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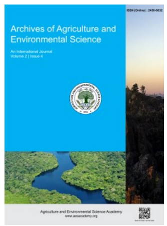

ORIGINAL RESEARCH ARTICLE

Optimizing silicon fertilization for improved growth and yield in *Boro* rice

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ABSTRACT

In the present era, sustaining rice productivity is increasingly challenged by various biotic and abiotic stresses, nutrient imbalances, and climate variability, prompting interest in beneficial elements like silicon (Si) for enhancing plant resilience and improving yield. To evaluate the impact of silicon on *Boro* rice (cv. Binadhan-25), a field experiment was conducted during the 2024 *Boro* season at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. The study comprised eleven treatments where recommended dose of fertilizers (RDF) were applied combining with 0 to 200 kg SiO_2 ha^{-1} in 20 kg increments. This research was arranged in a randomized complete block design (RCBD) with three replications. Results revealed that the application of 40 kg SiO_2 ha^{-1} alongside RDF significantly improved plant height, effective tillers $hill^{-1}$ and grain yield outperforming all other treatments. Grain yield increased by about 25.7% with the application of 40 kg SiO_2 ha^{-1} compared to no silicon application to the soil. These findings emphasize the beneficial role of moderate silicon supplementation in enhancing growth and yield of *Boro* rice and suggest 40 kg SiO_2 ha^{-1} as the optimum dose for productivity enhancement. Future research should explore the long-term effects of silicon on soil health and crop sustainability across different rice varieties and agro-ecological zones, considering the limitation that this study focused on a single variety under one growing season.

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INTRODUCTION

Rice (*Oryza sativa* L.) is the most important and broadly cultivated staple food crop that feeds approximately half of the human population, providing over 21% of the human caloric and up to 76% of the caloric intake of Southeast Asian inhabitants (Roy *et al.*, 2024; Salam *et al.*, 2020; Zhao *et al.*, 2020). In 2024, world production of rice reached 820 million tons, with China and India maintaining their lead, contributing a combined 50% of the total (Ahmad *et al.*, 2024; Paul *et al.*, 2020). In Bangladesh, rice is central to agriculture and food security, covering 76% of cropped land and involving about 13 million farms across 10.5 million hectares (Akter *et al.*, 2022; Biswas *et al.*, 2022). In 2023, rice production totaled 36.35 million tons, with an average yield of 3.13 tons per hectare (BBS, 2023). However, sustaining and improving rice productivity remains a challenge under increasing biotic and abiotic stresses, nutrient imbalances and changing climatic conditions (Paul *et al.*, 2025; Hasan *et al.*, 2025; Islam *et al.*, 2024; Zohora *et al.*, 2023). In this context, the role of beneficial elements like silicon has gained attention for their potential to enhance plant resilience and yield performance.

Silicon (Si) is ranked as the second-most abundant element (after oxygen) in the earth's crust with nearly 29% mean content (Farooq & Dietz, 2015). Si is naturally present in soil, where silicon dioxide (SiO_2) accounts for approximately 50–70% of the soil's mass (Ahsan *et al.*, 2023; Wang *et al.*, 2021). It plays a crucial role in improving crop yield and quality, as well as enhancing crop resistance to various stresses (Ali & Singh, 2025). The beneficial effects of Si characteristically differ with the plant species particularly in rice, containing high amount of silica in the stem and leaves, ranging from 10 to 20%. Its absorption brings several benefits as the increase of cell wall thickness below the cuticle, imparting mechanical resistance to the penetration of fungi, decrease in transpiration and improvement of leaf angle, making leaves more erect, thus reducing self-shading, especially under high nitrogen rates (Ahammed & Yang, 2021). Previous studies reported the beneficial impact of using silicon in different forms in improving yield attributes of rice (Ahmad *et al.*, 2012; Kheyri *et al.*, 2019; Pati *et al.*, 2016). The use of silicon varied with agroecological zones as well as different conditions and unbalance uses ultimately influences the growing capacity and yield performance. To explore this research gap, the present study will be undertaken to evaluate the effects of different Silicon doses on the growth and yield performance of *Boro* rice (cv. Binadhan-25).

MATERIALS AND METHODS

Location and climate

The experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh (24°25′ N latitude and 90°50′ E longitude at an elevation of 18m above the sea level) during October, 2023 to May, 2024 to investigate the effects of different Silicon doses on the growth and yield performance of *Boro* rice. The experimental field belongs to non- calcareous dark grey floodplain soil under the Sonatala soil series which falls under Agro-ecological Zone of the Old Brahmaputra Floodplain (AEZ-9) (UNDP & FAO, 1988). The experimental field was a medium high land with moderate drainage facilities. The soil was silty loam in texture, almost neutral in reaction and low in organic matter content with pH 6.45, 0.85% organic matter, 0.68% total nitrogen, 16.67 ppm available phosphorus, 0.20 Mg/100g exchangeable potassium, and 12.75 ppm available sulfur. From October 2023 to May 2024, the meteorological data (Figure 1) showed temperatures, rainfall, and relative humidity.

Experimental design

The experiment was laid out using a randomized complete block design with three replications and eleven different silicon treatments, including recommended dose of fertilizers- urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, boric acid @ 217, 119, 130, 77, 6.94, 14.7 kg ha^{-1}, respectively such as (RDF) + 0 kg SiO_2 ha^{-1} (control) (T_1), RDF+20 kg SiO_2 ha^{-1} (T_2), RDF + 40 kg SiO_2 ha^{-1} (T_3), RDF+60 kg SiO_2 ha^{-1} (T_4), RDF + 80 kg SiO_2 ha^{-1} (T_5), RDF + 100 kg SiO_2 ha^{-1} (T_6), RDF + 120 kg SiO_2 ha^{-1} (T_7), RDF+140 kg SiO_2 ha^{-1} (T_8), RDF + 160 kg SiO_2 ha^{-1} (T_9), RDF + 180 kg SiO_2 ha^{-1} (T_{10}) and RDF + 200 kg SiO_2 ha^{-1}(T_{11}). Each block was divided into 11-unit plots, where the 11 treatments were allocated at random. Altogether there were 33-unit plots in the experiment. The net size of each unit plot was 2.5 m × 2.0m. The spaces between replications and between plots were 1 m and 0.5 m, respectively.

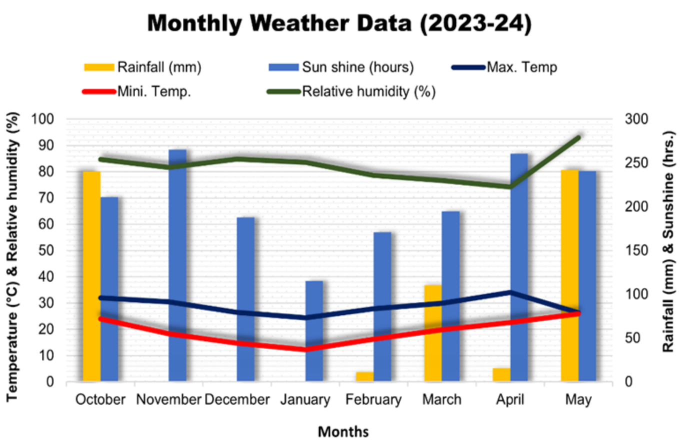

Figure 1. *Meteorological data for November 2023 to February 2024 of the experimental site.*

Land preparation and intercultural operation

Seeds of rice variety Binadhan-25 were collected from Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. Then seeds were immersed in a water bucket for 24 hrs. These seeds were taken out from the bucket and tightly covered by gunny bags. The seeds started sprouting after 48 hrs. which became prepared for sowing in next 72 hrs. The nursery bed was prepared by puddling with repeated ploughing nursery beds of 1.0 m length and 1.0 m width. Later the seed was covered immediately and then a light irrigation was given. The field was prepared by ploughing with tractor drawn cultivars followed by cross harrowing to pulverize the soil. All uprooted weeds and crop residues were removed from the field after plowing and laddering. The experimental plots were fertilized with urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, boric acid @ 217, 119, 130, 77, 6.94, 14.7 kg ha^{-1}, respectively (RDF). Super silica was used as a source of SiO_2. Except urea, the whole amount of other fertilizer was applied before final land preparation. Urea was top dressed in three installments at 15, 30 and 45 days after transplanting. The seedlings of 35 days were transplanted in the main field with a spacing cm as row to row and hill to hill distance, respectively with 2-3 seedlings hill^{-1}. A thin layer of water was kept at the time of transplanting for better establishment of the seedlings. From the third day onwards, 2 to 3 cm depth of water was maintained up to the panicle initiation stage except at the time of top dressing of urea, where the water was drained out and re-irrigated to maintain 5 cm depth of water up to physiological maturity. After dough stage, water was entirely drained out to make harvesting easier.

Data collection and harvesting

The crop was harvested at full maturity, when approximately 80% of the seeds turned golden yellow. Five hills (excluding border hills) were randomly pre-selected from each plot and uprooted before harvest to record data on various plant characteristics. After harvesting, the crops from each plot were separately bundled, tagged, and brought to the threshing floor. The crops were threshed using a pedal thresher, and the grains were sun-dried and cleaned. The straws were also properly sun-dried. Both grain and straw yields were then converted to t ha^{-1}.

Plant height: Five hills were randomly selected soon after transplanting and marked with bamboo sticks in each plot excluding border rows to record the data on plant height at 45, 60 and 75 DAT. Then the plant height at 45, 60 and 75 DAT was measured from the base to the tip of the longest panicle and expressed in cm.

Total tillers hill^{-1}: Five hills were randomly selected in each plot excluding border rows to record the data of number of tillers hill^{-1} at 45, 60 and 75 DAT. Then the number of tillers hill^{-1} at 45, 60 and 75 DAT was measured.

Effective tillers hill^{-1}: The panicles which had at least one grain were considered effective tillers. The number of effective tillers hill^{-1} was recorded and finally averaged for counting number of effective tillers hill^{-1} and non-effective tiller hill^{-1}. The tiller having no panicle was regarded as ineffective tillers. The number of effective tillers hill^{-1} was recorded and finally averaged for counting ineffective tillers number hill^{-1}.

Panicle length: Panicle length was recorded from the basal node of the rachis to the apex of each panicle.

Grains panicle^{-1}: Grain was considered to be filled if any kernel was present there. The number of total filled grains present on five panicles were recorded and finally averaged.

Sterile spikelet panicle^{-1}: Unfilled grains mean the absence of any kernel inside and such grains present on each of five panicles were counted and finally averaged.

1000-grain weight: One thousand cleaned dried grains were counted randomly from each sample and weighed by using a digital electric balance at the stage the grain retained about 14% moisture and the mean weights were expressed in grams.

Grain yield: Grain yield was determined from the central 1 m^2 areas of each plot and expressed as t ha^{-1} on about a 14% moisture basis. Grain moisture content was measured by using a digital moisture tester.

Straw yield: The straw yield was determined from the central 1 m^2 areas of each plot. After separating of grains, the subsamples were oven-dried to a constant weight and finally converted to t ha^{-1}.

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

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

Harvest index (%): It denotes the ratio of grain yield to biological yield and was calculated with the following formula:

Harvest Index (%) = Grain yield/Biological yield×100

Statistical analysis

The data collected for various traits were subjected to statistical analysis to evaluate significant differences among the treatments. Analysis of Variance (ANOVA) was conducted for all recorded parameters using the R software package (R Core Team, 2024). Treatment means were compared using Duncan's New Multiple Range Test (DNMRT), as described by Gomez & Gomez (1984).

RESULTS AND DISCUSSION

Plant height

The effect of silicon application on plant height varied significantly across different days after transplanting (DAT) (Table 1). At 45 DAT, the highest plant height was observed with the application of 200 kg SiO_2 ha^{-1} (T_{11}), which was statistically at par with 180 kg SiO_2 ha^{-1} (T_{10}), 160 kg SiO_2 ha^{-1} (T_9), and 100 kg SiO_2 ha^{-1} (T_6) when combined with recommended fertilizer doses. The lowest height was recorded under the control

Table 1. Effect of silicon on plant height at different days after transplanting of *Boro* rice.

Treatments	Plant height (cm)			
	45 DAT	60 DAT	75 DAT	At Harvest
T_1	40.12c	66.33	74.21b	107.53bc
T_2	41.20a-c	67.42	78.00ab	114.06 a
T_3	40.62bc	64.83	78.33ab	111.73a-c
T_4	40.37bc	68.00	79.58ab	108.00bc
T_5	41.83a-c	68.50	81.25ab	113.33 a
T_6	43.45a-c	67.25	79.92ab	111.00a-c
T_7	41.16a-c	68.75	78.16ab	107.33 c
T_8	40.87bc	65.67	76.00ab	109.33a-c
T_9	44.41ab	66.00	77.66ab	110.06a-c
T_{10}	44.16a-c	68.75	81.25ab	112.66 ab
T_{11}	45.08a	69.17	81.75a	111.40a-c
CV (%)	5.79	4.08	5.50	2.75
Level of significant	**	NS	**	**

Means with the same letters within the same column do not differ significantly; ** =Significant at 1% level of probability, NS = non-significant; RDF + 0 kg SiO_2 ha^{-1} (T_1), RDF+20 kg SiO_2 ha^{-1} (T_2), RDF + 40 kg SiO_2 ha^{-1} (T_3), RDF+60 kg SiO_2 ha^{-1} (T_4), RDF + 80 kg SiO_2 ha^{-1} (T_5), RDF + 100 kg SiO_2 ha^{-1} (T_6), RDF + 120 kg SiO_2 ha^{-1} (T_7), RDF+140 kg SiO_2 ha^{-1} (T_8), RDF + 160 kg SiO_2 ha^{-1} (T_9), RDF + 180 kg SiO_2 ha^{-1} (T_{10}), RDF + 200 kg SiO_2 ha^{-1} (T_{11}).

Table 2. Effect of silicon on total tillers hill^{-1} at different days after transplanting of *Boro* rice.

Treatments	Total tillers hill^{-1}			
	45 DAT	60 DAT	75 DAT	At Harvest
T_1	4.41b	10.58b	10.33c	8.06c
T_2	6.08a	12.75ab	12.58ab	9.67b
T_3	5.25ab	11.83ab	11.33abc	10.20a
T_4	5.41ab	13.25a	11.66abc	9.53b
T_5	5.25ab	12.08ab	11.75abc	9.00bc
T_6	5.83a	12.91a	12.58ab	9.33b
T_7	6.16a	13.50a	13.00a	9.20b
T_8	5.41ab	11.33ab	11.08abc	9.80ab
T_9	5.25ab	11.58ab	11.25abc	9.00bc
T_{10}	6.08a	11.83ab	11.58abc	9.20b
T_{11}	5.58ab	11.48ab	10.56bc	9.47b
CV (%)	13.93	11.15	10.61	16.55
Level of significant	**	**	**	**

Means with the same letters within the same column do not differ significantly; ** =Significant at 1% level of probability; RDF + 0 kg SiO_2 ha^{-1} (T_1), RDF+20 kg SiO_2 ha^{-1} (T_2), RDF + 40 kg SiO_2 ha^{-1} (T_3), RDF+60 kg SiO_2 ha^{-1} (T_4), RDF + 80 kg SiO_2 ha^{-1} (T_5), RDF + 100 kg SiO_2 ha^{-1} (T_6), RDF + 120 kg SiO_2 ha^{-1} (T_7), RDF+140 kg SiO_2 ha^{-1} (T_8), RDF + 160 kg SiO_2 ha^{-1} (T_9), RDF + 180 kg SiO_2 ha^{-1} (T_{10}), RDF + 200 kg SiO_2 ha^{-1} (T_{11}).

(no silicon) treatment. At 60 DAT, no significant differences were detected among treatments. However, at 75 DAT, trends similar to 45 DAT reappeared, with T_{11} showing the maximum plant height, statistically comparable to T_{10}, 80 kg SiO_2 ha^{-1} (T_5), and T_6, while the control exhibited the lowest values. At harvest, the tallest plants (114.06 cm) were found in 20 kg SiO_2 ha^{-1} (T2), statistically similar to T_3, T_5, T_6, T_8, T_9, T_{10}, and $_{11}$. The shortest plants were recorded in 120 kg SiO_2 ha^{-1} (T_7), which did not differ significantly from the control (T_1) and T_4. The increment of plant height with application of higher Si levels is attributed to promote cell wall strengthening, enhance photosynthesis, and improve stress tolerance, thereby encouraging taller plants (Manimaran *et al.*, 2025). Similar findings on silicon fertilizer were reported elsewhere (Dong *et al.*, 2024; Khanam *et al.*, 2020; Pati *et al.*, 2016). Pati *et al.* (2016) mentioned that increase in silicon greatly influences parameters of rice.

Total tillers hill^{-1}

The effect of silicon application on total tillers hill^{-1} varied substantially across different DAT (Table 2). At 45 DAT, the highest number of tillers was recorded in 120 kg SiO_2 ha^{-1} (T_7), statistically similar to T_2, T_6, and T_{10}, while the lowest was observed in no application of Silicon (T_1). At 60 DAT, T_7 again produced the highest tiller number, statistically at par with T_1, T_2, T_4, and T_6. The lowest tillers were recorded in control treatment. A similar trend continued at 75 DAT, with T_7 showing the highest value, comparable to T_2, T_6, and T_9, whereas T_1 produced the fewest tillers. At harvest, the number of effective tillers hill^{-1} was significantly influenced by silicon application. The maximum value (10.20) was found in 40 kg SiO_2 ha^{-1} (T_3), followed by T_2, T_6, T_5, T_4, T_7, T_8, and T_9. The lowest number (8.06) occurred in the control treatment (T_1). This indicates that Si application optimally supports tiller formation in rice by ensuring adequate Si supply from tillering to elongation stage, enhancing nutrient absorption, crop growth, source–sink relationship, and yield attributes (Jinger *et al.*, 2022). These outcomes align with studies by Pati *et al.* (2016) and Sultana *et al.* (2021) who reported a direct relationship between silicon dose and the number of tillers per hill, with higher silicon levels leading to a significant increase.

Yield components and yield

Silicon application significantly influenced several yield and yield-contributing parameters of rice (Table 3). The maximum panicle length was recorded in RDF + 160 kg SiO_2 ha^{-1} (T_9), which was statistically similar with most treatments except the control (T_1: RDF + 0 kg SiO_2 ha^{-1}), where the minimum length was observed. The number of grains per panicle was significantly highest in RDF + 40 kg SiO_2 ha^{-1} (T_3), statistically at par with T_2, T_4 to T_{10}, while the lowest was found in T_1 and T_{11}, resulting in a 9.7% increase over the lowest value. This is attributed to the efficiency of Si application in increasing the assimilation of carbohydrates in panicles also reported by Veer *et al.* (2020). However, silicon application had no significant effect on sterile spikelets per panicle and 1000-grain weight. Similar result is reported by Jan *et al.* (2018). Regarding grain yield, silicon application had a clear and significant impact. The highest grain yield was recorded in optimal uses of silicon (T_3: 40 kg SiO_2ha^{-1}), which was statistically superior to all other treatments (Figure 2). Compared to the lowest yield in T_1 which is statistically similar with T_9, T_{10}, and T_{11}. This represents a 25.7% increase, indicating a substantial improvement in productivity due to moderate silicon supplementation. For straw yield, the highest value was recorded in T_4, statistically similar with T_2, T_5 to T_7, while the lowest was in T9, comparable with T_1, T_8, T_{10}, and T_{11}. Similarly, biological yield showed significant variation, with application of 40 kg SiO_2 ha^{-1} (T_3) producing the highest result, statistically similar with T_2, T_4 to T_7. The lowest biological yield was recorded in T_1 and T_8 to T_{11}, indicating a 22.0% increase compare to control. The harvest index was also significantly affected, with the highest value observed in T_3, statistically similar with T_1, T_8 to T_{10}, while the lowest was recorded in T_4, followed by T_2, T_5, and T_6 resulting in a 13.9% increase from lowest to highest.

Table 3. Effect of silicon on yield and yield contributing characters of *Boro* rice.

Treatments	Effective tillers hill^{-1}	Panicle length (cm)	Grains panicle^{-1}	Sterile spiklet^{-1}	Thousand grain weight (g)	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	8.06b	27.06b	208.43f	13.80	18.67	4.91de	9.26 cd	47.00a-c
T_2	8.86ab	27.35ab	220.92b	13.03	18.48	5.90bc	10.29b	42.66de
T_3	9.26a	27.48ab	228.61a	13.82	18.92	5.63c	10.86a	48.17a
T_4	8.53ab	27.47ab	220.80b	12.88	18.77	6.23a	10.80a	42.28e
T_5	8.33ab	27.51ab	217.08bc	13.13	18.75	6.10ab	10.64ab	42.67de
T_6	8.60ab	27.29ab	215.00cd	12.79	18.65	5.86bc	10.38b	43.50de
T_7	8.26ab	27.26ab	213.49c-e	12.88	18.63	5.78c	10.28b	43.77d
T_8	8.33ab	27.36ab	212.00d-f	12.53	18.80	4.80de	9.20cd	47.82ab
T_9	8.26ab	27.77a	214.10c-e	12.58	18.87	4.73e	8.90d	46.82bc
T_{10}	8.20b	27.48ab	218.00bc	12.77	18.87	5.00de	9.30c	46.25c
T_{11}	8.13b	27.15ab	210.14ef	12.95	18.63	5.06d	9.36c	45.91c
CV (%)	8.35	1.34	1.23	6.26	1.60	3.17	2.18	1.65
Level of significant	**	**	**	NS	NS	**	**	**

Means with the same letters within the same column do not differ significantly; ** =Significant at 1% level of probability, NS = non-significant; RDF + 0 kg SiO_2 ha^{-1} (T_1), RDF+20 kg SiO_2 ha^{-1} (T_2), RDF + 40 kg SiO_2 ha^{-1} (T_3), RDF+60 kg SiO_2 ha^{-1} (T_4), RDF + 80 kg SiO_2 ha^{-1} (T_5), RDF + 100 kg SiO_2 ha^{-1} (T_6), RDF + 120 kg SiO_2 ha^{-1} (T_7), RDF+140 kg SiO_2 ha^{-1} (T_8), RDF + 160 kg SiO_2 ha^{-1} (T_9), RDF + 180 kg SiO_2 ha^{-1} (T_{10}), RDF + 200 kg SiO_2 ha^{-1} (T_{11}).

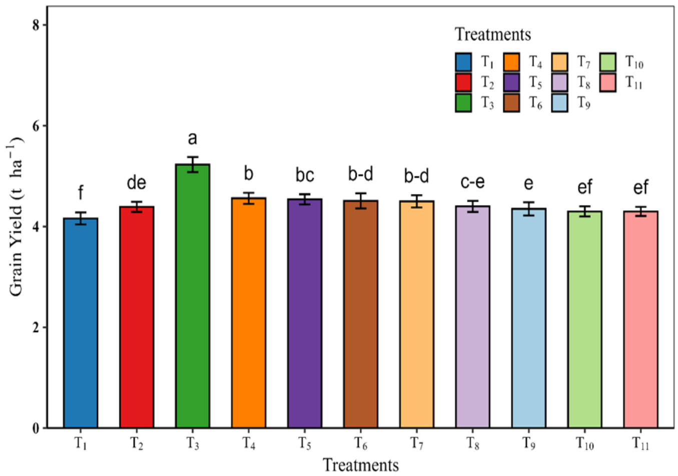

Figure 2. *Effect of silicon levels on grain yield (t ha^{-1}) of Boro rice. Treatments: T_1 = Recommended dose of fertilizers (RDF) + 0 kg SiO_2 ha^{-1}(control), T_2 = RDF + 20 kg SiO_2 ha^{-1}, T_3 = RDF + 40 kg SiO_2 ha$_{-1}$, T_4 = RDF + 60 kg SiO_2 ha$_{-1}$, T_5 = RDF + 80 kg SiO_2 ha^{-1}, T6 = RDF + 100 kg SiO_2 ha^{-1}, T7 = RDF + 120 kg SiO_2 ha^{-1}, T_8 = RDF + 140 kg SiO_2 ha^{-1}, T_9 = RDF + 160 kg SiO_2 ha^{-1}, T_{10} = RDF + 180 kg SiO_2 ha$_{-1}$, and T_{11} = RDF + 200 kg SiO^2 ha^{-1}.*

The increase in grain and biological yields was likely attributed to improved rice growth and yield traits, along with silicon's role in alleviating both biotic and abiotic stresses. Silicon addition also promoted plant growth, possibly by boosting photosynthetic efficiency, which in turn positively impacted productive tillers, panicle length, grains per panicle and reduced pest and disease infestation. These findings are consistent with those reported by a number of researchers (Ahmad *et al.*, 2012; Das *et al.*, 2023; Emam *et al.*, 2014; Khanam *et al.*, 2020; Pati *et al.*, 2016). Likewise, Khanam *et al.*, (2020) reported that silicon had a positive impact on the overall growth and yield performance of rice. Singh *et al.* (2006) found out that silicon in lesser amounts can be beneficial in increasing grain yield and growth of cereal crops as dry matter production, flag leaf performance, yield-related traits, and grain yield of rice improved markedly with increasing silicon application rates, reaching optimal results at 120 kg/ha.

Conclusion

The present study confirms that silicon application significantly enhances the growth and yield performance of rice, with RDF + 40 kg SiO_2 ha^{-1} (T_3) emerging as the most effective treatment across key agronomic and yield parameters. This moderate dose of silicon consistently outperformed other treatments, indicating its potential to improve plant height, tillering ability, panicle length, grain number, grain weight, and overall productivity. The integration of silicon into rice nutrient management not only supports higher yields but also offers a practical approach for farmers to improve crop resilience against biotic and abiotic stresses. Future research should explore the long-term impact of silicon on soil health and crop resilience. For farmers, its adoption at optimal doses can enhance yield and income sustainably.

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DECLARATION

Author contribution statement: Conceptualization: S.K.P and A.K.H.; Methodology: M.R.H and S.K.P.; Software and validation: A.M and M.M.; Formal analysis and investigation: M.R.H., A.M. and S.K.S; Resources: S.K.P and A.K.H.; Data curation: M.R.H. and A.M.; Writing—original draft preparation: M.R.H. and A.M.; Writing—review and editing: S.K.S. and S.K.P.; Visualization: A.M.; Supervision: S.K.P.; Project administration: S.K.P.; Funding acquisition: S.K.P. All authors have read and agreed to the published version of the manuscript.

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