. In respect of yield BRRI dhan34 and Kataribhog are suitable for Dinajpur region in Bangladesh during T. aman season, according to their findings.

CHAPTER III

MATERIALS AND METHODS

A field experiment was conducted with a view to find out the yield and grain quality of aromatic rice as influenced by exogenous application of Lanthanum during aman season, 2023. This chapter deals with the materials and methods that were used in the experiment. It includes short description of location of the experimental plot, characteristic of soil, climate, materials of the experiment, raising of seedlings, treatments, layout and design, land preparation, manuring and fertilizing, transplanting, intercultural operations, harvesting, collection of data and statistical analysis which are given below:

3.1 Description of the experimental site

3.1.1 Location

The experiment was carried out at the Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur during July to December. Geographically the location of the experimental site is at 25°38' N latitude and 88°41' E longitude at an average height of 34.5 m above the mean of sea level. The land of the experimental site was a medium high land belonging to the Agro-ecological Zone (AEZ) which is named as Old Himalayan Piedmont Plain (UNDP and FAO, 1988) (Appendix II).

3.1.2 Soil

The soil of the experimental field belongs to the Old Himalayan Piedmont Plain (Agro ecological Zone-1). The general soil type of the experimental field was non-calcareous dark gray floodplain. Topsoil was sandy loam in texture. Organic matter content was 1.48 % and soil pH varies from 5.8-6.0 (Appendix II). The land is above flood level and well drained.

3.1.3 Climate

The climate of the experimental site is subtropical, characterized by three distinct seasons, the monsoon from November to February and pre-monsoon period or hot season from March to April and monsoon period from May to October. The weather data including temperature and rainfall during the period of experiment recorded from the Bangladesh Meteorological Department. The climate in Dinajpur during the period of experimentation has been presented in Appendix III.

3.2 Experimental period

The experiment was conducted in the Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur; during the Aman season (July - December) of 2023.

3.3 Planting material

Aromatic rice (Kataribhog) seeds were used in this experiment.

3.3.1 Properties of the rice variety

The variety of aromatic rice was Kataribhog. It was a local rice variety. The variety possesses medium sized plants (90-100 cm), short life span (110-120 days).

3.3.2 Source of the seeds

The seeds were collected from the agronomy laboratory of Hajee Mohammad Danesh Science and Technology University, Dinajpur.

3.4 Experimental design

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 6 m^2 (3.0 m × 2.0 m). Irrigation and drainage channels were made with maintaining 70 cm wide and 25 cm between blocks and 50 cm wide and 25 cm depth between plots.

3.5 Experimental treatments

The experiment consisted of two types of treatments.

Factor A: It included different doses of Lanthanum which are mentioned below-

L_1= 0.0 of Lanthanum (control)

L_2= 100 ppm of Lanthanum

L_3= 200 ppm of Lanthanum

L_4= 300 ppm of Lanthanum

Factor B: It consisted of three different time of Lanthanum application which are mentioned below-

T_1= Tillering stage (at 25 DAT)

T_2= Panicle initiation stage (at 50 DAT)

T_3= Dough stage (at 75 DAT)

Total 12 treatment combinations were as follows:

L_1T_1= 0 ppm Lanthanum (control) at 25 DAT

L_1T_2= 0 ppm Lanthanum (control) at 50 DAT

L_1T_3= 0 ppm of Lanthanum (control) at 75 DAT

L_2T_1= 100 ppm of Lanthanum at 25 DAT

L_2T_2= 100 ppm of Lanthanum at 50 DAT

L_2T_3= 100 ppm of Lanthanum at 75 DAT

L_3T_1= 200 ppm of Lanthanum at 25 DAT

L_3T_2= 200 ppm of Lanthanum at 50 DAT

L_3T_3= 200 ppm of Lanthanum at 75 DAT

L_4T_1= 300 ppm of Lanthanum at 25 DAT

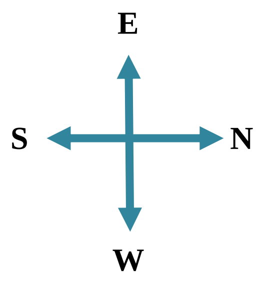
L_4T_2= 300 ppm of Lanthanum at 50 DAT

L_4T_3= 300 ppm of Lanthanum at 75 DAT

Three equal blocks made up the total area. According to the experimental's design, each block contained 12 plots with 12 randomly assigned treatments for Lanthanum dose and time. The experiment included a total of 36-unit plots (Figure1).

3.6 Layout of the experiment

Block 1	Block 2	Block 3
L_2T_1	L_1T_1	L_4T_3
L_3T_1	L_2T_2	L_2T_1
L_4T_1	L_4T_2	L_3T_1
L_3T_3	L_1T_2	L_4T_1
L_1T_3	L_4T_3	L_3T_3
L_3T_2	L_2T_1	L_1T_3
L_2T_3	L_3T_1	L_3T_2
L_1T_1	$L4T_1$	L_2T_3
L_2T_2	L_3T_3	L_1T_1
L_4T_2	L_1T_3	L_2T_2
L_1T_2	L_3T_2	L_4T_2
L_4T_3	L_2T_3	L_1T_2



Replication

Block 1, block 2 and block 3

Unit plot size: 6 m^2

Block to block distance: 70cm

Plot to plot distance: 50cm

Figure1. Layout of the experimental plot

3.7 Field and other operations

3.7.1 Land preparation

The land was prepared by two plowing and one cross plowing with a tractor mounted disc plough. Three days later the land was again plowed and cross plowed with the country plough followed by laddering to get a good puddle condition. Weeds and stubbles were removed from the field prior to sowing of seeds and transplanting of seedlings. Manures and fertilizers were applied as per the recommended doses and irrigation channels were made around each block.

3.7.2 Nursery bed preparation and rising of seedling

Each nursery bed was prepared with 2 m length and 1m width and recommended doses of manures and fertilizers were applied. A 50 cm drainage channel was allowed between two adjacent seedbeds to drain out excess water whenever needed. The grains were soaked in water for 24 hours and then incubated in a moist jute sack for 48 hours with a view of quick germination. 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 5cm that partially controlled weeds, and the remaining weeds were removed to raise healthy and vigorous seedlings.

3.7.3 Fertilizer application

A total of 2.4 kg plot^{-1} of cow dung, 90, 60, 42, 36 g plot^{-1} of urea, TSP, MoP and gypsum were utilized as fertilizers. The cow dung was applied at the beginning of land preparation and all the fertilizers except urea were applied as basal dose at the time of final land preparation. Urea was applied in equal three splits. The first dose of urea was applied at 21 days after transplanting, the second dose of urea was added as top dressing at 45 days (active vegetative stage) after transplanting and third dose was applied at 60 days (panicle initiation stage) after transplanting as recommended by BRRI.

3.7.4 Uprooting of seedlings

The seedbeds were made wet by applying water both in the morning and in the evening on the previous day of uprooting the seedlings. Seedlings were uprooted carefully without causing any injury to the roots and were kept in a shade to transplant in the next day.

3.7.5 Transplanting

Seedlings of the Kataribhog rice cultivars were transplanted in the main field with a single seedling $hill^{-1}$ on 20 July in 2023 with a spacing 20 cm from row to row and 15 cm from hill to hill.

3.8 Preparation and application of Lanthanum solution

For preparing the treatment, 0.1 g, 0.2 g and 0.3 g Lanthanum was dissolved in 1000 ml or 1 L of water. First spray with Lanthanum was done after 25 days of transplanting, second spray was done after 50 days of transplanting and last spray was done at 75 days of transplanting.

3.9 Intercultural operations

The following necessary intercultural operations were taken during the entire cropping period for proper growth and development of the plants and to receive a good harvest from the research field.

3.9.1 Gap filling

Some gaps were created within a plot due to establishment failure of some transplanted seedlings. These gaps were filled in after seven days of transplanting by the excess seedlings kept between the plots.

3.9.2 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 denitrification and leaching.

3.9.3 Irrigation and drainage

No watering was used prior to the seedling’s emergence. Necessary irrigation was provided to the plots when required during the growing period of rice crop. During irrigation, great care was taken to ensure that water didn't cross plot boundaries or run into adjacent plots. The extra water was drained away to keep the pest and disease infestation to a minimum level.

3.9.4 Plant protection measures

There were some insects specially stem borers which were controlled by Furadan 5G @ 10 kg ha^{-1} at 30 days after transplanting. Brown spot of rice controlled by spraying tilth.

Rifit was used as herbicide @ 1.0 L ha^{-1}. Ripcord was used as insecticide @ 200 ml ha^{-1} and batir was also applied as insecticide @ 12. 54 g ha^{-1}.

3.9.5 Harvesting

Maturity of crops was determined when 80% of the seeds became physiologically mature. The rice plants reached maturity stage on November 25, 2023 then they were harvested. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The yield of grain was recorded after thoroughly drying in the sun.

3.9.6 Processing

After harvesting, the grains were threshed, cleaned and sun dried to record the grain yield $plot^{-1}$. The grain was adjusted to 14% moisture content. Then grain yield was converted to t ha^{-1}.

3.10 Sampling and recording of data

The data of the different parameters of the rice plant were collected from randomly selected five plant samples which were collected from each plot. The data were recorded from 25 DAT and continued until the end of the recording of yield contributing characters of the crop after harvest. The following data are recorded during the experiment.

A. Growth parameters

- Plant height

B. Yield contributing characteristics

- Panicle length (cm)
- Number of effective tiller $hill^{-1}$
- Number of total grains $panicle^{-1}$
- Number of grains $panicle^{-1}$
- Number of sterile grains $panicle^{-1}$
- Weight of 1000-grain (g)
- Grain yield (t ha^{-1})
- Straw yield (t ha^{-1})
- Biological yield (t ha^{-1})
- Harvest index (%)

3.11 Detailed procedure of recording data

A. Growth parameters

3.11.1 Plant height (cm)

Plant height was measured from the ground level of a plant to the top of a panicle from randomly selected plant just after transplanting at 25 days intervals from 25 DAT to 75 DAT and final harvesting time. Plants of five hills measured and averaged from each plot.

B. Yield contributing characteristics.

3.11.2 Panicle length (cm)

Measurement was taken from the basal node of the reaches to the apex of each panicle. Each observation was an average of ten hills.

3.11.3 Number of effective tiller 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.

3.11.4 Number of total grains panicle^{-1}

Every grain either filled or unfilled present on the panicle was physically counted. Randomly selected ten panicles from each plot, and the total number of grains per panicle were counted and averaged.

3.11.5 Number of filled grains panicle^{-1}

Any food substance was present in any spikelet was regarded as a grain. Randomly selected ten panicles from each plot, and the number of filled grains per panicle were counted and averaged.

3.11.6 Number of sterile grains panicle^{-1}

If no food substance present in the spikelet, then it was regarded as a sterile grain. Randomly selected ten panicles from each plot, and the number of sterile grains per panicle were counted and averaged.

3.11.7 Weight of 1000-grain (g)

Thousand grains were randomly selected from samples of each plot and were dried in an oven and adjusted at 14% moisture content and weighted by an electric balance.

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

Each unit plot's grain harvest was properly weighted after being sun dried. In order to calculate the grain yield per plot, the dry weights of the grains from five sample plants were added to the appropriate unit plot. Finally, grain yield was converted to t ha^{-1}.

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

Straw obtained from each unit plot including the straw of five sample plants were dried in sun and weighted to record the final straw yield per plot and then converted to t ha^{-1}.

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

Biological yield was calculated by using the following formula: Biological yield (t ha^{-1}) = Grain yield (t ha^{-1}) + Straw yield (t ha^{-1}).

3.11.11 Harvest index (%)

Harvest index was determined by dividing the economic yield (seed yield) to the biological yield (grain yield + straw yield) from the same area and then multiplied by 100.

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield (tha}^{-1}\text{)}}{\text{Grain yield (tha}^{-1}\text{)} + \text{Straw yield (tha}^{-1}\text{)}} \times 100$$

3.12 Data analysis

Data collected from different factors was properly organized and summarized. The Statistix-10 computer package program performed the necessary statistical analysis. Duncan's new multiple range test (DMRT) at a 5% probability level was used to test differences among mean values (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter comprised presentation and discussion of the results obtained from the study to ascertain the yield and grain quality of aromatic rice as influenced by exogenous application of dose and foliar application of Lanthanum. Data on different growth, yield contributing characters and yield of rice were recorded. The results have been presented and discussed in different tables and graphs and possible interpretations are given under the following headings:

4.1 Plant height (cm)

4.1.1 Effect of different doses of Lanthanum

The plant height at different intervals was taken but results showed that except 25 DAT all data statistically significantly varied due to different concentrations of Lanthanum solution at 50 DAT, 75 DAT and at harvesting time (Appendix IV and Table 1). There is an effect of Lanthanum solution to increase the plant height of aromatic rice at all sampling dates. At 25 DAT, the tallest plant (36.25 cm) was observed at treatment L_4 (300 ppm of Lanthanum) and the shortest plant height (34.729 cm) was observed at L_2 treatment (100 ppm of Lanthanum). At 50 DAT, 75 DAT and harvesting time, the tallest plant (82.54 cm and 115.01 cm and 148.08cm) was found at treatment L_4 (300 ppm of Lanthanum). But the shortest plant height from 50 DAT, 75 DAT and at harvest (73.67 cm, 99.90 cm and 134.77 c,m respectively) was observed at control treatment (0 ppm of Lanthanum). The growth performance and changes in nitrogen assimilation activities by supplementation of Lanthanum thus, plant height was increased. Luo *et al.,* (2021a) stated that the $LaCl_3$ application significantly affected the plant height. They recorded the maximum plant height (26.29±0.46 cm) from the treatment with 80 mg kg^{-1} $LaCl_3$ for Meixiangzhan-2 rice seedlings and (26.98±0.30 cm) from the treatment with 100 mg kg^{-1} $LaCl_3$ for Xiangyaxiangzhan rice seedlings. Crop growth and development are substantially affected by La this has been previously reported in several plant species, such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and soybean (*Glycine max* (L.) (Zhang *et al.,* 2004; Liu *et al.,* 2016; Huang *et al.,* 2015).

Table 1: Effect of different doses of Lanthanum on plant height (cm) at different days intervals

Dose of Lanthanum	Plant height (cm)			
	25 DAT	**50 DAT**	**75 DAT**	**At harvest**
L_1	35.94	73.67 c	99.90 c	134.77 d
L_2	34.73	77.60 b	110.61 b	141.39 c
L_3	35.57	79.39 b	111.74 b	145.02 b
L_4	36.25	82.54 a	115.01 a	148.08 a
CV(%)	9.51	3.58	4.09	5.67
$LSD_{(0.05)}$	3.31	2.74	2.24	2.32
LS	NS	**	**	**

In a column, figures having common letter(s) bearing the 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= Coefficient of variance
LSD=Least Significant Difference
Here,
L_1= 0 ppm of Lanthanum (control)
L_2= 100 ppm of Lanthanum
L_3= 200 ppm of Lanthanum
L_4= 300 ppm of Lanthanum

4.1.2 Effect of different times of application

Plant height had a significant effect on 50 DAT, 75 DAT and at harvest, whereas Lanthanum had no significant effect on 25 DAT plant (Appendix IV and Table 2). At 25 DAT and 50 DAT the tallest plant height (36.58 cm and 85.26 cm, respectively) was observed at T_1 treatment (at tillering stage). But at 75 DAT and at harvest the tallest plant (117.39 cm and 146.43 cm) was found at T_2 treatment (at panicle initiation stage). At 50DAT the shortest plant height (74.79 cm) was found in T_2 treatment (at panicle initiation stage) which was statistically similar with T_3 treatment (at dough stage). At 75 DAT the shortest plant height (102.30 cm) was found in T_3 treatment (at dough stage). At harvest the shortest plant height (139.17 cm) was found in T_1 treatment (at tillering stage).

Table 2: Effect of different application time of Lanthanum on plant height (cm) at different days intervals

Time of Application	Plant height (cm)			
	25 DAT	50 DAT	75 DAT	At harvest
T_1	36.58	85.26 a	108.26 b	139.17 c
T_2	35.01	74.79 b	117.39 a	146.43 a
T_3	35.28	74.86 b	102.30 c	141.34 b
CV (%)	9.51	3.58	4.09	5.67
$LSD_{(0.05)}$	2.87	2.37	1.94	2.01
LS	NS	**	**	**

In a column, figures having common letter(s) bearing the same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
NS= Not Significant
LS= Level of significance
CV= Coefficient of variance
LSD= Least Significant Difference
Here,
T_1= Tillering stage (at 25 DAT)
T_2= Panicle initiation stage (at 50 DAT)
T_3= Dough stage (at 75 DAT)

4.1.3 Combined effect of dose and time

The foliar application of Lanthanum at various DAT combined with different doses caused a significant increase in plant height up to a certain period (Appendix VI and Table 3). Application of Lanthanum @ 300 ppm of Lanthanum (L_4) at 25 DAT (T_1) i.e., L_4T_1 (300 ppm of Lanthanum at tillering stage) was found superior over other treatments for increasing plant height of rice plant and found highest plant (91.23 cm) at 50 DAT which is identically similar with L_3T_1 (200 ppm of Lanthanum at tillering stage) treatment. But at 75 DAT and at harvest the highest plant (125.73 cm, 153.38 cm, respectively) was observed at L_4T_2 (300 ppm of Lanthanum at 50 DAT i.e., panicle initiation stage). On the other hand, the shortest plant at 50 DAT and at harvest (72.59 cm, 134.67 cm, respectively) was found from L_1T_3 treatment (0 ppm of Lanthanum at dough stage). At 75 DAT, the shortest plant height (99.00cm) was observed at L_1T_1 (0 ppm of Lanthanum at tillering stage) treatment. Lanthanum has different rules in plants during growth and development and reducing abiotic stress that’s why higher antioxidant enzyme activity can better maintain the stability of cells and ensure the progress of various physiological activities (Zhong *et al.,* 2020). Kastori *et al.,* 2023 stated that

Lanthanum at lower concentrations, can favorably influence certain physiological processes of plants (enzyme activity, hormone content, photosynthesis, seed germination, plant growth, etc.). Plant height is mostly governed by the genetic makeup of the cultivar, but the environmental factors also influence it.

Table 3: Effect of interaction of different dose and application time of Lanthanum on plant height (cm) at different days intervals

Interaction of dose and time		Plant height (cm)			
		25 DAT	**50 DAT**	**75 DAT**	**At harvest**
	T_1	35.36	75.68 cd	99.00 f	134.77 gh
L_1	**T_2**	36.58	72.75 d	100.03 ef	134.87 gh
	T_3	35.89	72.60 d	100.68 ef	134.67 h
	T_1	34.85	83.90 b	107.82 d	138.98 f
L_2	**T_2**	35.15	74.16 cd	120.73 b	146.42 cd
	T_3	34.18	74.75 cd	103.27 e	138.76 fg
	T_1	37.71	90.23 a	110.49 d	140.35 ef
L_3	**T_2**	33.31	74.12 cd	123.06 ab	151.06 ab
	T_3	35.68	73.82 cd	101.67 ef	143.65 de
	T_1	38.40	91.23 a	115.73 c	142.58 def
L_4	**T_2**	34.99	78.12 c	125.73 a	153.38 a
	T_3	35.36	78.27 c	103.56 e	148.29 bc
CV (%)		9.51	3.58	4.09	5.67
$LSD_{(0.05)}$		5.74	4.75	3.87	4.02
LS		NS	**	**	**

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

Legend:
*=Significant at 5% level of significance
LS= Level of significance
CV= Coefficient of variance
LSD= Least Significant Difference
Here,

L_1T_1= 0 ppm of Lanthanum (control) 25 DAT
L_1T_2= 0 ppm of Lanthanum (control) 50 DAT
L_1T_3= 0 ppm of Lanthanum (control) 75 DAT
L_2T_1= 100 ppm of Lanthanum 25 DAT
L_2T_2= 100 ppm of Lanthanum 50 DAT
L_2T_3= 100 ppm of Lanthanum 75 DAT
L_3T_1= 200 ppm of Lanthanum 25 DAT
L_3T_2= 200 ppm of Lanthanum 50 DAT
L_3T_3= 200 ppm of Lanthanum 75 DAT
L_4T_1= 300 ppm of Lanthanum 25 DAT
L_4T_2= 300 ppm of Lanthanum 50 DAT
L_4T_3= 300 ppm of Lanthanum 75 DAT

4.2 Number of effective tiller hill^{-1}

4.2.1 Effect of different doses of Lanthanum

Total tiller production was increased with the advancement of time up to at harvest. The Effective tillers i.e., panicle bearing tillers is an important parameter which effects the yield of rice showed the individual effect of Lanthanum on number of tillers hill^{-1} at different days after transplanting(Appendix V and Table 4). It was found that effective tillers per hill was significantly influenced by dose of Lanthanum at 1% level of probability. At harvest, 200 ppm of Lanthanum of gave the best result (19.94) which was significantly different from other doses and lowest (15.57) result recorded from L_1 (0 ppm of Lanthanum) (Table 4). From the result it has been shown that increasing doses Lanthanum increases the vegetative characteristics such as plant height, number of tillers etc.

Table 4: Effect of different doses of Lanthanum on effective tiller hill^{-1} (no.), panicle length (cm), total grain panicle^{-1}, filled grain panicle^{-1}, sterile grain panicle^{-1} and 1000-grain weight of Kataribhog rice

Dose of Lanthanum	Effective tiller hill^{-1} (No.)	Panicle length (cm)	Total grain panicle^{-1} (No.)	Filled grain panicle^{-1} (No.)	Sterile grain panicle^{-1} (No.)	1000-grain weight (g)
L_1	15.57 c	23.28 c	164.11 b	137.98 d	26.13 a	10.02 c
L_2	18.24 b	24.20 b	169.14 b	152.89 c	16.26 b	10.15b c
L_3	19.94 a	26.40 a	184.99 a	174.87 a	10.11 c	10.35 a
L_4	18.27 b	14.27 b	186.42 a	167.00 b	19.42 b	10.19 b
CV (%)	7.73	2.22	4.02	4.24	18.44	2.48
$LSD_{(0.05)}$	1.36	0.53	6.92	6.56	3.24	0.15
LS	**	**	**	**	**	**

In a column, figures having common letter(s) bearing the 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= Coefficient of variance
LSD= Least Significant Difference
Here,
L_1= 0 ppm of Lanthanum (control)
L_2= 100 ppm of Lanthanum
L_3= 200 ppm of Lanthanum
L_4= 300 ppm of Lanthanum

4.2.2 Effect of different times of application

The number of effective tillers hill rise as the sowing date was advanced by panicle initiation stage i.e., at 50 DAT Lanthanum application time had significantly influenced at 1% level of probability (appendix V). T_2 (50 DAT i.e., panicle initiation stage) produced the most tillers per plant (19.14). On the other hand, T_1 (at tillering stage i.e., 25 DAT) recorded the fewest effective tillers hill^{-1} (17.16) which is significantly similar with T_3 treatment (Table 5).

Table 5: Effect of different application time of Lanthanum on effective tiller hill^{-1} (no.), panicle length (cm), total grain panicle^{-1}, filled grain panicle^{-1}, sterile grain panicle^{-1} and 1000-grain weight of Kataribhog rice

Time of Application	Effective tiller hill^{-1} (No.)	Panicle length (cm)	Total grain panicle^{-1} (No.)	Filled grain panicle^{-1} (No.)	Sterile grain panicle^{-1} (No.)	1000-grain weight (g)
T_1	17.16 b	24.18 b	172.68 b	151.83 b	20.85 a	10.05 a
T_2	19.14 a	25.11 a	179.21 a	163.72 a	15.48 b	10.32 a
T_3	17.71 b	24.67 a	176.61 ab	159.00 a	17.61 b	10.16 b
CV (%)	7.73	2.22	4.02	4.24	18.44	2.48
$LSD_{(0.05)}$	1.78	0.46	5.99	5.683	2.81	0.13
LS	**	**	*	**	**	**

In a column, figures having common letter(s) bearing the same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
NS= Not Significant
LS= Level of significance
CV= Coefficient of variance
LSD= Least Significant Difference
Here,
T_1= Tillering stage (at 25 DAT)
T_2= Panicle initiation stage (at 50 DAT)
T_3= Dough stage (at 75 DAT)

4.2.3 Combined effect of dose and time

The interaction effect of dose and time of Lanthanum on number of effective tillers hill^{-1} had significantly influenced at 5% level of probability (Table 6 and Appendix V). The highest number of effective tiller hill^{-1} (21.82) were recorded from the treatment L_3T_2 (200 ppm Lanthanum at 50 DAT i.e., panicle initiation stage) which were different from other treatment combinations and the lowest number of effective tiller hill^{-1} (14.95) were recorded from L_1T_1 (0 ppm of Lanthanum at 25 DAT).

Table 6: Effect of interaction of different dose and application time of Lanthanum on effective tiller hill^{-1} (no.), panicle length (cm), total grain panicle^{-1}, filled grain panicle^{-1}, sterile grain panicle^{-1} and 1000-grain weight of Kataribhog rice

Interaction of dose and time		Effective tiller hill^{-1} (No.)	Panicle length (cm)	Total grain panicle^{-1} (No.)	Filled grain panicle^{-1} (No.)	Sterile grain panicle^{-1} (No.)	1000-grain weight (g)
	T_1	15.49 ef	22.42 g	164.03 cd	133.30 i	30.73 a	9.77 c
L_1	T_2	16.29 def	23.86 ef	165.50 cd	142.50 ghi	23.00 b	10.22 b
	T_3	14.95 f	23.57 f	162.80 d	138.13 hi	24.67 b	10.06 b
	T_1	17.28 ef	23.99 ef	166.80 cd	147.13 fgh	19.67 bc	10.05 b
L_2	T_2	19.38 bc	24.43 def	171.43 cd	157.77 def	13.67 de	10.25 b
	T_3	18.06 bcd	24.18 def	169.20 cd	153.77 efg	15.43 cde	10.15 b
	T_1	18.25 bcd	25.83 bc	175.33 bc	163.00 cde	12.33 def	10.22 b
L_3	T_2	21.82 a	27.14 a	192.53 a	184.53 a	8.00 f	10.57 a
	T_3	19.76 ab	26.24 ab	187.09 ab	177.09 ab	10.00 ef	10.27 b
	T_1	17.64 b-e	24.49 de	184.57 ab	163.90 cde	20.67 bc	10.17 b
L_4	T_2	19.08 bc	25.01 cd	187.37 a	170.10 bc	17.27 cd	10.50 b
	T_3	18.08 bcd	24.68 de	187.33 a	167.00 bcd	20.33 bc	10.15 b
CV (%)		7.73	2.22	4.02	4.24	18.44	2.48
$LSD_{(0.05)}$		2.36	0.93	11.98	11.37	5.61	0.26
LS		*	*	*	*	*	*

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

Legend:

*=Significant at 5% level of significance

LS= Level of significance

CV= Coefficient of variance

LSD= Least Significant Difference

Here,

L_1T_1= 0 ppm of Lanthanum (control) 25 DAT
L_1T_2= 0 ppm of Lanthanum (control) 50 DAT
L_1T_3= 0 ppm of Lanthanum (control) 75 DAT
L_2T_1= 100 ppm of Lanthanum 25 DAT
L_2T_2= 100 ppm of Lanthanum 50 DAT
L_2T_3= 100 ppm of Lanthanum 75 DAT
L_3T_1= 200 ppm of Lanthanum 25 DAT
L_3T_2= 200 ppm of Lanthanum 50 DAT
L_3T_3= 200 ppm of Lanthanum 75 DAT
L_4T_1= 300 ppm of Lanthanum 25 DAT
L_4T_2= 300 ppm of Lanthanum 50 DAT
L_4T_3= 300 ppm of Lanthanum 75 DAT

4.3 Panicle length (cm)

4.3.1 Effect of different doses of Lanthanum

Panicle length is a crucial rice crop yield-contributing characteristic. In the long run, it has an impact on grain yield and the overall number of grains. Panicle length was significantly influenced by the different doses of Lanthanum at 1% level of probability (Appendix V and Table 4). A significantly higher panicle length (26.40 cm) was recorded in L_3 (200 ppm of Lanthanum) treatment. On the other hand, L_1 (0 ppm of Lanthanum i.e., control) recorded the lowest (23.28 cm) panicle length. It was shown that the higher dose of Lanthanum produces the higher length of panicle.

4.3.2 Effect of different times of application

Panicle length was also significantly influenced by the time of application of Lanthanum at 1% level of probability (Appendix V). The highest panicle length of 25.11 cm was found in treatment T_2 (50 DAT i.e., panicle initiation stage) which was statistically similar with T_3 treatment (75 DAT i.e., dough stage). The lowest panicle length of 24.18 cm was observed in the treatment T_1 (25 DAT i.e., tillering stage) (Table 5).

4.3.3 Combined effect of dose and time

Statistically significant variation was recorded in terms of length of panicle due to different doses of Lanthanum and its time of application at 5% level of probability (Table 6 and Appendix V). The longest panicle (27.14 cm) was recorded from L_3T_2 (200 ppm of Lanthanum at 50 DAT) which was statistically similar with L_3T_3 treatment (200 ppm of Lanthanum at 75 DAT), whereas the shortest panicle (22.42 cm) was found from L_1T_1 (0 g of Lanthanum at 25 DAT). Xie *et al.* (2003) agreed with this result.

4.4 Number of total grain panicles^{-1}

4.4.1 Effect of different doses of Lanthanum

The number of total grains panicle^{-1} varied as a result of different Lanthanum doses (Appendix V and Table 4). It was shown that rice plants produced the highest grains panicle^{-1} (186.42) when Lanthanum at 300 ppm was applied which was statistically similar with L_3 (200 ppm of Lanthanum) and the fewest grains panicle^{-1} (164.11) when Lanthanum was not applied or the control. A study conducted by (Luo *et al.*, 2021a) who investigated the impact of several doses of Lanthanum on different varieties of rice. The findings revealed that applying La treatments substantially increased the grains panicle^{-1} of the aromatic rice cultivars.

4.4.2 Effect of different times of application

Due to the application timing of Lanthanum treatment, the number of total grains panicle^{-1} of rice showed statistically significant at 1% level of probability (Appendix V). At T_2 (50 DAT i.e., panicle initiation stage) the highest grains panicle^{-1} (179.21) was discovered which was statistically similar with T_3 treatment (75 DAT i.e., dough stage). The lowest number of grains panicle^{-1} (172.68) from T_1 (at tillering stage i.e., 25 DAT) (Table 5).

4.4.3 Combined effect of dose and time

For the Lanthanum dose and time combination, there was statistically significant difference in the quantity of rice grains panicle^{-1} at 5% level of probability (Appendix V). The foliar application of Lanthanum @ 200 ppm of Lanthanum at 50 DAT (L_3T_2) resulted in the greatest grains panicle (192.53), which was statistically similar with L_4T_2 and L_4T_3 treatment. The lowest result (133.30) in terms of grains panicle was produced by treatment L_1T_1 (0 ppm of Lanthanum i.e., control at 25 DAT) (Table 6).

4.5 Number of filled grains panicle^{-1}

4.5.1 Effect of different doses of Lanthanum

The number of grains panicle^{-1} varied as a result of different Lanthanum doses (Appendix V and Table 4). It was shown that rice plants produced the most grains panicle^{-1} (174.87) when Lanthanum at 200 ppm was applied and the fewest grains panicle^{-1} (137.98) when Lanthanum was not applied or the control. The statistical analysis showed that the variation in the number of rice grains panicles at the 1% level of probability was significant. A reduced number of grains per panicle that was compensated for by a higher degree of photosynthetic mobilization to individual grains would be preferred in order to maintain a superior yield. Xie *et al.*, (2002) recorded the alike result in their experiment that low concentrations of La could promote rice growth including yield (0.05 mg L^{-1} to 1.5 mg L^{-1}), dry root weight (0.05 mg L^{-1} to 0.75 mg L^{-1}) and grain numbers (0.05 mg L^{-1} to 6 mg L^{-1}).

4.5.2 Effect of different times of application

Due to the application timing of Lanthanum treatment, the number of grains panicle^{-1} of rice showed statistically significant at 1% level of probability (Appendix V). At T_2 (50 DAT i.e., panicle initiation stage) the highest grains panicle^{-1} (163.72) was discovered which was statistically similar with T_3 treatment (75 DAT i.e., dough stage). The lowest number of grains panicle^{-1} (151.83) from T_1 (50 DAT i.e., tillering stage) (Table 5).

4.5.3 Combined effect of dose and time

For the Lanthanum dose and time combination, there was statistically significant difference in the quantity of rice grains panicle^{-1} at 5% level of probability (Appendix V). The foliar application of Lanthanum @ 200 ppm of Lanthanum at 50 DAT (L_3T_2) resulted in the greatest grains panicle (184.53), which was statistically similar with L_3T_3 treatment. The lowest result (133.30) in terms of grains panicle was produced by treatment L_1T_1 (0 ppm of Lanthanum i.e., control at 25 DAT), which was statistically similar with L_1T_3 treatment (Table 6). It was evident that varietal differences regarding the number of filled grains panicle^{-1} might be due to their differences in genetic constituents. These results might be in agreement with the results obtained by Mannan *et al.* (2012).

4.6 Number of sterile grains panicle^{-1}

4.6.1 Effect of different doses of Lanthanum

The number of sterile grains panicle^{-1} varied only slightly as a result of different Lanthanum doses (Appendix V). It was shown that rice plants produced the most sterile grains panicle^{-1} (26.13) when Lanthanum at 0 ppm was given as foliar and the fewest sterile grains panicle^{-1} (10.11) when Lanthanum was applied @ 200 ppm (Table 4). When no Lanthanum was applied then produce higher sterile grain which indicates the reduction of seed setting rate. Similar findings supported by (Luo *et al.,* 2021a) stated that the $LaCl_3$ application @ 80 mg ka^{-1}significantly affected the seed setting rate.

4.6.2 Effect of different times of application

Due to the timing of Lanthanum treatment, the number of sterile grains panicle^{-1} of rice showed significant difference at 1% level of probability (Appendix V). At T_2 (50 DAT i.e., panicle initiation stage) the lowest sterile grains panicle^{-1} (15.48) was discovered which is statistically similar with T_3 (75 DAT i.e., dough stage). The highest number of sterile grains panicle^{-1} (20.85) obtained from T_1 (at 25 DAT i.e., tillering stage) treatment (Table 5).

4.6.3 Combined effect of dose and time

For the Lanthanum dose and application time combination, there was statistically significant difference in the quantity of sterile grains panicles at 5% level of probability

(Appendix V). The foliar application of Lanthanum @ 200 ppm of Lanthanum at 50 DAT (L_3T_2) resulted in the lowest number of sterile grains panicle^{-1} (8.00), which was statistically similar with L_3T_3 treatment. The highest result (30.73) in terms of sterile grains panicle^{-1} was produced by treatment L_1T_1 (0 ppm of Lanthanum i.e., control at 25 DAT), which was statistically distinct from all other treatments (Table 6).

4.7 1000-grain weight (g)

4.7.1 Effect of different doses of Lanthanum

Dose of Lanthanum had a significant impact on the weight of 1000-grain at 1% level of probability (Appendix V and Table 4). Rice plants used in this study recorded the highest 1000-grain weight (10.35 g) when Lanthanum was applied @ 200 ppm. On the other hand, rice plants recorded the lowest 1000-grain weight (10.02 g) when no Lanthanum was applied. The variation in 1000-grain weight might be due to the difference of length and breadth of the grain that were partly controlled by genetic make-up of variety. Similar findings supported by Di *et al.* (2010) who observed that the application of 100 mg kg^{-1} $LaCl_3$ had the highest 1000-grain weight. But 1000-grain weight at different doses of Lanthanum application showed insignificant variation among the treatments (Luo *et al.*, 2021a).

4.7.2 Effect of different times of application

Different times of application of Lanthanum on rice crops showed a significant difference in the terms of 1000-grain weight at 1% level of probability (Appendix V and Table 5). It was found that T_1 (25 DAT i.e., tillering stage) plant produced the lowest (10.05 g) 1000-grain weight of rice, while T_2 (50 DAT i.e., panicle initiation stage) plant produced the highest (10.32 g) 1000-grain weight. This was because increasing application time increases the 1000-grain weight of rice by inducing size of the grain. Mannan *et al.* (2012) reported that the 1000-grain weight did not vary significantly due to planting dates however; it varied significantly due to the varieties.

4.7.3 Combined effect of dose and time

The interaction effect of doses and time of application of Lanthanum showed significant influence on weight of 1000-grain at 5% level of probability (Appendix V and Table 6). The maximum weight of 1000-grain (10.57 g) was observed from L_3T_2 @ 200 ppm of Lanthanum at 50 DAT. On the other hand, the minimum weight of 1000-grain (9.77 g) from L_1T_1 @ 0 ppm of Lanthanum (control) at 25 DAT.

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

4.8.1 Effect of different doses of Lanthanum

Grain yield (t ha^{-1}) is the result of all the elements that encourage better development, which finally results in an increase in the yield per plant and, ultimately, the yield per hectare. There was a remarkable difference in respect of grain yield. The Lanthanum dose has a significant impact on rice seed production at 1% level of probability (Appendix VI and Figure 2). However, applying Lanthanum @ 200 ppm (L_3) to rice plants resulted in the highest grain yield (1.98 t ha^{-1}) which was statistically similar to L_4 (300 ppm of Lanthanum) treatment. On the other hand, the lowest grain yield (1.62 t ha^{-1}) was found when no Lanthanum was used (L_1). The high yield of rice that Lanthanum contributes together with the fact that yield varies at different doses, may be attributed to a combination of management techniques, genetic factors, and environmental factors. Luo *et al.*, (2021a) stated that the La treatments substantially increased the grain yield of the aromatic rice cultivars.

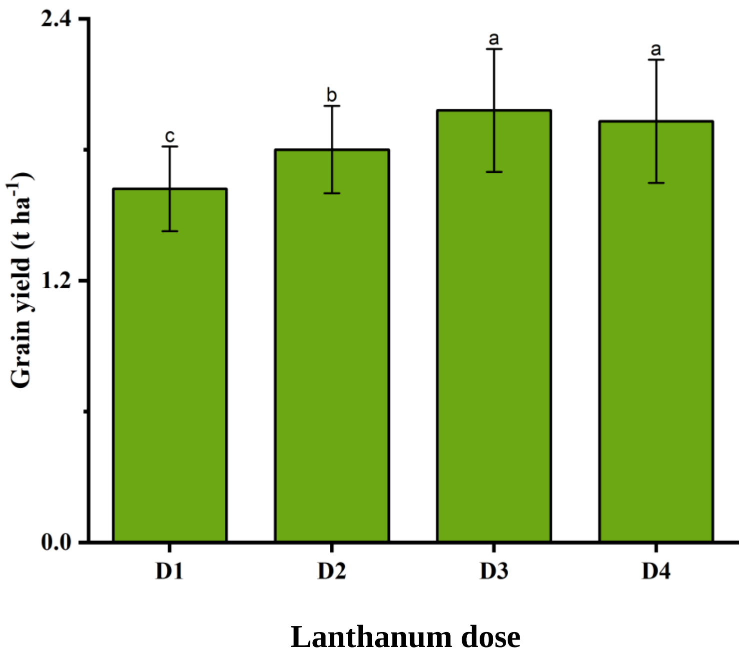


Figure 2: Effect of different dose of Lanthanum on grain yield (t ha^{-1})

Here,

L_1= 0 ppm of Lanthanum (control) L_2= 100 ppm of Lanthanum

L_3= 200 ppm of Lanthanum L_4= 300 ppm of Lanthanum

4.8.2 Effect of different times of application

Rice grain yield varied significantly depending on time when Lanthanum was applied (Appendix VI and Figure 3). The results showed that T_1 (at 25 DAT i.e., tillering stage) had the lowest grain yield (1.75 t ha^{-1}). T_2 (at 50DAT i.e., panicle initiation stage) had the highest grain yield (1.91 t ha^{-1}), and it was identical to T_3 (75 DAT i.e., dough stage) which was statistically significant at 1% level of probability. These results were consistent with the study of Luo *et al.*, (2021a) who demonstrated that the total aboveground biomass at the booting stage, heading stage, grain-filling stage and maturity stage (total yield) also increased due to La application.

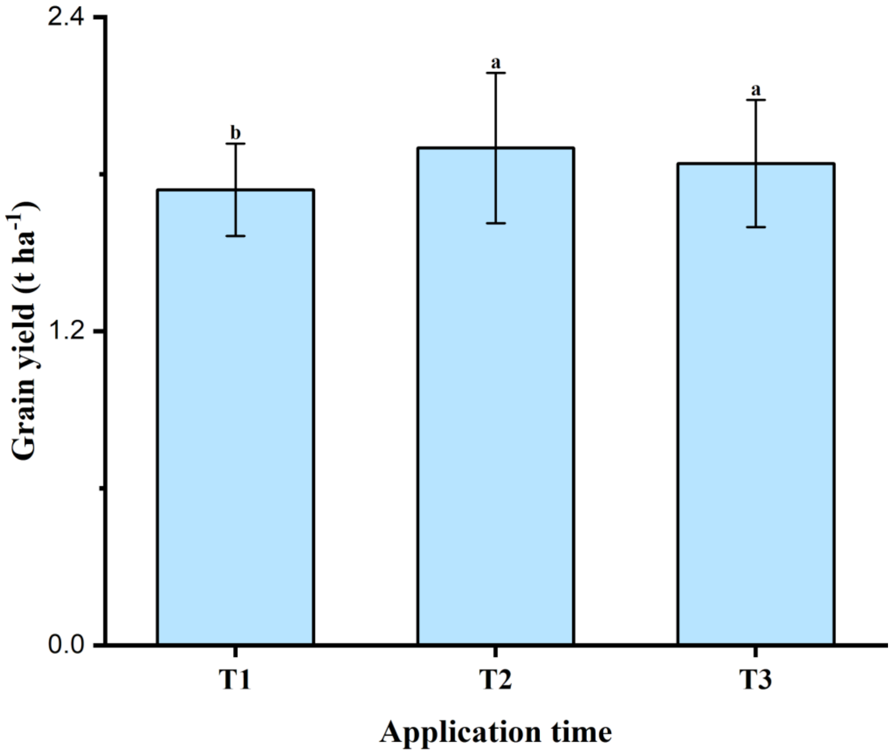


Figure 3: Effect of different application time of Lanthanum on grain yield (t ha^{-1})

Here,
T_1= Tillering stage (at 25 DAT)
T_2= Panicle initiation stage (at 50 DAT)
T_3= Dough stage (at 75 DAT).

4.8.3 Combined effect of dose and time

The interaction effect of doses and time of application of Lanthanum showed significant influence on grain yield of rice at 5% level of probability (Appendix VI and Figure 4). The maximum grain yield 2.08 t ha^{-1}) was found from L_3T_2 (200 ppm of Lanthanum at 50 DAT) treatment combinations. Again, the minimum grain yield (1.48 t ha^{-1}) was observed from L_1T_1 (0 ppm of Lanthanum i.e., control at 25 DAT) which was statistically different from other treatment combinations. The increment in grain yield due to Lanthanum application was attributed to improvement in grain number per panicle and seed-setting rate. Di *et al.*, (2010) researched the effects of different applications of $LaCl_3$ as base fertilizer on yield and aroma contents of aromatic rice in pots by using one conventional aromatic rice cultivar. Their results showed that applications of 80, 100 mg kg^{-1} $LaCl_3$ improved the yield and increased aroma contents of aromatic rice. Xie *et al.*, (2002) recorded the similar result in their experiment that low concentrations of La could promote rice growth and yield (0.05 mg L^{-1} to 1.5 mg L^{-1}). Exogenous application of Lanthanum significantly increased grain yield (Xie *et al.*, 2003).

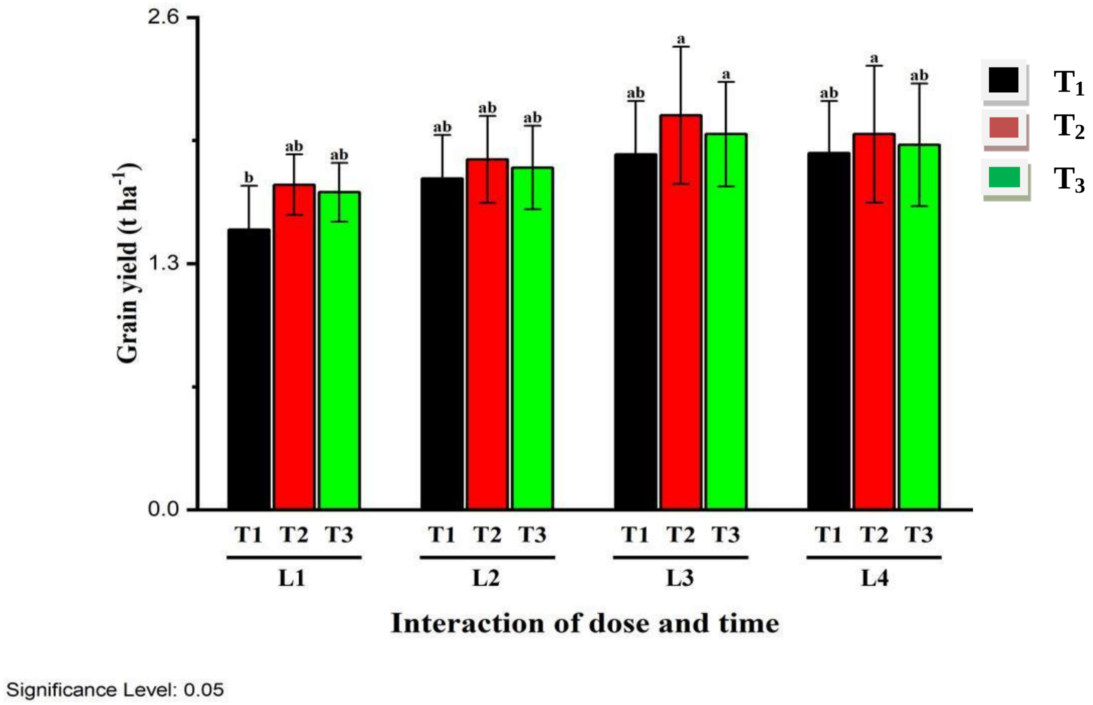


Figure 4: Combined effect of different doses and application times of Lanthanum on grain yield (t ha^{-1})

Here,

L_1= 0 ppm of Lanthanum (control)

L_2= 100 ppm of Lanthanum

L_3= 200 ppm of Lanthanum

L_4= 300 ppm of Lanthanum

T_1= Tillering stage (at 25 DAT)

T_2= Panicle initiation stage (at 50 DAT)

T_3= Dough stage (at 75 DAT).

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

4.9.1 Effect of different doses of Lanthanum

The increase in straw yield is closely related to the increase in vegetative development and to a lesser extent, the reproductive component of the plants. Straw production varies greatly due to different treatments (Appendix VI and Table 7). Applying Lanthanum @ 200 ppm (L_3) to rice plant resulted in the highest straw yield (4.38 t ha^{-1}) which was statistically similar with L_4 treatment when Lanthanum was applied @ 400ppm and the lowest straw yield (4.27 t ha^{-1}) when Lanthanum applied @ 100 ppm (L_2). This may be because higher doses of Lanthanum increased the number of effective and non-effective tillers as well as increase in straw yield.

Table 7: Effect of different dose of Lanthanum on straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) of Kataribhog rice

Dose of Lanthanum	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
L_1	4.29 b	5.92 c	27.37 c
L_2	4.27 b	6.07 b	29.61 b
L_3	4.38 a	6.37 a	30.99 a
L_4	4.34 ab	6.27 a	30.65 a
CV (%)	4.7	4.05	3.10
$LSD_{(0.05)}$	0.07	0.12	0.90
LS	*	**	**

In a column, figures having common letter(s) bearing the 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= Coefficient of variance
LSD=Least Significant Difference
Here,
L_1= 0 ppm of Lanthanum (control)
L_2= 100 ppm of Lanthanum
L_3= 200 ppm of Lanthanum
L_4= 300 ppm of Lanthanum

4.9.2 Effect of different times of application

There was non-significant variation observed on straw yield of rice plant for the effect of different time of application of Lanthanum treatments at 5% level of probability (Appendix VI and Table 8). It was revealed that the highest straw yield (4.34 t ha^{-1}) was recorded at T_2 (50 DAT i.e., panicle initiation stage) which was statistically similar with Lanthanum applied at T_1 (25 DAT i.e., tillering stage) and T_2 (75 DAT i.e., dough stage) treatments. From the statistical analysis, the straw yield of rice showed no significant variation at 5% level of probability.

Table 8: Effect of different application time of Lanthanum on straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) of Kataribhog rice

Time of application	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	4.31	6.06 b	28.70 b
T_2	4.34	6.25 a	30.37 a
T_3	4.31	6.16 ab	29.88 a
CV (%)	4.70	4.05	3.10
$LSD_{(0.05)}$	0.06	0.11	0.78
LS	NS	**	**

In a column, figures having common letter(s) bearing the same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
**= Significant at 1% level of significance
NS= Not Significant
LS= Level of significance
CV= Coefficient of variance
LSD= Least Significant Difference
Here,
T_1= Tillering stage (at 25 DAT)
T_2= Panicle initiation stage (at 50 DAT)
T_3= Dough stage (at 75 DAT)

4.9.3 Combined effect of dose and time

Due to diverse treatment combinations of dose and time of Lanthanum application, straw yield varied significantly at 5% level of probability (Appendix VI and Table 9). The maximum straw yield (4.40 t ha^{-1}) was found to be produced by the treatment combination of L_3T_1 (200 ppm of Lanthanum at 25 DAT) which was statistically similar with L_3T_2 (200 ppm of Lanthanum at 50 DAT) combination. The lowest (4.23 t ha^{-1}) straw yield was observed from L_2T_1 (100 ppm of Lanthanum at 25 DAT) combination and it was statistically similar with L_1T_1 (0 ppm of Lanthanum i.e., control at 15 DAT) treatment. It was evident that straw yield differed due to combined effect of plant height and tillers number (Begum, 2013).

Table 9: Effect of interaction of different dose and application time of Lanthanum on straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) of Kataribhog rice variety

Interaction of dose and time		Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
L1	T_1	4.25 cd	5.73 f	25.74 f
	T_2	4.35 a-d	6.06 de	28.27 de
	T_3	4.29 a-d	5.96 e	28.086 e
L2	T_1	4.24 d	5.99 e	29.17 cde
	T_2	4.31 a-d	6.16 bcde	29.98 bc
	T_3	4.27 bcd	6.07 cde	29.68 bcd
L3	T_1	4.406 a	6.28 abc	29.77 cd
	T_2	4.38 ab	6.47 a	32.06 a
	T_3	4.37 abc	6.35 ab	31.14 ab
L4	T_1	4.35 a-d	6.23 bcd	30.13 bc
	T_2	4.34 a-d	6.32 ab	31.20 ab
	T_3	4.34 a-d	6.26 a-d	30.63 abc
CV (%)		4.71	4.05	3.10
$LSD_{(0.05)}$		0.13	0.21	1.55
LS		*	*	*

In a column, figures having common letter(s) bearing the same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
*=Significant at 5% level of significance
LS= Level of significance
CV= Coefficient of variance
LSD= Least Significant Difference
Here,
L_1T_1= 0 ppm of Lanthanum (control) 25 DAT
L_1T_2= 0 ppm of Lanthanum (control) 50 DAT
L_1T_3= 0 ppm of Lanthanum (control) 75 DAT
L_2T_1= 100 ppm of Lanthanum 25 DAT
L_2T_2= 100 ppm of Lanthanum 50 DAT
L_2T_3= 100 ppm of Lanthanum 75 DAT
L_3T_1= 200 ppm of Lanthanum 25 DAT
L_3T_2= 200 ppm of Lanthanum 50 DAT
L_3T_3= 200 ppm of Lanthanum 75 DAT
L_4T_1= 300 ppm of Lanthanum 25 DAT
L_4T_2= 300 ppm of Lanthanum 50 DAT
L_4T_3= 300 ppm of Lanthanum 75 DAT

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

4.10.1 Effect of different doses of Lanthanum

The sum of the grain yield and straw yield was referred to as biological yield. The biological yield of rice was considerably impacted by the types of variations (Appendix VI). The observation was made that L_3 (200 ppm of Lanthanum) reported the highest biological yield of rice (6.37 t ha^{-1}) which was statistically identical to L_4 (300 ppm of Lanthanum) treatment. On the other hand, the L_1 (0 ppm of Lanthanum i.e., control) treatment had the lowest biological yield (5.92 t ha^{-1}). According to the statistical study, there was a significant difference in the biological yield of rice at the 1% level of probability (Table 7). Luo *et al.,* (2021a) stated that the $LaCl_3$ application significantly affected the total yield (g pot^{-1}). In their study the maximum total yield was recorded from the treatment with 100 mg kg^{-1} $LaCl_3$ for different rice variety. Our results also were consisted with (Xie *et al.,* 2003) who examined the effects of Lanthanum on rice growth, phosphorus uptake and phosphorus chemical fractions and find a positive that low concentration of La (0.05 similar to 1.5 mg L^{-1}) significantly in-creases rice yield.

4.10.2 Effect of different times of application

There was significant variation observed on biological yield of rice for the effect of different Lanthanum application time at 5% level of probability (Figure 8) revealed that the highest biological yield (6.25 t ha^{-1}) was recorded from T_2 (50 DAT i.e., panicle initiation stage) which was statistically similar with T_4 (75 DAT i.e., dough stage) treatment and the lowest biological yield (6.05 t ha^{-1}) was obtained from T_1 (25 DAT i.e., tillering stage).

4.10.3 Combined effect of dose and time

Lanthanum administration at various doses and times resulted in statistically significant variations in biological yield at 5% level of probability (Appendix VI and Table 9). The L_3T_2 treatment combination (200 ppm of Lanthanum at 50 DAT) produced the highest biological yield (6.47 t ha^{-1}). In contrast, the L_1T_1 treatment combination (0 ppm of Lanthanum i.e., control at 25 DAT) gave the lowest biological yield (5.73 t ha^{-1}).

4.11 Harvest index (%)

4.11.1 Effect of different doses of Lanthanum

The ratio of grain yield to biological yield served as the basis for calculating the harvest index, which is presented as a percentage. The harvest index was considerably affected by the Lanthanum dose at 1% level of probability (Figure 7 and Appendix VI). The application of 200 ppm of Lanthanum (L_3) to the rice plant resulted in the greatest harvest index (30.99 %) which was statistically identical to L_4 (300 ppm of Lanthanum) treatment. In contrast, no Lanthanum application yielded the lowest harvest index numerically (27.37 %). Hong *et al.,* (2000) promoted germination of natural aged rice seeds by treating them with Lanthanum nitrate. They found Lanthanum significantly increased the germination rate, germination index, and vigor index of natural aged rice seeds.

4.11.2 Effect of different times of application

There was significant variation observed on the harvest index of Kataribhog rice for the effect of different time of application of Lanthanum treatments at 1% level of probability (Appendix VI and Table 8). It was revealed that the highest harvest index (30.38%) was recorded at 50 DAT (T_2) which was statistically similar with Lanthanum applied at 75 DAT (T_3) and the lowest harvest index (28.70%) was obtained at 25 DAT (T_1).

4.11.3 Combined effect of dose and time

Applying Lanthanum dose along with different application times showed a significant impact on harvest index of rice plant at 5% level of probability (Appendix VI and Table 9). The highest harvest index (32.06%) was produced by the treatment combination L_3T_2 (200 ppm of Lanthanum at 50 DAT) was statistically similar with L_3T_3 and L_4T_2 treatments and the lowest harvest index (25.74%) was obtained from the control treatment combination L_1T_1 (0 ppm of Lanthanum i.e., control at 25 DAT), which was statistically different from other treatments.

CHAPTER IV
SUMMARY AND CONCLUSION

The experiment was carried out at Agronomy Research Field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur during July 2023 to December 2023. The main objectives of the experiments were to evaluate the effect of dose and time of Lanthanum on growth and yield of aromatic rice (Kataribhog). Therefore, this part of study was undertaken to investigate the appropriate dose and time of Lanthanum and growth and yield contributing characters of Kataribhog rice variety. The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications with two factors; Factor A: included different doses of Lanthanum viz. L_1 = 0 ppm of Lanthanum (control), L_2 = 100 ppm of Lanthanum, L_3 = 200 ppm of Lanthanum and L_4 = 300 ppm of Lanthanum and Factor B: consisted of three different time of Lanthanum application viz. T_1 = 25 days after transplanting (DAT) i.e. tillering stage; T_2 = 50 days after transplanting (DAT) i.e. panicle initiation stage and T_3 = 75 days after transplanting (DAT) i.e. dough stage. There were 36-unit plots altogether in the experiment. The size of the plot was 3.0 m x 2.0 m. Block to block distance was 70 cm and plot to plot was 25 cm. Data on growth and yield contributing characteristics namely plant height (cm); effective tiller hill^{-1} (no.), length of panicle (cm); number of grains panicle^{-1}, number of sterile grains panicle^{-1}; weight of 1000-grain (g); grain yield (t ha^{-1}); straw yield (t ha^{-1}); biological yield(t ha^{-1}) and harvest index (%) recorded. Data were statistically analyzed as per design of the experiment using the Statistix-10 computer package program for evaluation of the effects of different treatments.

The application of various doses of Lanthanum resulted in a notable among the studied parameters of the Kataribhog rice variety. 300 ppm of Lanthanum gave the best result for plant height at 50 DAT, 75 DAT and at harvest (82.54 cm, 115.01 cm and 148.08 cm, respectively). On the other hand, the control treatment (L_1 treatment) gave the dwarf plant at the 50, 75 DAT, and harvest (73.67 cm, 99.90 cm and 134.77 cm, respectively). 200 ppm of Lanthanum (L_3 treatment) gave the best result for number of effective tiller hill^{-1} (19.94), panicle length (26.40 cm); grains panicle^{-1} (174.87), fewest sterile grains panicle^{-1} (10.11); weight of 1000-grain (10.35 g); grain yield (1.98 t ha^{-1}); straw yield (6.38 t ha^{-1}); biological yield (6.36 t ha^{-1}) and harvest index (30.99 %). On the other hand, the lowest results for number of effective tiller hill^{-1} (15.57), panicle length (23.28 cm); grains panicle^{-1} (137.98), highest sterile grains panicle^{-1} (26.13); weight of 1000-

grain (10.02 g); grain yield (1.62 t ha^{-1}); biological yield (5.92 t ha^{-1}) and harvest index (27.37%) were recorded from control treatments i.e. where no Lanthanum was applied.

Considering the application time of Lanthanum, the plant height at 25 DAS showed insignificant variation among the treatments. At 50 DAT the top plant height was recorded from T_1 (85.26 cm) and lowest from T_2 (74.79 cm). At 75 DAT, and harvest the highest plant height was recorded from T_2 (117.39 cm and 146.43 cm, respectively). The longest panicle was recorded from T_2 (at 50 DAT i.e., panicle initiation stage) treatment. The highest number of effective tiller $hill^{-1}$ (19.14), longest panicle length (25.11 cm); maximum filled grains $panicle^{-1}$ (163.72), fewest sterile grains $panicle^{-1}$ (15.84); maximum weight of 1000-grain (10.32 g); top grain yield (1.91 t ha^{-1}); highest straw production (4.34 t ha^{-1}); top most biological yield (6.25 t ha^{-1}) and highest harvest index (30.38%) were recorded at T_2 (at 50 DAT i.e., panicle initiation stage) treatment. On the other hand, at 25 DAT i.e., tillering stage gave the lowest result for number of effective tiller $hill^{-1}$ (17.16), panicle length (14.18 cm); grains $panicle^{-1}$ (172.68), highest sterile grains $panicle^{-1}$ (20.85); weight of 1000-grain (10.05 g); grain yield (1.75 t ha^{-1}); biological yield (6.06 t ha^{-1}) and harvest index (28.70%).

Considering the combined application of Lanthanum at different times, all treatment combinations gave the statistically alike performance among them at 25 DAT. At 50 DAT, L_4T_1 gave the maximum plant height (91.23 cm) statistically alike to L_3T_1. However, L_4T_2 gave the best result (125.73 and 153.38 cm, respectively) at 75 and harvest time, while lowest value was recorded from L_2T_3 treatment (138.76 cm) at harvest time. However, The L_3T_2 combinations (Application of 200 ppm of Lanthanum at panicle initiation stage at 50 DAT) recorded the highest number of effective tiller $hill^{-1}$ (21.82). The lowest number of effective tiller $hill^{-1}$ (14.95) was recorded from L_1T_3 treatment combinations (Application of 0 ppm of Lanthanum at dough stage at 75 DAT). The L_3T_2 combinations (Application of 200 ppm of Lanthanum at panicle initiation stage at 50 DAT) recorded the longest panicle (27.14 cm) statistically alike to L_3T_3 (26.24 cm). The shortest panicle (22.42 cm) was recorded from L_1T_1 treatment combinations (Application of 0 ppm of Lanthanum at tillering stage at 25 DAT). The L_3T_2 combinations recorded the highest filled grain $panicle^{-1}$ (184.53) statistically alike to L_3T_3 (177.09) while the L_1T_1 treatment combinations resulted in the lowest filled grain $panicle^{-1}$ (133.30). The L_1T_1 combinations recorded the maximum sterile grain $panicle^{-1}$ (30.73) but the lowest sterile grain $panicle^{-1}$ was found in the L_3T_2 treatment (8.00). The

L_3T_2 combinations recorded the topmost 1000-grain weight (10.57 g) while the lowest 1000-grain weight (9.77 g) was recorded from L_1T_1 treatment combinations. The combinations of L_3T_2 resulted in the highest grain yield of 1.98 t ha^{-1} but the lowest grain yield (1.62 t ha^{-1}) was recorded from L_1T_1 treatment combinations. The L_3T_1 combinations gave the highest straw yield of 4.40 t ha^{-1}. The lowest straw yield (4.24 t ha^{-1}) was recorded from L_2T_1 treatment combinations. The maximum biological yield (6.47 t ha^{-1}) was recorded from L_3T_2 treatment combinations and the minimum biological yield (5.73 t ha^{-1}) was recorded from L_1T_1 treatment combinations. The L_3T_2 combinations recorded the topmost harvest index (32.06%) but the minimum harvest index (25.74 %) was recorded from L_1T_1 treatment combinations.

Conclusion

The results provide a thorough understanding of the Kataribhog yield potentiality when Lanthanum is applied exogenously. As a result of the findings above, it may be concluded:

- Lanthanum @ 200 ppm can be applied on rice for maximum yield.
- Lanthanum applied at 50 DAT can be effective for maximum yield.
- For better growth and yield, exogenous application of Lanthanum @ 200 ppm at 50 DAT (L_3T_2) can be used as combined treatment.

Recommendation

An accurate evaluation of the functioning of any biological entity cannot be made from the experimental results of a single year of study. Therefore, a second run of the identical experiment is necessary to confirm the test results. Additionally, subsequent Lanthanum dosages at various DAT should be used in further studies

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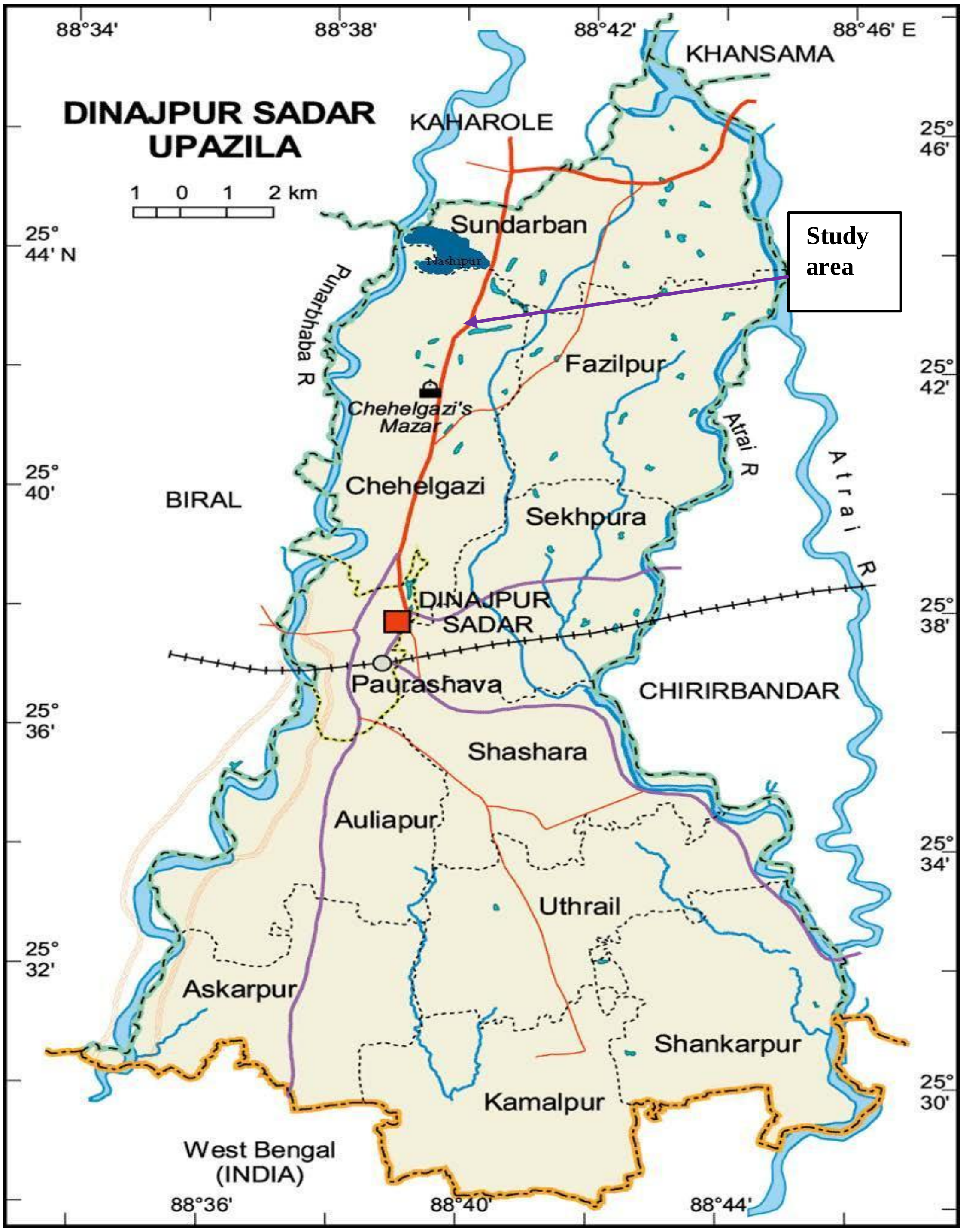
APPENDICES

Appendix I. Location of the experimental site



Appendix II: Morphological, physical and chemical characteristics of soil of experimental field (Agronomic research field, HSTU)

A. Morphological characteristics of soil

Morphological parameters	Characteristics
Location	Agronomy research field, HSTU, Dinajpur
Agro-ecological Zone (AEZ-1)	Old Himalayan Piedmont Plain
Geographical position	$25^0$38N latitude and $88^0$41E longitude
General soil types	Non-calcareous dark gray floodplain soil
Parent materials	Old Brahmaputra 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

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

B. Physical characteristics of soil

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

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

C. Chemical properties of soil

Characteristics	Value (%)
pH (soil: water= 1: 1.25)	5.41
Organic matter	1.48
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

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

Appendix III. Monthly average temperature, and total rainfall of the experimental site during the period of July, 2023 to December, 2023

Month	Air temperature (^{o}C)		Total rainfall (mm)
	Maximum	Minimum	
July	34.1	26.4	356
August	33.4	26.5	458
September	33.4	25.6	533
October	31.7	22.6	213
November	30.8	16.8	0
December	26.5	12.5	15

Source: Bangladesh Meteorological Department

Appendix IV. Analysis of variance (mean square) of the data for plant height of aromatic rice

Source of variation	Degrees of freedom	Mean Squares			
		25 DAT	50 DAT	75 DAT	At harvest
Factor A	3	3.89^{NS}	123.21**	385.52**	295.23**
Factor B	2	8.48^{NS}	435.71**	693.24**	166.79**
Factor AB	6	6.15^{NS}	32.43**	90.52**	22.70**
Error	22	11.48	7.87	5.23	5.63
CV (%)		9.51	3.58	4.09	5.67

Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV= Coefficient of variance
df= Degrees of freedom
Factor A= Lanthanum dose
Factor B= Application time
Factor AB= Lanthanum Dose and Application time

Appendix V. Analysis of variance (mean square) of the data for yield traits of aromatic rice

Source of variation	Degrees of freedom	Mean Squares					
		Effective tiller hill^{-1}	Panicle length	Total grain panicle^{-1}	Filled grain panicle^{-1}	Sterile grain panicle^{-1}	1000-grain weight
Factor A	3	29.33**	15.44**	1132.79**	2377.87**	400.35**	0.17**
Factor B	2	12.48**	2.58**	129.47*	430.17**	87.65**	0.22**
Factor AB	6	1.17*	0.29*	43.90*	35.84*	5.07*	0.03*
Error	22	1.94	0.30	50.07	45.06	10.99	0.02
CV (%)		7.73	2.22	4.02	4.24	18.44	2.48

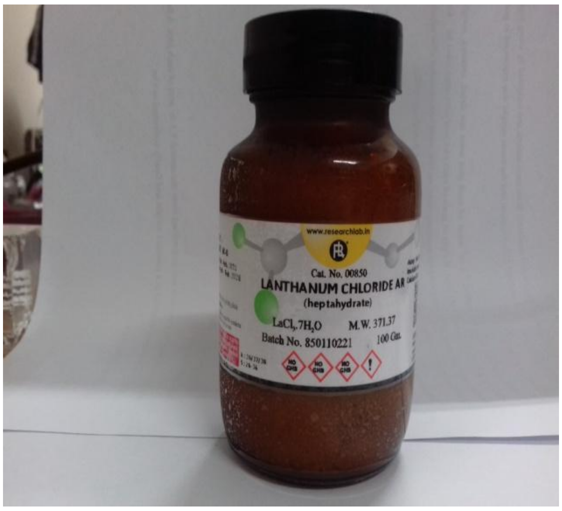
Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV= Coefficient of variance
df= Degrees of freedom
Factor A= Lanthanum dose
Factor B= Application time
Factor AB= Lanthanum Dose and Application time

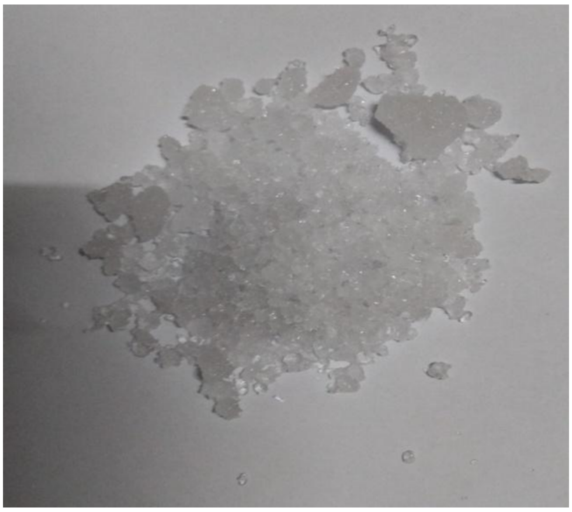
Appendix VI. Analysis of variance (mean square) of the data for yield traits of aromatic rice

Source of variation	Degrees of freedom	Mean Squares			
		Grain yield	Straw yield	Biological yield	Harvest index
Factor A	3	0.23**	0.02*	0.36**	24.07**
Factor B	2	0.08**	0.004^{NS}	0.12**	8.90**
Factor AB	6	0.005*	0.002*	0.01*	0.81*
Error	22	0.008	0.005	0.016	0.84
CV (%)		4.88	4.71	4.05	3.10

Legend:
**= Significant at 1% level of significance
*= Significant at 5% level of significance
CV= Coefficient of variance
df= Degrees of freedom
Factor A= Lanthanum dose
Factor B= Application time
Factor AB= Lanthanum Dose and Application time

SOME PICTURES OF MY EXPERIMENT





Lanthanum Chloride

Growing of seedlings on seedbed

Transplanting of the seedlings

Tillering stage

Panicle initiation stage

Chemical spray

Dough stage

Maturity stage