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Research Article

Comparative Efficacy of Foliar Silicon Application on Disease Reduction, Yield, and Nutrient Concentration of Wheat (*Triticum aestivum* L.) Under Blast Pathogen Stress

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Abstract

Wheat blast, caused by *Magnaporthe oryzae* pathotype *Triticum* (MoT), is a destructive disease that can lead to significant or even total yield loss depending on how severe the infection was. Silicon-mediated disease tolerance is well-established in the literature. To evaluate the effect of Si on blast disease management, a pot experiment was conducted. The experiment utilized Randomized Complete Block Design (RCRD). The study included absolute control (T_a, no fertilizer), silicon-free control (T_0), and silicon treatments. Silicon was applied as potassium silicate at 0.1% (T_1), 0.2% (T_2), and 0.3% (T_3), and calcium silicate at 0.1% (T_4), 0.2% (T_5), and 0.3% (T_6). Silicon fertilizers were applied as a foliar spray. The incidence and severity of blast disease were significantly reduced by silicon application across assessment points at 9, 11-, 13-, 15-, and 17-days post-inoculation. The maximum incidence (29%) and severity (62%) reduction was found in T_6 treatment over the control. Silicon treatment significantly increases the yield contributing parameters and the yield of wheat. The highest yield was found at the T_6 treatment. Again, Si concentration was also highest at the T_6 treatment. Except for S, other nutrients (Ca, Mg, K, P, and B) concentration was significantly increased in different Si treatments, though the higher concentration slightly varied among different treatments in relation to different nutrients. Overall, $CaSiO_3$ at a rate of 0.3% foliar spray showed a better performance than K_2SiO_3. So, $CaSiO_3$ at a rate of 0.3% foliar spray could be an effective, eco-friendly input to manage wheat blast disease.

Introduction

The global food security is being threatened by the outbreaks of plant diseases (Ristaino et al., 2021). Wheat (*Triticum aestivum* L.) cultivation has recently faced a severe threat from wheat blast, a pandemic disease. This devastating fungal infection is caused by *Magnaporthe oryzae* pathotype *Triticum* (MoT) and can lead to complete yield loss when environmental conditions are favorable for its development (Cruz and Valent, 2017). The first reports of wheat blast were made in the Brazilian state of Paraná in 1985 (Igarashi, 1986) and over time, it expanded to the neighboring countries (Alberione et al., 2008; Viedma, 2005). Before 2011, the only known reports of this illness came from a few South American nations, including Brazil, Bolivia, Paraguay, Argentina, and Uruguay. One case came from an experimental field in the United States (Callaway, 2016). In 2016, the fatal wheat blast was revealed to have emerged in Bangladesh—the first known outbreak of the disease outside of South America (Islam et al., 2016; Malaker et al., 2016). In the first wheat blast incident in Bangladesh, approximately 15% of the total wheat land, or 15,000 hectares, was damaged (Islam et al., 2016). Since then, the risk of wheat blast spreading to other countries has made it a possible danger to wheat output for Bangladesh and other South Asian nations. To safeguard wheat production, care should be taken to stop pathogen dissemination.

Unfortunately, it is difficult to regulate wheat blast, and no one method can provide a high enough level of control (Kohli et al., 2011). It has been demonstrated that when the disease pressure is strong, chemical management methods are ineffective in preventing

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wheat blast. Moreover, Brazil has already shown signs of resistance to triazole and strobilurin fungicides (Castroagudín et al., 2015; Dorigan et al., 2019). The best way to handle these issues and sustainably manage diseases is to use wheat varieties resistant to blasts, but the source information is still insufficient (Cruz and Valent, 2017).

As an eco-friendly source, silicon (Si) has been reported to be very effective in controlling fungal diseases (Ahmmed et al., 2018). Numerous studies have shown that providing plants with external silicon (Si) can reduce the incidence of fungal infections and bolster their natural defenses against various fungal pathogens. This beneficial effect is observed in both monocot and dicot plants, targeting diseases that affect both their leaves and roots (A. Rodrigues et al., 2015; Debona et al., 2017).

Silicon supplementation in soil has been observed to successfully mitigate a range of diseases. For instance, it decreases leaf spot, blast, and sheath blight in rice (*Oryza sativa* L), controls powdery mildew across wheat, barley (*Hordeum vulgare* L), cucumber (*Cucumis sativus* L), and bitter gourd (*Momordica charantia* L), and reduces anthracnose in sorghum *Sorghum bicolor* L) (Ahammed and Yang, 2021). Silicon mainly increases the plant's resistance to pathogen infection through the reduction in colony size, lesion size, and quantity, and inhibition of fungal inoculum formation (Debona et al., 2017). Feng et al. reported in 2021 that the lesion length of sclerotinia rot in rapeseed (*Brassica napus* L.) was reduced by 34.9-39.3% under basal Si application in the pot trial. Again, in the field trial, the sclerotinia rot disease incidence and disease index were significantly reduced due to the application of solid Si fertilizer, foliar spray of Si fertilizers, and the combined application of both(Feng et al., 2021).

So, there is enough evidence that Si may be applied to wheat for the management of wheat blast disease. Therefore, this study was designed to evaluate the efficiency of foliar spray of two Si fertilizers at variable doses on the wheat blast disease mitigation potential.

Materials and Methods

Site of the experiment

A pot experiment was conducted at the Bangladesh Institute of Nuclear Agriculture (BINA) Headquarters Farm in Mymensingh. This location, situated at 24°75' N latitude and 90°50' E longitude with an elevation of 18 meters above sea level, is characterized by non-calcareous dark grey floodplain soil within the Old Brahmaputra Floodplain Agro-Ecological Zone (AEZ-9), as classified by FAO and UNDP in 1988. The experimental area experiences a sub-tropical climate, featuring moderate to high temperatures, heavy rainfall, high humidity, and longer days during the *Kharif* season (April to September). Conversely, the *Rabi* season (October to March) brings scant rainfall, low humidity, lower temperatures, and shorter days.

Soil collection and preparation for the pot experiment

The non-calcareous dark grey floodplain soil (AEZ-9) used in the experiment was collected from a depth of 0-15 cm in selected fallow land. Before use, the soil samples were cleared of plant residues and other foreign materials, air-dried, ground, and sieved through a 2 mm sieve. The soil's physicochemical properties were then analyzed using standard methods (Page et al., 1982; Tandon, 2005) and are detailed in Table 1.

Table 1. Details on the physicochemical composition of the experimental soil.

Parameter	Value	Parameter	Value
Texture	Silty loam	Phosphorus (mg kg^{-1})	3.06
Bulk density	1.29	Potassium (meq 100 kg^{-1})	0.15
Particle density (g cm^{-3})	2.57	Sulfur (mg kg^{-1})	4.09
Moisture content (%)	29.24	Zinc (mg kg^{-1})	1.87
pH	6.4	Boron (mg kg^{-1})	0.064
Organic matter (%)	1.15	Calcium (meq 100 g^{-1})	3.62
Total nitrogen (%)	0.063	Magnesium (meq 100 g^{-1})	0.76

Fertilizer application and pot filling

The plastic pot used in this experiment— measuring 40 cm high with a 35 cm top diameter and 30 cm bottom diameter— was filled with 18 kg of processed soil. The soil of each pot was thoroughly mixed with 45 grams of well-decomposed cow dung per. Inorganic fertilizers— based on Bangladesh's fertilizer recommendation guide (BARC, 2018), were then added as a basal dose for wheat. These included 100-20-75-13-6-2-1.5 kg/ha of N-P-K-S-Mg-Zn-B— applied from Urea (5.06 g/pot), TSP (2.32 g/pot), MoP (3.50 g/pot), gypsum (1.62 g/pot), magnesium sulfate (1.43 g/pot), zinc sulfate heptahydrate (0.21 g/pot), and solubor boron (0.17 g/pot), respectively.

Two-thirds of the urea and the full dose of all other fertilizers were applied during final soil preparation and pot filling. The remaining one-third of the urea was applied 17 days after sowing (DAS), at the crown root initiation stage.

Design and treatment details of the experiment

The experiment utilized the Randomized Complete Block Design (RCBD) with three replications. The specific details of each treatment are provided in Table 2. Foliar sprays of Si sources were applied at three installments i.e., 30, 40, and 50 DAS. For the preparation of the foliar spray solution, distilled water was used as the solvent. Exactly 0.50, 1.00, and 1.50 g of K_2SiO_3 and $CaSiO_3$ were weighed using an analytical balance- dissolved in approximately 80% of the target volume (500 mL) of distilled water with continuous stirring for 15–20 minutes- after which the volume was made up to the final mark. Only for $CaSiO_3$, slight heat was applied to completely dissolve the substances. Tween-20 at 0.05% was added to all preparations to improve leaf wetting and adhesion. All solutions were freshly prepared on each spray date (30, 40, and 50 DAS), and the spray bottles were shaken vigorously for 30–60 seconds immediately before each application to ensure uniformity. The foliar sprays were applied to the point of runoff on both adaxial and abaxial leaf surfaces in the early morning, and control pots were treated with an equal volume of distilled water containing 0.05% Tween-20.

Table 2. Treatment description of the experiment.

Treatment symbol	Treatment details	Rate of Si	Source of silicon	Other fertilizers dose	Application method
Ta	Absolute control	0	None	0	None
T_0	Control	0	None	Recommended	Basal
T1	K_2SiO_3	0.1%	K_2SiO_3	Recommended	Foliar spry
T2	K_2SiO_3	0.2%	K_2SiO_3	Recommended	Foliar spry
T3	K_2SiO_3	0.3%	K_2SiO_3	Recommended	Foliar spry
T4	$CaSiO_3$	0.1%	$CaSiO_3$	Recommended	Foliar spry
T5	$CaSiO_3$	0.2%	$CaSiO_3$	Recommended	Foliar spry
T6	$CaSiO_3$	0.3%	$CaSiO_3$	Recommended	Foliar spry

Inoculation of fungal pathogen

To ensure accurate and uncontaminated results, the entire experimental area was covered with a polythene sheet before inoculation— isolating the site from the surrounding field. Following this, fungal suspension of *Magnaporthe oryzae* pathotype *Triticum* (MoT) was sprayed. The inoculum of MoT was previously collected from the local epidemic field of Faridpur. Then, its identity was confirmed through morphological analysis- cultured and stored. The inoculum from the stored culture media was used to prepare the suspension using distilled water and the surfactant- Tween-20 to ensure uniform leaf adherence. Its concentration was adjusted around 1×10^5 spores/mL. The inoculum suspension was sprayed at the complete heading stage (Feekes 10.5) following the Feekes Scale of Heading.

Measurement of disease incidence, disease severity, and disease reduction

Wheat blast incidence and severity percentages were assessed at 7, 9, 11, 13, 15, and 17 Days after inoculation (DAI). These measurements followed the techniques outlined by Ramathani et al. (2011) and Roy et al. (2021).

$$\%\ \text{Incidence} = \frac{No.of\ infected\ Plants}{Total\ no.of\ plants}\times 100 \qquad (1)$$

$$\%\ \text{Severity} = \frac{Length of\ infected\ portion of\ the spike}{Total\ length\ of\ spike}\times 100 \qquad (2)$$

% Disease reduction =

$$\frac{Disease of\ control\,(\%) - Disease of Treatment(\%)}{Disease of control(\%)}\times 100 \qquad (3)$$

Measurement of yield and yield components

After harvest, the following parameters were measured: spike length, number of spikes per pot, number of seeds per spike, weight of seeds per spike, and thousand-seed weight. Additionally, three flag leaf samples were collected from each pot before head emergence to analyze their nutritional content for each treatment.

Extract preparation and determination of nutrients

After being collected, wheat leaf samples were oven-dried at 65°C until they reached a constant weight. They were then cooled and ground using a grinding machine. Plant extracts for most nutrient analyses were prepared by a wet oxidation method using a di-acid mixture (HNO_3: $HClO_4$ = 2:1), following the procedure outlined by Singh et al. (1999). However, for silicon (Si) determination, the plant extract was prepared following Estefan et al. (2013).

Calcium (Ca) and Magnesium (Mg) concentrations were determined by a complexometric titration method, using 0.01M Na_2EDTA as a chelating agent (Page, 1982). Potassium (K) samples were determined with a flame emission spectrophotometer (Model: JENWAY-PFP7), following Page (1982). Phosphorus (P) was determined spectrophotometrically (T60U-Vis, UK) using stannous chloride as a reductant, based on the procedure stated by Tandon (2005). Sulfur (S) was determined turbidimetrically with a spectrophotometer (T60U-Vis, UK), also as stated by Tandon (2005). Boron (B) in plant samples was determined by the Azomethine-H method, following instructions from Page (1982). Silicon concentration was determined spectrophotometrically (T60U-Vis, UK) at a 410 nm wavelength

Statistical analysis

The collected data were compiled, tabulated, and statistically analyzed using "Minitab 21,"— a statistics package from Pennsylvania State University. To identify significant differences between the means— after ANOVA— a post hoc Tukey Test was performed for pairwise comparisons.

Results

Disease development

The wheat spikes were challenged with a virulent field isolate of *Magnaporthe oryzae* pathotype *Triticum* (MoT). The sprayed inoculum was prepared from previously stored media at a standardized concentration of around 1×10^5 spores/mL with about >90% viability. Initial symptoms appeared within 3 days after inoculation, especially in the control groups (T_a and T_0), confirming the successful establishment of infection across all inoculated treatments.

Effects of different silicon fertilizers on the disease incidence, severity, and disease reduction of wheat blast

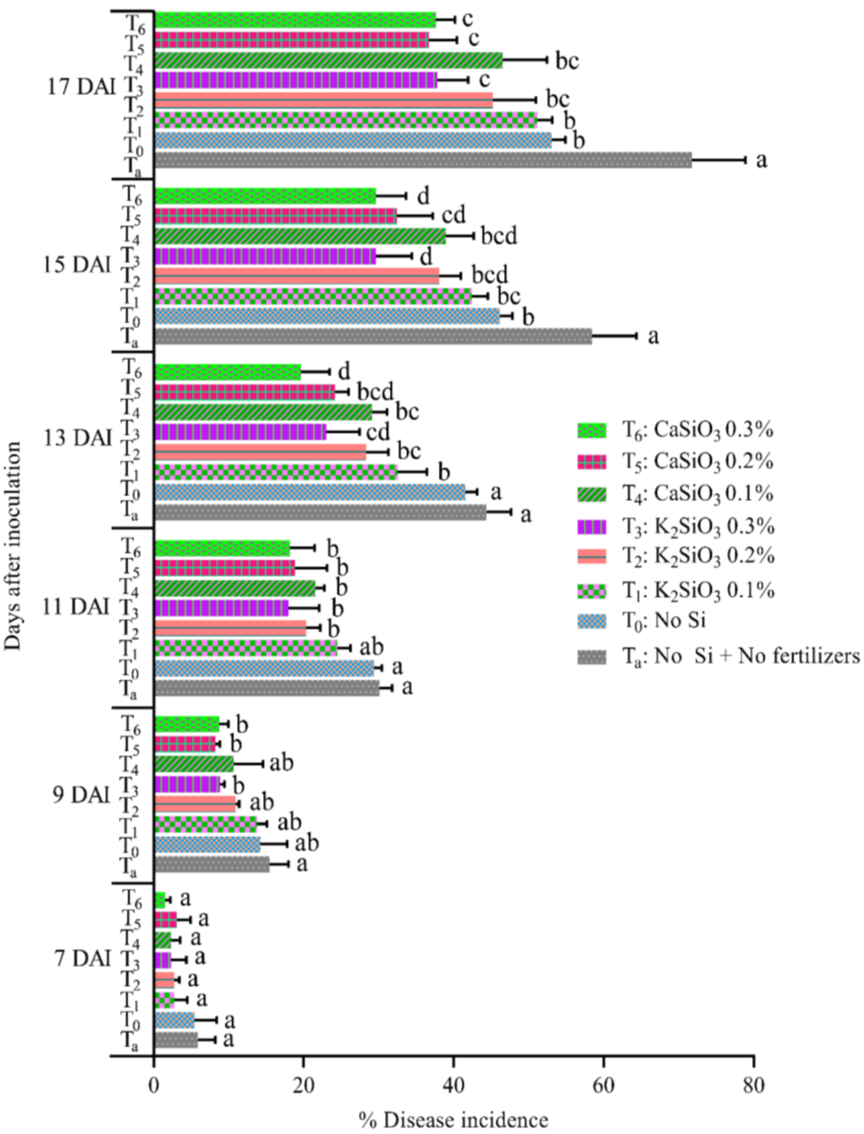

Figure 1: The impact of various silicon treatments on wheat blast disease incidence over a period from 7 to 17 DAI. Each bar represents the mean ± the standard error of the mean. Statistical comparisons, conducted via Tukey's test at a 5% significance level. Bars marked with the same letter do not differ significantly.

After the inoculation of the Wheat blast pathogen at the complete heading stage (Feekes 10.5) a significant variation of disease incidence under different Si treatments was found at 9, 11, 13, 15, and 17 DAI but not at 7 DAI (Figure 1). However, Si application reduced the disease incidence at 7 DAI, where the lowest incidence was found at T_6, where 0.3 $CaSiO_3$ was sprayed, and the highest incidence was found in the control and absolute control. At 9 DAI, the minimum incidence was found at T_3, T_5, and T_6 treatment, which was statistically different from absolute control (T_a) and control (T_0) treatment, respectively. At 11 DAI, except for T_1 treatment, all the Si treatments showed significantly lower incidence than the absolute control and control treatments, respectively. All the Si treatments showed significantly lower incidence at 13 DAI than absolute control and control treatments, respectively, where the lowest incidence was found at the T_6 treatment. The percentage of disease incidence was more deteriorated in absolute control, both 15 and 17 DAI, and showed significantly higher incidence than all other treatments. However, Si treatments showed a variable degree of incidence reduction compared to the control treatments. Both 15 and 17 DAI, the T_3, T_5, and T_6 treatments showed significantly lower disease incidence than the control treatment, where the minimum incidence was found at T_6 treatment at 15 DAI and T_5 treatment at 17 DAI.

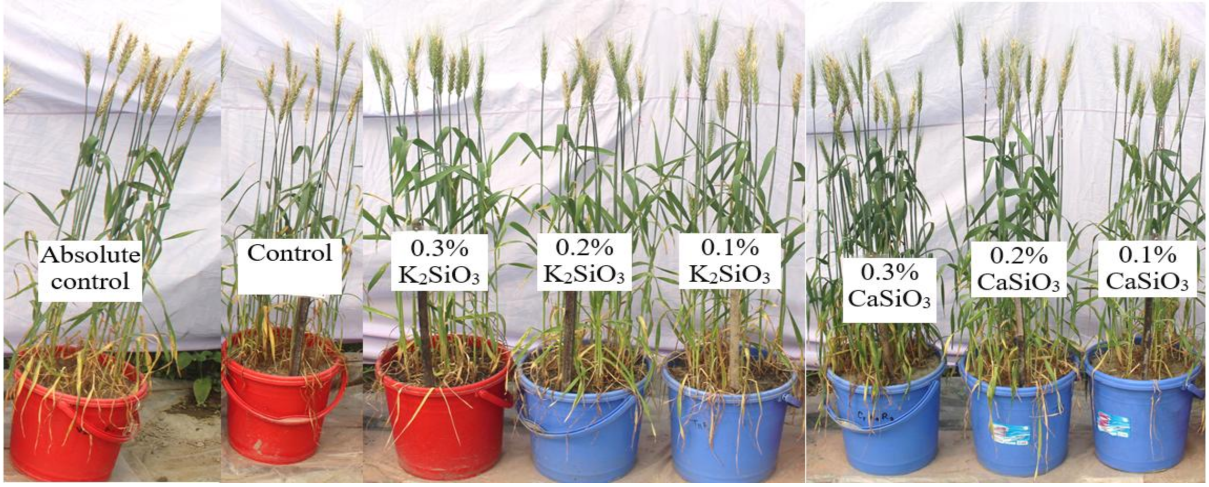

Figure 2: Visual assessment of wheat blast disease incidence in plants treated with K_2SiO_3 and $CaSiO_3$ at different concentrations versus untreated control.

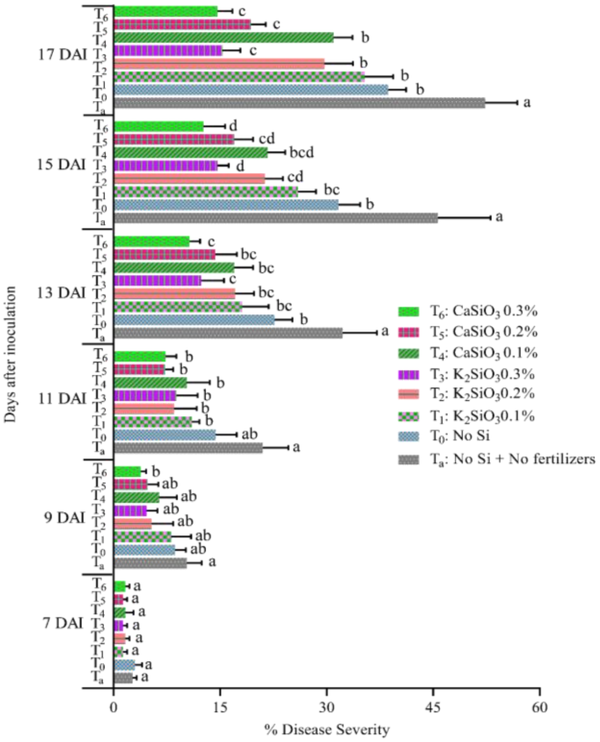

Figure 3: The impact of various silicon treatments on wheat blast disease severity over a period from 7 to 17 DAI. Each bar represents the mean ± the standard error of the mean. Statistical comparisons, conducted via Tukey's test at a 5% significance level. Bars marked with the same letter do not differ significantly.

Silicon application showed a significant reduction of wheat blast disease severity at 9, 11, 13, 15, and 17 DAI, where no significant effect was found at 7 DAI (Figure 3). At 9 DAI, only T_6 treatment showed a significant reduction in severity than absolute control, but all other treatments were identical. At 11 DAI, the severity of all the Si treatments (T_1, T_2, T_3, T_4, T_5, and T_6) was significantly reduced than absolute control, but they were identical to the control treatment. The severity of control and all other Si treatments was significantly reduced than absolute control treatment at 13, 15, and 17 DAI, respectively. At 13 DAI, a significantly lower severity was found at T_3 and T_6 treatments, respectively, than the control treatment, and the minimum value was found at T_6 treatment. The severity of T_2, T_3, T_5, and T_6 treatments at 15 DAI was significantly lower than control treatment, where the lowest severity was found at T_6 treatment. At 17 DAI, T_3, T_5, and T_6 treatments showed a significantly lower severity than control treatments, where the minimum value was found at T_6 treatment. Again, T_3, T_5, and T_6 treatments were identical among them.

The Si treatments on wheat through foliar spray under blast inoculation showed a variable degree of disease reduction (Figure 4). The maximum incidence reduction over control and absolute control was found in T_5 treatments, followed by T_6 and T_3 treatments, respectively. The lowest incidence reduction was found in the T_1 treatment. Again, the T_6 treatment showed the highest severity reduction over control and absolute control treatments, respectively. The second-highest severity reduction was found at T_3 treatment. The rest trend was $T_5 > T_2 > T_4 > T_1$, respectively.

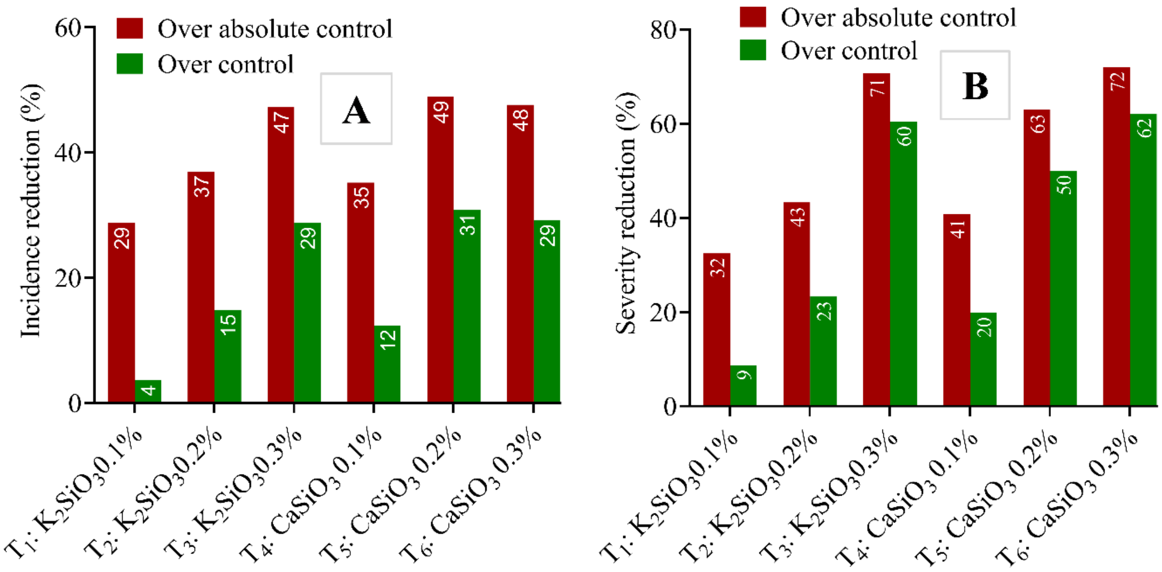

Figure 4: Wheat blast disease reduction under different Si treatments.

Effects of different silicon fertilizers on yield and yield attributes of wheat blast

The inoculation of blast pathogen reduced the yield attributing parameters and yield of wheat but Si fertilizers application through foliar spray significantly ($p < 0.05$) increased the yield contributing parameters and yield of wheat (Table 3). The total spike pot $^{-1}$ significantly increased in T_3, T_5, and T_6 treatments, with the highest mean value at T_6 treatment. However, none of the Si treatments showed any significant differences among them. Again, the results of T_1, T_2, and T_4 treatments were identical to the control treatment. The number of seeds per spike significantly increased in the T_5 treatment compared to both the absolute control and control treatments, which were identical to all other Si treatments, respectively. A significantly higher total number of seeds per pot was found at T_6 treatment than in the absolute control, control, T_1, and T_4 treatments, respectively, which was identical to T_2, T_3, T_5, and T_6 treatments. Again, the results of T_3 treatment showed a statistical similarity with T_2 and T_4 treatments, respectively. The weight of the thousand seeds was identical among all the Si and control treatments, where only T_3 and T_6 showed a significant increase in WTS compared to the absolute control treatment. The seed yield per pot largely varied among different treatments. A significantly higher seed yield was found at the T_6 treatment than at all other treatments except the T_3 and T_5 treatments. Again, the seed yield of the T_5 treatment was also significantly higher than the absolute control and control treatments, respectively, which shows the statistical identity with T_2 treatments only. The lowest yield was found in the absolute control treatment, followed by the control treatment.

Table 3. The impact of different silicon fertilizer applications on the yield and associated yield traits of wheat

Treatments	Total spike pot $^{-1}$	No. of seed spike $^{-1}$	Total no. of seeds pot $^{-1}$	WTS (g)	Yield pot $^{-1}$ (g)
T_a	9.33±0.88b	26.33±1.45c	248.33±37.36d	25.96±2.37b	6.54±1.31d
T_0	12.00±1.15ab	35.67±2.73bc	429.33±54.86cd	29.92±2.26ab	12.80±1.81cd
T_1	12.67±0.88ab	36.67±2.33abc	466.67±52.51cd	30.03±2.21ab	14.25±2.51cd
T_2	14.33±0.33ab	38.33±2.85abc	551.33±54.48abc	35.47±2.10ab	19.37±1.12bc
T_3	17.33±1.76a	43.00±2.89ab	742.00±76.17ab	37.60±1.35a	27.84±2.69ab
T_4	13.67±1.45ab	36.67±2.19abc	495.00±26.96bcd	29.81±1.87ab	14.73±1.06cd
T_5	16.00±1.15a	49.33±3.71a	788.00±77.87a	33.21±2.17ab	26.12±2.71ab
T_6	17.67±1.20a	45.67±2.33ab	803.33±41.77a	36.93±1.66a	29.72±2.41a

Each value represents the mean ± SEM. The values with the same letter are statistically similar according to Tukey's test at 5% level of significance.

Note: T_a: No Si + No fertilizers; T_0: No Si; T_1: K_2SiO_3 0.1%; T_2: K_2SiO_3 0.2%; T_3: K_2SiO_3 0.3%; T_4: $CaSiO_3$ 0.1%; T_5: $CaSiO_3$ 0.2%; T_6: $CaSiO_3$ 0.3%.

Effects of different silicon fertilizers on different nutrient concentrations in the leaf tissues of plants

Table 4. Different nutrient concentrations in leaf tissues of plants treated with different silicon fertilizers.

Treatment	Ca (%)	Mg (%)	K (%)	P (%)	S (%)	B (mg kg^{-1})	Si (%)
T_a	0.21±0.01b	0.25±0.01b	1.13±0.02c	0.25±0.01b	0.24±0.03a	13.33 ±1.60b	1.02±0.07d
T_0	0.34±0.01a	0.30±0.02ab	1.78±0.08c	0.44±0.02a	0.26±0.03a	18.52±0.84ab	1.61±0.16c
T_1	0.38±0.02a	0.33±0.02a	1.85±0.01ab	0.41±0.03a	0.26±0.02a	19.58±1.65ab	1.75±0.06bc
T_2	0.37±0.02a	0.34±0.01a	1.91±0.07ab	0.43±0.02a	0.29±0.03a	21.71±1.66a	2.02±0.15abc
T_3	0.39±0.01a	0.35±0.02a	2.04±0.07a	0.48±0.02a	0.27±0.01a	23.37±0.26a	2.23±0.14ab
T_4	0.35±0.01a	0.33±0.03a	1.84±0.01ab	0.42±0.02a	0.26±0.02a	17.29±1.44ab	1.82±0.06bc
T_5	0.38±0.01a	0.34±0.01a	1.90±0.03ab	0.43±0.04a	0.28±0.03a	20.54±1.46a	2.18±0.04ab
T_6	0.41±0.02a	0.34±0.01a	1.88±0.04ab	0.45±0.04a	0.29±0.02a	24.19±1.76a	2.43±0.07a

Each value represents the mean ± SEM. The values with the same letter are statistically similar according to Tukey's test at 5% level of significance.

Note: T_a: No Si + No fertilizers; T_0: No Si; T_1: K_2SiO_3 0.1%; T_2: K_2SiO_3 0.2%; T_3: K_2SiO_3 0.3%; T_4: $CaSiO_3$ 0.1%; T_5: $CaSiO_3$ 0.2%; T_6: $CaSiO_3$ 0.3%.

The Si treatment under blast pathogen inoculation of wheat showed a variable effect on nutrient concentrations of the flag leaf (Table 4). Except for absolute control, Si treatments showed identical Ca concentrations in the flag leaf, with the highest Ca concentration found at the T_6 treatment. Mg concentration followed about the same trend, but the control treatment showed the identity with the absolute control treatment. The highest Mg concentration was found at the T_3 treatment. Potassium concentration greatly varied, where significantly higher K was found in T_3 treatment than in control and absolute control treatments, respectively, which showed statistical similarity with all other Si treatments. The phosphorus concentration of all Si and control treatments was identical among them, but statistically different from the P concentration of the absolute control treatment. The highest P concentration was found in the T_3 treatment. However, S concentration didn't show any significant variation among all the treatments, but the highest concentration was found in the T_6 treatment. Significantly higher B concentration was found in the T_6 treatment than absolute control treatment, which was identical to all other treatments, respectively. The Si concentration was greatly varied among different treatments. A significantly higher Si concentration was found in T_6 than in control, absolute control, T_1, and T_4 treatments, which was identical to T_2, T_3, and T_5 treatments, respectively.

Discussion

Disease development

In this experiment, *Magnaporthe oryzae* pathotype *Triticum* (MoT) inoculum at a defined conidial concentration was inoculated in spikes of wheat at the completion of heading. This type of controlled inoculation approaches is widely used to study pathogenicity, disease progress, and host response in wheat blast (Martinez et al., 2021). The rapid appearance of symptoms within 3 days, particularly in Si untreated controls, indicates that environmental conditions and inoculum quality were suitable for infection and early colonization of spike tissues (Martinez et al., 2021). Early spike symptoms — within a few days — match reports where MoT inoculation at heading or flowering produces rapid bleaching and rachis discoloration, often progressing to severe spike damage and grain shriveling (Surovy et al., 2023; Martinez et al., 2021; Cruz and Valent, 2017). High disease incidence and severity in the T_a and T_0 control groups suggest high susceptibility of the studied wheat cultivar, similar to susceptible cultivars in pathogenicity and epidemiology studies that show high spike severity, extensive bleaching, and major yield loss (Surovy et al., 2023).

Effects of different silicon fertilizers on the disease incidence, severity, and disease reduction of wheat blast

As an eco-friendly approach, Si have a stimulating effect on plant growth and mitigating abiotic and biotic stress (Etesami and Jeong, 2018; Zargar et al., 2019). In this experiment, we evaluated the effect of foliar Si application on wheat under the inoculation of the wheat blast pathogen. The results showed that Si application increases plant resistance against the wheat blast pathogen and finally increases the yield of wheat. The disease incidence and severity showed a significant variation among different Si treatments, whereupon the increase in days after inoculation, the variation was very prominent, and all the Si treatments reduced blast incidence, and the higher doses showed a maximum reduction of disease incidence. To infect a plant pathogen must assess its tissue by invading the physical barrier, like wax, cuticle, and cell wall (Freeman and Beattie, 2008). Along with the plant's physical barrier, Si produces an extra barrier upon accumulation in the plant cell wall. After application, Si adsorbs and accumulates below the cuticle layer and above the cell wall, making the cell wall less susceptible to enzymatic degradation by pathogens and preventing disease establishment (Yoshida et al., 1962). Silicon also accumulates in the subcuticular layer and intercellular spaces, which make more physical barriers for pathogens to prevent their entrance and enhance disease resistance by plants (Bakhat et al., 2018). Again, under biotic stress Si increases the activity of antioxidant enzymes e.g., peroxidase (POX), chalcone synthase (CHS), polyphenol oxidase (PPO), and pathogenesis-related (PR) proteins; increase the production and accumulation of defense compounds (cellulose, lignin, flavonoids, phenolics, and defense enzymes) through primary and secondary metabolic pathways (A. Rodrigues et al., 2015; Ahammed and Yang, 2021; Elsherbiny and Taher, 2018). The significant reduction of disease incidence and severity in this experiment may be attributed to the physical and biochemical defense mechanisms induced by Si application under biotic stress. The maximum reduction of disease (Figure 4) due to the reduction of incidence and severity in higher Si concentration is mainly due to the higher accumulation of Si in plant tissue at higher doses of application because increasing Si concentration proportionally suppresses the disease (Datnoff and Rodrigues, 2015). However, the better performance of $CaSiO_3$ than K_2SiO_3 is unknown to us. In line with our experiment, Ali et al. (2024) showed that Si application reduces the disease incidence and severity matrix by 35.27% and 54.3%, respectively, over the control treatment. Wang et al. (2017) reported that foliar application of Si directly reduced disease severity than plant alleviation over control treatment.

Effects of different silicon fertilizers on yield and yield attributes of wheat blast

Growing evidence points to silicon as a beneficial element in agriculture, playing a key part in improving crop growth and yield, particularly through its capacity to mitigate disease incidence and severity. The reduction of blast disease incidence and severity under different Si treatments reduced the pathogen infections both on the wheat spike and photosynthetic area resulting in improvement of yield contributing parameters in this experiment. Again, the application of Si-based fertilizers has been reported to impart a positive effect on plant growth and yield by enhancing chlorophyll synthesis, photosynthesis, and biomass accumulation (Dorairaj et al., 2017). Cuong et al. (2017) reported that grain yield (23% increased), along with yield contributing parameters, increased under four different doses of Si fertilizer application with other recommended doses of mineral fertilizers.

However, overall results suggest that the observed increase in Si, Ca, and Mg concentrations in treated wheat plants might be coordinated to boost the defense mechanism in wheat. Silicon provides a physical subcuticular barrier against blast penetration, while elevated Ca stabilizes cell wall pectates and Mg preserves chlorophyll integrity against pathogen-induced chlorosis. In this experiment, $CaSiO_3$ outperformed K_2SiO_3 likely due to the synergistic effect of Ca as a secondary messenger in stress signaling, which complements Si structural reinforcement, though the actual mechanisms weren't studied in this experiment.

Effects of different silicon fertilizers on different nutrient concentrations in the leaf tissues of plants

The healthy condition of a plant is essential to carry out metabolic processes successfully and uptake and translocation of nutrients in plants, but infection with pathogens creates stress and hampers the normal metabolic processes. In this experiment, nutrient concentration decreased in the control and absolute control treatment is mainly due to the stress imparted by blast pathogen infection. However, in this experiment, Si application showed a positive effect on nutrient concentration in the wheat flag leaf. This effect is mainly attributed to disease reduction under different Si treatments, where the higher doses showed a more synergistic effect on nutrient concentration. The higher concentration of Si (Table 4) in higher doses of application confirms the Si-mediated positive effect on nutrient concentration in the flag leaf. Several pieces of literature reported that Si showed a positive effect on Ca (Greger et al., 2018), Mg (Zhang et al., 2019), K (Buchelt et al., 2020) , P (Soratto et al., 2019), S (Zhang et al., 2019), and B (Pavlovic et al., 2021) uptake and accumulation in plants. Our results are justified by the findings of Ali et al. (2024), where they found that Si application increases the Ca, Mg, K, P, S, and B concentrations over the control treatment under the infestation of sheath blight disease of rice. However, overall results suggest that the observed increase in Si, Ca, and Mg concentrations in treated wheat plants might be coordinated to boost the defense mechanism in wheat. Silicon provides a physical subcuticular barrier against blast penetration, while elevated Ca stabilizes cell wall pectates and Mg preserves chlorophyll integrity against pathogen-induced chlorosis. In this experiment, $CaSiO_3$ outperformed K_2SiO_3 likely due to the synergistic effect of Ca as a secondary messenger in stress signaling, which complements Si structural reinforcement, though the actual mechanisms weren't studied in this experiment.

Conclusion

The devastating nature of the wheat blast pathogen is now a headache for researchers, where pesticidal control and tolerant cultivars are still insufficient. Silicon-mediated disease tolerance is well-known in the literature. In this experiment, Si treatment significantly reduced the disease incidence and severity over the control treatment. The disease reduction was very satisfactory, especially at higher concentrations of Si application. The yield attribute and yield were also increased significantly under Si treatments. Overall disease reduction and the synergistic effect of Si increase the nutrient concentration in the flag leaf of wheat. However, $CaSiO_3$ at a rate of 0.3% foliar spray showed higher performance than K_2SiO_3 at a rate of 0.3% foliar spray, though the results were comparable between them. So, $CaSiO_3$ at a rate of 0.3% foliar spray could be an advisable option for the mitigation of wheat blast disease as an eco-friendly approach. Upon our results, we suggest further field trials and diverse climatic evaluation of the Si effect on the management of wheat blast disease.

Author's Contribution

F.F.S.: Design, formulation and supervision of experiment, and writing of manuscript; A.K.N.: Performing the lab experiments and analysis of data; M.K.U.: Performing data analysis and writing the draft manuscript; M.Z.I.S.: Review of manuscript; M.A.R.: Review of manuscript; K.M.M.: Supervision of experiments and review of manuscript.

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