Indonesian Journal of Agricultural Science
Vol. 21 No. 2 December 2020: 49–58
DOI: http//dx.doi.org/10.21082/ijas.v.21.n2.2020.p.49–58

INCREASING YIELD OF SUSCEPTIBLE AND RESISTANT RICE BLAST CULTIVARS USING SILICON FERTILIZATION

Peningkatan Hasil Kultivar Padi Rentan dan Tahan Penyakit Blas Menggunakan Pemupukan Silikon

NurulNahar Esa[*a], Adam Puteh[a], Mazidah Mat[b], Roslan Ismail[c], and Mohd Rafii Yusop[d]

[a]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia*
43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[b]*Industrial Crop Research Centre, MARDI Headquarters*
Serdang, PO Box 12301, 50774 Kuala Lumpur, Malaysia
[c]*Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia*
43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[d]*Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia*
43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

[*]*Corresponding author: naharesa@mardi.gov.my*

Submitted 20 March 2020; Revised 6 June 2020; Accepted 20 August 2020

ABSTRACT

Rice blast is one of the most critical limiting factors for rice plant growth performance. Silicon has been shown to have positive effects in controlling several plant diseases. The study aimed to investigate the impact of silicon levels on rice yield, silicon content, and panicle blast in rice plants. The study was set up as a 2 x 5 factorial experiment with three replications and arranged in a randomized complete block design. The first factors were two rice cultivars, MARDI Siraj 297 (resistant) and MR 263 (susceptible). The second factors were five levels of calcium silicate (0 g, 4 g, 8 g, 12 g, and 16 g) applied to 40 kg soil per pot. The standard fertilizers, i.e., N, P_2O_5, and K_2O, were applied four times at the recommended dosage. High virulent of *Pyricularia oryzae* conidia (4 x 10^4 conidia ml^{-1}) was sprayed using a hand sprayer (30 ml pot^{-1}) at the time of fully completed panicle development (65 days after planting). Observed parameters were plant growth (height and culm length), yields (spikelets per panicle, grain filling percentage, and harvest index), panicle blast severity, and silica content in leaf, stem, and panicle. The results showed that silicon application reduced panicle blast severity, leading to higher yield per plant. The increase of the rice yield was a result of a significant increae in panicle per m^2, spikelet per m^2, and percentage of filled grain. Panicle blast greatly affected the performance of spikelet number per m^2, percentage of filled grain, grain weight, and yield per plant for the susceptible cultivar. Application of calcium silicate 10 g 40 kg^{-1} soil per pot at panicle initiation is recommended to reduce panicle blast severity hereby improve grain yield.

[**Keywords**: Calcium silicate, plant growth, *Pyricularia oryzae*, rice]

ABSTRAK

Penyakit blas merupakan salah satu faktor pembatas paling kritis bagi performans tanaman padi. Silikon (Si) telah terbukti memiliki efek positif dalam mengendalikan beberapa penyakit tanaman. Penelitian ini bertujuan untuk mengetahui pengaruh takaran silikon terhadap hasil padi, kadar silikon, dan penyakit blas pada tanaman padi. Percobaan dilakukan menggunakan rancangan acak kelompok berpola faktorial 2 x 5 dengan tiga ulangan. Faktor utama ialah dua kultivar padi, MARDI Siraj 297 (tahan) dan MR 263 (rentan), sedangkan faktor kedua adalah lima level kalsium silikat (0 g, 4 g, 8 g, 12 g, dan 16 g) yang diberikan pada 40 kg tanah per pot. Pupuk dasar menggunakan N, P_2O_5, dan K_2O, diberikan empat kali pada dosis yang dianjurkan. Konidia Pyricularia oryzae *yang sangat virulen (4 x 10^4 konidia ml^{-1}) disemprotkan menggunakan semprotan tangan sebanyak 30 ml per pot pada saat malai berkembang sempurna (65 hari setelah tanam). Parameter yang diamati yaitu pertumbuhan tanaman (tinggi tanaman dan panjang batang), hasil (spikelet per malai, persentase pengisian gabah, dan indeks panen), keparahan penyakit blas pada malai, dan kandungan silika dalam daun, batang, dan malai. Hasil penelitian menunjukkan bahwa aplikasi silikon meningkatkan hasil gabah per tanaman dan mengurangi keparahan penyakit blas pada malai. Peningkatan hasil gabah terjadi karena meningkatnya jumlah malai per m^2, spikelet per m^2, dan persentase gabah isi. Penyakit blas pada malai sangat memengaruhi jumlah spikelet per m^2, persentase gabah isi, bobot 1.000 gabah, dan hasil per tanaman pada kultivar rentan. Aplikasi kalsium silikat pada dosis 10 g 40 kg^{-1} tanah per pot pada stadia awal pembentukan malai direkomendasikan untuk menekan blas leher dan meningkatkan hasil gabah.*

[**Kata kunci**: *Kalsium silikat, pertumbuhan tanaman,* Pyricularia oryzae, padi]

INTRODUCTION

Rice (*Oryza sativa*) is a staple food and an important food security crop in most Asian countries. One of the main concerns of the rice industry is the yield losses due to disease. Blast disease caused by *Magnaporthe grisea* or also known as *Pyricularia oryzae* is considered a significant rice disease in rice cultivation. Rice blast is a widely distributed pathogen of rice, could be found in any rice field. According to Fisher et al. (2012), rice blast disease occurs in 85 countries and causes 10–35% grain yield losses.

The origin of *M. grisea* has been found in the foothills of the Himalayas (South China–Laos–North Thailand) and Western Nepal which, presumed the center of all *M. grisea* populations on rice and most migrations to other continents were from this region (Saleh et al. 2014). Grain yield losses could achieve as much as 50% once infected by rice blast in Malaysia (Saad et al. 2004) and 50–70% in the Philippines (Durgeshlal et al. 2019; Gianessi 2014). In Indonesia, about 12% of the total area of rice cultivation was infected by rice blast (Suryadi et al. 2013).

The most effective and economical approach for controlling the blast disease in rice is the use of resistant cultivars. Nonetheless, the use of such cultivars has a limited effect due to the breakdown of resistance genes with increasing blast breeds overcoming rice resistance (Fukuta et al. 2014).

In addition to the cultivar-specific resistance breeding, chemical control is the most widely used method and effective plant disease management. Although they are effective in controlling the fungal infections in rice, public concerns about the use of synthetic fungicides are growing (Law et al. 2017).

Silicon (Si) has been reported to increase the growth and yield of a broad range of crops and beneficial in controlling diseases caused by both fungi and bacteria in different plant species. Silocon is the second most abundant element after oxygen in the earth's crust (Heckman 2012), and silicon dioxide forms about 60% of the earth's crust, and it occupies more than 50% of the soil (Marschner 1995). Silicon has not yet been considered essential (Liang et al. 2015). Since most plants could be grown without Si, many plant physiologists have found this element was unessential (Epstein 1999). Silicon application increased grain yield and also improved crop yield (Cuong et al. 2017).

Furthermore, Si deposition in plant tissues could enhance tolerance of rice plants to biotic and abiotic stresses (Dai et al. 2005; Etesami and Jeong 2018; Pati et al. 2016). Further, Si increased rice resistance to leaf and neck blast, sheath blight, brown spot, leaf scald, and stem rot (Datnoff et al. 1997). The deposition of Si in the epidermis of rice leaves is a part of plant defense system that acts as a physical barrier that efficiently increases rice resistance to rice blast (Rodrigues et al. 2015).

Panicle blast causes direct yield losses because infected panicles are poorly filled with grains. Panicle blast is the most extreme blast disease than leaf blast because it happens late in the season when the farmer has spent all of his crop production inputs (Bastiaans et al. 1994). Application of nutrients at panicle initiation significantly increased filled grains, 1000-grain weight, and total grain yield (Bah et al. 2009). Moreover, fertilizer application at panicle initiation is well known to increase flower number per panicle, which is one of the essential traits in rice productivity determination (Ding et al. 2014). Despite numerous studies on the role of Si, the question remains does Si contribute to disease defense and consequently improve plant growth and yield. Therefore, in this study, calcium silicate was tested on resistant and susceptible to panicle blast rice cultivars and applied at panicle initiation phase. The objective of this study was to investigate the effect of Si levels on rice yield, Si content and panicle blast.

MATERIALS AND METHODS

Plant Materials, Treatment Structure, and Experimental Design

Two rice cultivars, MARDI Siraj 297 (blast resistant) and MR 263 (blast susceptible) were used in this study. The characteristics of these two cultivars are given in Table 1. The seeds were sown in the seedling trays, which was preceded by seed soaking treatment and pre-germination. Soaking was done for 24 hours, while pre-germination took one day before sowing. Seedlings were later transplanted into plastic containers after 14 days. The seedlings that were of the same height were selected for uniformity purposes.

The factorial experiment of 2 x 5 was arranged in a randomized complete block design and replicated three times. Two cultivars (MARDI Siraj 297 and MR 263) were the first factor and five levels of Si (0, 4, 8, 12, and 16 g per pot) as the second factor. Calcium silicates were used as the source of silicon.

Table 1. MARDI Siraj 297 and MR 263 agronomic characteristic and their resistance to rice blast.

Characteristic	MARDI Siraj 297	MR 263
Maturity period (day)	110–115	105–110
Culm length (cm)	64.4–70.0	63.0–70.0
Panicle length (cm)	21.0–27.0	21.5–24.6
Panicles per m^2	523	421
Filled grain (%)	77.1–86.2	59.8–66.6
Spikelet per panicle	86–106	104–136
1000-grain weight (g)	27.8–29.2	24.9–25.1
Resistance		
Foliar blast	Resistant	Susceptible
Panicle blast	Resistant	Susceptible

The experiment was carried out for two planting cycles. Plastic pot (60 cm x 40 cm x 30 cm) was filled with 40 kg of soil. The soil used was collected from Sawah Sempadan, Tanjung Karang, Selangor. Generally, the soil pH was slightly acidic and the soil texture was clay loam. Three seedlings of rice cultivar were planted per hill. Each pot contained four hills. Two weeks after sowing, pots were flooded, and a 2.5 cm standing water was maintained until 2–3 weeks before harvest. All crop management followed the guidelines of the *Manual Teknologi Penanaman Padi Lestari* (Othman et al. 2008). The first fertilization was applied seven days after seedling transplanting with 23.8 kg N, 28 kg P_2O_5 and 14 kg K_2O ha^{-1}. The second application of the fertilizers was made three weeks after planting with 36.80 kg N ha^{-1}, followed with another fertilizer application at 45 days after planting with 34 kg N, 23 kg P_2O_5, and 35 kg K_2O ha^{-1}. The fourth fertilization was administered at 65 days after transplanting with 8.5 kg N, 1.5 kg P_2O_5, and 12.5 kg K_2O ha^{-1}. The silicon was applied at 45 days after planting (panicle initiation phase).

Blast Inoculation

A highly virulent strain of *P. oryzae* (rice blast fungus) was used. The inoculum was obtained from MARDI Research Station in Seberang Perai, Pulau Pinang. Harvesting of conidia followed procedures as described by Hayashi et al. (2009). A total of 20 ml of distilled water was poured into a Petri dish, while the surface of sporulated plates was gently scraped with a paintbrush. The conidial suspension was filtered through a cheesecloth. Later, the spores were counted using a hemocytometer. One drop of spore suspension was placed on the hemocytometer and coverslip was put on to expel some contents. The spores were counted in one mm square. The volume in one meter square is approximately 10-4 ml. Therefore, if there are 10 spores per mm square, then the spore count is 10 x 10^4, which is equal to 10^5 or equivalent to 100,000 spores ml^{-1}.

Conidial concentration was adjusted to 105 (100,000) conidia per milliliter. The conidia concentration was then added with 0.01% Tween 20 to aid the adhesion of the conidia to the plant. Inoculation was done at the time of fully completed panicle development (65 days after planting). A conidial suspension of *P. oryzae* (4 x 104 conidia ml^{-1}) was used. This suspension was applied as a fine mist to the whole panicle with a hand sprayer. Individual pots received 30 ml of the adjusted spore solution.

Sampling and Measurements

Yield and Yield Components

The rice plant height was measured from soil surface level to tip of the tallest plant using a standard scale meter by gently grab all plants in the hill with one hand. The plants were carefully raised to determine the hills' highest plant using a meter stick from the ground level to the most top hill plant. A total of four plants were measured. Culm length was measured from the tallest plant in the hill and from the soil surface to the neck node (panicle base node). Panicles were hand-threshed, and filled spikelets were separated from unfilled spikelets. The total number of filled and empty spikelets were added to determine the entire spikelets per panicle. A 1000-grain weight was determined from well-developed whole grains (filled spikelets), which was dried to 14% moisture content and weighed on a precision balance (ME3002, Mettler Toledo). Grain moisture content was measured with a digital moisture tester meter (Model SS-7, Satake). Spikelets per panicle, grain filling percentage (100 x filled spikelets m^{-2}/total spikelets m^{-2}), and harvest index (100 x yield/ total dry weight) were calculated.

Panicle Blast Severity

Panicle blast severity was calculated based on the Standard Evaluation System for Rice (IRRI 2013). The symptoms of panicle blast are dark, necrotic lesions partially or wholly around the panicle base (node) or the uppermost internode or the lower part of the panicle axis. The panicles were greyish and had either partially filled or unfilled grains. The severity was recorded at 20–25 days after heading.

Determination of Silicon Content

The determination of Si contents followed Dai et al. (2005). Silicon standard solution (SiO_2 in NaOH 0.5 mol l^{-1}, 1000 mg l^{-1} Si, Merck) at 0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 ml were transferred into a 50 ml volumetric flask, respectively. Then, 30 ml of 20% acetic acid and 10 ml ammonium molybdate solution (54 g l^{-1}, pH 7.0) were added to each of the volumetric flasks and were shaken up to mix thoroughly. The solution was kept for 5 minutes and followed by adding 5 ml of 20% tartaric acid and 1 ml reducing solution. Solutions were then adjusted to 50 ml with 20% acetic acid. After 30 minutes, the absorbance was measured at 650 nm using Cary 60 UV-Vis (Agilent Technologies).

The reducing solution was made by mixing two solutions, i.e., solution A (2 g of Na_2SO_3 and 0.4 g 1-amino-2-naphthol-4-sulfonic acid in 25 ml ddH_2O) and solution B (25 g $NaHSO_3$ in 200 ml ddH_2O). Reducing solution was prepared within 24 hours of preparing a standard curve and samples determination. Reducing solutions were kept in a tightly stoppered plastic bottle in the dark.

Bulk samples of leaf, stem, and panicle from each treatment were ground and sifted through a 60-mesh sieve. A total of 0.1 g samples was weighed with precision balance and transferred into a 100 ml polyethylene tube. Each tube was added 3 ml of 50% NaOH and covered with loose-fitting plastic cap, gently vortex, then autoclave at 121°C for 20 minutes (Autoclave HVE-50, Hirayama Manufacturing Corp.). A total of 1 ml sample solution was transferred into a 50 ml volumetric flask. A total of 30 ml 20% acetic acid and 10 ml ammonium molybdate solution (54 g l^{-1}, pH 7.0) were added to each volumetric flask and shaken up to mix thoroughly. The solution was kept for 5 minutes and followed by adding 5 ml 20% tartaric acid and 1 ml reducing solution. Solutions were then adjusted to 50 ml, with 20% acetic acid. After 30 minutes, the absorbance was measured at 650 nm using Cary 60 UV-Vis (Agilent Technologies).

Data Analysis

Analysis of variance (ANOVA) was performed using Statistical Analysis Software (SAS 9.3). The combined experiments data were analyzed based on Moore and Dixon (2015), which planting cycles as a random effect, Si treatment and cultivar as a fixed effect. Treatment means were compared based on the Least Significant Difference test at $p \leq 0.05$ probability level. Significant Si treatments were then followed the procedures of orthogonal polynomials contrast using SAS 9.3.

RESULTS

Plant Growth, Yield Components, and Yield

Silicon application had a significant effect on plant height (Table 2). Although small differences occurred in the mean plant height, it increased significantly under rising Si rates from 0 to 12 g per pot but remained stable under a further increase in Si rates. The highest value of plant height was observed at 12 g Si (96 cm). However, there was no significant difference in plant height between 12 g Si and 16 g Si per pot. No difference in plant height was found between cultivars (Table 2). Silicon rates at 12 g and 16 g per pot significantly increased the culm length compared to control (0 g). However, the application of 12 g Si per pot resulted in maximum culm length (69 cm), which is also statistically at par with 16 g Si (68 cm). There were no differences observed between cultivars in culm length (Table 2). Statistical analysis showed that cultivar and Si rates did not affect spikelets per panicle

Table 2. Plant height and culm length of MARDI Siraj 297 and MR 263 rice cultivars as influenced by silicon rates.

Parameter	Plant height (cm)	Culm length (cm)	Spikelets per panicle
Cultivar			
MR 263	91.7a	64.5a	198a
MARDI Siraj 297	96.6a	69.1a	191a
Silicon rate (g pot^{-1})			
0	92.9c	65.8c	185a
4	93.6bc	66.3bc	193a
8	92.7c	65.2c	194a
12	96.0a	68.7a	195a
16	95.3ab	67.9ab	203a
Interaction	ns	ns	ns

The effect of Si rates on the panicle number per m^2 was significant. Cultivars did not affect panicle number per m^2 (Figure 1). All the Si rates tested, i.e., 4 g, 8 g, 12 g, and 16 g pot^{-1} were not significantly different in increasing panicle number per m^2 (193–203 panicles per m^2), but it was significantly different from the control treatment (179 panicles per m^2). The result also showed that the effect of Si rates was not significant on spikelet number per m^2. Also, the impact of the cultivars was not significant on the spikelet number per m^2. The mean number of spikelets per m^2 increased steadily from 33,358 to 45,352 (36%) in response to the increased Si rates from 0 to 8 g pot^{-1}. Further Si rate increases did not promote a higher number of spikelets per m^2 (Figure 2).

The percentage of filled grain under the influence of the Si rate showed significant differences between cultivars. The percentage of filled grain (Figure 3) was remarkably higher in MARDI Siraj 297 (79%) than that in MR 263 (59%). Si rate significantly increased the percentage of filled grain. The filled grain increased by 17% and 22% from 0 to 4 g Si pot^{-1} and from 0 to 8 g Si pot^{-1}, respectively. However, no significant differences were observed between 4 and 8 g Si pot^{-1}. Besides, the highest percentage of filled grain was produced with 16 g Si pot^{-1} (75% filled grain) but did not differ with 8 and 12 g Si pot^{-1} (Figure 4).

There was a significant main effect of cultivar on 1000-grain weight. Silicon rate did not affect the

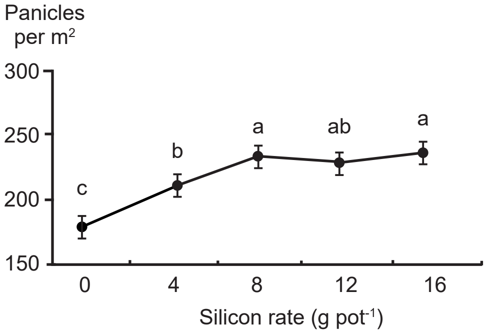

Fig. 1. Number of rice panicles per m² as a function of increasing silicon rate.

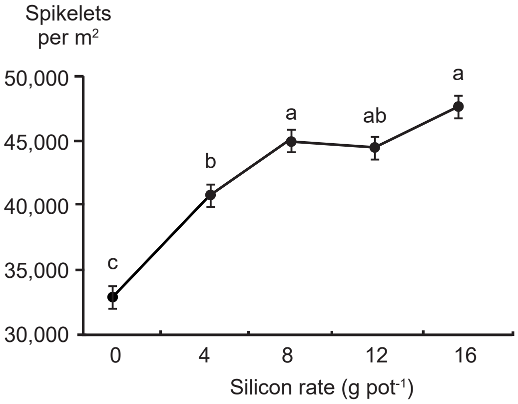

Fig. 2. Number of rice spikelets per m² as a function of increasing silicon rate.

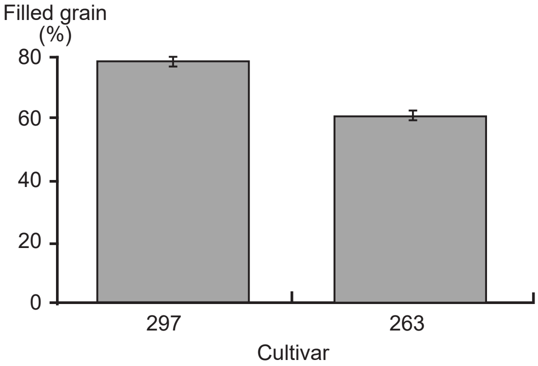

Fig. 3. Rice filled grain (%) comparison between MARDI Siraj 297 and MR 263 cultivars.

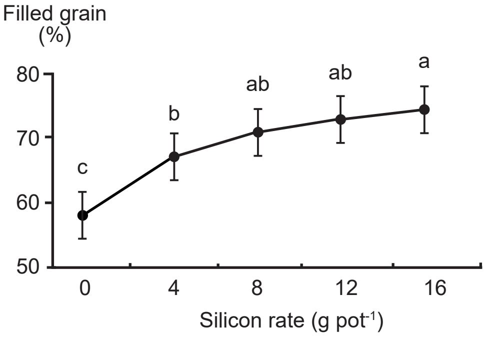

Fig. 4. Rice filled grain as a function of increasing silicon rate.

1000-grain weight. The superior rice variety of MARDI Siraj 297 (27.1%) exhibited a higher 1000-grain weight than in MR 263 (22.2%) by 22% (Figure 5).

There were significant effects of cultivar and Si rate on grain yield per plant. The grain yield per plant (Figure 6) of MARDI Siraj 297 (4.2 g) was higher by 50% than that of MR 263 (2.8 g). The Si rate was significant and fit to quadratic regression. Yield per plant for both cultivars follows the quadratic equation of, $y = -0.01x^2 + 0.17x + 3.01$ ($R^2 = 0.97$). Thus, the Si rate that could maximize the yield was 10 g pot^{-1} (Figure 7).

Silica Content in Leaf, Stem, and Panicle

There were significant main effects of cultivar and Si rates on Si content in leaves. Silica content was significantly higher by 7.5% in MR 263 (35.8 g kg^{-1}) than that in MARDI Siraj 297 (33.1 g kg^{-1}) (Figure 8). On the other hand, there was a significant effect of Si rate on Si content in the stem but did not affect by cultivars. The increased Si rate from 0 to 12 g per pot showed an increase in Si content in leaves and stems (Figure 9 and 10). There was no significant effect of cultivar and Si rates on Si content in a panicle. The average Si content in the rice panicle was 33.4 g kg^{-1}.

Panicle Blast Severity

There was a significant interaction between cultivar and Si rates on panicle blast severity. MARDI Siraj 297 had no panicle blast symptoms as compared to MR 263. Thus, only MR 263 is discussed. Regression analysis on panicle blast severity on MR 263 showed a significant linear function of $y = -2.09x + 83.44$ ($R^2 = 0.96$). Silicon rate showed that the panicle blast severity decreased as the Si rates level increased. The panicle blast severity in MR 263 decreased by 39% from 0 to16 g Si per pot (Figure 11).

Correlation Analysis

Correlations analysis between panicle blast severity and yield components are presented in Table 3 and Figure 11. Generally, the panicle blast severity appears to be

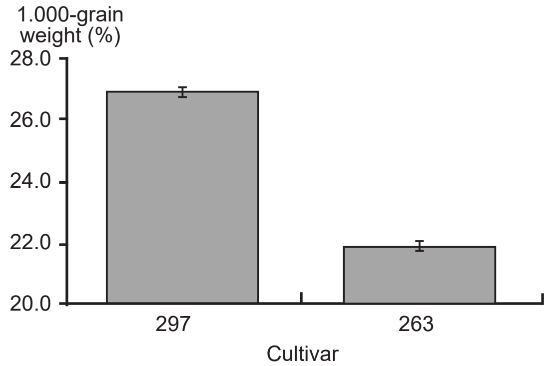

Fig. 5. One-thousand-grain weight comparison between MARDI Siraj 297 and MR 263 rice cultivars.

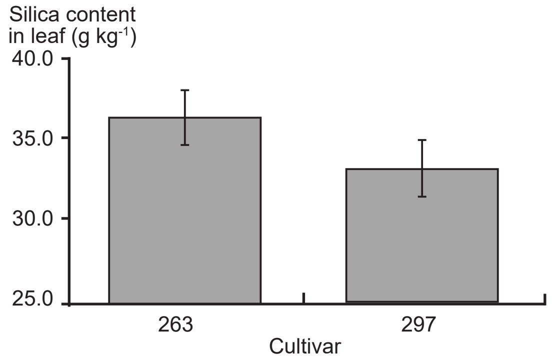

Fig. 8. Silica content in leaves of MR 263 and MARDI Siraj 297 rice cultivars.

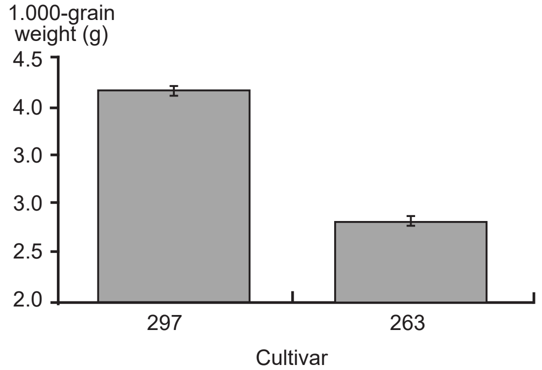

Fig. 6. Rice yield comparison between MARDI Siraj 297 and MR 263 cultivars.

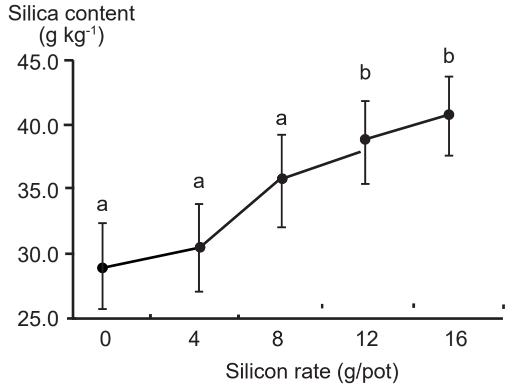

Fig. 9. Silica content in rice leaves as a function of silicon rates.

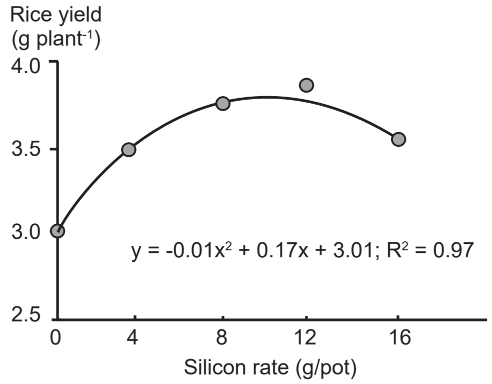

Fig. 7. Rice yield as a function of silicon rates.

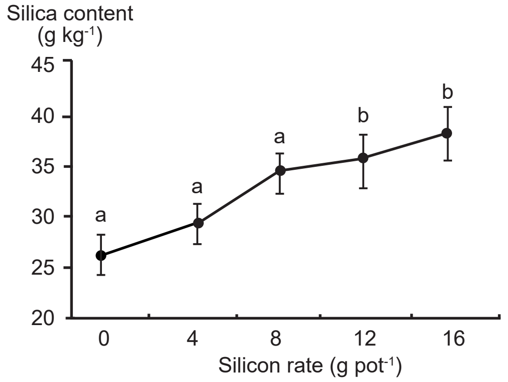

Fig. 10. Silica content in rice stems as a function of silicon rates.

Table 3. Correlation matrix of various observed parameters.

Variable	1	2	3	4	5	6
Panicle blast severity	-					
Harvest index	-0.739**	-				
Spikelets per panicle	0.108^{ns}	-0.014^{ns}	-			
Filled grain (%)	-0.763**	0.695**	0.027^{ns}	-		
1000-grain weight (g)	-0.862**	0.726**	-0.227^{ns}	0.722**	-	
Yield per plant	-0.829**	0.791**	-0.021^{ns}	0.815**	0.827**	-

Note: ** significant at <0.0001, ns = not significant

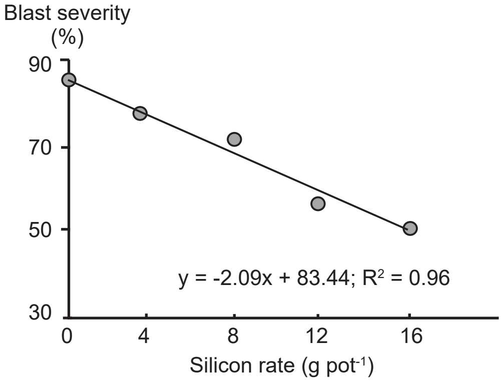

Fig 11. Panicle blast disease severity in MR 263 as a function of silicon rates.

associated with low harvest index, fewer filled grain (%), reduced 1000-grain weight (g), and lower yield per plant.

DISCUSSION

A significant increase in plant height and culm length of rice plants treated with Si is in line with Salman et al. (2012). A significant improvement could be due to changes in internode length that contributed to changes in rice plant height (Zhang et al. 2017). Plant height is a primary agronomic function of rice that directly affects crop yield, which the dwarf phenotype is useful to solve the rice lodging problem. If the plants are short, it will result in weak growth and ultimately affect the rice yield (Zhang et al. 2017) we identified the novel MYB-like transcription factor OsMPH1 (MYB-like gene of plant height 1. The taller plant possesses a higher ability to compete with weed or trap solar radiation during the growth period. The disadvantages of the taller plant is an undesirable trait in rice cultivation as it is more prone to lodging and less responsive to nitrogen (Yoshida 1981).

Silicon application would show a little effect at the vegetative stage unless it was added during the reproductive phase (Ma et al. 1989). Kim et al. (2012) reported that Si application at panicle initiation significantly increased panicle number as compared to early use. Thus, in this study Si application at panicle initiation did increase panicle number per m^2. In line with Kim et al. (2012) and Mauad et al. (2003), we performed two experiments. Spikelet number increased in the conditions of temperature drops from 31°C to 25°C (Yoshida 1973), while spikelet fertility declined as the temperature increases from 29.6°C to 36.2°C (Jagadish et al. 2007). Greater heat tolerance at anthesis will be required in rice. The effect of high temperature at anthesis on spikelet fertility was studied on IR64 (lowland indica). Thus, spikelet/panicle number is a characteristic influenced by temperatures rather than Si applications. The spikelet number per m^2 corresponds to the panicle number per m^2 multiplied by spikelet/panicle. The significant increase in spikelet number per m^2 is due to the rise in panicle number per m^2.

Nonstructural carbohydrate (NSC) plays an essential role in grain filling and consequently increased the percentage of filled grain (Arai-Sanoh et al. 2011). NSC accumulation at the final reproductive stage in rice panicle contributes to the grain filling, and higher grain filling suggests that NSC translocation was also higher (Takai et al. 2006) especially in tropical environments. We conducted field experiments in Kyoto, Japan (temperate climate). This could indicate that high source ability (NSC) is the significant contribution of a substantial increase in grain filling (%), and NSC improved in rice plants because of Si application. A 1000-grain weight is a constant characteristic because it is controlled by the size of the hull (Yoshida 1981). Thus, the grain cannot grow more significant than that hull regardless of the optimum weather and nutrient supply to the rice plant. This is in line with the present study that 1000-grain weight was not improved by Si fertilization.

The results in this study suggest that the high filled-grain (%) and 1000-grain weight (g) were the key contributors for higher grain yield per plant in MARDI Siraj 297 compared to MR 263. The higher filled-grain and 1000-grain weight for MARDI Siraj 297 were because of the superior genotype as compared to MR 263. High grain weight genotype has lower total NSC in stem and higher total NSC in panicle at harvest (Samonte et al. 2001). Thus, it could suggest MARDI Siraj 297 have greater NSC in panicle at maturity phase than the MR 263.

The increase in the grain yield could occur by enlarge the sink size (Li et al. 2019) and sink size (yield potential) is determined by spikelet number per unit area and the sink source (NSC accumulation) at grain filling formation (Lubis et al. 2003). Thus, the increase in the sink size (yield per plant) was a result of significant increase in panicles per m^2, spikelets per m^2, and percentage of filled grain. On the other hand, while sink size generally contributes to yield increment, there is inadequate availability due to decline in sink demand to sufficiently increase rice grain yield (Ohsumi et al. 2011). The decline in grain yield at optimum Si rate (10 g per pot) could be due to Si application affected the accumulation of NSC (sink source) in the panicle and consequently affected the spikelet and filled grain development.

The increased Si content in leaves and stems could be due to the increased Si availability in the soil and root system, which could encourage the plant to absorb more Si from the soil (Pati et al. 2016). High Si content in leaves and stems is because rice is known as Si accumulator, a high Si demanding crop (Ma and Takahashi 2002), and rice can absorb Si both actively and passively (Sun et al. 2010). Further, the application of Si fertilizer caused a higher Si content in rice leaves of MR 263 than that in MARDI Siraj 297. The differences between cultivars could be the impact of the accumulation of Si in epidermal cells on partially resistant and susceptible rice varieties treated with Si (Seebold et al. 2000). On the other hand, non-significant Si content in rice panicle is because it is very difficult to be detected (Buck et al. 2008). Silica deposition in plant parts could cause positive effects on plant growth, but it may be relatively small under optimal conditions, which is also difficult to detect (Ma et al. 2001).

Panicle blast severity is greatly affected by the Si rates. However, in this present study, a higher Si rate of more than 10 g per pot decreased the yield per plant. Thus, the optimal rate of Si (10 g per pot) could reduce 24% of panicle blast severity. This result is in line with Santos et al. (2011) that reported panicle blast linearly decreased with the increase of calcium silicate. The reduction of panicle blast disease severity could be due to a thick cuticle layer of 2.5 µm Si serves as a barrier (Yoshida 1981), and this cuticle-Si double-layer prevents penetration by fungi, which helps to prevent infection process (Ma and Yamaji 2008). Besides, Si deposited in the cell walls could physically strengthen the cell wall to prevent the rice blast infection (Sun et al. 2010). Thus, it is believed that a similar mechanism may have occurred in which *P. oryzae* was blocked or at least did not fully gained access into the panicle due to Si deposition and consequently reduce panicle blast severity.

CONCLUSION

Silicon application to the rice plants on both cultivars MARDI Siraj 297 and MR 263 increased the yield per plant. Silicon application on susceptible rice variety reduced panicle blast severity. The increase of the rice yield was a result of a significant increase in panicles per m^2, spikelets per m^2, and filled grain (%). Panicle blast greatly affected spikelet number per m^2, filled grain (%), grain weight (g), and yield per plant for the susceptible cultivar. Calcium silicate at levels of 10 g per 40 kg soil per pot is recommended for application at panicle initiation to reduce panicle blast severity hereby improve grain yield.

ACKNOWLEDGEMENTS

This research was supported by the Malaysian Agricultural Research and Development Institute. We thank Siti Norsuha Misman for assistance with rice blast inoculum preparation and sampling technique for panicle rice blast.

REFERENCES

Arai-Sanoh, Y., Ida, M., Zhao, R., Yoshinaga, S., Takai, T., Ishimaru, T., Maeda, H., Nishitani, K., Terashima, Y., Gau, M., Kato, N., Matsuoka, M., & Kondo, M. (2011) Genotypic variations in non-structural carbohydrate and cell-wall components of the stem in rice, sorghum, and sugar cane. *Bioscience, Biotechnology and Biochemistry.* 75(6), 1104–1112. DOI:10.1271/bbb.110009.

Bah, A., Syed Omar, S. R., Anuar, A. R., & Husni, M. H. A. (2009) Critical time of nitrogen application during panicle initiation on the yield of two Malaysian rice cultivars (*Oryza sativa* l.). *Pertanika Journal of Tropical Agricultural Science.* 32(2), 317–322.

Bastiaans, L., Rabbinge, R., & Zadoks, J. C. (1994) Understanding and modeling leaf blast effects on crop physiology and yield. In: Zeigler, R. S., Leong, S. A., and Teng, P. S. (eds.) *Rice Blast Disease*. Manila: International Rice Research Institute.

Buck, G. B., Korndorfer, G. H., Nolla, A., & Coelho, L. (2008) Potassium silicate as a foliar spray and rice blast control. *Journal of Plant Nutrition.* 31, 231–237. DOI:10.1080/01904160701853704.

Cuong, T. X., Ullah, H., Datta, A., & Hanh, T. C. (2017) Effects of silicon-based fertilizer on growth, yield and nutrient uptake of rice in the tropical zone of Vietnam. *Rice Science.* 24(5), 283–290. DOI:10.1016/j.rsci.2017.06.002.

Dai, W.-M., Zhang, K.-Q., Duan, B.-W., Sun, C.-X., Zheng, K.-L., Cai, R., & Zhuang, J.-Y. (2005) Rapid determination of silicon content in rice. *Rice Science.* 12(2), 145–147.

Datnoff, L. E., Deren, C. W., & Snyder, G. H. (1997) Silicon fertilization for disease management of rice in Florida. *Crop Protection.* 16(6), 525–531. DOI:10.1016/S0261-2194(97)00033-1.

Ding, C., You, J., Chen, L., Wang, S., & Ding, Y. (2014) Nitrogen fertilizer increases spikelet number per panicle by enhancing cytokinin synthesis in rice. *Plant Cell Reports.* 33, 363–371. DOI:10.1007/s00299-013-1536-9.

Durgeshlal, C., Sahroj Khan, M., Prabhat, S. A., & Aaditya Prasad, Y. (2019) Antifungal activity of three different ethanolic extract against isolates from diseased rice plants. *Journal of Analytical Techniques and Research.* 01(01), 47–63. DOI:10.26502/jatri.007.

Epstein, E. (1999) Silicon. *Annual Review of Plant Physiology and Plant Molecular Biology.* 50, 641–664.

Etesami, H., & Jeong, B. R. (2018) Silicon (Si): Review and future prospects on the action mechanisms in alleviating biotic and abiotic stresses in plants. *Ecotoxicology and Environmental Safety.* 147, 881–896. DOI:10.1016/j.ecoenv.2017.09.063.

Fisher, M. C., Henk, D. A., Briggs, C. J., Brownstein, J. S., Madoff, L. C., McCraw, S. L., & Gurr, S. J. (2012) Emerging fungal threats to animal, plant and ecosystem health. *Nature.* 484(7393), 1–18. DOI:10.1038/nature10947.

Fukuta, Y., Koga, I., Ung, T., Sathya, K., Kawasaki-tanaka, A., Koide, Y., & Kobayashi, N. (2014) Pathogenicity of rice blast (*Pyricularia oryzae* Cavara) isolates from Cambodia. Japan Agricultural Research Quarterly 48 (2), 155–166.

Gianessi, L. P. (2014) Importance of pesticides for growing rice in South and Southeast Asia. In: *International Pesticide Benefit Case Study.* Crop Protection research Institute. Washington.

Hayashi, N., Kobayashi, N., Cruz, C. M. V, & Fukuta, Y. (2009) *Protocols for the sampling of diseased specimens and evaluation of blast disease in rice*. JIRCAS Working Report 2009 No.63 pp.17-33 ref.12.

Heckman, J. R. (2012) The soil profile. *The State University of New Jersey*: 12.

IRRI (2013) *Standard Evaluation System for Rice*. 5th Edn. Manila: International Rice Research Institute. DOI:10.1063/1.1522164.

Jagadish, S. V. K., Craufurd, P. Q., & Wheeler, T. R. (2007) High-temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *Journal of Experimental Botany.* 58(7), 1627–1635. DOI:10.1093/jxb/erm003.

Kim, Y. H., Khan, A. L., Shinwari, Z. K., Kim, D. H., Waqas, M., Kamran, M., & Lee, I. J. (2012) Silicon treatment to rice (*Oryza sativa* L. cv. 'Gopumbyeo') plants during different growth periods and its effects on growth and grain yield. *Pakistan Journal of Botany.* 44(3), 891–897.

Law, J. W., Ser, H., Khan, T. M., Chuah, L., Pusparajah, P., Chan, K., Goh, B., Lee, L., & Lee, L. (2017) The potential of streptomyces as biocontrol agents against the rice blast fungus, *Magnaporthe oryzae* (*Pyricularia oryzae*). *Frontiers in Microbiology.* 8(3), 1–10. DOI:10.3389/fmicb.2017.00003.

Li, R., Li, M., Ashraf, U., Liu, S., & Zhang, J. (2019) Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. *Frontiers in Plant Science.* 10(543), 12. DOI:10.3389/fpls.2019.00543.

Liang, Y., Nikolic, M., Belanger, R., Gong, H., & Song, A. (2015) Effect of silicon on crop, growth, yield and quality. In: *Silicon in Agriculture*. London: Springer. DOI:10.1007/978-94-017-9978-2.

Lubis, I., Shiraiwa, T., Ohnishi, M., Horieg, T., Lubis, I., Shiraiwa, T., Ohnishi, M., Horie, T., & Inoue, N. (2003) Contribution of sink and source sizes to yield variation among rice cultivars. *Plant Production Science.* 6(2), 119–125. DOI:10.1626/pps.6.119.

Ma, J. F., Miyake, Y., & Takahashi, E. (2001) Silicon as a beneficial element for crop plants. In: Datnoff, Lawrence E., Synder, G. H., & Korndorfer, G. H. (eds.) *Silicon in Agriculture*. Amsterdam: Elsevier Science.

Ma, J., Nishimura, K., & Takahashi, E. (1989) Effect of silicon on the growth of rice plant at different growth stages. *Soil Science and Plant Nutrition.* 35(3), 347–356. DOI:10.1080/00380768.1989.10434768.

Ma, J. F., & Yamaji, N. (2008) Review functions and transport of silicon in plants. *Cellular and Molecular Life Sciences.* 65, 3049–3057. DOI:10.1007/s00018-008-7580-x.

Ma, Jian Feng, & Takahashi, E. (2002) *Soil Fertilizer And Plant Silicon Research* in Japan. Amsterdam: Elsevier Science

Marschner, H. (1995) *Mineral Nutrition of Higher Plants*. 2nd Edn. London: Academic Press.

Mauad, M., Crusciol, C. A. C., Grassi Filho, H., & Corrêa, J. C. (2003) Nitrogen and silicon fertilization of upland rice. *Scientia Agricola.* 60(4), 761–765. DOI:10.1590/s0103-90162003000400023.

Moore, K. J., & Dixon, P. M. (2015) Analysis of combined experiments revisited. *Agronomy Journal.* 107(2), 763–771. DOI:10.2134/agronj13.0485.

Ohsumi, A., Takai, T., Ida, M., Yamamoto, T., Arai-sanoh, Y., Yano, M., Ando, T., & Kondo, M. (2011) Field Crops Research evaluation of yield performance in rice near-isogenic lines with increased spikelet number. *Field Crops Research.* 120(1), 68–75. DOI:10.1016/j.fcr.2010.08.013.

Othman, O., Abu Hassan, D., Alias, I., Ayob, A. H., Azmi, A. R., Azmi, M., Badrulhadza, A., Maisarah, M. S., Muhamad, H., Saad, A., Sariam, O., Siti Norsuha, M., Syahrin, S., & Yahaya, H. (2008) *Manual Teknologi Penanaman Padi Lestari*. Kuala Lumpur: MARDI Press.

Pati, S., Pal, B., Badole, S., Hazra, G. C., & Mandal, B. (2016) Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. *Communications in Soil Science and Plant Analysis.* 47(3), 284–290. DOI:10.1080/00103624.2015.1122797.

Rodrigues, F. A., Resende, R. S., Dallagnol, L. J., & Datnoff, L. E. (2015) Silicon potentiates host defense mechanisms against infection by plant pathogens. In: Rodrigues, F. A. & Datnoff, L. E. (eds.) *Silicon and Plant Diseases*. London. DOI:10.1007/978-3-319-22930-0.

Saad, A., Othman, O., Azlan, S., Alias, I., & Habibudin, H. (2004) Impact and contribution of resistant varieties in rice pest management in Malaysian modern rice farming. In: Sivapragasm, A. (eds.) *Modern Rice Farming: International Rice Conference 2003*. Alor Setar, Kedah: MARDI Press.

Saleh, D., Adreit, H., Fournier, E., & Tharreau, D. (2014) South-East Asia is the center of origin, diversity and dispersion of the rice blast fungus, *Magnaporthe oryzae*. *New Phytologist.* 201, 1440–1456.

Salman, D., Morteza, S., Dariush, Z., Nasiri, A., Reza, Y., Delavar Ehsan, G., & Nasiri Ali Reza, N. (2012) Application of nitrogen and silicon rates on morphological and chemical lodging-related characteristics in rice (*Oryza sativa* L.) at North of Iran. *Journal of Agricultural Science.* 4(6), 11–18. DOI:10.5539/jas.v4n6p12.

Samonte, S. O. P., Wilson, L. T., McClung, A. M., & Tarpley, L. (2001) Seasonal dynamics of non-structural carbohydrate partitioning in 15 diverse rice genotypes. *Crop Science.* 41, 902–909.

Santos, G. R., Neto, M. D. C., Ramos, L. N., Sarmento, R. A., Korndörfer, G. H., & Ignácio, M. (2011) Effect of silicon sources on rice diseases and yield in the State of Tocantins, Brazil. *Acta Scientiarum Agronomy.* 33(3), 451–456. DOI:10.4025/actasciagron.v33i3.6573.

Seebold, K. W., Datnoff, L. E., Correa-Victoria, F. J., Kucharek, T. A., & Snyder, G. H. (2000) Effect of silicon rate and host resistance on blast, scald, and yield of upland rice. *Plant Disease.* 84(8), 871–876. DOI:10.1094/PDIS.2000.84.8.871.

Sun, W., Zhang, J., & Fan, Q. (2010) Silicon-enhanced resistance to rice blast is attributed to silicon-mediated defense resistance and its role as a physical barrier. *European Journal of Plant Pathology.* 128, 39–49. DOI:10.1007/s10658-010-9625-x.

Suryadi, Y., Susilowati, D. N., Riana, E., & Mubarik, N. R. (2013) Management of rice blast disease (*Pyricularia oryzae*) using formulated bacterial consortium. *Emirates Journal of Food and Agriculture.* 25(5), 349–357. DOI:10.9755/ejfa.v25i5.12564.

Takai, T., Matsuura, S., Nishio, T., Ohsumi, A., Shiraiwa, T., & Horie, T. (2006) Rice yield potential is closely related to crop growth rate during the late reproductive period. *Field Crops Research.* 96, 328–335. DOI:10.1016/j.fcr.2005.08.001.

Yoshida, S. (1973) Effects of temperature on growth of the rice plant (*Oryza sativa* L.) in a controlled environment. *Soil Science and Plant Nutrition.* 19(4), 299–310. DOI:10.1080/00380768.1973.10432599.

Yoshida, S. (1981) *Fundamentals of Rice Crop Science*. *Plant Production Science*. Manila, International Rice Research Institute.

Zhang, Y., Yu, C., Lin, J., Liu, J., Liu, B., Wang, J., Huang, A., Li, H., & Zhao, T. (2017) OsMPH1 regulates plant height and improves grain yield in rice. *Plos ONE*. 12(7), 11–13. DOI:10.1371/journal.pone.0180825.