



Silicon Application Improves Lodging Resistance and Grain Yield of Traditional Rice Genotypes in the Coastal Ecosystem of Bangladesh

U. K. Shanta¹, M. A. Haque^{1*}, S. Akter¹, M. K. Hossain¹ and M. F. Hoque¹

¹Department of Soil Science, Patuakhali Science and Technology University, Bangladesh

Abstract

Lodging is a major constraint to rice farming in the coastal ecosystem of Bangladesh, particularly among traditional tall genotypes that are otherwise well-adapted to local stress conditions. This study was aimed to evaluate the effects of silicon (Si) supplementation on lodging resistance, growth, and yield performance of ten traditional rice genotypes under pot culture conditions. Two levels of silicon (0 and 100 mg Si kg⁻¹ soil) were tested in a factorial randomized design. Results revealed that Si application significantly reduced lodging percentage (from 21.4% to 15.4%) and enhanced grain yield (from 12.1 g to 13.7 g pot⁻¹) and straw yield (from 30.8 g to 34.0 g pot⁻¹). Significant genotypic variation was observed for all measured parameters. Sakkorkhana and Kalojira showed the highest increases in grains panicle⁻¹ (142.6% and 51.2%, respectively) under Si treatment. Moulata and Sadamota achieved the highest biomass and yield, while Dudhkalom exhibited strong lodging resistance. Silicon uptake and content in both grain and straw increased significantly with Si application and correlated positively with yield components. These findings suggest that silicon application enhances lodging resistance and yield in traditional rice genotypes, with varied responses among genotypes. Integration of silicon fertilization with genotype selection could be an effective strategy for improving rice production in coastal Bangladesh.

Keywords: Coastal ecosystem, Genotype variation, Lodging resistance, Silicon, Traditional rice

* Corresponding author: masadulh@pstu.ac.bd

Received: 11.07.2025

Accepted: 31.12.2025

Introduction

Rice (*Oryza sativa* L.) is the staple food crop for over half of the global population and plays a critical role in food security, particularly in countries like Bangladesh. The coastal ecosystem of southern Bangladesh contributes substantially to national crop production; however, its productivity is often limited by unique environmental constraints such as soil salinity, drought, poor nutrient status etc. (Sikder et al., 2016; Kumar et al., 2018; Khanam et al., 2020; Haque and Hoque, 2023). The high tidal inundation along with wave generated by gusty wind speed makes plant susceptible to lodging (Haque et al., 2023ab; 2024a). Frequent cyclone due to recent climate change seriously lodge standing crops and hamper production of multiple crops in the coastal ecosystem (Jodder et al., 2016; Hossain and Joshi, 2025; Haque et al., 2025a). Lodging, the bending or breaking of rice stems near the ground is a major physiological disorder that reduces photosynthetic capacity, hinders nutrient translocation, and ultimately diminishes grain yield and quality (Shah et al., 2019).

Traditional rice genotypes are still widely cultivated in the coastal regions due to their adaptability and resilience under low-input and stress-prone environments (Haque et al., 2025b). However, these landraces are particularly vulnerable to lodging due to their tall stature and weak stem morphology (Akter et al., 2025; Pranto et al., 2023). Efforts to enhance the lodging resistance of traditional genotypes without compromising their adaptability are crucial for sustainable rice production in these marginal environments.

Silicon (Si), though not considered an essential nutrient, is recognized as a beneficial element for many crops, especially grasses like rice (Sultana et al., 2021; Akter et al., 2021; Mobaswera et al., 2023). Silicon has been reported to strengthen plant cell walls, enhance mechanical strength, reduce susceptibility to pests and diseases, and improve tolerance to abiotic stresses including lodging, salinity, and drought (Epstein, 1994; Ma & Takahashi, 2002; Sume et al., 2023). Silicon enhances stem rigidity and resistance to bending by promoting silica deposition in plant tissues, especially in the epidermal cells and vascular bundles (Liang et al., 2007). It also contributes to improved photosynthetic efficiency, water use, and nutrient uptake, leading to better growth and higher yield (Jinger et al., 2020).

In Bangladesh, research on the role of silicon in traditional rice genotypes remains limited, particularly under the unique edaphic and climatic conditions of the coastal zone. Identifying genotypes that are responsive to silicon supplementation could provide practical insights into integrated nutrient and genotype management strategies for lodging control and yield enhancement. Given the limited accessibility and high costs of modern lodging-resistant varieties for marginal farmers, enhancing the performance of indigenous genotypes through silicon fertilization may offer a more viable and cost-effective alternative.

Therefore, this study aimed to evaluate the effects of silicon on plant growth, lodging resistance, and yield of ten traditional rice genotypes under controlled conditions using calcium silicate as a silicon source in the coastal ecosystem of Bangladesh

Materials and Methods

Experimental site and duration

The experiment was conducted at the net house of the Department of Soil Science, Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali, Bangladesh. The study was carried out during the Aman season of 2023, under controlled pot conditions to simulate the coastal rice-growing environment while minimizing external variability.

Experimental design and treatments

The experiment was laid out in a two-factor Completely Randomized Design (CRD) with three replications. The two factors were: Silicon dose (Si_0 - 0 mg Si kg^{-1} soil and Si_{100} - 100 mg Si kg^{-1} soil) and ten traditional rice genotypes (Sadamota, Lalmota, Mothamota, Komlamota, Karangamota, Dudhkalom, Moulata, Kalokhoia, Kalojira, and Sakkorkhana). A total 60 pots were used in the experiment (2 Si levels \times 10 genotypes \times 3 replications). Calcium silicate ($CaSiO_3$) was used as the source of silicon. The 100 mg Si kg^{-1} soil was equivalent to 414 mg Si kg^{-1} soil.

Soil preparation and pot setup

Each pot was filled with 6 kg of air-dried, sieved, and homogenized soil collected from the coastal non-saline region of Patuakhali. The soil was characterized as silty clay loam with moderate fertility status. Baseline soil pH and nutrient levels were recorded before fertilizer application. The composite soil was used for physical and chemical analysis following Page et al. (1982). The soil was silty clay loam in texture having pH value of 5.9 and electrical conductivity of 1.65 dSm^{-1} . The soil contains 0.11% total N, 5.1 mg kg^{-1} available P, 0.24 cmol kg^{-1} exchangeable K, and 24 % total Si.

Fertilizer application

Fertilizers were applied at a rate of 120 mg N kg^{-1} soil using urea, 20 mg P kg^{-1} soil using triple superphosphate (TSP) and 100 mg K kg^{-1} soil using muriate of potash (MoP). Urea was applied in three equal splits at 7, 20, and 35 days after transplanting. The TSP and MoP was applied as basal.

Seedling preparation and transplanting

Seeds of the selected traditional rice genotypes were collected from local sources and germinated in seedbeds. Healthy seedlings of uniform size (21 days old) were transplanted into the pots on 9 August 2023, maintaining five seedlings per hill per pot. For rice transplanting in the field condition, 3-4 seedlings per hill is recommended by Bangladesh Rice Research Institute. In the pot condition sometimes all the seedlings cannot survive. Therefore, we have increased one seedling per hill for successful establishment of seedlings in all the pots.

Crop management

The pots were maintained under ambient conditions in the net house. Irrigation was provided regularly to keep one centimeter water height above the soil surface. Manual weeding was done as required. Algal growth was removed as and when necessary. Insecticide was sprayed twice to control stem borer infestation.

Data collection

The growth and morphological traits including plant height (cm), number of tillers hill⁻¹, panicle length and lodging percentage (%) was recorded pot basis. Lodging was assessed at maturity based on stem bending. The 0–100 score was used to measure the bending, where 0 indicates no lodging and 100 shows complete lodging of all tillers per pot. Chlorophyll a, chlorophyll b and total chlorophyll content was measured at the maximum tillering stage using acetone extraction method and spectrophotometry (Combs et al., 1985). The grain and straw yield data were recorded on pot basis and expressed on sun dry basis.

Silicon analysis

Silicon content in grain and straw samples was determined following digestion with a tri-acid mixture (nitric acid, perchloric acid and sulfuric acid at 5:2:1 ratio), and Si concentration was measured accordingly (Yoshida et al., 1976).

Statistical analysis

All collected data were subjected to analysis of variance (ANOVA) using statistical software (e.g., STAR). Treatment means were separated using Least Significant Difference (LSD) at 5% probability level. Correlation coefficients among traits were also calculated to examine inter-relationships between morphological, physiological, and yield parameters.

Results

Growth attributes

The application of silicon (Si) at 100 mg kg⁻¹ soil had a marginal but positive influence on plant height of rice (Table 1). Silicon control treatment recorded plant height of 166 cm but it rose to 170 cm under 100 mg Si kg⁻¹ soil treatment. Among the genotypes, Dudhkalom showed the highest plant height (185 cm), while Komlamota exhibited the lowest (152 cm). The positive response of Si was also noticed in tiller production having 10.9 tiller in Si control treatment and 11.3 tillers in 100 mg Si kg⁻¹ soil treatment. Moulata and Komlamota produced the highest tiller numbers per hill (12.0 and 12.2, respectively), suggesting greater vegetative vigor. Dudhkalom had the lowest tillering capacity (10.0). Like plant height and tiller production, the Si application also had a positive effect on panicle length of rice (Table 1). The Si control and 100 mg Si kg⁻¹ soil treatments recorded panicle length of 26.5 and 26.7 cm, respectively. The longest panicle was recorded in Lalmota (28.8 cm), while Sakkorkhana had the shortest (23.7 cm). Although plant height, tiller

number, and panicle length did not show statistically significant differences due to Si alone, a reduction in lodging percentage was observed with Si application (Table 1). Specifically, lodging decreased significantly from 21.4% in the control (Si₀) to 15.4% under Si₁₀₀ treatment ($p < 0.001$), indicating the mechanical strengthening effect of silicon. Moulata experienced the highest lodging (27.5%), whereas Dudhkalom was least affected (12.3%), highlighting substantial genotypic variability in lodging resistance. No significant interaction effects between silicon and genotypes were found for growth parameters, indicating that silicon's effect on growth was generally uniform across genotypes.

Table 1. Single and interaction effect of silicon and rice genotypes on different growth parameters of rice

Treatments	Plant height (cm)	Tillers hill ⁻¹ (no.)	Panicle length (cm)	Plant lodging (%)
Silicon dose				
Si ₀ mg kg ⁻¹ soil	166	10.9	26.5	21.4 a
Si ₁₀₀ mg kg ⁻¹ soil	170	11.3	26.7	15.4 b
Significance level	ns	ns	ns	***
SE (±)	2.89	0.298		0.74
Rice genotypes				
Sadamota	169 bc	10.5 bc	26.4 bcd	21.0 b
Lalmota	161 cd	11.0 abc	28.8 a	16.8 cd
Mothamota	170 bc	11.0 abc	26.5 bcd	18.2 bc
Komlamota	152 d	12.2 a	27.7 abc	14.5 de
Karangamota	166 bc	10.5 bc	28.3 ab	18.8 bc
Dudhkalom	185 a	10.0 c	26.2 bcd	12.3 e
Moulata	175 ab	12.0 a	27.5 abc	27.5 a
Kalokhoia	166 bc	10.3 bc	25.6 cde	17.3 cd
Kalojira	171 bc	11.7 ab	24.4 de	17.2 cd
Sakkorkhana	164 bcd	11.5 ab	23.7 e	14.7 de
Significance level	**	*	***	***
SE (±)	6.45	0.666		1.65
Interactions				
Silicon×rice genotypes	ns	ns	ns	ns
SE (±)	9.13	0.942	1.50	2.33
CV (%)	6.66	10.4	6.91	11.02

Similar small letter in a column indicates that the mean values were not significantly different at 5% level. *-Significant at 5% level, **-Significant at 1% level, ***-Significant at 0.1% level, ns- Not significant; SE- Standard error of means; CV- Coefficient of variation

Yield component of rice

Silicon application significantly increased the number of grains panicle⁻¹ across genotypes ($p < 0.001$) (Table 2). Notably, the increase in grains panicle⁻¹ varied widely among genotypes. Sakkorkhana exhibited the highest increase of 142.6%, followed by Dudhkalom (104.5%) and Kalojira (51.2%), indicating a strong positive response to silicon. In contrast, Moulata and Mothamota responded minimally, with only 0.6% and 0.5% increases, respectively. This differential response highlights the genotype-specific role of silicon in reproductive development. Interaction effects between silicon and genotype were statistically significant, suggesting varied silicon responsiveness among traditional genotypes.

Table 2. Interaction effect of silicon and rice genotypes on the number of grains panicle⁻¹ of rice

Rice genotypes	Silicon rate		% increase over Si control
	Si 0 mg kg ⁻¹ soil	Si 100 mg kg ⁻¹ soil	
Sadamota	73.6 cd	86.3 c	17.2 *
Lalmota	67.0 cd	75.4 cd	12.5 ns
Mothamota	64.3 d	64.7 de	0.5 ns
Komlamota	61.3 d	62.2 ef	1.4 ns
Karangamota	65.3 d	67.7 de	3.6 ns
Dudhkalom	24.4 e	50.0 f	104.5 *
Moulata	86.3 ab	86.9 c	0.6 ns
Kalokhoia	66.0 d	67.0 de	1.6 ns
Kalojira	93.7 a	141.7 b	51.2 *
Sakkorkhana	78.3 bc	190.0 a	142.6 *

Significance level: Single effect of Si-***, Single effect of rice genotypes-***, Silicon×rice genotypes interaction-***

Mean separation test: Similar small letter in a column indicated that the rice genotypes were not significantly different in each level of silicon. Silicon effect: ns-Not significant, *-Significant at 5% level

SE (±): Single effect of Si-1.92, Single effect of rice genotypes-4.30, Silicon×rice genotypes interaction-6.08, CV (%) - 9.47

Yield performance of rice

Application of 100 mg Si kg⁻¹ soil significantly improved both grain and straw yields ($p < 0.001$). Grain yield increased from 12.1 g pot⁻¹ in Si₀ to 13.7 g pot⁻¹ in Si₁₀₀ (Table 3). Among genotypes, Moulata recorded the highest grain yield (17.5 g pot⁻¹), followed by Sadamota (15.8 g), whereas Dudhkalom had the lowest (7.4 g). The Si control and 100 mg Si kg⁻¹ soil produced straw yield of 30.8 g and 34.0 g pot⁻¹,

respectively. Among the genotypes, Moulata produced the highest straw yield (41.2 g pot⁻¹), suggesting that it was the most productive genotype in terms of total biomass. The genotype Dudhkalom produced the least (28.4 g pot⁻¹) straw in the experiment. Interaction effects of Si and genotype on grain and straw yield were not significant.

Table 3. Single and interaction effect of silicon and rice genotypes on grain and straw yield of rice

Treatments	Grain yield (g pot ⁻¹)	Straw yield (g pot ⁻¹)
Silicon dose		
Si ₀ mg kg ⁻¹ soil	12.1 b	30.8 b
Si ₁₀₀ mg kg ⁻¹ soil	13.7 a	34.0 a
Significance level	***	***
SE (±)	0.38	0.61
Rice genotypes		
Sadamota	15.8 b	29.0 cd
Lalmota	12.7 c	33.2 b
Mothamota	13.3 c	32.6 b
Komlamota	13.6 c	32.7 b
Karangamota	13.6 c	32.1 b
Dudhkalom	7.4 e	28.4 d
Moulata	17.5 a	41.2 a
Kalokhoia	12.2 cd	32.5 b
Kalojira	10.9 d	31.0 bcd
Sakkorkhana	12.0 cd	31.3 bc
Significance level	***	***
SE (±)	0.84	1.36
Interactions		
Silicon×rice genotypes	ns	ns
SE (±)	1.19	1.93
CV (%)	11.29	7.28

The grain:straw ratio of different rice genotypes under Si control and Si applied treatment has been shown in Fig. 1. Over the genotypes grain:straw ratio varied from 0.26 to 0.54 having lowest in Dudhkalom and highest in Sadamota. The high grain production compares to straw indicating the high yielding property of Sadamota rice genotype. Silicon application had a positive effect on grain:straw in Sakkorkhana, Klotjira, Kalokhoia and Lalmota rice genotype. Similar trend of grain:straw ratio was also found in harvest index of rice. Harvest index varied from 21 to 35% over the tested ten traditional rice genotypes (Fig. 2). The Sadamota had the highest harvest

index. All other genotypes had harvest index lower than 30, indicating their higher straw production compare to grain.

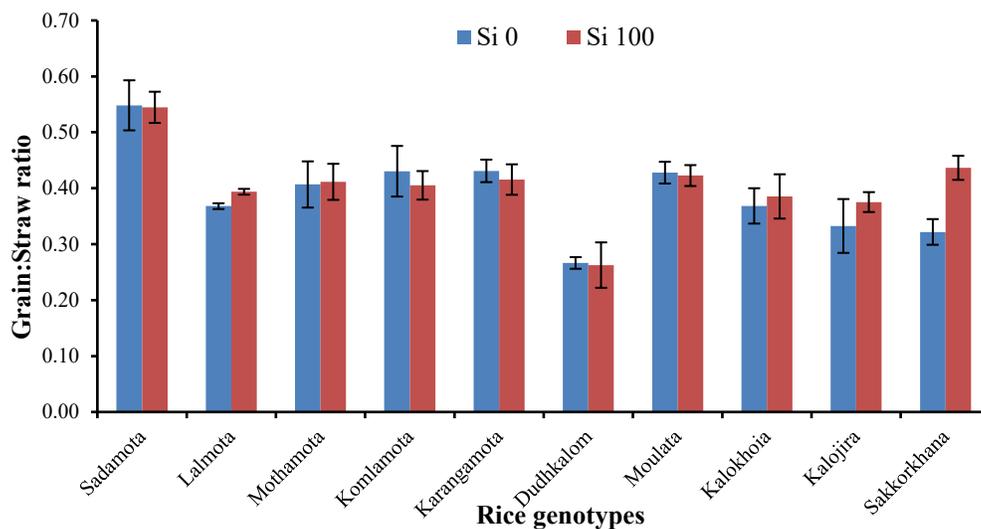


Fig. 1. Grain:straw ratio of rice genotypes under different Si application treatments

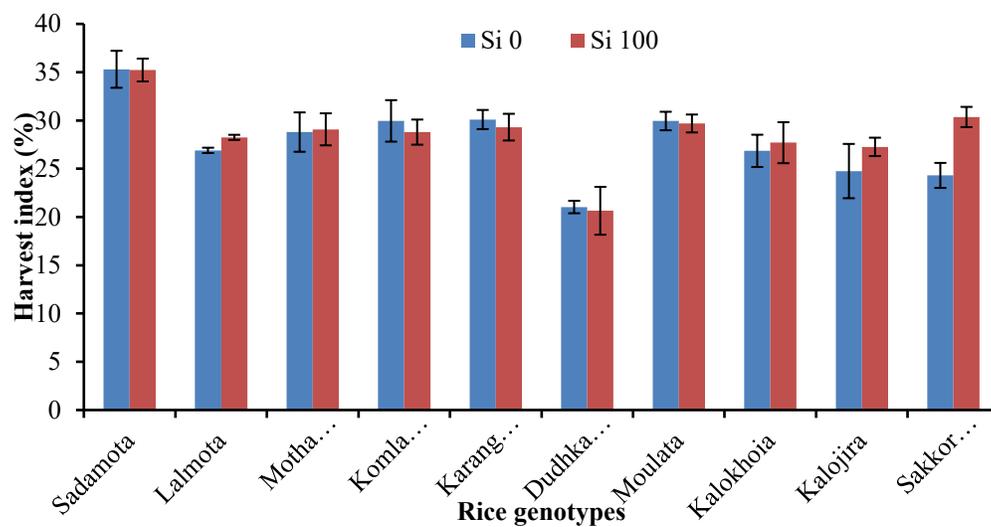


Fig. 2. Harvest index of rice as influenced by silicon application in different genotypes of rice

Silicon content in grain and straw

Silicon application significantly enhanced Si content in both grain and straw ($p < 0.001$) (Table 4). The grain Si content increased from 2.56% in Si₀ to 3.07% in Si₁₀₀, while straw Si content rose from 5.33% to 5.73%. The rice genotypes were also significantly varied for Si content both in grain and straw. Highest grain Si content (3.78%) was recorded by Dudhkalom; the Mothamota and Sakkorkhana had the second rank. The genotypes Kalokhoia and Kalojira had the least grain Si content (Table 4). Among the genotypes Moulata had the highest straw Si content (6.29%) which was similar with Mothamota (6.15%). Although the main effects were significant, the interaction of Si × rice genotype was not statistically significant, suggesting a general positive response to Si across genotypes.

Silicon uptake by grain and straw

The Si uptake by grain, and straw was significantly improved by silicon application in soil ($p < 0.001$). The grain Si uptake rose from 0.305 g pot⁻¹ in Si₀ to 0.415 g pot⁻¹ in Si₁₀₀, similarly straw Si uptake rose from 1.65 g pot⁻¹ in Si₀ to 1.96 g pot⁻¹ in Si₁₀₀ (Table 4). The total Si uptake in Si₀ and Si₁₀₀ were 1.96 and 2.37 g pot⁻¹, respectively. The rice genotypes were significantly different for uptake of silicon by grain and or straw or total Si uptake ($p < 0.001$). Among the genotypes, Moulata showed the highest total Si uptake (3.03 g pot⁻¹), followed by Mothamota (2.45 g pot⁻¹). The lowest uptake was found in Kalojira (1.81 g pot⁻¹).

Table 4. Single and interaction effect of silicon and rice genotypes on silicon content and uptake by rice grain and straw of rice

Treatments	Grain Si content (%)	Straw Si content (%)	Grain Si uptake (g pot ⁻¹)	Straw Si uptake (g pot ⁻¹)	Total Si uptake (g pot ⁻¹)
Silicon dose					
Si ₀ mg kg ⁻¹ soil	2.56 b	5.33 b	0.305 b	1.65 b	1.96 b
Si ₁₀₀ mg kg ⁻¹ soil	3.07 a	5.73 a	0.415 a	1.96 a	2.37 a
Significance level	***	***	***	***	***
SE (±)	0.08	0.08	0.015	0.043	0.047
Rice genotypes					
Sadamota	2.76 c	5.03 d	0.436 a	1.46 g	1.90 ef
Lalmota	2.73 c	5.01 d	0.351 bc	1.68 def	2.03 de
Mothamota	3.31 b	6.15 a	0.439 a	2.01 b	2.45 b
Komlamota	2.66 c	5.96 ab	0.365 b	1.94 bc	2.31 bc
Karangamota	2.88 c	5.67 bc	0.390 ab	1.82 bcd	2.21 cd
Dudhkalom	3.78 a	5.48 c	0.283 cd	1.56 fg	1.84 ef
Moulata	2.50 cd	6.29 a	0.439 a	2.59 a	3.03 a

Treatments	Grain Si content (%)	Straw Si content (%)	Grain Si uptake (g pot ⁻¹)	Straw Si uptake (g pot ⁻¹)	Total Si uptake (g pot ⁻¹)
Kalokhoia	2.13 d	4.95 d	0.258 d	1.60 efg	1.86 ef
Kalojira	2.14 d	5.05 d	0.238 d	1.57 fg	1.81 f
Sakkorkhana	3.28 b	5.72bc	0.404 ab	1.80 cde	2.20 cd
Significance level	***	***	***	***	***
SE (±)	0.19	0.18	0.033	0.097	0.106
Interactions					
Silicon×rice genotypes	ns	ns	ns	ns	ns
SE (±)	0.28	0.27	0.047	0.137	0.150
CV (%)	12.2	6.21	11.1	9.36	8.52

Chlorophyll content

Silicon application had no significant effect on chlorophyll a, chlorophyll b, or total chlorophyll content of rice leaf (Table 5). Likewise, there were no significant differences among genotypes or in Si × rice genotype interactions for chlorophyll traits, implying that Si did not influence photosynthetic pigment concentration under the studied conditions. However, although not significant but silicon application had a positive impact on improving chlorophyll a, chlorophyll b and total chlorophyll content of rice. Under Si control condition the chlorophyll a, chlorophyll b and total chlorophyll content were 3.85, 0.869 and 4.72 mg g⁻¹ fresh leaf, and that under 100 mg Si kg⁻¹ soil treatment were 3.95, 0.898 and 4.85 mg g⁻¹ fresh leaf, respectively.

Table 5. Single and interaction effect of silicon and rice genotypes on chlorophyll content of rice

Treatments	Chlorophyll a content (mg g ⁻¹ fresh leaf)	Chlorophyll b content (mg g ⁻¹ fresh leaf)	Total chlorophyll content (mg g ⁻¹ fresh leaf)
Silicon dose			
Si ₀ mg kg ⁻¹ soil	3.85	0.869	4.72
Si ₁₀₀ mg kg ⁻¹ soil	3.95	0.898	4.85
Significance level	ns	ns	ns
SE (±)	0.093	0.027	0.111
Rice genotypes			
Sadamota	3.69	0.823	4.51
Lalmota	3.83	0.900	4.73
Mothamota	3.89	0.917	4.81

Straw yield	-0.011	0.322*	0.176	0.220	0.166	0.59***							
Grain Si content	0.28*	0.024	0.084	-0.032	-0.47***	0.157	-0.047						
Straw Si content	0.106	0.285*	0.121	0.126	-0.051	0.35**	0.47***	0.38**					
Grain Si uptake	0.143	0.265*	0.264*	0.296*	-0.057	0.72***	0.44***	0.54***	0.54***				
Straw Si uptake	0.061	0.361**	0.173	0.207	0.102	0.57***	0.88***	0.164	0.82***	0.56***			
Total Si uptake	0.085	0.369**	0.211	0.245	0.071	0.66***	0.85***	0.270*	0.82***	0.72***	0.98***		
Chlorophyll a content	0.073	-0.12	0.071	0.012	-0.42***	0.35**	0.212	0.291*	-0.021	-0.089	-0.154	-0.152	
Chl. b content	0.054	0.040	0.179	-0.004	-0.253	0.147	0.047	0.205	0.132	0.034	0.100	0.092	0.592***
Total chl. content	0.075	-0.094	0.103	0.008	-0.42***	0.33**	0.166	0.295*	0.014	-0.068	-0.104	-0.105	0.981***
													0.73***

*Significant at 5% level, **-Significant at 1% level, ***- Significant at 0.1% level

Discussion

The results of this study clearly demonstrate that silicon (Si) supplementation at 100 mg kg⁻¹ soil had a beneficial impact on lodging resistance and yield performance of traditional rice genotypes grown under controlled coastal conditions. These findings align with previous research indicating that Si plays a vital role in enhancing plant structural integrity and physiological efficiency, particularly in gramineous crops like rice (Ma & Takahashi, 2002; Haque et al., 2023c; 2024b).

One of the most notable outcomes was the significant reduction in lodging percentage with Si application. This supports the hypothesis that Si reinforces cell wall structure and stem rigidity, thereby minimizing stem bending or collapse (Liang et al., 2007). Reduction of lodging from 21.4% to 15.4% across genotypes with silicon application is consistent with findings by Soundararajan et al. (2014), who reported improved culm strength and lower lodging in rice with Si supplementation. Among genotypes, Dudhkalom and Komlamota exhibited the least lodging, suggesting innate structural advantages possibly enhanced by Si addition. Conversely, Moulata showed the highest lodging, despite high biomass production, indicating a mismatch between growth and structural support that was only partially mitigated by Si.

Although silicon did not significantly alter plant height, tiller number, or panicle length at the aggregate level, genotypic differences were pronounced. Moulata and Komlamota produced the highest tiller numbers, while Dudhkalom grew the tallest. These differences are likely due to genotypic plasticity in response to nutrient availability, especially in traditional landraces that evolved under diverse agroecological niches (Akter et al., 2025). The nonsignificant Si × genotype interactions for growth traits suggest that while genotypes vary in growth potential, the effect of silicon on these parameters is relatively uniform.

The positive and significant effects of silicon on the number of grains panicle⁻¹ and grain yield corroborate earlier reports by Deren et al. (1994) and Farooq et al. (2011), who found that Si improved reproductive development and source-sink dynamics in rice. Genotypes such as Sakkorkhana, Kalojira, and Dudhkalom showed dramatic increases in grain number (over 100% in some cases), suggesting high responsiveness to silicon. Grain yield improvements (from 12.1 to 13.7 g pot⁻¹) indicate that silicon not only supported structural development but also enhanced reproductive success. The yield level found in the study is relatively low, which in fact was the typical of traditional tall rice varieties. The grain yield was positively correlated with grains panicle⁻¹, panicle length, and tiller number, indicating that Si's yield-enhancing effects are multifaceted. Despite this, not all genotypes responded equally. Mothamota and Moulata, for example, exhibited minimal gains in grains panicle⁻¹ despite high biomass and tillering. This discrepancy highlights the need to match silicon management strategies with genotype-specific nutrient use efficiency.

The enhanced Si content and uptake in both grain and straw under Si application confirm that calcium silicate was an effective Si source. Total Si uptake was highest in Moulata and Mothamota, correlating positively with both grain and straw yield. This supports the concept that Si uptake efficiency is an important physiological trait linked to biomass accumulation and stress mitigation (Jinger et al., 2020). Genotypic variation in Si uptake could be attributed to root morphology, transpiration rates, and transporter gene expression (Ma et al., 2007). Interestingly, even genotypes with lower yields like Dudhkalom showed high Si content, suggesting that internal Si partitioning and utilization efficiency may vary independently of absolute uptake.

Contrary to expectations, chlorophyll content was not significantly affected by Si treatment. Although Si is known to enhance photosynthetic capacity under stress conditions, the controlled environment of this study may have masked such effects (Gong et al., 2005). The nonsignificant variation across genotypes and treatments indicates that pigment biosynthesis was not a major pathway influenced by Si under these conditions.

Correlation analysis provided critical insight into interrelationships among traits. Grain yield was significantly and positively associated with Si uptake, grains panicle⁻¹, and straw yield. Interestingly, lodging showed a negative correlation with both grain yield and Si content, reaffirming that Si-mediated lodging control is a key driver of yield stability. Total Si uptake was also highly correlated with straw yield and grain Si content, supporting its potential use as a selection index in breeding programs aimed at enhancing nutrient use efficiency and stress tolerance.

The findings of this study hold substantial promise for rice production in the stress-prone coastal ecosystem of Bangladesh. Traditional genotypes, although well adapted to local conditions, are generally prone to lodging and have low yield potential. Supplementation with Si offers a sustainable agronomic strategy to bridge this yield gap without compromising genotype adaptability. Furthermore, genotype-specific

responses highlight the importance of selecting Si-responsive landraces for integrated nutrient-genotype management.

Conclusion

The study clearly demonstrates that silicon application at 100 mg kg⁻¹ soil significantly improves plant structural integrity, reduces lodging, and enhances grain and straw yields in traditional rice genotypes grown in coastal environments. While the overall response to silicon was positive across genotypes, the magnitude of improvement varied, indicating differential genotype responsiveness. Genotypes such as Sakkorkhana, Kalojira, and Dudhkalom benefited most from Si supplementation in terms of reproductive traits and lodging control, whereas Moulata and Sadamota achieved the highest biomass and yield accumulation. Enhanced silicon uptake and its strong positive correlation with yield and lodging resistance reinforce the importance of Si in the cultivation of tall, traditional rice varieties. These findings highlight the potential of combining silicon fertilization with genotype selection to improve rice productivity and resilience in the stress-prone coastal regions of Bangladesh. However, the findings presented in the paper were generated from a pot experiment which was the main limitation of the work; a comprehensive field study consist of several Si rates is suggested to validate the findings of the experiment.

Acknowledgements

The authors acknowledge the financial support of the project entitled “Crop yields and heavy metal concentrations in saline soils as affected by exogenous silicon application at coastal region of Bangladesh” to conduct the experiment.

References

- Akter, N., Haque, M. A., & Hoque, M. F. (2021). Improvement of growth of maize by application of silicon through its suppressing effect on sodium uptake under salt stress condition. *Journal of Bangladesh Academy of Sciences*, 45(2): 251–253. <https://doi.org/10.3329/jbas.v45i2.57213>
- Akter, T., Afrad, M. S. I., Habib, M. A., Zhang, Y., Sarkar, M. A. R., Nayak, S., Qin, X., McKenzie, A. M., & Kamal, M. Z. U. (2025). Farmers' adoption of newly released climate-resilient rice varieties in the coastal ecosystem of Bangladesh: effectiveness of a head-to-head adaptive trial. *Food and Energy Security*, 14: e70075 <https://doi.org/10.1002/fes3.70075>
- Coombs, J., Hind, G., Leegood, R. C., Tieszen, L. L., & Vonshak, A. (1985). Analytical Techniques. In: Coombs, J., D. O. Hall, S. P. Long and J. M. O. Scurlock (Editors), *Techniques in Bioproductivity and Photosynthesis*. Pergamon Press, Pergamon International Library of Science, Technology, Engineering and Social Studies. 2nd edition. pp 219–228.
- Deren, C. W., Datnoff, L. E., Snyder, G. H., & Martin, F. G. (1994). Silicon concentration,

- disease response, and yield components of rice cultivars grown on flooded organic Histosols. *Crop Science*, 34(3): 733–737.
- Epstein, E. (1994). The anomaly of silicon in plant biology. *Proceedings of the National Academy of Sciences*, 91(1): 11–17.
- Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2011). Plant drought stress: Effects, mechanisms and management. *Agronomy for Sustainable Development*, 29(1): 185–212. <https://doi.org/10.1051/agro:2008021>
- Gong, H., Zhu, X., Chen, K., Wang, S., & Zhang, C. (2005). Silicon alleviates oxidative damage of wheat plants in pots under drought. *Plant Science*, 169(2): 313–321. <https://doi.org/10.1016/j.plantsci.2005.02.023>
- Haque, M. A. & Hoque, M. F. (2023). Nitrogen fertilizer requirement and use efficiency in sunflower at Ganges delta coastal salt-affected soils, *Communications in Soil Science and Plant Analysis*, 54(16): 2248–2262 <https://doi.org/10.1080/00103624.2023.2211627>
- Haque, M. A., Bhuyan, M. I., & Jahiruddin, M. (2025b). Impacts of plant spacing and nitrogen on wet season rice yield in the non-saline coast of Bangladesh. *International Journal of Plant Production*, 19: 439–448. <https://doi.org/10.1007/s42106-025-00345-3>
- Haque, M.A., Hoque, M.F., Jahiruddin, M., Hossain, M.B., Satter, M.A., Haque, M.E., & Bell, R.W. (2023c). Performance evaluation of different sources and rates of silicon in rice at eastern Gangetic coastal plains. *Journal of Soil Science and Plant Nutrition*. 23: 5084–5096. <https://doi.org/10.1007/s42729-023-01520-z>
- Haque, M. A., Jahiruddin, M., & Bell, R. W. (2025a). Early sowing of wheat with minimum tillage on wet soils increases yield potential and phosphorus fertilizer requirements on the coastal ecosystem. *Journal of Soil Science and Plant Nutrition*, 25: 1047–1058. <https://doi.org/10.1007/s42729-024-02183-0>
- Haque, M. A., Jahiruddin, M., Hoque, M. F., Islam, M. S., Hossain, M. B., Satter, M. A., Haque, M. E., & Bell, R. W. (2023b). Increasing the use efficiency of fertilizer phosphorus for maize in low-P Ganges delta soils. *Journal of Plant Nutrition*, 46(10): 2257–2275 <https://doi.org/10.1080/01904167.2022.2155544>
- Haque, M. A., Kabir, M. E., Akhter, S., Hoque, M. F., Sarker, B. C., Anik, M. F. A., Ahmed, A., Pranto, S., Sima, A. S., Lima, F., Jahiruddin, M., Hossain, M. B., Haque, M. E., Satter, M. A., & Bell, R. W. (2023a). Crop nutrient limitations in intensified cropping sequences on the Ganges delta coastal floodplains. *Journal of Soil Science and Plant Nutrition*. 23: 1996–2006. <https://doi.org/10.1007/s42729-023-01154-1>
- Haque, M. A., Mobaswera, A., Sume, M. A., Pranto, S., Jahiruddin, M., Hoque, M. F., & Bell, R. W. (2024b). Silicon supplementation improves yield and silicon uptake in maize at eastern Ganges delta coastal soils. *Journal of Plant Nutrition*, 47(2): 190–204. <https://doi.org/10.1080/01904167.2023.2275066>
- Haque, M. A., Sima, A. S., Jahiruddin, M., & Bell, R. W. (2024a). Minimizing phosphorus mining through optimum phosphorus fertilization in maize. *Journal of Soil Science and Plant Nutrition*. 24: 5436–5448. <https://doi.org/10.1007/s42729-024-01917-4>

- Hossain, K. K., & Joshi, N. P. (2025). Climate change effects on the manor crops of Bangladesh and the adaptations measures- A review of literature. *SAARC Journal of Agriculture*, 23(1): 54–67. <https://doi.org/10.3329/sja.v23i1.76874>
- Jinger, D., Devi, M. T., Shar, S., Dass, A., Sharma, V. K., Kumar, V., Joshi, E., Jatav, H. S., & Singh, N. (2020). Silicon application mitigates abiotic stresses in rice: A review. *Indian Journal of Agricultural Sciences*, 90(11): 2043–50. <https://doi.org/10.56093/ijas.v90i11.108557>
- Jodder, R., Haque, M. A., Kumar, T., Jahiruddin, M., Rahman, M. Z., & Clarke, D. (2016). Climate change effects and adaptation measures for crop production in South-West coast of Bangladesh. *Research in Agriculture Livestock and Fisheries*, 3(3): 369–378. <http://dx.doi.org/10.3329/ralf.v3i3.30727>
- Khanam, S., Haque, M. A., Hoque, M. F., & Islam, M. T. (2020). Assessment of salinity level and some nutrients in different depths of soil at Kalapara Upazila of Patuakhali district. *Annual Research & Review in Biology*. 35(12): 1–10. <https://doi.org/10.9734/arrb/2020/v35i1230306>
- Kumar, T., Haque, M. A., Islam, M. S., Hoque, M. F., & Jodder, R. 2018. Effect of polythene mulch on growth and yield of sunflower (*Helianthus annuus*). *Archives of Crop Science*, 2(1): 38–46. <https://doi.org/10.36959/718/600>
- Liang, Y., Sun, W., Zhu, Y. G., & Christie, P. (2007). Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: A review. *Environmental Pollution*, 147(2): 422–428. <https://doi.org/10.1016/j.envpol.2006.06.008>
- Ma, J. F., & Takahashi, E. (2002). *Soil, Fertilizer, and Plant Silicon Research in Japan*. Elsevier. <https://doi.org/10.1016/B978-0-444-51166-9.X5000-3>
- Ma, J. F., Yamaji, N., Mitani, N., Tamai, K., Konishi, S., Fujiwara, T., & Katsuhara, M. (2007). An efflux transporter of silicon in rice. *Nature*, 448(7150): 209–12. <https://doi.org/10.1038/nature05964>.
- Mobaswera, A., Haque, M. A., Sume, M. A., & Hoque, M. F. (2023). Exogenous silicon application improves growth and morpho-physiological properties of rice. *Journal of Bangladesh Agricultural University*, 21(4): 421–429. <https://doi.org/10.5455/JBAU.161004>
- Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of Soil Analysis*. American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison, Wisconsin.
- Pranto, S., Haque, M. A., & Hoque, M. F. (2023). Requirement and use efficiency of nitrogen in transplanted Aman rice at Ganges tidal water flooded coastal ecosystem. *Journal of Bangladesh Academy of Sciences*. 47(2): 169–180. <https://doi.org/10.3329/jbas.v47i2.67665>
- Shah, A., Akhtar, J., & Yang, W. (2019). Plant lodging: Significance, causes and management in cereals. *Agronomy*, 9(11): 512.
- Sikder, M. U., Haque, M. A., Jodder, R., Kumar, T., & Mondal, D. (2016). Polythene mulch and irrigation for mitigation of salinity effects on maize (*Zea mays* L.). *The Agriculturists*, 14(2): 01–13. <http://dx.doi.org/10.3329/agric.v14i2.31336>.

- Soundararajan, P., Sivanesan, I., Jana, S., & Jeong, B. R. (2014). Influence of silicon supplementation on the growth and tolerance to high temperature in *Salvia splendens*. *Horticulture, Environment, and Biotechnology*, 55: 271–279. <http://dx.doi.org/10.1007/s13580-014-0023-8>
- Sultana, N., Haque, M. A., Hoque, M. F., Hossain, M. B., Satter, M. A., & Jahiruddin, M. (2021). Effect of silicon application on growth and biomass yield of rice under salinity stress. *Journal of Bangladesh Agricultural University*, 19(4): 429–436. <https://doi.org/10.5455/JBAU.117294>
- Sume, M. A., Haque, M. A., Mobaswera, A., Hoque, M. F., Jahiruddin, M., & Bell, R.W. (2023). Identifying varietal differences for silicon mediated improvement of leaf architecture and plant growth in rice. *Silicon*. 15: 6299–6311. <https://doi.org/10.1007/s12633-023-02514-3>
- Yoshida, S., Forno D. A., Cock J. H., & Gomez, K. A. (1976). *Laboratory manual for physiological studies of rice*. International Rice Research Institute, Philippines, 3rd ed. pp 17–22.