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Research Article

Application of Diverse Silicon Sources to Soil for Reducing Wheat Blast Disease

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ABSTRACT

Despite the economic potential of wheat for food security, blast disease is one of the major constraints to wheat production in warm and humid areas. Silicon (Si) increases crop yields and resistance to both biotic and abiotic stresses. The effect of various Si sources, including Na_2SiO_3, $MgSiO_3$, $CaSiO_3$, and rice hull ash (RHA), on suppressing wheat blast (WB) incidence was studied at Bangladesh Institute of Nuclear Agriculture field from November 2019 to March 2020 using a complete randomized design (CRD) with three replications. Total 42 plastic pots were filled with the recommended doses of fertilizers and Si. On 17 days after inoculation (DAI), the lowest WB incidence (83.16%) and severity matrix (80.20%) were found with the treatment of $CaSiO_3$ @ 100 kg ha^{-1}. At 15 DAI, the same treatment reduced the WB incidence and severity matrix by 21.10% and 41.73%, respectively. Most yield indicators were significantly improved by the Si fertilizers, except for grain spike^{-1} quantity, weight, and thousand grain weight (g). However, pots that were fertilized with Si distinguished out from both the control and absolute control groups. While $CaSiO_3$ at 75 kg ha^{-1}, RHA at 6.0 t ha^{-1}, and $MgSiO_3$ at 100 kg ha^{-1} produced respectable yields, the maximum was achieved by $CaSiO_3$ at 100 kg ha^{-1}. There was a significant positive relationship between the leaf concentrations of K and Si, with the highest concentration found in plants treated with $CaSiO_3$. A large number of yield metrics showed moderate to strong positive associations with leaf K and Si concentrations, whereas the disease severity matrix revealed the maximum significant negative correlation with these elements. The best outcomes were obtained by applying Si as $CaSiO_3$ @100 kg ha^{-1}, which has potential as an environmentally acceptable source for controlling WB disease and increasing wheat yields.

Introduction

Wheat (*Triticum aestivum*) is the most important crop worldwide for human nutrition since it contains a wide variety of macro- and micronutrients, including carbs (75–80%), protein (9–18%), fiber, several vitamins, calcium, and iron (Igrejas and Branlard, 2020). It is a staple crop all across the globe due to its versatility as an agricultural crop, its ability to be stored as grain without much difficulty, and its usefulness as a culinary ingredient in a broad variety of tasty and nutritious dishes. Acevedo et al. (2018) predict that wheat production will need to be nearly double by 2050 to feed the world's population, a trend driven by the westernization of diet and the ease of producing processed foods. Tadesse et al. (2017) and Shewry and Hay (2015) found that wheat consumption has increased globally. Widespread cultivation of wheat occurs in a wide range of climates, from the subtropical to the temperate. A total of more area is devoted to wheat cultivation and commerce than to any other food crop (FAOSTAT, 2023) in the world. Still, there have always been a number of obstacles, both biotic and abiotic, associated with wheat production. *Magnaporthe oryzae* pathotype *Triticum* is a fungal pathogen that causes wheat blast (WB), a devastating disease, which causes severe yield losses up to 100% depending on the environmental conditions (Duveiller et al., 2016; Cruz and Valent, 2017; Kohli et al., 2011; Goulart and Paiva, 2000). Different parts of the affected wheat are given different names for this disease: leaf blast, collar rot node blast, spike blast, and rotten neck blast. The first report of this wheat disease was in Brazil in 1985. Fifty percent of Brazil's wheat production was lost in 2009 due to a disease epidemic. Due to the severe incidence of this disease, wheat cannot be cultivated in some locations of South America (Callaway, 2016). Presence of WB was also reported in Argentina, Bolivia, Paragua, and Urugua (Igarashi et al.,

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1986; Prabhu et al., 1992; Perelló et al., 2015). After the first sighting in Kentucky in 2011, the WB was able to be contained because of the implementation of stringent surveillance procedures (Callaway, 2016).

A worldwide expansion of WB, as seen recently in Bangladesh, is a real concern since the disease might spread via contaminated seed or grain (Cruz and Valent, 2017). When the WB first appeared in Bangladesh in 2016, it affected around 15% of the country's wheat fields and caused yield losses of about 90% (Malaker et al., 2016). Comparative genome analyses revealed that the fungal isolates from different parts of Bangladeshi's wheat fields were related to aggressive *Magnaporthe oryzae* pathotype *Triticum* from South America and seemed to be clonal (Farman et al., 2017; Malaker et al., 2016). Scientists have either found a way to prevent the disease from becoming widespread or created a new resistant wheat cultivar since then. Unfortunately, WB pathogen is able to infect the majority of wheat cultivars cultivated in Bangladesh. This is may be influenced by meteorological circumstances, infected plants' nutritional state, and their growth stage during infection (Chowdhury et al., 2022; Debona et al., 2014; Igarashi et al., 1986). Numerous references have discussed the effects of Si, K, P, Ca, and Mg on plant disease resistance and their capacity to decrease the incidence of WB disease (Sarker et al., 2022; Debona et al., 2014; Cruz et al., 2011). Farmers often apply excessive amounts of agrochemicals (such as pesticides, insecticides, fungicides, herbicides, etc.) to combat plant diseases which raises major issues about food contamination, environmental damage, and pesticide resistance. Considering the complexity involved in managing WB disease, it is important to explore other methods of control alongside genetic host resistance and synthetic fungicides (Pagani et al., 2014). Having sufficient nutrition is often necessary to maintain a high degree of disease resistance; however, mineral nutrients are what plants use to control metabolic activity linked to resistance (Huber and Haneklaus, 2007).

A number of plant diseases have been effectively controlled by silicon (Si), which is one of several such nutrients (Sathe et al., 2021). By either directly enhancing the activity of certain proteins or indirectly by sequestering cations, Si causes the plant to rapidly and extensively deploy its natural defences in the event of an assault by harmful fungus (Guntzer et al., 2011). Two studies (Pagani et al., 2014; Filha et al., 2011) showed that wheat with synthetic Si formulations might decrease yield losses caused by WB. Soil contains silicate minerals, aluminum silicates, and other types of silicon dioxide; however, monosilicic acid (MSA), which plants may use, is not present in soil. There is a negligible soil conversion of these to MSA. To get around this, more Si fertilizers such silicates, biogenic silica (rice husk ash), silicon dioxide sources, etc. are used to increase the MSA concentration, which in turn leads to increase Si uptake. Various research has shown that the most efficient fertilizers for plant development and disease resistance are Na_4SiO_4, $CaSiO_3$, ash, and silica gel (Guntzer et al., 2011; Mecfel et al., 2007). The metallurgical smelting process produces calcium silicate slags, which are by-products with various percentages of Si. These slags have been shown to have beneficial effects on soil acidity correction, plant development, and stress reduction. Potassium silicate and sodium metasilicate are two common Si fertilizers that use regularly, and wheat grown with these Si fertilizers showed considerable improvements in growth metrics when subjected to biotic, drought, and salt stress (Cruz et al., 2011). So, overall evidences we can hypothesized that, Si has the capability to reduce the disease severity of WB and this experiment was undertaken to examine the influence of various Si supplement sources on the severity and incidence of WB diseases.

Materials and Methods

Experimental site

A pot experiment was set up at the Bangladesh Institute of Nuclear Agriculture (BINA) farm in Mymensingh. The farm is located on the campus of Bangladesh Agricultural University in Mymensingh, at an altitude of 18 meters above sea level, at 24°75'N latitude and 90°50'E longitude. This area is placed in soil class Agro-Ecological Zone 9 (AEZ-9) of the Old Brahmaputra Floodplain, which is composed of non-calcareous dark grey soil. The experiment was done in rabi season (October to March) which is characterized by short days, low humidity, low temperatures, and little rainfall.

Soil collection and preparation for pot experiment

Soils at a depth to 15 cm were taken from certain areas of the Non-calcareous Dark Grey Floodplain (AEZ-9). After collecting the soil sample, it was cleaned of any plant residues or other unwanted substances, allowed to air-dry, and then crushed and passed through a 2 mm sieve for further processing. For the purpose of physical and chemical analysis, around 500 g of prepared soil was stored in a polythene bag. According to the established protocols, the soil's physicochemical characteristics were examined (Page et al., 1982). Physicochemical properties of experimental soil are presented in Table 1.

Table 1. Physicochemical properties of experimental soil

Parameter (Unit)	Class or concentration	Parameter (Unit)	Concentration
Texture	Silty loam	Phosphorus (mg kg^{-1})	3.00
Bulk density	1.26	Potassium (meq 100 kg^{-1})	0.13
Particle density (g cm^{-3})	2.59	Sulfur (mg kg^{-1})	4.00
Moisture content (%)	27.24	Zinc (mg kg^{-1})	1.81
pH	5.9	Boron (mg kg^{-1})	0.06
Organic matter (%)	1.05	Calcium (meq $100g^{-1}$)	3.32
Total nitrogen (%)	0.06	Magnesium (meq $100g^{-1}$)	0.78

Pot preparation

A blend of inorganic fertilizers and well-decomposed cow manure (45 g pot^{-1} or 3 t ha^{-1}) was applied to the soil. In each plastic pot (40 × 35 × 30 cm), 18 kg of processed soil was taken with leaving a 3 cm gap at the top.

Test crop, experimental design and treatments

Wheat variety BARI Gom-26, cultivated on the premises of the Bangladesh Institute of Nuclear Agriculture in Mymensingh, was used in the experiment. We used a completely randomized design (CRD). Total 42 plastic pots were prepared with recommended fertilizers and Si sources as per treatments named T_A (absolute control, without all fertilizers), T_0 (control, without Si sources), T_1 (Na_2SiO_3 @ 50 kg ha^{-1}), T_2 (Na_2SiO_3 @ 75 kg ha^{-1}), T_3 (Na_2SiO_3 @ 100 kg ha^{-1}), T_4 ($CaSiO_3$ @ 50 kg ha^{-1}), T_5 ($CaSiO_3$ @75 kg ha^{-1}), T_6 ($CaSiO_3$ @100 kg ha^{-1}), T_7 ($MgSiO_3$ @ 50 kg ha^{-1}), T_8 ($MgSiO_3$ @ 75 kg ha^{-1}), T_9 ($MgSiO_3$ @ 100 kg ha^{-1}), T_{10} (rice hull ash, RHA @ 3 t ha^{-1}), T_{11} (RHA @ 4.5 t ha^{-1}) and T_{12} (RHA @ 6.0 t ha^{-1}). According to the fertilizer recommendation guide, Bangladesh (BARC, 2018), the wheat crop was fertilized with the following standard doses of N, P, K, S, Mg, Zn, and B: 100, 20, 75, 13, 6, 2, and 1.1 kg ha^{-1}, respectively, from Urea, TSP, MoP, gypsum, magnesium sulfate, zinc sulfate heptahydrate, and solubor. During the land preparation process, urea and other fertilizers were applied in full dosages. On the 17 DAS, the crown root initiation stage, 1/3 of the urea was applied. Three instalments of RHA were used: one-third of the ash was applied before planting, and the second and third parts were applied as top dressing at 7 and 14 DAS.

Intercultural operation and harvesting

On November 29, 2019, BARI Gom-26 seeds were sown in every pot. It was planned to irrigate on alternating days. At 15 and 30 DAS, soil loosening was carried out. Weeding was done by hand at 15, 30, and 45 DAS. Crop was harvested at 120 DAS; spikes were collected, dried and threshed for grains.

Inoculation of fungal pathogen

At 60 DAS suspension of *Magnaporthe oryzae* pathotype *Triticum*, was sprayed on the crop to inoculate the pathogen, and then the whole plot was covered with polythene sheet for 24 to 48 hours to keep it isolated from the rest of the field and to maintain high humidity (>80%), temperature (29±2°C), and prevent contamination (Sarker et al., 2022).

Pathological Parameters

Measurement of disease incidence and disease severity

At 7, 9, 11, 13, 15, and 17 days after inoculation (DAI), the incidence, severity percentage, and disease severity matrix of WB in spike were determined using the methods described by Ramathani et al. (2011) and Roy et al. (2021).

$$\%\ \text{Incidence} = \frac{\text{No.of infected plants}}{\text{Total no.of plants}} \times 100$$

$$\%\ \text{Severity} = \frac{\text{Length of infected portion of the spike}}{\text{Total length of a spike}} \times 100$$

$$\%\ \text{Disease Severity Matrix} = \frac{\%\ \text{Incidence}}{100} \times \frac{\%\ \text{Severity}}{100} \times 100$$

Again, the disease reduction over control was calculated by using the following formula.

$$\%\ \text{Reduction over control} = \frac{\%\ \text{disease of control} - \%\ \text{disease of treatment}}{\%\ \text{disease of control}} \times 100$$

Yield and yield components

Plant height was measured at 75 DAS from the base to the panicle tip. Following harvesting, measurements were made of spike length, spike pot^{-1}, number of grains $spike^{-1}$, weight of grain $spike^{-1}$, and thousand grain weight. Before the head emerged from wheat plant, three flag leaf samples were taken in order to assess the nutritional value of each treatment.

Extract preparation and determination of nutrients

Wheat flag leaf samples were collected, dried for 48 hours at 65°C in an oven, cooled, and then crushed using a grinding machine. Following preparation, the samples were stored in plastic bottles. The di-acid mixture (HNO_3: $HClO_4$= 2:1) was used to produce the plant extract using the wet oxidation process (Singh et al., 1999). In order to determine Si, the plant extract was prepared in accordance with Estefan et al. (2013).

The concentration of Ca and Mg was measured by titrating with 0.01M Na_2EDTA as a chelating agent, using the complexometric method (Page et al., 1982). Potassium and Na of plant samples were measured using a flame emission spectrophotometer (JENWAY-PFP7) (Page et al., 1982). According to Tandon's (2005) guidelines, P was measured spectrophotometrically (Model: TG-60 U) with stannous chloride acting as a reductant, whereas, S was detected turbidimetrically. The Azomethine-H technique was used to measure the amount of B in plant samples (Page et al., 1982), and a spectrophotometric technique at 410 nm wavelength was used to determine Si.

Statistical analysis

The recorded data were compiled, calculated and statistically analyzed. Statistical analysis was carried out using the "Minitab 19.0" statistics tool developed by Pennsylvania State University. A post-hoc "Tukey Test" was used to compare the means pairwise to identify where there was a significant difference. Correlation matrix and heatmap was produced by using GraphPad Prism 9.0 version.

Results

Effect of Si fertilizers on WB incidence

The WB incidence was significantly affected by the application of Si fertilizers ($p < 0.01$). The WB incidence varied from 17.22% to 27.33% at 9 DAI, from 44.91% to 66.03% at 11 DAI, from 56.90% to 77.12% at 13 DAI, from 66.91% to 92.75% at 15 DAI, and from 83.16% to 98.04% at 17 DAI, as shown in Table 2 and Figure 1A, depending on the treatment applied. In the absence of Si fertilizer and the recommended amount of fertilizer, the control group showed the highest incidence of WB after 7 DAI, where no incidence was found at 7 DAI. The treatment T_{12} had the lowest disease incidence (17.22%) at 9 DAI, which was significantly identical to T_3 and T_6, and that T_3 had the lowest incidence (44.91%) at 11 DAI (Table 2). Compared to T_a and T_0, T_6 had the lowest incidence at 13 DAI (56.90%) and 15 DAI (66.91%), indicating that this treatment was quantitatively superior (Table 2). Statistically, all treatments except T_a, T_0, T_{11}, and T_{12} had identical WB incidence at 17 DAI (Table 2). The highest incidence was 98.04% for T_a, while the lowest was 83.16% for T_6. In terms of disease incidence, T_6 was followed by T_3 (84.92%), T_5 (86.14%), and T_2 (88.55%), all of which were statistically identical but had an incidence below 90%.

Table 2. Effects of different Si fertilizers on wheat blast incidence (%)

Treatment No.	Disease Incidence (%)					
	7 DAI	9 DAI	11 DAI	13 DAI	15 DAI	17 DAI
T_a	0.00	27.33a	66.03a	77.12a	92.75a	98.04a
T_0	0.00	26.22a	64.42abc	76.37ab	84.81ab	97.54a
T_1	0.00	24.92ab	52.50bcd	61.67abc	73.25bcd	91.33a-d
T_2	0.00	22.24bc	57.40a-d	68.30abc	75.48bcd	88.25a-d
T_3	0.00	17.93d	44.91d	58.45bc	69.15cd	84.92cd
T_4	0.00	19.98cd	51.21cd	61.15abc	68.90cd	92.91a-d
T_5	0.00	19.63cd	55.65a-d	59.72abc	68.44cd	86.14bcd
T_6	0.00	17.92d	53.35a-d	56.90c	66.91d	83.16d
T_7	0.00	19.85cd	63.33abc	67.50abc	82.92ab	91.32a-d
T_8	0.00	25.49ab	62.01abc	64.71abc	78.19bcd	91.80a-d
T_9	0.00	18.95cd	60.53abc	63.95abc	72.97bcd	90.94a-d
T_{10}	0.00	17.89d	64.64abc	70.78abc	84.53ab	91.00a-d
T_{11}	0.00	20.47cd	55.42a-d	60.97abc	79.94bc	95.54abc
T_{12}	0.00	17.22d	66.01ab	70.63abc	78.61bcd	95.83ab
Level of significance	NS	**	**	**	**	**

Figures in a column with same letter(s) do not differ significantly. * Significant at 5% level of significance. ** Significant at both 5% and 1% level of significance. NS= Non-significant.

Legends: T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

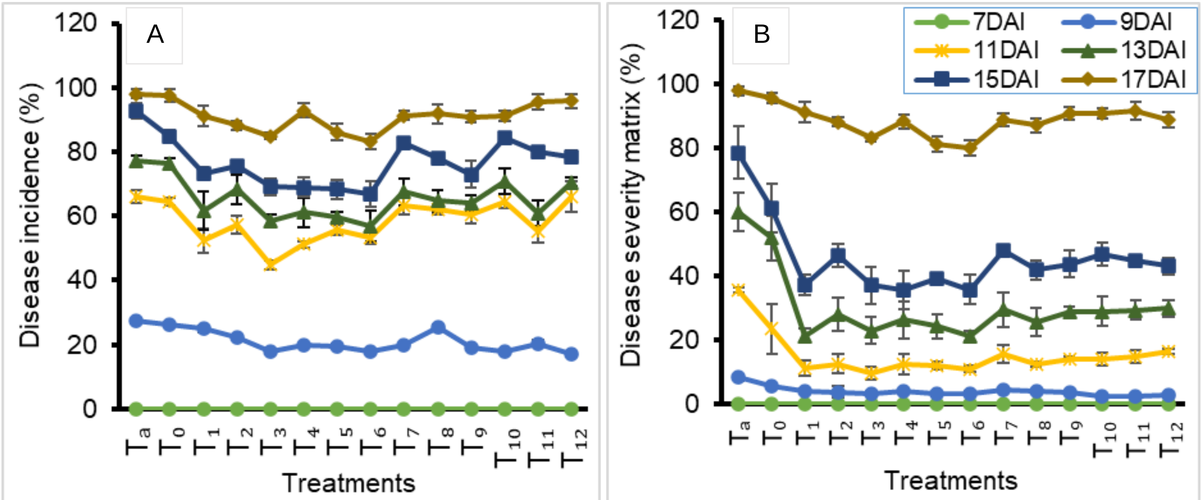

Figure 1. Effects of different Si fertilizers on the WB incidence (A) and severity matrix (B).

Legends: T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

Effect of Si fertilizers on WB disease severity matrix

The application of Si fertilizers influenced the WB disease severity matrix and significantly ($p < 0.01$) reduced the severity of the disease (Table 2 and Figure 1B). For the WB severity matrix, no severity data was identified at 7 DAI. The highest WB disease severity matrix was observed at T_a (no fertilizers) after 7 DAI; and for the majority of the treatment, this case was statistically identical to T_0 (no Si). The overall WB disease severity matrix varied with the application of various treatments; it was 2.43 to 8.15% at 9 DAI, 9.51 to 35.66% at 11 DAI, 21.21% to 60.61% at 13 DAI, 35.56% to 78.56% at 15 DAI, and 80.20% to 98.04% at 17 DAI (Table 3 and Figure 1B). At 9 DAI, the T_{11} treatment showed the lowest disease severity matrix (2.43%), which was significantly lower from T_a alone. Conversely, at 11 DAI, T_3 had the lowest disease severity matrix (9.51%), showing significant similarity with all other treatments except T_a (Table 2). A significant difference between T_a and T_0 was observed at 13 DAI, when the minimal WB disease severity matrix was found at T_6 (21.21%). Out of all the treatments except T_a and T_0, T_4 had the lowest WB severity matrix at 15 DAI (35.56%) (Table 2). In terms of disease severity matrix data, the highest disease severity matrix was at 17 DAI was T_a with 98.04% and the lowest at T_6 with 80.20%; all other cases were statistically identical except T_a, T_0, T_1, and T_{11} (Table 3).

A significant difference ($p < 0.05$) was noted in the lowering of WB disease incidence and severity matrix when various Si supplements were used compared to the control group (Figure 2). At 15 DAI, T_6 showed a significant decrease in disease incidence (21.10%) compared to control, followed by T_5 (19.31%), T_4 (18.76%), and T_3 (18.47%), all of which were statistically identical except T_7, T_{10}, and T_{11}. Again, the treatment T_4 (41.73%) had the greatest disease severity matrix decrease over control, followed by T_6 (41.33%), T_3 (39.33%), and T_1 (39.07%), which were statistically different from T_2, T_7, T_9, T_{10}, T_{11}, and T_{12}. The lowest severity matrix reduction was observed at T_7 (21.31%). At 17 DAI, the highest reductions in disease incidence (14.74%) and disease severity matrix (16.35%) compared to control were found for T_6, as they were at 15 DAI as well.

Effect of Si fertilizers on yield and yield attributes

Effects on plant height and spike length

Variations in wheat plant height and spike length were observed in response to varying dosages and sources of Si fertilizers (Figure 3 and 4). The results revealed significant differences in plant height, with ranging from 67.56 cm to 76.22 cm ($p < 0.05$). The exception of absolute control which produced the lowest plant height of 67.56 cm, the following plants reached their specific mentioned height: T_7 (76.22 cm), which is statistically similar to T_4 (76.11 cm), T_9 (73.89 cm), T_6 (73.67 cm), T_8 (73.33 cm), and others (Figure 3).

Table 3. Effects of different Si fertilizers on WB disease severity matrix (%)

Treatment	Disease Severity Matrix (%)					
	7 DAI	9 DAI	11 DAI	13 DAI	15 DAI	17 DAI
T_a	0.00	8.15a	35.66a	60.11 a	78.56 a	98.04 a
T_0	0.00	5.69ab	23.41ab	51.96 ab	61.19 ab	95.88 a
T_1	0.00	4.01b	11.06b	21.34c	37.18 c	91.33 ab
T_2	0.00	3.65b	12.53b	27.90c	46.30 bc	88.25 abc
T_3	0.00	3.19b	9.51b	22.94 c	37.02 c	83.16 bc
T_4	0.00	3.93b	12.26b	26.18 c	35.56 c	88.337 abc
T_5	0.00	3.11b	11.87b	24.22 c	39.23 bc	81.34 bc
T_6	0.00	3.11b	10.81b	21.21 c	35.80 c	80.20 c
T_7	0.00	4.17b	15.38b	29.43 bc	48.02 bc	88.93 abc
T_8	0.00	3.95b	12.40b	25.68 c	41.93 bc	87.17 abc
T_9	0.00	3.57b	14.09b	28.88 c	43.79 bc	90.94 abc
T_{10}	0.00	2.44b	13.85b	28.93 c	46.81 bc	91.00 abc
T_{11}	0.00	2.43b	14.75b	29.37 bc	44.82 bc	91.64 ab
T_{12}	0.00	2.73b	16.41b	29.91 bc	43.05 bc	89.05 abc
Level of sig.	NS	**	**	**	**	**

Figures in a column with same letter(s) do not differ significantly. * Significant at 5% level of significance. ** Significant at both 5% and 1% level of significance. NS= Non-significant.

Legends: T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

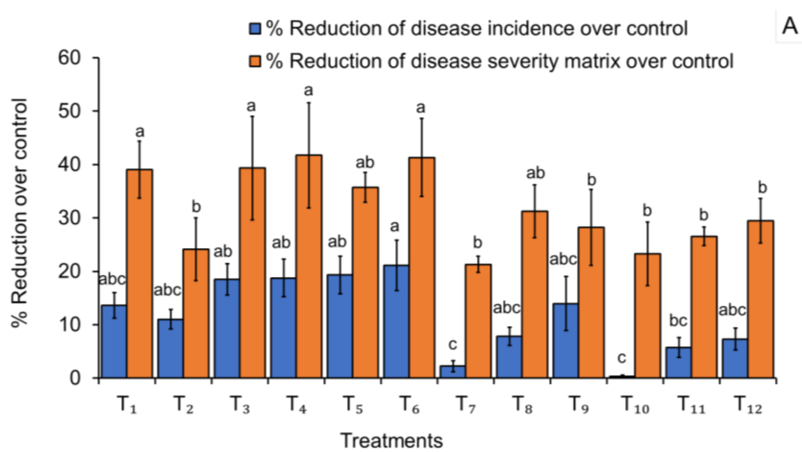

Figure 2A. Wheat blast reduction over control at 15 DAI treated with different Si supplements. Bars with the same letter(s) do not differ significantly.

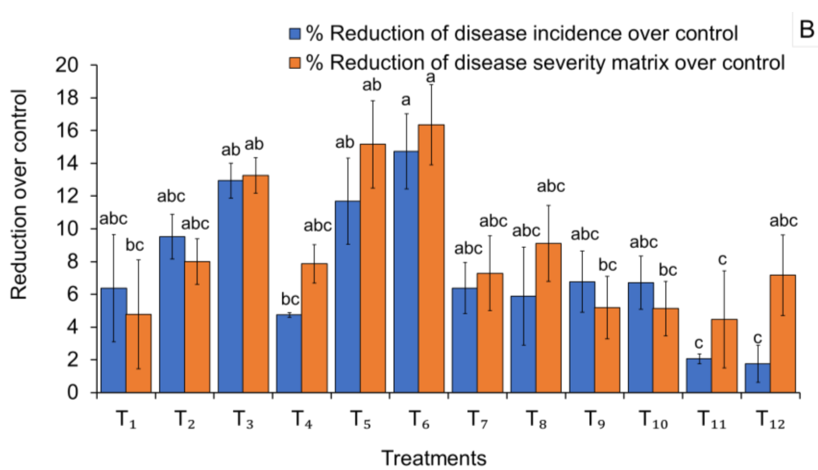

Figure 2B. Wheat blast reduction over control at 17 DAI treated with different Si supplements. Bars with the same letter(s) do not differ significantly.

Figures in a column with same letter(s) do not differ significantly. **Legends:** T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

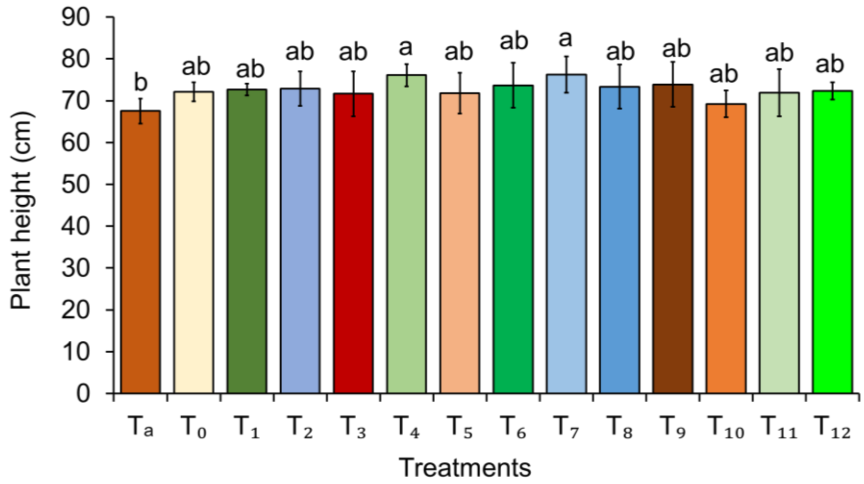

Figure 3. Effects of different silicon fertilizers on plant height. Figures in a column with same letter(s) do not differ significantly (at 5% level of significance).

Figures in a column with same letter(s) do not differ significantly. **Legends:** T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

The Si treatments significantly increased the spike length ($p < 0.05$) compared to control (Figure 4). Except for T_a, all other treatments significantly and identically followed T_1 in terms of maximal spike length (11.22 cm). The absolute control had the shortest spikes of 8.18 cm, which was noticeably different from the others (Figure 3).

Number of total spikes

The number of total spikes pot^{-1} were varied significantly among the treatment groups (Table 4). The total number of spikes varied between 11.67 to 17.33. The largest total spikes were observed in T_6, followed significantly by T_5 (17.00) and T_9 (15.33), except for T_a, T_3, and T_{10}. Results also showed that the overall number of spikes was lowest in T_{10} (11.67) and T_3 (11.67), followed by T_a (12.00) (Table 4).

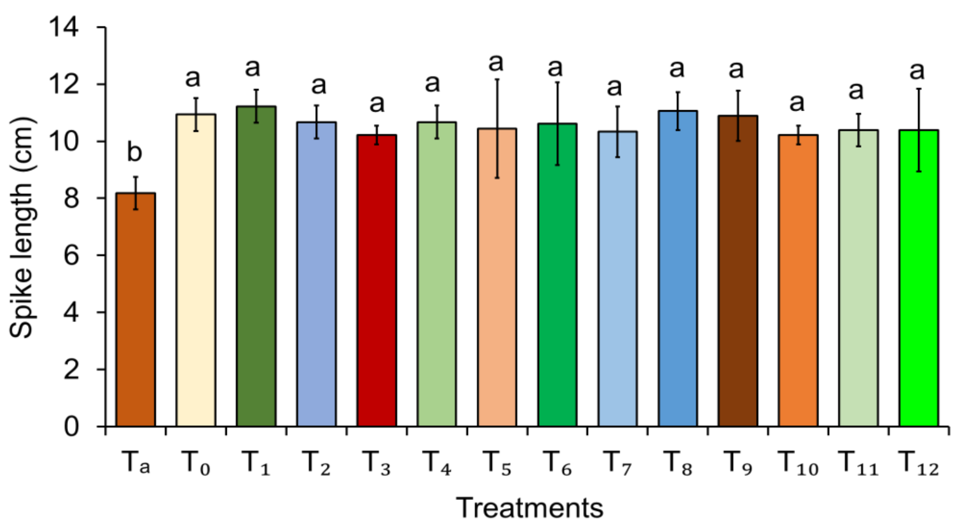

Figure 4. Effects of different silicon fertilizers on spike length of wheat plant. Figures in a column with same letter(s) do not differ significantly (at 5% level of significance).

Figures in a column with same letter(s) do not differ significantly. **Legends:** T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

Number and weight of grains spike^{-1}

No significant change occurred in the average number of grain spike^{-1} owing to the Si treatment applied (Table 4). The number of grain spike^{-1} varied from 45.00 to 56.33. The highest number of grain spike^{-1} was recorded in treatment T_{10} (56.33), followed by T_4 (54.00), T_{12} (53.67), and T_7 (53.33). The lowest number of grain spike^{-1} was observed in the T_a treatment (45.00), followed by T_9 (45.33) and T_3 (46.00) (Table 4).

The weight of grain spike^{-1} (g) did not significantly change despite the various Si treatments that were applied (Table 4). Grain spike^{-1} was between 0.33 and 0.59 g in weight. Grain spike^{-1} weighed a maximum of 0.59 g in T_{12}, followed by 0.58 g in T_{11}, 0.57 g in T_{10}, 0.57 g in T_2, and 0.55 g in T_9. Ta had the lowest weight of grain spike^{-1} (0.33 g), followed by T_0 (0.47 g), T_1 (0.50 g), and T_7 (0.50 g).

Total number of grain pot^{-1} and weight of thousand grain (WTS)

Si treatments significantly ($p < 0.05$) affected the total number of grains pot^{-1} varying from 536.7 to 832.3 (Table 4). The T_5 had the highest total number of grains (832.3), followed by T_6 (824.3), T_{12} (782.0), and other groups, except for T_a (540.3) and T_3 (536.7), which had significantly lower results (Table 4).

Treatments with Si had no statistically significant effect on WTG ($p > 0.05$) (Table 4). The WTS varied from 7.25 to 12.22 g, with T_9 having the highest WTG at 11.74 g, followed by T_6 (11.50 g), and T_2 (11.41 g). The absolute control had the lowest WTG (7.25 g), followed by T_0 (9.34 g), T_1 (9.84 g), and T_7 (9.48 g) (Table 4).

Table 4. Effects of different Si fertilizers on yield attributes of WB infected plants

Treatments	No. of spike pot^{-1}	No. of grain spike^{-1}	Weight of grain spike^{-1} (g)	No. of grain pot^{-1}	WTG (g)
T_a	12.00 b	45.00	0.33	540.3 b	7.25
T_0	14.00 ab	49.67	0.47	694.0 ab	9.34
T_1	14.00 ab	51.00	0.50	711.3 ab	9.84
T_2	13.00 ab	50.33	0.57	655.3 ab	11.41
T_3	11.67 b	46.00	0.54	536.7 b	11.74
T_4	13.00 ab	54.00	0.58	699.7 ab	10.59
T_5	17.00 a	48.67	0.54	832.3 a	11.10
T_6	17.33 a	47.33	0.54	824.3 ab	11.50
T_7	13.33 ab	53.33	0.50	714.7 ab	9.48
T_8	13.67 ab	49.33	0.48	672.7 ab	9.80
T_9	15.33 ab	45.33	0.55	695.0 ab	12.22
T_{10}	11.67 b	56.33	0.57	657.3 ab	10.06
T_{11}	14.00 ab	51.67	0.58	722.7 ab	11.08
T_{12}	14.67 ab	53.67	0.59	782.0 ab	11.05
Level of sig.	**	NS	NS	*	NS

Figures in a column with same letter(s) do not differ significantly. * Significant at 5% level of significance. ** Significant at both 5% and 1% level of significance. NS= Non-significant.

Legends: T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

Yield pot^{-1}

The grain production of wheat plants infected with WB was significantly affected ($p < 0.01$) by various Si treatments (Figure 5), ranging from 3.96 to 9.24 g pot^{-1}. The highest yield was observed in treatment T_6, with a recorded value of 9.24 g pot^{-1}. This was followed by treatments T_5 (8.97 g pot^{-1}), T_{12} (8.67 g pot^{-1}), T_9 (8.58 g pot^{-1}), and all other treatments except T_a, which had the lowest yield of 3.96 g pot^{-1}. The treatment with the lowest yield was followed by all other treatments except for T_5, T_6, T_9, and T_{12} (Figure 5).

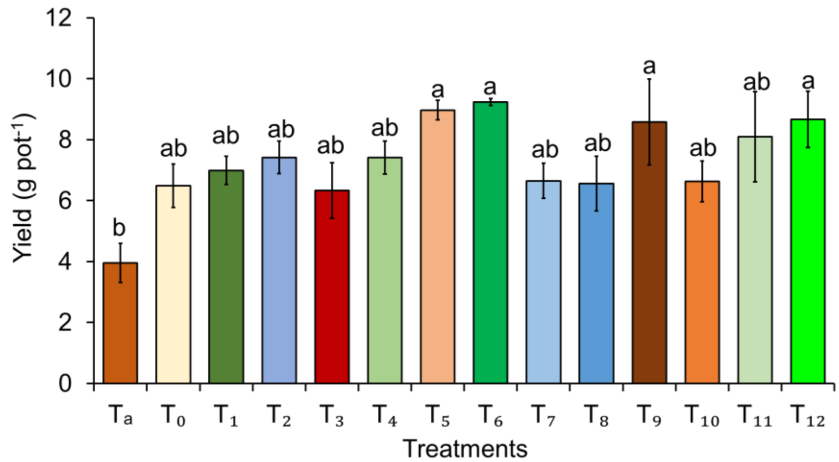

Figure 5. Effects of different Si fertilizers on the yield of WB infected plants.

Figures in a column with same letter(s) do not differ significantly (at 5% level of significance). **Legends:** T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

Si fertilizers on different nutrient concentration in wheat leaves

The flag leaf nutrient levels were significantly impacted by several sources of Si fertilizers ($p < 0.01$) (Table 5). Noticeable variations were found in the calcium (Ca) levels of wheat leaves. The Ca concentration varied between 0.021% and 0.080%, with an average concentration of 0.049%. The highest Ca concentration was found in T_6, followed by T_5 (0.074%), which were significantly different from the other treatments. However, the lowest and markedly distinct Ca concentration was found in T_0, with a value of 0.021% (Table 5).

The concentration of Magnesium (Mg) varied between 0.24% and 0.44%, with an average concentration of 0.34%. There was a significant difference in concentration across the treatments. The T_9 had a higher level of Mg, which was significantly distinct from the other treatments. The next maximum concentration was achieved from T_5 to T_8. Treatment T_4 had the lowest concentration of Mg, which was significantly different from the other treatments (Table 5).

The investigation revealed significant difference in the potassium (K) levels across flag leaf samples from plants infected with WB. The concentration of K varied between 1.15% and 2.17%, with an average concentration of 1.84%. The highest concentration of K was found in T_{12} and T_5, followed by T_{11} (2.09%). The T_a treatment had the lowest amount of K, which was statistically distinct from the other treatments (Table 5).

Table 5. Nutrient concentrations in leaf tissues of wheat plants treated with different Si fertilizers

Treatment	% Ca	% Mg	% K	% P	% S	ppm B	% Si	% Na
T_a	0.021 g	0.25 e	1.15 j	0.25 g	0.23 g	20.14 f	0.87 j	0.34 g
T_0	0.040 f	0.34 c	1.19 i	0.46 c	0.43 b	6.07 k	1.11 i	0.39 f
T_1	0.041 f	0.34 c	1.53 h	0.40 e	0.30 cd	9.03 i	2.17 f	0.54 c
T_2	0.040 f	0.29 d	1.98 c	0.49 b	0.44 b	1.63 l	2.41 d	0.57 b
T_3	0.041 f	0.34 c	1.87 f	0.39 e	0.30 cd	12.00 h	2.64 b	0.63 a
T_4	0.057 b	0.24 e	1.98 c	0.39 e	0.83 a	33.47 a	2.52 c	0.54 c
T_5	0.074 a	0.39 b	2.17 a	0.36 f	0.28 de	6.07 k	2.64 b	0.48 d
T_6	0.080 a	0.39 b	1.90 e	0.46 c	0.29 cde	6.81 j	3.82 a	0.41 f
T_7	0.043 ef	0.39 b	1.79 g	0.44 cd	0.28 de	23.10 d	1.93 h	0.41 f
T_8	0.048 cde	0.39 b	2.07 b	0.65 a	0.27 ef	20.88 e	2.41 d	0.45 e
T_9	0.047 de	0.44 a	1.94 d	0.43 c	0.27 ef	6.81 j	2.64 b	0.46 e
T_{10}	0.049 cd	0.34 c	1.98 c	0.45 cd	0.31 c	13.48 g	2.29 e	0.45 e
T_{11}	0.051 bcd	0.24 e	2.09 b	0.39 e	0.25 fg	26.81 b	2.051	0.45 e
T_{12}	0.054 bc	0.34 c	2.17 a	0.49 b	0.31 c	24.59 c	2.41 d	0.49 d
Level of sig.	**	**	*	**	**	**	**	**
Average	0.049	0.34	1.84	0.43	0.34	15.06	2.28	0.48

Figures in a column with same letter(s) do not differ significantly. * Significant at 5% level of significance. ** Significant at both 5% and 1% level of significance. NS= Non-significant.

Legends: T_A = absolute control, T_0 = control, T_1 = Na_2SiO_3 @ 50 kg ha^{-1}, T_2 = Na_2SiO_3 @ 75 kg ha^{-1}, T_3 = Na_2SiO_3 @ 100 kg ha^{-1}, T_4 = $CaSiO_3$ @ 50 kg ha^{-1}, T_5 = $CaSiO_3$ @75 kg ha^{-1}, T_6 = $CaSiO_3$ @100 kg ha^{-1}, T_7 = $MgSiO_3$ @ 50 kg ha^{-1}, T_8 = $MgSiO_3$ @ 75 kg ha^{-1}, T_9 = $MgSiO_3$ @ 100 kg ha^{-1}, T_{10} = rice hull ash, RHA @ 3 t ha^{-1}, T_{11} = RHA @ 4.5 t ha^{-1} and T_{12} = RHA @ 6.0 t ha^{-1}.

The plant leaves in the research showed a large variation in phosphorus (P) concentration, ranging from 0.25% to 0.65%, with an average concentration of 0.43%. The highest concentration of P was observed in T_8, whereas the second highest concentration was obtained from T_{12} (0.49%). The T_a sample had the lowest quantity of P, which was significantly different from the other treatments (Table 5).

The research found significant differences in the sulfur (S) concentration of the WB infected leaf samples. The average concentration was 0.34%, with a range of 0.23–0.83%; T_4 had the highest S concentration and T_a had the least amount of S (Table 5).

With significant differences among the treatments, T_4 had the highest B concentration at 33.47 ppm, followed by T_{11} at 26.81 ppm, and T_{12} at 24.59 ppm; the concentrations varied from 1.63 ppm to 33.47 ppm, with an average concentration of 15.06 ppm. The lowest B concentration was found in T_2 (1.63 ppm) followed by T_0 (6.07ppm), T_5 (6.07ppm), T_6 (6.81 ppm) (Table 5).

Flag leaf samples from WB-infected plants varied significantly in Si concentration, with values ranging from 0.87% to 3.82% and an average of 2.28%. The treatment T_6 had the most Si concentration (3.82%), which was significantly different from the others; T_3, T_5, and T_9 had the second-highest concentrations, at 2.64%, whereas lowest concentration was observed in T_a (0.87%) and then in T_1 (1.11%) (Table 5).

The study found significant differences in the sodium (Na) concentration of the leaf samples. The treatment T_3 had the highest amount (0.63%), followed by T_2 (0.57%), T_1 (0.54%), and T_4 (0.54%), while T_a had the lowest concentration (0.34%), followed by T_0 (0.39%) (Table 5).

Correlation among wheat leave tissue nutrients and disease index and yield parameters

The correlation between various nutrients, disease index, and yield attributing characteristics may be comprehended by referring to Table 6 and Figure 6. Within the study, it was found that Ca showed a favorable relationship with certain elements such as Mg, K, P, and Si. On the other hand, B and S showed a negative association. Notably, K and Si had a significant correlation (r > 0.50), while Mg (r = 0.47) exhibited a moderate correlation with Ca. Of the several components that contribute to yield, yield pot^{-1} (r = 0.65), total number of grain pot^{-1} (r = 0.58), and total spike pot^{-1} (r = 0.60) showed a high and positive association. The other parameters exhibited either a moderate or weak correlation with Ca concentration. Conversely, there was a significant negative association (r > 0.50) between disease incidence, disease severity matrix, and the concentration of Ca in plant leaves, as shown in Table 6 and Figure 6.

Table 6. Correlation matrix between wheat leaf tissue nutrients, disease index and yield parameters

Parameters	% Ca	% Mg	% K	% P	% S	ppm B	% Si	% Na	% Incidence	% Severity matrix	Total spike pot^{-1}	No. of grain spike^{-1}	Wt. of grain spike^{-1} (g)	Total no. of grain pot^{-1}	WTG (g)	Yield pot^{-1} (g)
% Ca	1.00															
% Mg	0.47	1.00														
% K	0.58	0.31	1.00													
% P	0.21	0.29	0.37	1.00												
% S	-0.03	-0.55	0.05	-0.24	1.00											
ppm B	-0.09	-0.55	0.06	-0.05	0.46	1.00										
% Si	0.57	0.06	0.74	0.24	0.52	0.20	1.00									
% Na	0.05	0.10	-0.16	0.17	-0.09	-0.36	0.03	1.00								
% Incidence	-0.62	-0.34	-0.51	-0.12	-0.16	0.20	-0.73	-0.24	1.00							
% Severity matrix	-0.59	-0.33	-0.62	-0.34	-0.06	0.02	-0.73	-0.22	0.78	1.00						
Total spike pot^{-1}	0.60	0.47	0.25	0.10	-0.23	-0.26	0.15	0.01	-0.35	-0.23	1.00					
No. of grain spike^{-1}	0.08	-0.08	0.20	0.20	0.18	0.31	0.18	0.15	0.11	-0.23	-0.13	1.00				
Wt. of grain spike^{-1} (g)	0.39	0.09	0.49	0.22	0.06	0.02	0.48	0.17	-0.36	-0.48	0.04	0.40	1.00			
Total no. of grain pot^{-1}	0.58	0.37	0.32	0.18	-0.11	-0.06	0.22	0.09	-0.25	-0.32	0.83	0.44	0.24	1.00		
WTG (g)	0.40	0.19	0.46	0.18	-0.05	-0.17	0.44	0.12	-0.48	-0.44	0.13	-0.09	0.87	0.05	1.00	
Yield pot^{-1} (g)	0.65	0.35	0.51	0.22	-0.10	-0.14	0.43	0.11	-0.46	-0.47	0.63	0.20	0.79	0.67	0.76	1.00

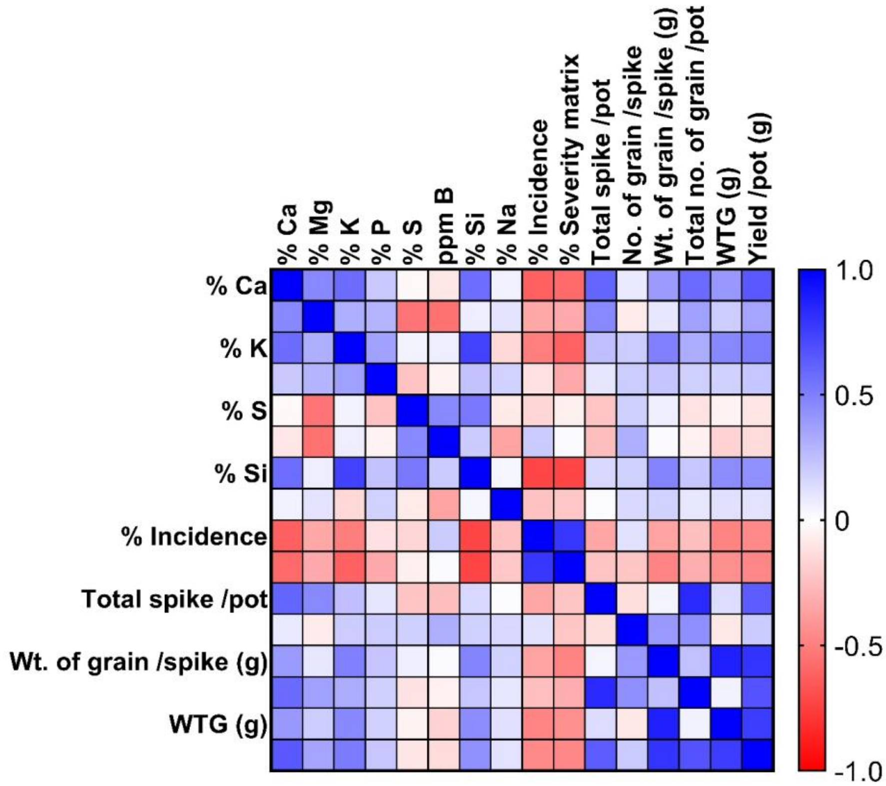

Figure 6. Heatmap of the correlation matrix between wheat leaf tissue nutrients, disease index and yield parameters

Once again, there was a significant negative correlation between the concentration of Mg and S and B, whereas the concentration of other elements showed a positive correlation. The yield metrics showed a positive association, with the exception of the number of grain spike^{-1}, which had a little negative correlation. There was a modest and negative correlation between the disease severity matrix and incidence. The research found a positive association between P and other elements such as K, Ca, Mg, Si and Na. However, B and S revealed a negative correlation with P. All the yield components exhibited a positive association with P, although a weak one. The P levels in plant leaf tissue have a positive link with both disease incidence and disease severity. The correlation is small for disease incidence and moderate for disease severity, as shown in Table 6.

In the research, S exhibited a negative association with other elements such as Ca, Mg, P, and Na, while it showed a positive correlation with K, B, and Si. All yield components, except for the number and weight of grains spike^{-1}, showed a negative correlation with S. Table 6 showed that both disease incidence and disease severity matrix had a negative connection with S concentration. Sodium had a weak inverse relationship with the disease index and a positive relationship with all the yield metrics. The concentration of K presented a strong positive correlation with Si concentration and yield pot^{-1}, whereas a significant negative relationship was seen with the disease index. Notably, B had a little positive relationship with the matrix of disease severity and incidence. The Si ion concentration had a strong negative relationship (r = 0.73) with the disease index, whereas the yield parameters showed a modest correlation with this element.

Discussion

Si fertilizers to manage the severity of the WB disease index

Wheat and other higher plants store Si in their shoot tissues, which is a beneficial element for these plants (Dallagnol et al., 2020). The current research found that applying Si fertilizers significantly ($p < 0.01$) decreased WB incidence and severity matrix at various DAIs. In wheat plants treated with Si, lesions were smaller, less coalesced, and fewer number, regardless of the Si source or dosage, varying disease incidence and severity compared with control plants. The Si sources worked well in this research, including Na_2SiO_3, but for large-scale field application, alternative Si fertilizers including $CaSiO_3$, $MgSiO_3$, and RHA may be better since Na_2SiO_3 may produce field salinization. Previous research by Dallagnol et al. (2020) found that fertilization with $CaSiO_3$ and $MgSiO_3$ enhanced the Si concentration in wheat spike and leaf tissues, which in turn reduced the severity of tan spot and *Fusarium* head blight. Tan spot was caused by an increase in the biochemical and histocytological defence reactions of wheat plants when they were exposed to Si (Dorneles et al., 2017). The results are consistent with those of previous research by Santos et al. (2011) that revealed a reduction in the incidence of brown spot and panicle blast in rice when $CaSiO_3$ was applied. Despite experimenting with several Si source treatments for blast reduction, we found no significant differences in the disease parameter. According to Ali et al. (2024), the application of $CaSiO_3$ resulted in the largest sheath blight disease incidence and severity matrix reduction in rice, at 35.27% and 54.3%, respectively. A study found that soil with CaSiO3 and $MgSiO_3$ mitigated *Fusarium* head blight (*Fusarium graminearum*) by as much as 32% (Pazdiora, 2019). In contrast, Silva et al. (2010) found that in the case of bacterial leaf streak caused by *Xanthomonas translucens* pv. undulosa, the application of soil Si resulted in a reduction in chlorotic leaf area by as much as fifty percent, but it had no impact on the necrotic leaf area or severity. Domiciano et al. (2010) found that soil fertilization with $CaSiO_3$ decreased the area under the disease progress curve for spot blotch (*Bipolaris sorokiniana*) by 59%. The research found that the physical barrier established by the cuticle-Si double layer reduced the infection rate of to spot blotch by *B. sorokiniana* in wheat epidermal cells when plants were given Si-supply (Domiciano et al., 2013). A silicate epidermal cell layer has indeed been proposed as the mechanism by which plants develop resistance to Si (Kumar et al., 2007; Ueno et al., 2004). This is thought to hinder fungal infections' ability to physically penetrate plant cell walls and reduce enzyme degradation. It is possible that a comparable process prevented *Bipolaris oryzae* and *Magnaporthe oryzae* from entering the leaves in the investigation conducted by Santos et al. (2011). Similarly, it is possible that Si particles reduced the incidence of WB by blocking *Pyricularia oryzae* access in our study. Leaf blast intensity was shown to be 70% less in plants cultivated in medium containing Si compared to plants grown in media without addition of Si source in previous greenhouse studies for blast (*Magnaporthe oryzae* pathotype *Triticum*) (Perez et al., 2015).

Si fertilizers on yield and yield contributing parameters

Vegetative growth, measured in terms of plant height, is, in fact, significantly affected by approaches to plant production management and fertilizer sources. The Si fertilizers significantly affected most yield indicators, while grain spike^{-1} number, weight, and thousand grain weight (g) were insignificant; however, Si-applied pots stood apart from absolute control and control. The maximum height was observed from $MgSiO_3$ @ 50 kg ha^{-1}, which was closer to $CaSiO_3$ @ 50 kg ha^{-1} (Figure 3), whereas other treatments exhibited comparable statistical findings for spike length, with Na_2SiO_3 @ 50kg Si ha^{-1} having the numerically highest result. While Cuong et al. (2017) found significant changes by applying Si to grains panicle^{-1} of rice, Carvalho (2000) and Mauad (2003) likewise did not find any significant effects of Si fertilization on this yield component. Wheat plants that were cultivated with Si supplement had taller plants than those that were grown without, suggesting that Si deposition in cell walls may cause plants to grow taller (Gong et al., 2003). In a comparable manner, Abro et al. (2009) found that applying Si influenced wheat and rice plants with taller height. Moreover, Pati et al. (2016) and Cuong et al. (2017) found that plants grew taller when Si fertilizer was applied which is similar to our current fundings.

Si fertilizer-treated plants had more spikes and longer spikes than the absolute control. Ma and Takahashi (2002) also found that Si fertilization on rice increased panicle number which supported current results. Our investigation revealed significant variations among WTG for Si treatments which is supported by previous findings that Si application influenced 1000 grain weight of rice (Cuong et al., 2017). Current works found that Si treatments with $CaSiO_3$ increased yield which is comparable to Datnoff et al. (1991), who reported 20%, 18%, 4% yield increases in 1990 and 26%, 18%, 11% by fine, standard, pelletized forms of $CaSiO_3$, respectively. Recently, Ali et al. (2024) found highest rice yield in sheath blight induced plants by the foliar application of $CaSiO_3$. A prior pot experiment showed that Ca / Mg-silicate increased wheat growth and yield (Sarto et al., 2015). This may apply to Ca and Mg's physiological and biological roles. Ca is an essential component of the cell wall construction, and inhibiting fungal-secreted pectolytic enzymes increases defense-related gene expression in wheat to resist leaf blast after *P. oryzae* infection (Ligaba-Osena et al., 2020). Magnesium is involved in energy transfer activities, respiration, DNA and RNA production, enzyme cofactors, fast growth, active mitosis, high protein levels, carbohydrate metabolism, and oxidative phosphorylation (Marschner, 2012). In India, it was found that soil fertilization using $CaSiO_3$ and P increased wheat production and stress resilience (Dinesh et al., 2017). Most yield parameters performed better with $CaSiO_3$@100 kg ha^{-1}, which is consistent with Jinger et al. (2020) showing that Si deficiency can be corrected with $CaSiO_3$ slag @120-200 kg ha^{-1}. Si fertilization on rice increased yield by 17% in another field study by Ma and Takahashi (2002), comparable to Sorrato et al. (2012).

Relationship between yield, disease index, and leaf Si concentrations

The quantity of Si that plants can accumulate in their tissues and, therefore, the benefits of Si are determined by two factors: the uptake capacity of wheat plants and the amount of Si present in the soil. Our results showed that leaf samples from WB-infected plants had a Si content ranging from 0.87 to 3.82%, which is consistent with the findings of Dallagnol et al. (2020), who found a Si concentration in wheat straw ranging from 11.3 g kg^{-1} to 23.4 g kg^{-1} of dry weight. In addition, current study showed a significant positive correlation between Si and K leaf concentrations which is supported by the previous study Cuong et al. (2017), who found that K accumulation increased significantly with increasing Si dosages.

Current work also found that Si positively correlated with all elements agrees with the findings of Cuong et al. (2017), who found that P and K correlated positively with Si. In subsequent research, Hanan (1996) and Liang et al. (1996) found that plant shoots absorbed more K when Si applied in soil, but a contradicting previous study by Islam et al. (1969) which showed that rice plants absorbed less K when soil applied with Si. Plants in the non-Si control pots had half the inorganic P level of plants in the Si-added rice plants, according to Ma and Takahashi (1989), while Marschner and Rimmington (1988) demonstrated that Si does not affect P absorption or translocation to the roots of plants directly. Overall, application of Si increased P accumulation in wheat biomass as well the concentration of Si and P in wheat biomass was positively correlated (Neu et al., 2017).

It is well-known that Si can decrease the occurrence and severity of plant diseases (Fauteux et al., 2005). Additionally, research has shown that agronomic crops, particularly rice, can increase their tolerance to biotic and abiotic stress (Ma and Takahashi, 2002) by appropriately absorbing Si. Our results show a strong association between Si and the disease incidence and severity matrix, which is in line with those of Filha et al. (2011). A prior study by Seebold et al. (2000) indicated a positive correlation between yields and Si treatment. The reason for this is that Si has structural effects on the host plant via cuticle deposition and accumulation (Cai et al., 2009; Datnoff et al., 2007) and it also integrates antifungal chemicals (Rémus-Borel et al., 2005). According to Brunings et al. (2009), this element also seems to have a broad signaling role that modifies the resilience of plants against stressors at the gene transcription level.

Conclusion

Wheat blast has become a great concern for farmers causing huge yield failures and enormous economic losses during epidemic years. In this research found that grain production and quality, particularly in the presence of WB stress, are both enhanced by Si. The Si lowers the severity of diseases by improving the expressed and coordinated defense systems. Among the Si sources, $CaSiO_3$ performed so far best and it could be concluded that application of $CaSiO_3$ can be suggested as Si fertilization for the lower incidence of WB. Nevertheless, for Si fertilization to become widely used by wheat growers, several issues still need to be clarified. The research was conducted in a controlled setting with a single stressor applied to the plant, which is an essential first point. Hence, further field studies at different locations with more biotic and abiotic stresses along with WB are required to see the overall impact of Si on stress management and collect more data which can be analyzed using meta-analyses to provide a more complete picture of the effect.

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References

Abro, S.A., Qureshi, R., Soomro, F.M., Mirbahar, A.A. and Jakhar, G.S. 2009. Effects of silicon levels on growth and yield of wheat in silty loam soil. *Pakistan Journal of Botany*, 41:1385-1390.

Acevedo, M., Zurn, J.D., Molero, G., Singh, P., He, X., Aoun, M., Juliana, P., Bockleman, H., Bonman, M., El-Sohl, M. and Amri, A. 2018. The role of wheat in global food security. In: Nagothu US, editor. Agricultural Development and Sustainable Intensification: Technology and Policy Challenges in the Face of Climate Change. 1st ed. New York: Routledge. pp. 81-110. https://doi.org/10.4324/9780203733301-4.

Ali, M.O., Uddin, M.K., Sarker, M.Z.I., Rahman, M.A. and Mohiuddin, K.M. 2024. Silicon Supplements Potentially Reduce the Sheath Blight Incidence and Severity in Rice (*Oryza sativa* L.). *Journal of Bangladesh Agricultural University*, 22: 52-59. https://doi.org/10.5455/JBAU.178844.

Perez, C.E.A., Rodrigues, F.Á., Moreira, W.R. and DaMatta, F.M. 2014. Leaf gas exchange and chlorophyll a fluorescence in wheat plants supplied with silicon and infected with *Pyricularia oryzae*. *Phytopathology*, 104: 143-149. https://doi.org/10.1094/PHYTO-06-13-0163-r.

Brunings, A.M., Datnoff, L.E., Ma, J.F., Mitani, N., Nagamura, Y., Rathinasabapathi, B. and Kirst, M. 2009. Differential gene expression of rice in response to silicon and rice blast fungus *Magnaporthe oryzae*. *Annals of Applied Biology*, 155: 161-170.

Cai, K., Gao, D., Chen, J. and Luo, S. 2009. Probing the mechanisms of silicon-mediated pathogen resistance. Plant signaling & behavior, 4: 1-3. https://doi.org/10.4161/psb.4.1.7280.

Callaway, E. 2016. Devastating wheat fungus appears in Asia for first time. Nature, 532: 421-422.

Carvalho, J.C. 2000. Análise de crescimento e produção de grãos da cultura do arroz irrigado por aspersão em função da aplicação de escórias de siderurgia como fonte de silício. Botucatu, Universidade Estadual Paulista p. 119 (Doctoral dissertation, Tese de Mestrado).

Chowdhury, M.S.R., Rahman, M.A., Nahar, K., Dastogeer, K.M., Hamim, I., & Mohiuddin, K.M. 2022. Mineral nutrient content of infected plants and allied soils provide insight into wheat blast epidemics. *Heliyon,* 8: e08966. https://doi.org/10.1016/j.heliyon.2022.e08966.

Cruz, C.D. and Valent, B. 2017. Wheat blast disease: danger on the move. *Tropical Plant Pathology*, 42: 210-222. https://doi.org/10.1007/s40858-017-0159-z.

Cruz, M.F.A.D., Diniz, A.P.C., Rodrigues, F.A. and Barros, E.G.D. 2011. Aplicação foliar de produtos na redução da severidade da brusone do trigo. [Foliar application of products on the reduction of wheat blast severity]. *Tropical Plant Pathology*, 36: 424-428. https://doi.org/10.1590/S1982-56762011000600014.

Cuong, T.X., Ullah, H., Datta, A. and Hanh, T.C. 2017. Effects of silicon-based fertilizer on growth, yield and nutrient uptake of rice in tropical zone of Vietnam. *Rice Science*, 24: 283-290. https://doi.org/10.1016/j.rsci.2017.06.002.

Dallagnol, L.J., Ramos, A.E.R. and da Rosa Dorneles, K. 2020. Silicon use in the integrated disease management of wheat: Current knowledge. *Current trends in wheat research*, 5-26. https://doi.org/10.5772/intechopen.95285.

Datnoff, L.E., Elmer, W.H. and Huber, D.M. 2007. Silicon and plant disease. In L. E. Datnoff, W. H. Elmer, & D. M. Huber (Eds), Mineral nutrition and plant disease. American Phytopathological Society (APS Press), St. Paul, MN. pp. 233–246.

Debona, D., Rodrigues, F.A., Rios, J.A., Nascimento, K.J.T. and Silva, L.C. 2014. The effect of silicon on antioxidant metabolism of wheat leaves infected by *Pyricularia oryzae*. *Plant pathology*, 63: 581-589. https://doi.org/10.1111/ppa.12119.

Dinesh, J., Shiva, D., Anchal, D. and Sharma, V.K. 2017. Silicon and phosphorus fertilization in aerobic rice-wheat system. In Proceedings of the 7th International Conference on Silicon in Agriculture, Bengaluru, India. pp. 24-28.

Domiciano, G.P., Rodrigues, F.A., Guerra, A. and Vale, F.X. 2013. Infection process of *Bipolaris sorokiniana* on wheat leaves is affected by silicon. *Tropical Plant Pathology*, 38: 258-263. https://doi.org/10.1590/S1982-56762013005000006.

Domiciano, G.P., Rodrigues, F.Á., Moreira, W.R., Oliveira, H.V.D., Vale, F.X.R.D. and Xavier Filha, M.S. 2010. Silício no progresso da mancha marrom na folha bandeira do trigo. *Tropical Plant Pathology*, 35: 186-189. https://doi.org/10.1590/S1982-56762010000300009.

Dorneles, K.R., Dallagnol, L.J., Pazdiora, P.C., Rodrigues, F.A. and Deuner, S. 2017. Silicon potentiates biochemical defense responses of wheat against tan spot. *Physiological and Molecular Plant Pathology*, 97: 69-78. https://doi.org/10.1016/j.pmpp.2017.01.001.

Duveiller, E., He, X. and Singh, P. K. 2016. Wheat blast: an emerging disease in South America potentially threatening wheat production. *World wheat book*, 3, 1107-1122.

Estefan, G., Sommer, R. and Ryan, J. 2013. Methods of soil, plant, and water analysis. A manual for the West Asia and North Africa region, International Center for Agricultural Research in the Dry Areas (ICARDA). Beirut, Lebanon. 3: 244.

FAOSTAT 2023. Food and Agriculture Organization. FAOSTAT - Crops. [Internet]. Available from: http://www.fao.org/faostat/en/#data/QC/ [Accessed: 2024-04-09].

Farman, M., Peterson, G., Chen, L., Starnes, J., Valent, B., Bachi, P., Murdock, L., Hershman, D., Pedley, K., Fernandes, J.M. and Bavaresco, J. 2017. The Lolium pathotype of *Magnaporthe oryzae* recovered from a single blasted wheat plant in the United States. *Plant Disease*, 101: 684-692. https://doi.org/10.1094/PDIS-05-16-0700-RE.

Fauteux, F., Rémus-Borel, W., Menzies, J.G. and Bélanger, R.R. 2005. Silicon and plant disease resistance against pathogenic fungi. *FEMS Microbiology letters*, 249: 1-6. https://doi.org/10.1016/j.femsle.2005.06.034.

Filha, M.X., Rodrigues, F.A., Domiciano, G.P., Oliveira, H.V., Silveira, P.R. and Moreira, W.R. 2011. Wheat resistance to leaf blast mediated by silicon. *Australasian Plant Pathology*, 40: 28-38. https://doi.org/10.1007/s13313-010-0010-1.

Gong, H.J., Chen, K.M., Chen, G.C., Wang, S.M. and Zhang, C.L. 2003. Effects of silicon on growth of wheat under drought. *Journal of plant nutrition*, 26: 1055-1063. https://doi.org/10.1081/PLN-120020075.

Goulart, A.C.P. and de Assis Paiva, F. 2000. Avaliação de perdas no rendimento de grãos de trigo causadas por Pyricularia grisea, no período de 1988 a 1992 em Mato Grosso do Sul (No. 7). Embrapa Agropecuária Oeste. *Summa Phytopathologica*, 26: 279-282.

Guntzer, F., Keller, C. and Meunier, J.D. 2012. Benefits of plant silicon for crops: a review. *Agronomy for sustainable development*, 32: 201-213. https://doi.org/10.1007/s13593-011-0039-8.

Hanan, M.S., 1996. Studies on silicon in some Egyptian soils (Doctoral dissertation), Cairo University Egypt.

Huber, D.M. and Haneklaus, S. 2007. Managing nutrition to control plant disease. *Landbauforschung Volkenrode*, 57: 313-322.

Igarashi S., Utiamada C.M., Kasuma A.H. and López R.S. 1986. *Pyricularia* sp em trigo. 1. Ocurrencia de *Pyricularia* sp no Estado do Paraná. *Fitopatología Brasilera*, 11: 351–352.

Igrejas, G. and Branlard, G. 2020. The Importance of Wheat. In: Igrejas, G., Ikeda, T., Guzmán, C. (Eds) Wheat Quality for Improving Processing and Human Health. Springer, Cham. https://doi.org/10.1007/978-3-030-34163-3_1

Islam, A. and Saha, R.C. 1969. Effects of silicon on the chemical composition of rice plants. Plant and soil, 30: 446-458.

Jinger, D., Dhar, S., Vijayakumar, S., Pande, V., Kakade, V., Jat, R. and Dinesh, D. 2020. Silicon nutrition. *Indian Farming*, 70: 18-21.

Kohli, M.M., Mehta, Y.R., Guzman, E., Viedma, L.D. and Cubilla, L.E. 2011. Pyricularia blast-a threat to wheat cultivation. *Czech Journal of Genetics and Plant Breeding,* 47: 130-134.

Kumar, S.P., Dalal, V., Singh, N.K. and Sharma, T.R. 2007. Cloning and in silico mapping of resistance gene analogues isolated from rice lines containing known genes for blast resistance. *Journal of phytopathology*, 155: 273-280.

Liang, Y., Shen, Q., Shen, Z. and Ma, T. 1996. Effects of silicon on salinity tolerance of two barley cultivars. *Journal of Plant Nutrition*, 19: 173-183. https://doi.org/10.1080/01904169609365115.

Ligaba-Osena, A., Guo, W., Choi, S.C., Limmer, M.A., Seyfferth, A.L. and Hankoua, B.B. 2020. Silicon enhances biomass and grain yield in an ancient crop tef [Eragrostis tef (Zucc.) Trotter]. *Frontiers in Plant Science*, 11: 608503. https://doi.org/10.3389/fpls.2020.608503.

Ma, J.F. and Takahashi, E. 2002. Soil, fertilizer, and plant silicon research in Japan. Elsevier. Amsterdam. pp. 1-270.

Ma, J., Nishimura, K. and Takahashi, E. 1989. Effect of silicon on the growth of rice plant at different growth stages. *Soil Science and Plant Nutrition*, 35: 347-356. https://doi.org/10.1080/00380768.1989.10434768.

Malaker, P.K., Barma, N.C., Tiwari, T.P., Collis, W.J., Duveiller, E., Singh, P.K., Joshi, A.K., Singh, R.P., Braun, H.J., Peterson, G.L. and Pedley, K.F. 2016. First report of wheat blast caused by *Magnaporthe oryzae* pathotype triticum in Bangladesh. Plant Disease, 100: 2330-2330. https://doi.org/10.1094/PDIS-05-16-0666-PDN.

Marschner, H. 2012. Mineral Nutrition of Higher Plants. 3rd ed., *Academic Press,* San Diego, CA, USA, pp. 257-261.

Marschner, H., and Rimmington, G. 1988. Mineral nutrition of higher plants. *Plant Cell Environment*, 11: 147-148.

Mauad, M., Crusciol, C.A.C., Grassi Filho, H. and Corrêa, J.C. 2003. Nitrogen and silicon fertilization of upland rice. *Scientia Agricola*, 60: 761-765.

Mecfel, J., Hinke, S., Goedel, W.A., Marx, G., Fehlhaber, R., Bäucker, E. and Wienhaus, O. 2007. Effect of silicon fertilizers on silicon accumulation in wheat. *Journal of Plant Nutrition and Soil Science*, 170: 769-772. https://doi.org/10.1002/jpln.200625038.

Neu, S., Schaller, J. and Dudel, E.G. 2017. Silicon availability modifies nutrient use efficiency and content, C: N: P stoichiometry, and productivity of winter wheat (*Triticum aestivum* L.). *Scientific Reports*, 7: 40829. https://doi.org/10.1038/srep40829.

Ning, D., Song, A., Fan, F., Li, Z. and Liang, Y. 2014. Effects of slag-based silicon fertilizer on rice growth and brown-spot resistance. *Plos one*, 9: e102681. https://doi.org/10.1371/journal.pone.0102681.

Nolla, A., Korndörfer, G.H., Da Silva, C.A.T., Da Silva, T.R.B., Zucarelli, V. and Da Silva, M.A. 2013. Correcting soil acidity with the use of slags. *African Journal of Agricultural Research*, 8: 5174-80. https://doi.org/10.5897/AJAR2013.6940.

Pagani, A.P.S., Dianese, A.C. and Café-Filho, A.C. 2014. Management of wheat blast with synthetic fungicides, partial resistance and silicate and phosphite minerals. *Phytoparasitica*, 42: 609-617. https://doi.org/10.1007/s12600-014-0401-x.

Page, A.L., Miller, R.H., and Keeny, D.R. 1982. Methods of Soil Analysis. Part-2: Chemical and Microbiological Properties. 2nd Edn. *American Society of Agronomy*. Inc. Madison, Wisconsin, USA, pp. 252-255.

Pati, S., Pal, B., Badole, S., Hazra, G.C. and Mandal, B. 2016. Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. *Communications in soil science and plant analysis*, 47: 284-290. http://dx.doi.org/10.1080/00103624.2015.1122797.

Perello, A.E., Martinez, I. and Molina, M.D.C. 2015. First report of virulence and effects of *Magnaporthe oryzae* isolates causing wheat blast in Argentina. *Plant Disease*, 99: 904-1042. http://dx.doi.org/10.1094/PDIS-11-14-1182-PDN.

Pazdiora, P.C. 2019. Silício, resistência parcial e fungicida no manejo da giberela do trigo (Silicon, partial resistance and fungicide on fusarium head blight wheat management) (Thesis). Pelotas: Federal University of Pelotas. pp. 1-76.

Prabhu, A.S., Filippi, M.C. and Castro, N. 1992. Pathogenic variation among isolates of *Pyricularia oryzae* affecting rice, wheat, and grasses in Brazil. *International Journal of Pest Management*, 38: 367-371. https://doi.org/10.1080/09670879209371729.

Rahman, A., Wallis, C.M. and Uddin, W. 2015. Silicon-induced systemic defense responses in perennial ryegrass against infection by *Magnaporthe oryzae*. Phytopathology, 105: 748-757. http://dx.doi.org/10.1094/PHYTO-12-14-0378-R.

Ramathani, I., Biruma, M., Martin, T., Dixelius, C. and Okori, P. 2011. Disease severity, incidence and races of Setosphaeria turcica on sorghum in Uganda. *European Journal of Plant Pathology*, 131: 383-392, https://doi.org/10.1007/s10658-011-9815-1.

Rémus-Borel, W., Menzies, J.G. and Bélanger, R.R. 2005. Silicon induces antifungal compounds in powdery mildew-infected wheat. Physiological and molecular plant pathology, 66: 108-115. https://doi.org/10.1016/j.pmpp.2005.05.006.

Roy, K.K., Reza, M.M.A., Muzahid-E-Rahman, M., Anwar, M.B., Kabir, M.R., Malaker, P.K. and Singh, P.K. 2021. Evaluation of elite bread wheat lines for resistance to blast disease in Bangladesh. *Euphytica*, 217: 151. https://doi.org/10.1007/s10681-021-02883-z.

Santos, G.R.D., Castro Neto, M.D.D., Ramos, L.N., Sarmento, R.A., Korndörfer, G.H. and Ignácio, M. 2011. Effect of silicon sources on rice diseases and yield in the State of Tocantins, Brazil. *Acta Scientiarum. Agronomy*, 33: 451-456. https://doi.org/10.4025/actasciagron.v33i3.6573.

Sarker, M.Z.I., Uddin, M.K., Kashem, M.A., Rahman, M.A., Ahmed, I. and Mohiuddin, K.M. 2022. Effects of soil amendments using potassium in elevating resistance against wheat blast disease. *Journal of Bangladesh Agricultural University,* 20: 225–237. https://doi.org/10.5455/JBAU.42442.

Sarto, M.V.M., do Carmo Lana, M., Rampim, L., Rosset, J.S. and Wobeto, J.R. 2015. Effects of silicate application on soil fertility and wheat yield. *Semina: Ciências Agrárias*, 36: 4071-4082. https://doi.org/10.5433/1679-0359.2015v36n6Supl2p4071.

Sathe, A.P., Kumar, A., Mandlik, R., Raturi, G., Yadav, H., Kumar, N., Shivaraj, S.M., Jaswal, R., Kapoor, R., Gupta, S.K. and Sharma, T.R. 2021. Role of silicon in elevating resistance against sheath blight and blast diseases in rice (*Oryza sativa* L.). *Plant Physiology and Biochemistry*, 166: 128-139. https://doi.org/10.1016/j.plaphy.2021.05.045.

Seebold, K.W., Datnoff, L.E., Correa-Victoria, F.J., Kucharek, T.A. and Snyder, G.H. 2000. Effect of silicon rate and host resistance on blast, scald, and yield of upland rice. *Plant Disease*, 84: 871-876. https://doi.org/10.1094/pdis.2000.84.8.871.

Shewry, P.R. and Hey, S.J. 2015. The contribution of wheat to human diet and health. *Food and energy security*, 4(3): 178-202. https://doi.org/10.1002/fes3.64.

Silva, I.T., Rodrigues, F.Á., Oliveira, J.R., Pereira, S.C., Andrade, C.C.L., Silveira, P.R. and Conceição, M.M. 2010. Wheat resistance to bacterial leaf streak mediated by silicon. *Journal of Phytopathology*, 158: 253-262. https://doi.org/10.1111/j.1439-0434.2009.01610.x.

Singh, D., Chonkar, P.K. and Pandey, R.N. 1999. Soil Plant Water Analysis: A Method Mannual. IARI, New Delhi, India. pp. 72-86.

Tadesse, W., Halila, H., Jamal, M., El-Hanafi, S., Assefa, S., Oweis, T. and Baum, M. 2017. Role of sustainable wheat production to ensure food security in the CWANA region. *Journal of Experimental Biology and Agricultural Sciences,* 5: S15-S32. https://doi.org/10.18006/2017.5(Spl-1-SAFSAW).S15.S32.

Tandon, H.L.S. 1995. Methods of Analysis of Soils, Plant, Water and Fertilizers. Fertilizers Development and Consultation Organisation. New Delhi. pp. 44-45

Ueno, M., Kihara, J., Honda, Y. and Arase, S. 2004. Indole-related compounds induce the resistance to rice blast fungus, *Magnaporthe grisea* in barley. *Journal of Phytopathology*, 152: 606-612. https://doi.org/10.1111/j.1439-0434.2004.00903.x.

Wang Lei, W.L., Chen YuTing, C.Y., Cai KunZheng, C.K. and Wang GuoPing, W.G. 2014. Effects of exogenous silicon supply on the activity of antioxidant enzymes of tomato leaves infected by *Ralstonia solanacearum*. *Journal of South China Agricultural University*, 35: 74–78.

Zhang, G., Cui, Y., Ding, X. and Dai, Q. 2013. Stimulation of phenolic metabolism by silicon contributes to rice resistance to sheath blight. Journal of plant nutrition and soil science, 176: 118-124. https://doi.org/10.1002/jpln.201200008.