

Azolla-based compost enhances growth and yield performance in rice (*Oryza sativa* L.)

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ABSTRACT

Azolla is a floating freshwater fern that fixes atmospheric nitrogen through its symbiotic association with cyanobacteria, making it a potential resource for improving soil fertility. Until now, interaction of *Azolla*-based compost, enhances soil nitrogen (N), growth, and yield has not been well explored. Therefore, the aim of the study was to evaluate the effects of *Azolla*-based compost on the growth and productivity of BRRI Rice-29 (*Oryza sativa* L.) under soil. The experiment was conducted with a randomized complete block design comprising four treatments, each with three replications. The study revealed that *Azolla* compost significantly enhanced soil N, growth, and yield performance in rice. Plants treated with 100% *Azolla* compost (T4) exhibited the highest plant height (98.23 cm), leaf area (238.20 cm²), chlorophyll content (2.69 mg g⁻¹ FW), and grain yield (414.07 g pot⁻¹). Grain yield increased by 61.38%, 104.99%, and 122.96% under T2, T3, and T4, respectively, relative to the control (T1). The control treatment resulted in the lowest performance across all parameters. These findings highlight the potential of *Azolla*-based compost as an eco-friendly manure that improves soil fertility and promotes rice productivity. This study paves the way for a cost-effective and eco-friendly alternative strategy for reducing chemical N fertilizer dependency during rice cultivation.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population, playing a crucial role in global food security [1]. In Bangladesh, particularly in the Barishal region, where rice cultivation is a primary agricultural activity, improving growth and productivity is vital for economic stability and food supply. The present rice farming system relies heavily on chemical N fertilizers to enhance productivity [2]. However, extensive use of chemical fertilizers leads to several environmental and agronomic challenges, including soil degradation, nutrient imbalances, reduced soil fertility, reduced yield, pest outbreaks, and pollution of water bodies. Consequently, there is a pressing need for sustainable agricultural practices that enhance crop yield without compromising soil health and environmental quality [3].

Azolla, a small aquatic fern, is known for its rapid biomass accumulation and high nitrogen-fixing capacity, making it an excellent candidate for biofertilization [3-5]. *Azolla* harbors a symbiotic relationship with the nitrogen-fixing cyanobacterium *Anabaena azollae* [6,7]. The symbiotic relationship between *Azolla* and *Anabaena azollae* is a well-studied example of mutualistic interaction in nature. *Anabaena azollae* resides in the leaf cavities of *Azolla*, where it fixes atmospheric N and provides the fern with essential nutrients. In return, *Azolla* provides a protected environment and photosynthates to the cyanobacterium. This symbiosis enables *Azolla* to fix atmospheric N, enriching the soil with organic nitrogen compounds [8]. The nitrogen-fixing capability of cyanobacteria is



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well-documented, with studies demonstrating their ability to convert atmospheric nitrogen (N₂) into ammonia (NH₃), which is readily available for plant uptake [9].

The use of *Azolla* as green manure and biofertilizer has been extensively researched. Incorporating *Azolla* into rice paddies has been shown to improve nitrogen use efficiency [10-13], soil fertility, increase organic matter content, and enhance soil microbial activity. A study reported that *Azolla* could replace up to 50% of the nitrogen requirement in rice fields, significantly reducing the dependency on chemical fertilizers [12]. Additionally, another study found that the decomposition of *Azolla* in the soil releases nutrients gradually, providing a sustained supply of nitrogen, phosphorus, and other essential nutrients to the rice plants [14].

The application of *Azolla*-based compost increased the availability of essential nutrients such as nitrogen, phosphorus, and potassium, leading to improved plant growth and higher grain yield [11, 15, 16]. Moreover, the organic matter from *Azolla* decomposition enhances soil structure, water retention, and root development [17]. In addition, cyanobacteria in *Azolla*-based compost produce growth-promoting substances like auxins and gibberellins, further stimulating plant growth [18,19]. Furthermore, cyanobacteria's role in suppressing soil-borne pathogens through the production of antimicrobial compounds has been documented [20,21] and suggests an additional benefit of using *Azolla*-based compost in rice cultivation. *Azolla* exhibits strong biocontrol potential due to its insecticidal activity against pests and pathogens. Recent findings demonstrate that aqueous and ethanolic extracts of *Azolla pinnata* and *A. microphylla* possess significant toxicity against both larvae and adults of *Tribolium castaneum*, with *A. pinnata* showing greater efficacy [22].

The environmental benefits of using *Azolla*-based compost are significant. *Azolla*'s rapid growth and high biomass production can help sequester carbon, contributing to climate change mitigation. Additionally, the use of *Azolla* reduces the need for synthetic fertilizers, decreasing the risk of nutrient runoff and water pollution. *Azolla* can reduce methane emissions from rice paddies [15, 23, 24].

Although *Azolla* has been widely recognized as a potential source of nutrients in sustainable rice production, further evaluation is needed to clarify the effects of *Azolla*-based compost on rice growth, yield attributes, and soil properties under different compost application regimes. Pot culture experiments can provide a controlled framework for comparing these treatments under a common set of growing conditions, complementing field-based investigations.

Therefore, this study aimed to evaluate the effects of different *Azolla*-based compost treatments on the growth, yield attributes, and soil properties of BRRI Rice-29 (*Oryza sativa* L.) in soil pots. In the present study, *Azolla*- compost significantly improved growth and yield performance in rice.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in a net house at the Agricultural Research Facility, University of Barishal (22°39'46"N 90°21'54"E) located in the Barisal Division of southern Bangladesh. The facility provides a controlled environment for pot culture experiments. This helps reduce external variability while maintaining near-natural conditions for plant growth. The net house was protected from excessive rain and direct sunlight, moderating

light intensity while allowing natural daylight conditions for rice growth, thereby ensuring uniform experimental conditions across all treatments.

The study was conducted during the 2023-2024 (December to April) rice-growing season (Boro season), mimicking field conditions for rice cultivation. Barishal's climate was classified as humid subtropical, characterized by distinct rainy and dry periods [25]. The region typically experiences 2000 - 2500 mm of annual rainfall, with most occurring between June and September, and average temperatures during the growing season range from 25°C to 30°C. The high relative humidity, around 70%, creates favorable conditions for rice growth.

Experimental design

The experiment was designed with a randomized complete block design (RCBD) in a pot culture system to evaluate the effects of different compost treatments on rice growth and productivity. The experiment was set up with 20-liter pots filled with soil collected from rice-growing areas of Kornokathi, Barishal (22°66'56"N 90°37'99"E), which was prepared by air-drying and sieving to remove debris. The soil in Barishal was predominantly classified as non-saline to low-saline, silty clay to clay loam belonging to the young Gangetic alluvium tract [26]. The soil pH was 5.5-6.0, which was suitable for rice cultivation. Pots were filled with 15 kg of soil, providing adequate root space for the rice plants. Each pot contained ten healthy rice seedlings. 35-day-old seedlings of BRRI Rice-29 were transplanted in the study.

Preparation of compost

The compost used in the experiment was prepared using locally available resources, particularly *Azolla*, a nitrogen-fixing aquatic fern. The collected materials were subjected to controlled composting under aerobic conditions until fully decomposed. The resulting stabilized organic matter was then used as fertilizer in the pot culture experiment. The steps involved in compost preparation were as follows: Firstly, *Azolla* biomass was harvested from local water bodies, rinsed, and dried in sunlight before being mixed with other composting materials. Secondly, rice straw, which provided a carbon-rich component, and cow dung, a source of microbial activity, were added to the compost pile. Green manure, such as fresh plant material, was also included to enhance nutrient availability.

Thirdly, the compost pile was constructed in layers, alternating between carbon-rich and nitrogen-rich materials, and was moistened to maintain a 50% moisture content. Finally, the pile was turned every 7-10 days to maintain aerobic conditions and promote even decomposition. After a period of 60 days, the compost was ready for application, with laboratory analysis confirming it was rich in nitrogen (N), phosphorus (P), and potassium (K). For treatments involving conventional compost, a similar method was followed, using crop residues and cow dung as the primary materials. The *Azolla*-based compost was mixed with conventional compost in the appropriate proportions for T3 and T4.

Elemental analysis in *Azolla* compost

The elemental composition of the prepared conventional and *Azolla* compost was analyzed to determine its nutrient content, including carbon (C), nitrogen (N),

phosphorus (P), potassium (K), and the carbon-to-nitrogen (C/N) ratio. Two compost samples were collected for analysis. The analysis was conducted using atomic absorption spectrometry (iCE™ 3300 AAS Atomic Absorption Spectrometer, Thermo Fisher Scientific) at the laboratory facilities provided by the Soil Resource Development Institute (SRDI), Barishal and Dhaka Office, and the pH of each sample was measured using a pH meter.

Selection of rice cultivar

The rice variety BRRI Rice-29 developed by Bangladesh Rice Research Institute was used as a plant material for this experiment. BRRI Rice-29 is a robust variety suitable for cultivation in the lowlands of Barishal. It reaches an average height of 95–100 cm, has a life span of approximately 95–100 days, and yields about 7.5 tons per hectare under suitable conditions [25].

***Azolla*-based compost treatments used in rice plants**

Four treatments (T1, T2, T3, and T4) were used for the experiment. Each treatment was replicated three times, and the pots were arranged randomly within three blocks to reduce variability caused by environmental factors within the net house. A total of 12 pots were used, with each pot representing one treatment replicate combination. The following treatments were applied, which are as follows:

T1: Control (no compost)– No organic compost was added to the soil. The plants were irrigated and fertilized by adding urea (1.2 g/pot $\approx$ 160 kg ha⁻¹), TSP (1.0 g/pot $\approx$ 133 kg ha⁻¹), MOP (0.8 g/pot $\approx$ 107 kg ha⁻¹), and gypsum (0.5 g/pot $\approx$ 67 kg ha⁻¹).

T2: Conventional compost (100% organic compost)– This treatment involved applying 100% conventional compost, prepared from a mixture of organic waste materials such as crop residues and cow dung. The compost was applied at a rate equivalent to 5 t ha⁻¹ (48.11 g pot⁻¹), calculated based on the upper surface area of each pot (35 cm in diameter). The same total compost application rate was used for the conventional compost and *Azolla*-based compost treatments, including the treatment containing a 1:1 mixture of the two compost types.

T3: 50% *Azolla*-based compost + 50% conventional compost– This treatment consisted of a 50:50 mixture of *Azolla*-based compost and conventional compost. The composts were thoroughly mixed before being added to the pots to ensure even distribution.

T4: 100% *Azolla*-based compost– The final treatment involved using 100% *Azolla*-based compost. *Azolla*, an aquatic fern, was composted as described in section 2.3 and applied to the pots at a rate equivalent to 5 tons per hectare.

All pots were irrigated at 3-day intervals. Soil moisture was maintained at field capacity throughout the experiment. The pots were placed 30 cm apart to ensure sufficient light and air circulation. Fertilizers were applied as urea (46% N), triple superphosphate (TSP, 46% P₂O₅), muriate of potash (MOP, 60% K₂O), and gypsum (18% S). All fertilizers except urea were applied as basal doses during soil preparation. Urea was applied in split doses at 10, 20, and 30 days after transplanting.

Data collection

Data collection focused on several key growth and yield parameters to assess the effects of different compost treatments on rice plant development. Plant height was measured at maturity, from the base of the plant to the tip of the tallest leaf. Measurements were taken from all surviving plants in each pot, and the values were averaged to obtain a single mean value for each pot. Each pot was considered the experimental unit for statistical analysis.

Number of tillers per plant: Tillers, which are secondary shoots, were counted for the same set of plants in each pot per treatment. The average number of tillers was recorded to assess the plant's vegetative growth. Using a leaf area meter, leaf area (cm²) of the upper three leaves of the plants was measured at the flowering stage. This parameter served as an indicator of photosynthetic potential and plant vigor.

The number of panicles, or flowering heads, was recorded at the reproductive stage. Each pot's average number of panicles was calculated as an important determinant of grain yield. Grain weight per panicle (g) was determined using five panicles from each pot that were harvested and dried. The grains were weighed to calculate the average grain weight per panicle. Total grain yield (g/pot) was calculated following rice harvesting; the grain yield from each pot was weighed and adjusted to a moisture content of 14%. Yield data were expressed in grams per pot.

Estimation of chlorophyll content in rice leaf

Leaf chlorophyll content was determined using the solvent extraction method with 80% (v/v) acetone, followed by spectrophotometric analysis, as described by [27]. Fresh leaf samples (the third fully expanded leaf from the top) were collected from each pot, immediately placed on ice, and processed within 2–4 hours of sampling.

Approximately 0.1 g of fresh leaf tissue was cut into small pieces and homogenized in a mortar and pestle with 10 mL of 80% acetone until the tissue was completely macerated. The homogenate was transferred to a centrifuge tube and centrifuged at 4,000 × g for 5 minutes to obtain a clear supernatant. The absorbance of the supernatant was measured at 663 nm and 645 nm using a UV–Vis spectrophotometer, with 80% acetone serving as the blank.

Chlorophyll concentrations were calculated using the following equations (Arnon, 1949):

$$\text{Chlorophyll a } (\mu\text{g mL}^{-1}) = 12.7(A_{663}) - 2.69(A_{645})$$

$$\text{Chlorophyll b } (\mu\text{g mL}^{-1}) = 22.9(A_{645}) - 4.68(A_{663})$$

$$\text{Total Chlorophyll } (\mu\text{g mL}^{-1}) = \text{Chlorophyll a} + \text{Chlorophyll b}$$

The total chlorophyll content was expressed on a fresh weight basis using the formula:

$$\text{Chlorophyll (mg g}^{-1}\text{ FW)} = \frac{(\text{Total chlorophyll, } \mu\text{g mL}^{-1}) \times V}{1000 \times W} \quad (\text{Eqn. 1})$$

Where V = final extract volume (mL), and W = fresh weight of the leaf tissue (g).

Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) to test the significance of treatment effects on plant growth and yield parameters. The main factors included plant height, number of tillers, leaf area, number of panicles, grain weight per panicle, and total grain yield were analysed. The ANOVA was performed using

STATISTIX 10.0 statistical software. Tukey's HSD was conducted to identify significant differences among the group means. All statistical tests were performed at a significance level of $p < 0.05$, and the results were presented as means to illustrate variability within treatment groups.

RESULTS

Azolla compost showed better elemental concentration in rice

The elemental analysis results of the conventional and *Azolla*-based compost used in this study are presented in Table 1. The pH of conventional compost was 7.1, whereas the *Azolla* compost samples showed slightly higher pH values of 7.4 and 7.3. The carbon content was 31.11% in conventional compost, compared with 33.75% and 35.50% in Samples 1 and 2, respectively. Nitrogen content was considerably higher in *Azolla* compost (3.12–3.15%) than in conventional compost (1.50%).

Similarly, phosphorus and potassium contents were higher in *Azolla* compost, ranging from 1.11–1.13% and 1.47–1.52%, respectively, compared with 0.70% P and 1.10% K in conventional compost. The C/N ratio was 20.74 in conventional compost, while substantially lower ratios of 10.81 and 11.26 were recorded in *Azolla* compost Samples 1 and 2, respectively. Overall, both *Azolla* compost samples exhibited higher nutrient contents and lower C/N ratios than conventional compost. The C/N ratio indicates good potential for nutrient release during compost decomposition, ensuring the supply of nitrogen essential for rice growth.

Table 1. Elemental composition and pH of the conventional and prepared *Azolla* compost samples.

	pH	Elements (%)				
		C	N	P	K	C/N ratio
Conventional Compost	7.1	31.11	1.5	0.7	1.1	20.74
Sample 1 (<i>Azolla</i> compost)	7.4	33.75	3.12	1.13	1.52	10.81
Sample 2 (<i>Azolla</i> compost)	7.3	35.5	3.15	1.11	1.47	11.26

Azolla compost enhanced rice growth and yield

The effects of different compost treatments on rice growth and productivity are summarized in Table 2. The treatments significantly influenced all measured growth parameters and yield components ($p < 0.05$). Rice plants treated with 100% *Azolla* compost (T4) consistently showed the best performance across all parameters. The highest plant height (98.23 cm plant⁻¹), number of tillers (17.33), leaf area (238.20 cm²), and number of panicles per plant (15.66) were recorded for T4.

Additionally, the grain weight per panicle (15.40 g) and total grain yield (414.07 g pot⁻¹) were significantly higher in T4 than in any other treatment. Grain yield differed among the compost treatments. Compared with the control (T1), grain yield increased by 61.38%, 104.99%, and 122.96% under T2, T3, and T4, respectively. The highest grain yield was recorded under T4 (100% *Azolla*-based compost), followed by T3. Furthermore, grain yield under T3 was 27.03% higher than under T2 (100% conventional compost). These results indicate a positive response of rice grain yield to *Azolla*-based compost application under the experimental pot culture conditions.

In comparison, T1 (no compost) led to the poorest results, with the shortest plant height (87.63 cm plant⁻¹), the fewest tillers (10.66), the smallest leaf area (190.97 cm²), the fewest panicles per plant (9.33), the lowest grain weight (7.71 g panicle⁻¹), and the lowest total grain yield (185.67 g pot⁻¹).

T3 and T2 produced intermediate results, with T3 generally outperforming T2 in plant height, number of tillers, leaf area, number of panicles, and total grain yield. Among these parameters, a statistically significant difference was specifically observed in total grain yield, with T3 yielding more than T2.

Table 2. Effect of different composts on growth parameters and grain yield of rice in a pot culture.

Treatment	Plant height (cm plant ⁻¹)	No. of tillers per plant	Leaf area (cm ²)	No. of panicles per plant	Grain weight (gm panicle ⁻¹)	Total grain yield (g pot ⁻¹)
T1	87.63b	10.66c	190.97c	9.33c	7.71c	185.67d
T2	94.20a	15b	223.30b	13b	10.73b	299.65c
T3	95.66a	16ab	224.43ab	14.66ab	13b	380.63b
T4	98.23a	17.33a	238.20a	15.66a	15.40a	414.07a
p-value	0.0041	0.0002	0.0001	0.0002	<0.0001	<0.0001

*Values followed by the same letter are not significantly different ($p < 0.05$).

***Azolla* compost regulated chlorophyll content in rice**

Application of *Azolla*-based compost significantly influenced the chlorophyll content of rice leaves at the flowering stage (Table 3). The highest chlorophyll a, chlorophyll b, and total chlorophyll concentrations were recorded in plants treated with 100% *Azolla*-based compost (1.81, 0.88, and 2.69 mg g⁻¹ FW, respectively), which were statistically superior to all other treatments ($p \leq 0.05$). The combined application of 50% *Azolla*-based compost and 50% conventional compost (T3) also showed a marked improvement in chlorophyll content (1.53, 0.73, and 2.26 mg g⁻¹ FW, respectively) compared with the control and conventional compost alone.

In contrast, the lowest chlorophyll levels were observed in the control treatment (1.40 mg g⁻¹ FW total chlorophyll), indicating a clear stimulatory effect of *Azolla*-based compost on leaf pigment synthesis. The progressive increase in chlorophyll a, b, and total chlorophyll with higher proportions of *Azolla*-based compost suggests enhanced photosynthetic capacity and better physiological status of rice plants under organic nutrient management.

Table 3. Effect of *Azolla*-based compost on leaf chlorophyll content of rice at the flowering stage.

Treatments	Chlorophyll a (mg g ⁻¹ FW)	Chlorophyll b (mg g ⁻¹ FW)	Total Chlorophyll (mg g ⁻¹ FW)
T1	0.92 ± 0.03 ^d	0.48 ± 0.02 ^c	1.40 ± 0.04 ^d
T2	1.26 ± 0.05 ^c	0.61 ± 0.03 ^{bc}	1.87 ± 0.06 ^c
T3	1.53 ± 0.04 ^b	0.73 ± 0.02 ^b	2.26 ± 0.05 ^b
T4	1.81 ± 0.06 ^a	0.88 ± 0.03 ^a	2.69 ± 0.07 ^a
LSD (0.05)	0.09	0.06	0.10

*Values represent the mean ± standard error (n = 3). Means followed by different letters within a column differ significantly at $p \leq 0.05$ according to the LSD test.

DISCUSSION

This superior performance of rice plants treated with *Azolla* compost for growth-related parameters such as plant height, the highest number of tillers, and the largest leaf area can be attributed to the high nutrient content of *Azolla* compost, particularly its N content, which plays a pivotal role in promoting vegetative growth. These results indicate that *Azolla* compost provides superior nutrient availability, contributing to improved plant growth and yield.

N is a key element in chlorophyll formation and the development of plant tissues, which ultimately results in increased plant height and leaf area [28]. The steady release of nitrogen from the decomposing *Azolla* compost likely contributed to sustained nutrient availability throughout the rice growth cycle, supporting continuous vegetative growth.

Moreover, *Azolla* compost promotes soil enzyme activities, including urease, phosphatase, and dehydrogenase, through the addition of organic matter and nutrients [29]. These inputs stimulate microbial growth and enhance microbial diversity. As a result, the availability of essential nutrients for enzymatic functions increases [30,31]. A study also reported that *Azolla* compost alters carbon and nitrogen mineralization and boosts microbial activity in paddy soils [17].

The higher number of tillers observed in the T4 treatment compared to the control. Further underscores the role of *Azolla* compost in enhancing plant growth. Tillering in rice is highly dependent on nitrogen availability, as it stimulates cell division and meristematic activity, leading to the production of additional shoots [32]. The nitrogen-fixing capacity of *Azolla* through its symbiotic association with cyanobacteria (*Anabaena azollae*) provides a continuous supply of nitrogen to the plants, which is critical for the development of secondary shoots or tillers. This result is consistent with previous studies showing that *Azolla*'s nitrogen fixation ability significantly boosts tillering and overall plant vigor [33, 34].

Leaf area is a direct indicator of a plant's photosynthetic capacity and health [35]. The largest leaf area (238.20 cm²) was observed in the T4. This indicates that plants treated with *Azolla* compost were able to develop a larger photosynthetic apparatus, allowing for greater light interception and energy capture, which translated into increased biomass production. The enhanced leaf area in T4 can be linked to the efficient uptake of nitrogen, phosphorus, and potassium provided by the *Azolla* compost, as well as its ability to improve soil structure and water retention, both of which are critical for photosynthesis and plant growth.

A larger leaf area not only allows for improved photosynthetic efficiency but also enhances transpiration, which supports nutrient uptake and water movement through the plant [36, 37]. The increased photosynthetic surface area in the T4 treatment likely contributed to the overall improved growth performance observed in the rice plants treated with *Azolla* compost. Similar findings have been reported in other studies, where *Azolla* compost application significantly increased leaf area and photosynthetic rates in rice and other crops [31].

Moreover, the increased level of chlorophyll content (Table 3) observed with *Azolla*-based compost application indicates that compost effectively enhanced the photosynthetic potential and physiological vigor of rice plants. *Azolla* is known to be rich in nitrogen, essential amino acids, and micronutrients such as iron, magnesium, and zinc, which play key roles in chlorophyll biosynthesis and the formation of chloroplast pigments [38]. The higher chlorophyll a and b concentrations in the T4 suggest improved nitrogen availability and better uptake efficiency, as nitrogen is a primary constituent of the chlorophyll molecule.

The enhancement of chlorophyll levels with increasing proportions of *Azolla* compost is consistent with previous studies reporting that organic amendments derived from *Azolla* improve leaf greenness, photosynthetic rate, and overall crop growth [31,39]. Therefore, the present findings confirm the potential of *Azolla*-based compost as an eco-friendly organic amendment that enhances the physiological efficiency of rice through improved chlorophyll synthesis and photosynthetic performance.

Panicle production is a critical determinant of rice yield, as it directly influences the number of grains produced per plant [40,41]. The application of 100% *Azolla* compost (T4) led to the highest number of panicles per plant (15.66), significantly outperforming the control (9.33) and conventional compost treatments. The improved panicle production in the T4 treatment can be attributed to the sustained supply of nutrients, particularly phosphorus and potassium, which are essential for reproductive growth and seed development. Phosphorus is involved in energy transfer and root development [37], while potassium regulates water use efficiency and enhances grain filling, both of which are critical for panicle and grain formation [42,43]. The grain weight per panicle (15.40 g) was also significantly higher in T4 compared to the control (7.71 g), indicating that the *Azolla* compost provided the necessary nutrients for effective grain filling. The enhanced grain filling observed in the T4 treatment suggests that *Azolla* compost not only supports vegetative growth but also plays a crucial role in the reproductive phase of rice plants. This aligns with previous studies reporting that *Azolla* compost improves nutrient availability, leading to better grain development and higher yields [31,34].

Total grain yield is the ultimate measure of agricultural productivity, and the results of this study showed that the T4 treatment produced the highest yield (414.07 g pot⁻¹), which was significantly higher than the control (185.67 g pot⁻¹) and the conventional compost treatment (299.65 g pot⁻¹). The superior grain yield in the *Azolla*-treated plants can be attributed to the combined effects of improved plant height, larger leaf area, more tillers, increased panicle production, and better grain filling.

The significant yield increase in the T4 treatment demonstrates the potential of *Azolla* compost as an effective organic fertilizer that can reduce or even replace conventional fertilizers. The nutrient-rich nature of *Azolla* compost, particularly its high nitrogen content, supports robust plant growth and maximizes grain production, making it a viable alternative for improving rice yields in a sustainable and environmentally friendly manner.

While conventional compost improved rice growth and yield compared to the control, it was less effective than 100% *Azolla* compost. This may be due to the higher nitrogen content and faster decomposition rate of *Azolla*, which provides a more immediate and sustained nutrient supply to the rice plants.

The combination of *Azolla* with conventional compost also showed better performance than conventional compost alone, indicating a synergistic effect of the two composts. The T3 produced higher grain yield (380.63 g pot⁻¹) than T2, likely due to the enhanced nutrient availability from the *Azolla* component.

The improved results with *Azolla*-based compost, compared to conventional compost, highlight the potential for *Azolla* to be integrated into existing composting practices to enhance the nutrient profile and effectiveness of organic fertilizers. Overall, the results indicate that 100% *Azolla* compost significantly enhances rice growth and productivity, outperforming both conventional compost and no-compost treatments. This highlights the potential of *Azolla* as a valuable organic amendment in rice cultivation for improving growth and yield.

This study was conducted as a single-year pot experiment with four treatments and three replications per treatment. The limited replication and single-year experimental scope may constrain the statistical precision and generalizability of the findings. These limitations are acknowledged, and further studies involving a larger number of replications and multiple growing seasons are recommended to validate the results and assess the consistency and generalizability of the observed effects of *Azolla*-based compost on rice growth and productivity.

CONCLUSIONS

This study explores a cost-effective strategy with declining dependency on N-based chemical fertilizer during rice cultivation. The *Azolla*-based compost enhances growth and productivity in rice. The nutrient-rich nature of *Azolla*, particularly its high N content, supports robust vegetative and reproductive growth, leading to higher grain yields. The findings of this study suggest that *Azolla*-based compost can play a significant role in improving rice productivity while promoting environmentally sustainable agricultural practices. Its application as a supplement can reduce dependency on chemical fertilizers, lower production costs, and enhance soil fertility over the long term. For farmers, particularly in regions like Barishal, where rice cultivation is a major agricultural activity, *Azolla*-based compost represents a viable, cost-effective, and eco-friendly alternative to traditional fertilizers. The study suggests that application of *Azolla*-based compost could be a cost-effective and environmentally friendly strategy that helps to reduce dependency on N-based chemical fertilizers in sustainable rice farming.

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AUTHOR CONTRIBUTIONS

ATMRI conceived and conceptualized the study, conducted the investigation, performed data analysis, and drafted the original manuscript. IA contributed to data analysis and revised the manuscript through critical review and editing. NA participated in the investigation and further reviewed and edited the manuscript. SIK reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

DECLARATION OF USING AI-ASSISTED TOOLS

During the preparation of this work, the author(s) used ChatGPT and Grammarly for language polishing and English editing. After using these tools/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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