

Full Length Research Paper

Suppressive effects of a polymer sodium silicate solution on powdery mildew and root rot diseases of miniature rose

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Sodium silicate was dissolved in water in either a monomer form or polymer form; the effects of both forms of sodium silicate aqueous solution on rose powdery mildew and root rot diseases of miniature rose were examined. Both forms of sodium silicate aqueous solution were applied to the roots of the miniature rose. Potassium silicate aqueous solution was used as a control and was compared to the effect of sodium silicate aqueous solution. The polymer sodium silicate aqueous solution was the most effective treatment against both powdery mildew and root rot diseases. Moreover, no inhibition effects of silicate solutions were observed *in vitro* on *Pythium helicoides*, the causal pathogen of rose root rot disease. The silicon contents in the roots of the miniature rose treated with polymer sodium silicate were significantly greater than that in plants treated with monomer sodium silicate. In conclusion, the suppressive effects of sodium silicate in the polymer form were confirmed against powdery mildew and root rot diseases of the miniature rose.

Key words: *Podosphaera pannosa*, *Pythium helicoides*, miniature rose, polymer and monomer sodium silicate.

INTRODUCTION

Potted miniature roses (*Rosa hybrida* Hort.) have dime-to quarter-size flowers in single, double and semi-double forms. Miniature roses grow well indoors or out and are useful colorful plantings in areas with limited space. The roses are available in almost every color, except blue. Flowers can be pressed or dried for use in arrangements and potpourri. Several hundred cultivars are available,

ranging in size from 3 to 18 inches in height and spread. The smallest varieties ("micro-minis") grow to 6 inches or less. Recently, environment-friendly agriculture attempts to minimize the use of fungicides (Elsharkawy et al., 2012a, 2012b, 2013; Hassan et al., 2014b, 2014c; Taguchi et al., 2014; 2015). Disease control by materials with low environmental effects is desired ((El-kazzaz et al., 2015).

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Silicon (Si), as a major soil constituent, is an element that is the second most abundant (after oxygen) in the surface layer of the earth (Exley, 1998). Silicic acid is often abundant in rock samples. Large differences in Si accumulation were observed in different parts of the identical plant (Hodson et al., 2005). The beneficial effects of silicon were discovered first in grasses and extended to only a few number of plant species (Jones and Handreck, 1967). Si is considered as a useful element for specific-species of plants, but it is not an essential element for the plant. Silicic acid application in crops (such as rice) controls diseases and could reduce the load of fungicides released into the environment, even when applied in large quantities in agriculture (Kim et al., 2002; Ma et al., 2004). Several hypotheses have been suggested concerning the role of Si in plant development including the positive effects on reproduction, alleviation of metal toxicity and nutrient imbalance, provision of structural rigidity and increased resistance to fungal diseases such as powdery mildews and root rots (Epstein, 1994; Fawe et al., 1998). Si positively affects rice plants, promotes photosynthesis and increases dry matter production. Root treatment could improve the resistance to insect damage and disease resistance. Rice blast has been suppressed through Si treatment in rice (Maekawa et al., 2001, 2002; Seebold et al., 2001; Hayasaka et al., 2005).

Additionally, disease suppression of powdery mildew using Si has been reported in strawberries, cucumbers, grapes, *Arabidopsis*, wheat and cantaloupe (Bowen et al., 1992; Cherif and Belanger, 1992; Menzies et al., 1992; Belanger et al., 2003; Ghanmi et al., 2004; Kanto et al., 2004, 2006). Si can also be found in the form of monosilicic acid, colloidal silicic acid, or organosilicon compounds in plant tissues (Yoshida et al., 1962). The absorption and movement of silicic acid to leaf blades and the end of the transpiration stream, such as rice husks, have been reported as major factors involved in impeding mycelial invasion of blast fungus. Si treatment has been reported to promote the production of phytoalexins and antibacterial substances (Cherif et al., 1994; Fawe et al., 1998). Si is usually present as silicate (SiO_2) in the soil. Some silicic acid molecules are polymerized and high concentrations of this polymerization concentration is known as the polymer state (Takahashi, 1987).

Therefore, the low molecular state is known as the monomer state and the high molecular state is the polymer state. Limited research considers plant disease control with both forms. Therefore, we focus on using both forms of Si in the present study. Sodium silicate was used as the silicate materials. Sodium silicate, when dissolved in water, is divided into silicate ions with a negative charge and sodium ions with a positive charge. When the pH is 7.0 or less, silicate ions become molecular silicic acid, losing charge. The polymerization concentration is high in these silicic acid molecules.

Because of the difference in concentration of sodium silicate, low molecular states are characterized in two forms: polymer and monomer. This is the first report using the polymer state to control powdery mildew and root rot diseases. Until now, calcium silicate and potassium silicate were the most used as silicate materials to control plant disease (Moyer et al., 2008). This study investigates the effect of using monomer and polymer sodium silicate on powdery mildew and root rot diseases of miniature rose.

MATERIALS AND METHODS

Powdery mildew experiments

Preparation of test plants

Miniature roses (variety, silk red) were prepared by cuttings. Seedlings were transplanted in plastic pots (9 cm in diameter) filled with soil (star bed and peat moss, 1:1). Plants were grown in a glass greenhouse for 14 days (Gifu Prefectural Agricultural Research Institute, Gifu, Japan). A bottom water supply system was used during cultivation.

Preparation of aqueous silicic acid solution and treatment method

Monomer and polymer sodium silicate aqueous solutions were prepared by dissolving the reagent of sodium silicate (Wako Pure Chemical Industries, Ltd.) in distilled water (DW). The ratio of sodium silicate solution to water (DW) was set to 1 g/1000 mL for the monomer form and 10 g/1000 mL for the polymer form. The sodium silicate was completely dissolved in water (DOWEX 50wx4 100-200 H-form, Muromachi Technos Co., Ltd.), and the ion exchange resin of both forms was adjusted to pH 6.0 to 7.0. Both forms of aqueous sodium silicate solutions were adjusted with DW (pH 5.5), to concentrations of 0.5 and 1.0 mM. The aqueous solution of potassium silicate was prepared using a potassium silicate solution (Wako Pure Chemical Industries, Ltd.). An ion exchange resin was adjusted to pH 6.0 to 7.0 using DW (pH 5.5), and then the concentration was adjusted to 0.5 and 1.0 mM. Each silicate aqueous solution (30 mL) was applied to the plants as a soil drench at three time points within a week (every two days).

Disease severity assessment

Powdery mildew infected plants were used as an inoculum source. In the first test, plants were treated with sodium silicate aqueous solutions 2 weeks before setting the diseased plants as inoculum source. Disease severity was measured in plants treated with both forms of sodium silicate aqueous solution. Treatment continued up to 4 weeks after installation. In the second test, sodium silicate treatments were applied 4 weeks before setting the diseased plants as the inoculum source and were continued in the identical manner of processing up to 4 weeks after the installation. In both the first and second tests, the number of small leaves infected with powdery mildew disease was measured every 7 days after setting the diseased plants as the inoculum source. Disease incidence was measured by counting and removing the percentage of infected leaflets among the complete leaflet. In the second test, in addition to disease incidence, disease severity was measured. The disease severity rate was evaluated in the small leaves as follows: (no disease) 0% infected of the whole leaves, (1) leaves showing 0 to 25% leaf area

infected, (2) leaves showing 25 to 50% leaf area infected, and (3) leaves showing 50 to 100% leaf area infected. The disease severity was measured in both the first and second tests up to 28 days after setting the diseased plants as the inoculum source.

Determination of silicon

Si contents in rose leaflets were analyzed calorimetrically using the molybdenum blue method. Leaflets (samples) from each treatment group were dried for 2 to 3 days in an oven at 65°C; the samples were then ground and subjected to ashing and silica extraction as described by Boone (2007). The Si concentration was the absorbance value at a wavelength of 650 nm.

Root rot experiments

Plants and pathogens

Miniature rose plants (variety: Silk Red) were prepared as described previously. Miniature rose root rot fungus (*Pythium helicoides* B1-21 strain) was used in this experiment. A potassium silicate aqueous solution and monomer and polymer sodium silicate aqueous solutions (Wako Pure Chemical Industries, Ltd.) were prepared by dissolving the salts in distilled water as described previously. The plants were separated in eight groups: (a) water treatment (Si-, P-), (b) silicic acid untreated plot (Si-, P+), (c) 0.5 mM monomer sodium silicate solution treatment (0.5 mM monomer, p+) (d), 1.0 mM monomer sodium silicate solution treatment (1.0 mM monomer, p+), (e) 0.5 mM polymer sodium silicate solution treatment (0.5 mM polymer, p+), (f) 1.0 mM polymer sodium silicate solution treatment (1.0 mM polymer, p+), (g) 0.5 mM potassium silicate aqueous solution treatments (0.5 mM potassium, p+), (h) 1.0 mM potassium silicate aqueous solution treatment (1.0 mM potassium, p+). The experiment was repeated twice with 5 plants per treatment.

Effect of silicate solution on the severity of miniature rose root rot disease

The pathogen inoculum was prepared using autoclaved bentgrass seeds (variety: Highland, Takiishubyo, 1 g in 4 mL DW). The seeds were inoculated in a 300 mL Erlenmeyer flask with 10–15 mycelial discs (5 mm) transferred from the actively growing margin of 3 to 5-day-old potato dextrose agar (PDA; 2% agar) cultures of *P. helicoides*. The seeds that were entirely covered with flora were used as pathogen inoculum. The pathogen inoculum was completely mixed with 9 g of potting medium by hand, and this mixture was used as a contact inoculum source. The pathogen inoculum was added to soil surface of the miniature rose at 10 days from transplanting to plastic pots (30 cm × 20 cm × 10 cm). These pots served as the disease stock. The experiment was conducted in a glass greenhouse (Gifu University, Faculty of Applied Biological Sciences). The miniature roses were planted in plastic pots (30 cm × 20 cm × 10 cm) into the waterlogging state. The pathogen strain and management treatments were cultivated and irrigated using a bottom water supply. The plants were pre-treated with each silicate aqueous solutions at 10 d after cultivation of the miniature rose. The treatments were continued up to 4 weeks (every two days) after installing the diseased plants as the inoculum source. The disease stock was installed in each plastic pot as a post-treatment. Both of the disease incidence and severity of aboveground parts of plants were evaluated every four days after inoculation to observe the progress of disease symptoms of the aboveground plants. The disease incidence and severity of the browning on the roots were examined at 32 days after pathogen inoculation.

Determination of silicon

Si contents in the roots and the leaves of the treated miniature plants were measured by the molybdenum-blue method using wet ashing as mentioned above.

Effect of silicate solutions on the growth of *P. helicoides*

In total, 100 µl of each silicic acid aqueous solution (1 mM) were dropped onto sterile thick paper discs (8 mm in diameter, produced by Advantec® Japan). The strain *P. helicoides* B1-21 and the treated paper discs were inoculated on PDA medium. Petri dishes were cultured for 3 days (at 25°C in the dark), and the growth of flora was observed.

Data analysis

The data were subjected to an analysis of variance (ANOVA) using EKUSERU-TOUKEI 2010 (Social Survey Research Information Co., Ltd). The experiments were repeated at least three times, and treatment averages were separated using a Fisher's least significant difference (LSD) test. All analyses were conducted at a significance value of $P \leq 0.05$.

RESULTS

Powdery mildew disease

Disease suppression experiment

First test: Twenty-eight days after setting the diseased plants as the inoculum source, the disease incidence of the silicate untreated plot was 51.1, whereas it was 41.3 and 43.2% in the 0.5 and 1.0 mM monomer sodium silicate aqueous solution treatments, respectively. Polymer sodium silicate aqueous solutions in concentrations of 0.5 and 1.0 mM recorded 12.0 and 11.3%, respectively. The polymer sodium silicate aqueous solution treatment displayed a significantly reduced disease incidence on leaflets. Among all treatments throughout the study period, the polymer sodium silicate aqueous solution treatment achieved the lowest incidence of powdery mildew disease on rose leaflets. Both the monomer sodium silicate aqueous solution treatment and silicic acid untreated plot showed approximately equal values of disease incidence without significant difference between them. The experiments were performed using different concentrations (1.0 and 0.5 mM) of both monomer and polymer sodium silicate aqueous solution, but no significant differences were found on disease incidence rate because of differences in concentrations (Table 1). Protection values were calculated using disease incidence. Polymer sodium silicate aqueous solutions showed high protection values compared with monomer sodium silicate aqueous solutions (Figure 1).

Second experiment: Twenty-eight days after setting the infected plants as the inoculum source, the disease

Table 1. Disease incidence of powdery mildew on miniature rose leaves up to 6 weeks after setting the infected plants as inoculum source in experiment I.

Treatments	Days after setting the diseased plant as inoculum source			
	7	14	21	28
Si-	5.0±0.7 ^b	10.8±2.2 ^b	29.0±7.2 ^c	51.1±8.7 ^b
0.5 mM monomer	5.3±1.1 ^b	11.9±1.0 ^b	17.6±3.4 ^{ab}	41.3±4.2 ^b
1.0 mM monomer	4.1±0.9 ^b	7.8±1.0 ^{ab}	26.7±1.1 ^{bc}	43.2±1.0 ^b
0.5 mM polymer	1.0±0.3 ^a	6.1±0.5 ^a	7.5±0.8 ^a	12.0±0.9 ^a
1.0 mM polymer	2.1±0.5 ^{ab}	9.0±2.2 ^{ab}	8.8±0.7 ^a	11.3±0.8 ^a

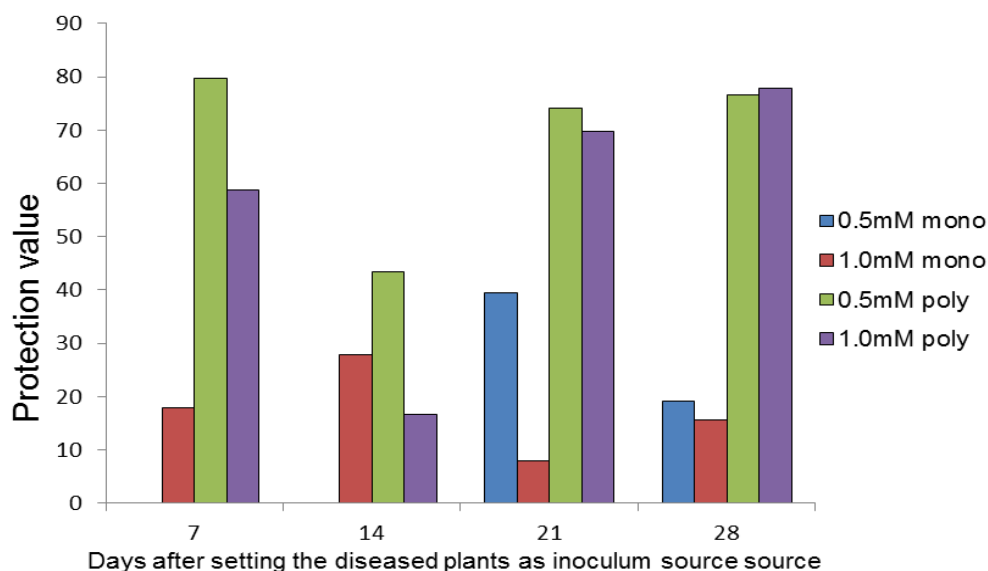


Figure 1. Protection values were calculated based on disease incidence at 7, 14, 21 and 28 days after setting the diseased plants as inoculum source. Si- = non-silicon treated plants; mono = monomer sodium silicate treated plants; poly = polymer sodium silicate treated plants.

incidence was 25.1% in silicate untreated plants. The monomer sodium silicate aqueous solution treatments in concentrations of 0.5 and 1.0 mM recorded 21.6 and 23.6 disease incidences, respectively, whereas 0.5 and 1.0 mM polymer sodium silicate aqueous solution treatments achieved 11.9 and 10.7%, respectively. The disease incidence of 0.5 and 1.0 mM potassium silicate aqueous solutions were 17.8 and 17.9%, respectively. The polymer sodium silicate aqueous solution treatment achieved the lowest incidence rate on the leaflet. The polymer sodium silicate aqueous solution treatments inhibited the onset of disease more than the potassium silicate aqueous solution treatments. The monomer sodium silicate aqueous solution treated plants recorded almost equivalent disease incidence rate as the silicate untreated plot (Table 2). The disease severity of the silicate untreated plot was 13.8, whereas it was 5.6 and 4.7 for the 0.5 and 1.0 mM polymer sodium silicate aqueous solution. The disease severity of polymer sodium silicate aqueous solution treatments showed the

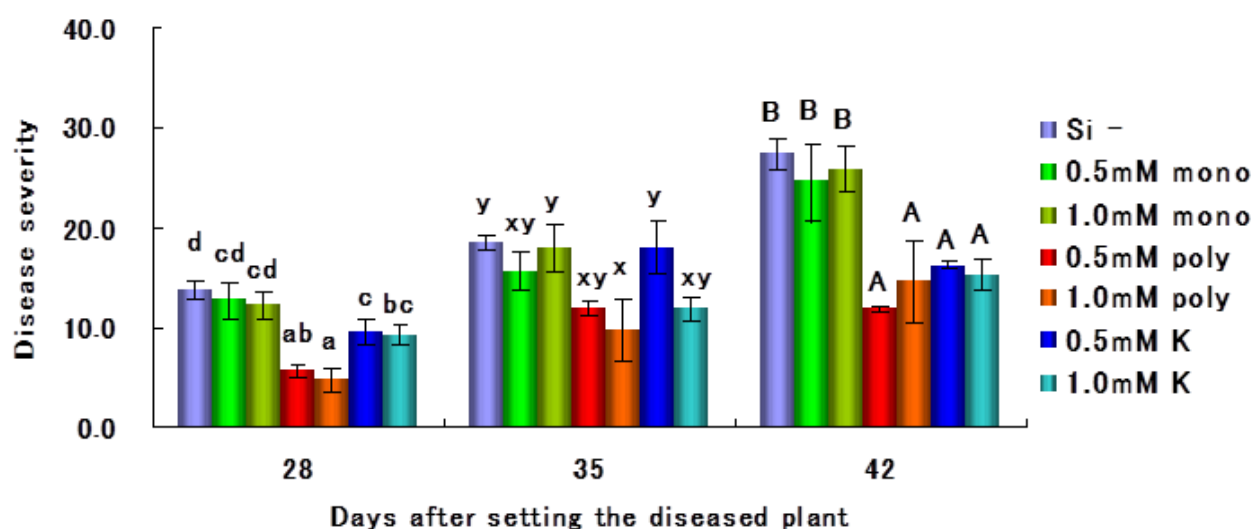
lowest value (Figure 2). In addition, no significant differences were observed in disease severity between the two provided concentrations of silicate aqueous solutions in the treated plants (Figure 2). The protection values were calculated from the disease severity and disease incidence rates. The protection values of the polymer sodium silicate aqueous solution calculated from the disease incidence rate ranged from 52.6 to 57.5, whereas the protection values calculated from the disease severity ranged from 59.3 to 65.8. The polymer sodium silicate aqueous solution showed inhibitory effects in both the symptoms and disease development (Figure 3).

Determination of silicon in the small leaves

First experiment: The leaflets were randomly sampled (regardless to disease symptoms on the small leaves) to quantify the silicon from each treatment group. No

Table 2. Disease incidence of powdery mildew on miniature rose leaves until 6 weeks after setting the infected plants as inoculum source in experiment II.

Treatments	Days after setting the diseased plant as inoculum source					
	7	14	21	28	35	42
Si-	1.1±0.3 ^c	0.4±0.3 ^a	11.4±1.0 ^b	25.1±1.8 ^d	30.4±1.3 ^c	45.9±2.4 ^d
0.5 mM monomer	0.7± 0.4 ^{bc}	0.8±0.5 ^a	8.9±2.9 ^{ab}	21.6±2.0 ^{bcd}	27.1±2.6 ^{bc}	35.6±3.9 ^{bc}
1.0 mM monomer	0.2±0.1 ^{ab}	0.7±0.5 ^a	11.9±4.0 ^b	23.6±2.8 ^{cd}	32.5±3.1 ^c	44.5±4.1 ^{cd}
0.5 mM polymer	0.1±0.1 ^{ab}	0.3±0.1 ^a	3.9±0.6 ^a	11.9±0.7 ^a	22.1±0.9 ^{ab}	21.5±0.7 ^a
1.0 mM polymer	0.1±0.1 ^{ab}	0.3±0.1 ^a	4.0±0.9 ^a	10.7±2.1 ^a	18.3±4.3 ^a	25.5±5.1 ^a
0.5 Mm K ₂ SiO ₄	0.1±0.1 ^a	0.2±0.1 ^a	7.9±1.7 ^{ab}	17.8±1.7 ^b	26.8±2.1 ^{bc}	28.3±0.7 ^{ab}
1.0 Mm K ₂ SiO ₄	0.2±0.1 ^a	0.2±0.1 ^a	8.8±1.5 ^{ab}	17.9±1.4 ^{bc}	23.2±1.5 ^{abc}	26.9±1.3 ^{ab}

**Figure 2.** Disease severity of powdery mildew at 28, 35 and 42 d after setting the diseased plants as inoculum source. Disease severity was assessed as index of ratio of symptom area on small leaves using a scale of 0 to 4; 0 = no symptoms, 1 = 0-25%, 2 = 25 to 50%, 3 = 50 to 100%. Disease severity = $\sum (P_{(0-3)} \times S_{(0-3)}) \times 100 / (3 \times \text{total small leaves})$, where $P_{(0-3)}$ = plant number in score 0, 1, 2, and 3, $S_{(0-3)}$ = score 0, 1, 2, and 3. (Si-) = non-silicon treated plants, (mono) = monomer sodium silicate treated plants, (poly) = polymer sodium silicate treated plants and (K) = potassium silicate treated plants. Bars labelled with the same letters are not significantly different according to LSD test at 5%. Vertical lines indicate the standard error.

significant differences were found in silicon contents between all treatments and the control (Figure 4).

Second experiment: Samples were separated into symptomatic leaflets and non-symptomatic leaflets in all treatments, and the Si contents were quantified. The Si contents were higher in sodium silicate treatments when compared to potassium silicate treatments. No significant differences were observed between 0.5 and 1.0 mM of monomer sodium silicate aqueous solution treated plants. In other treatments, significant differences were observed between different concentrations of each treatment in non-symptomatic leaves (Figure 5). Although the disease inhibition effects of Si application were found, no relation was observed between Si content and disease incidence

in each experiment. This result suggests that the Si content does not affect the incidence of powdery mildew.

Root rot disease

Effect of each silicate solution on the root rot of miniature rose

The disease incidence of root rot on the aboveground parts and roots of miniature rose was examined. For the aboveground parts, the disease incidence of the pathogen alone treatment (control) was 90%, whereas all silicate solution treatments showed lower incidences than the control. Among all treatments, the lowest incidence

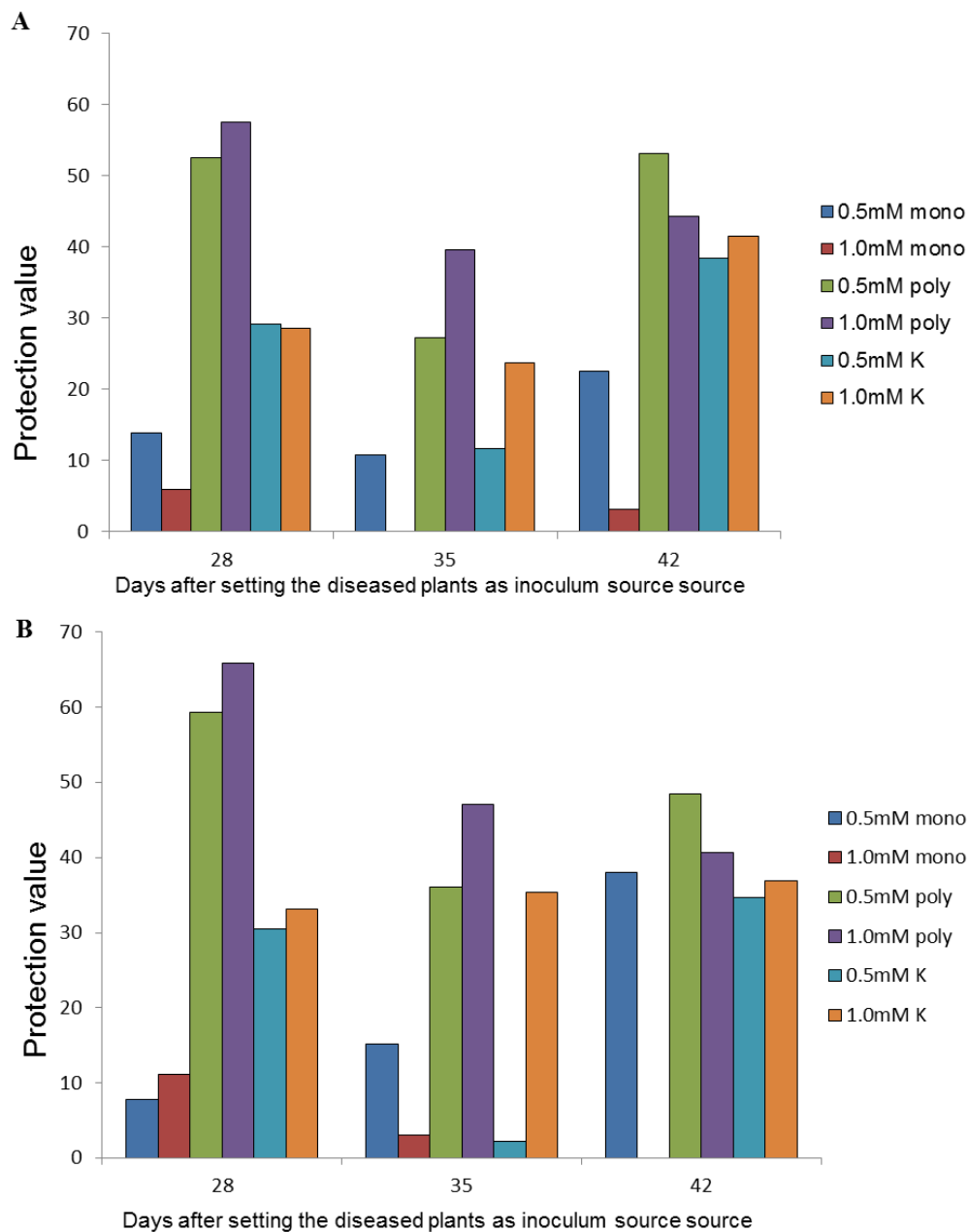


Figure 3. Protection values were calculated based on disease incidence (A) and disease severity (B) at 28, 35 and 42 days after setting the diseased plants as inoculum source. mono = monomer sodium silicate treated plants; poly = polymer sodium silicate treated plants; K = potassium silicate treated plants.

was achieved by the polymer treatments group (60%). The disease severity of the control treatment was 32.5, whereas it was 17.5 and 20.0 for 0.5 and 1.0 mM polymer sodium silicate treatments, respectively. The protection values were 46.2 and 38.5 for 0.5 and 1.0 mM polymer sodium silicate treatments, respectively (Table 3). Although the disease severity was not high in the control treatment, the polymer silicate treatments showed the lowest disease severity values throughout the study

period (Table 3). The 1.0 mM polymer sodium silicate treatment recorded the lowest incidence of root rot in the roots of the miniature rose. The root browning degree of the pathogen alone treated plants was 42.5, whereas it was 17.5 for the 1.0 mM polymer sodium silicate treatment, showing a 58.8% protection value (Table 4). The above results showed that the polymer sodium silicate treatment achieved the highest protection values for the aerial and root portions.

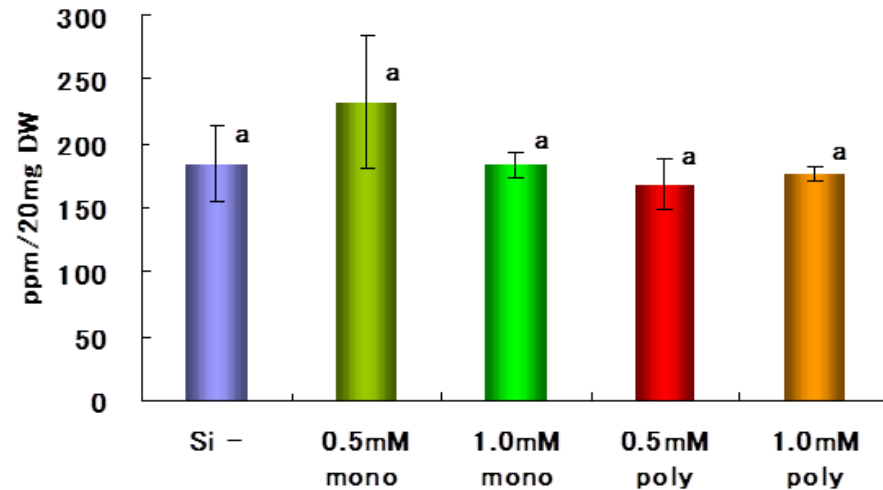


Figure 4. Silicon concentrations in small leaves at 28 d after setting the diseased plant as inoculum source in experiment I. Silicon concentration was measured by spectrophotometer with 650nm. Si- = non-silicon treated plants; mono; = monomer sodium silicate treated plants; poly = polymer sodium silicate treated plant. Bars labelled with the same letters are not significantly different according to LSD test at 5%. Vertical lines indicate the standard error.

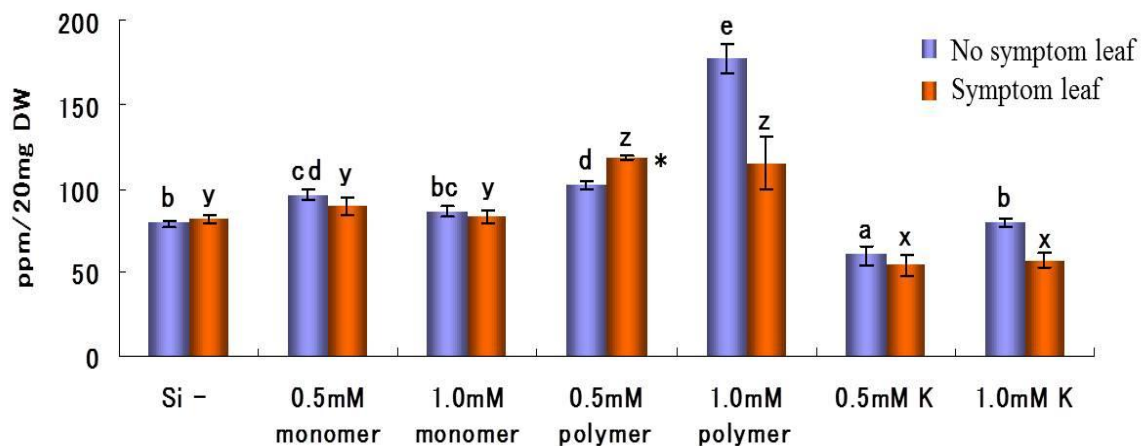


Figure 5. Silicon concentration of small leaves tissue at 42 d after setting the diseased plant as inoculum source. Silicon concentration was measured by spectrophotometer at 650nm. Si- = non-silicon treated plants; mono = monomer sodium silicate treated plants; poly = polymer sodium silicate treated plants; K = potassium silicate treated plants. Bars labelled with the same letters are not significantly different according to LSD test at 5%. Small letters refer to comparison between each treatment in non-symptomatic leaves and capital letter to comparison between each treatment in symptomatic leaves. Mark (*) approve significantly difference between non-symptomatic and symptomatic leaves with t- test at 5%. Vertical lines indicate the standard error.

Determination of silicon in the leaves and the roots

The Si contents were analyzed in the leaves and the roots. Plants treated with 1.0 mM polymer sodium silicate showed the highest Si contents in the roots compared to the other treatments. However, 1.0 mM monomer sodium silicate, 0.5 mM polymer sodium silicate, 1.0 mM polymer sodium silicate, and 1.0 mM potassium silicate treatment groups were significantly higher in Si contents in the

leaves than in the untreated and pathogen alone treated plants (Figure 6).

Effect of each silicate solution on growth of *P. helioides*

The inhibition effects of monomer and polymer sodium silicate solutions and potassium silicate solution on the

Table 3. Disease incidence and disease severity on miniature rose plants at 32 d after setting the infected plants as inoculum source.

Treatments	Plant number in score					Disease incidence ¹⁾	Disease severity ²⁾	Protection value ³⁾
	0	1	2	3	4			
Control (Si-P-)	10					0	0.0	
Pathogen (Si-P+)	1	6	2	1		90	32.5	
0.5 mM mono	2	4	2	2		80	35.0	0
1.0 mM mono	4	4	2			60	20.0	38.5
0.5 mM poly	4	5	1			60	17.5	46.2
1.0 mM poly	4	4	2			60	20.0	38.5
0.5 mM K ₂ SiO ₄	3	5	2			70	27.5	15.4
1.0 mM K ₂ SiO ₄	3	7				70	17.5	46.2

¹⁾ Disease incidence is the percentage of yellowed plants out of the total number of plants in the treatment. ²⁾ Disease severity was assessed as index of ratio of yellowing on plant using a scale of 0 to 4; 0=no yellowing, 1=0~25% yellowing, 2= 25~50%, 3= 50~75%, 4 = 75~100 and dead. Disease severity= $\sum (P_{0.4} \times S_{0.4}) \times 100 / (4 \times \text{total plants})$, where $P_{0.4}$ = plant number in score 0, 1, 2, 3 and 4, $S_{0.4}$ = score 0, 1, 2, 3, and 4, protection value was calculated based on disease severity. ³⁾ Protection value = (pathogen - each treatment) $\times 100$ /pathogen. (Control) = non-silicon treated and not inoculated plants, (pathogen) = non-silicon treated and inoculated plants, (mono) = sodium silicate treated plants, (poly) = polymer- sodium silicate treated plants and (K₂SiO₄) = potassium silicate treated plants.

Table 4. Disease incidence and discoloration severity on root at 32 d after setting the infected plants as inoculum source.

Treatments	Plant number in score					Disease incidence ¹⁾	Disease severity ²⁾	Protection value ³⁾
	0	1	2	3	4			
Control (Si-P-)	10					0	0.0	
Pathogen (Si-P+)		7		2	1	100	42.5	
0.5 mM mono	1	5	3	1		90	35.0	17.6
1.0 mM mono	3	7				70	17.5	58.8
0.5 mM poly	3	3	4			70	27.5	35.3
1.0 mM poly	4	5	1			60	17.5	58.8
0.5 mM K ₂ SiO ₄	4	5	1			60	17.5	58.8
1.0 mM K ₂ SiO ₄	1	2	3	3	1	90	52.5	0

¹⁾ Disease incidence is the percentage of discolored plants out of the total number of plants in the treatment. ²⁾ Disease severity was assessed as index of ratio of discoloration area on root using a scale of 0 to 4; 0 = no discoloration, 1 = 0~25% discoloration, 2 = 25~50%, 3 = 50~75%, 4 = 75~. Disease severity = $\sum (P_{0.4} \times S_{0.4}) \times 100 / (4 \times \text{total plants})$, where $P_{0.4}$ = plant number in score 0, 1, 2, 3 and 4, $S_{0.4}$ = score 0, 1, 2, 3, and 4. ³⁾ Protection value was calculated on discoloration severity. Protection value = (pathogen-each treatment) $\times 100$ /pathogen. (Control) = non-silicon treated and not inoculated plants, (pathogen) = non-silicon treated and inoculated plants, (mono) = monomer - sodium silicate treated plants, (poly) = polymer - sodium silicate treated plants and (K₂SiO₄) = potassium silicate treated plants.

growth of *P. helioides* were tested. No affect was found using the solution itself. Therefore, no direct inhibition effect was observed to pathogen growth (Figure 7).

DISCUSSION

Rose powdery mildew, caused by the fungus *Podosphaera pannosa*, infects a wide variety of roses. The disease is destructive and occurs wherever roses are grown outdoors and in greenhouses, notably for those grown in dryer climates (Gubler et al., 2011). Under favorable conditions for disease development (hot and dry weather with cool and moist nights) powdery mildew

can cause complete defoliation. The disease appears as a white powdery growth on young rose leaves, stems and all other portions of the rose, even buds and flowers. Pythium root rot continually threatens the productivity of several types of crops including cucumbers, sweet peppers, tomatoes, lettuce, spinach, roses, and chrysanthemums (Sutton et al., 2006). The principal causal agent of rose root rot disease is *P. helioides* (Kageyama et al., 2002; Watanabe et al., 2007). The root rot disease has also been observed in rockwool cultures of cutting rose and has spread in Japan. Integrated pest management (IPM) is an effective and environmentally sensitive approach to crop management to minimize losses from disease and insect pests (Mousa et al.,

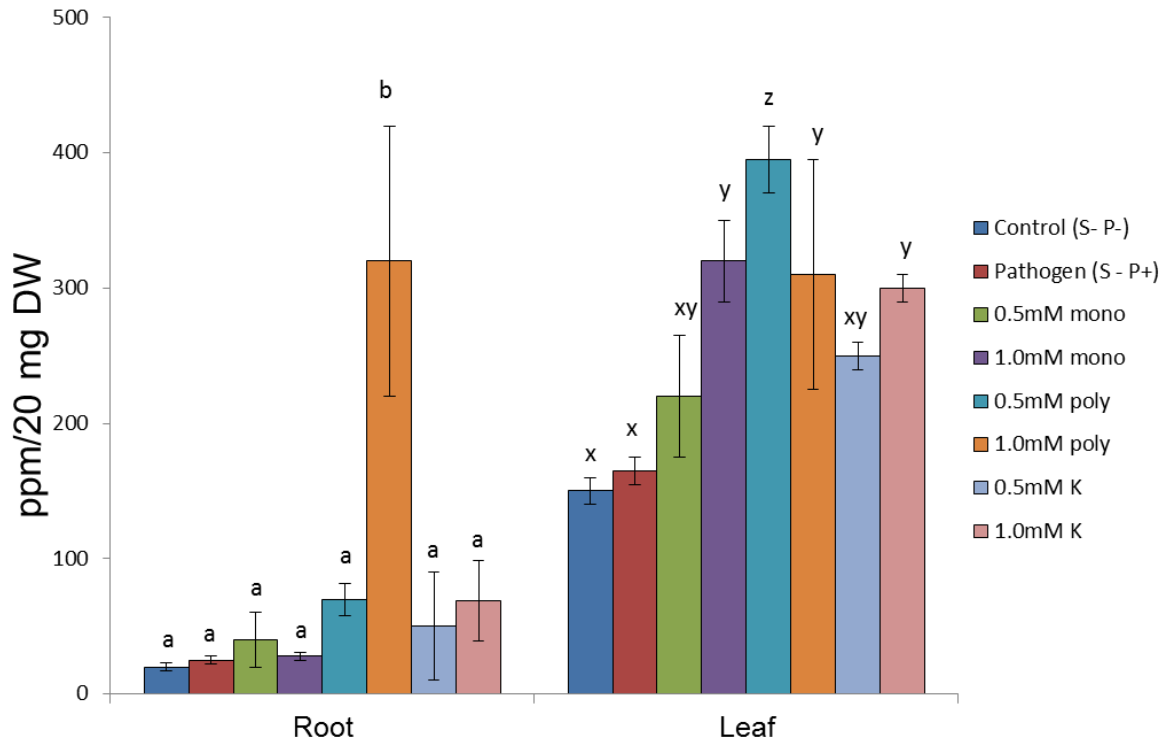


Figure 6. Silicon concentration in roots and leaves tissues at 32 d after setting the diseased plant as inoculum source. Silicon concentration was measured by spectrophotometer at 650 nm. Control = non-silicon treated and not inoculated plants; Pathogen = non – silicon treated plants; K = potassium silicate treated plants. Bars labelled with the same letters are not significantly different according to LSD test at 5%. Vertical lines indicate the standard error.

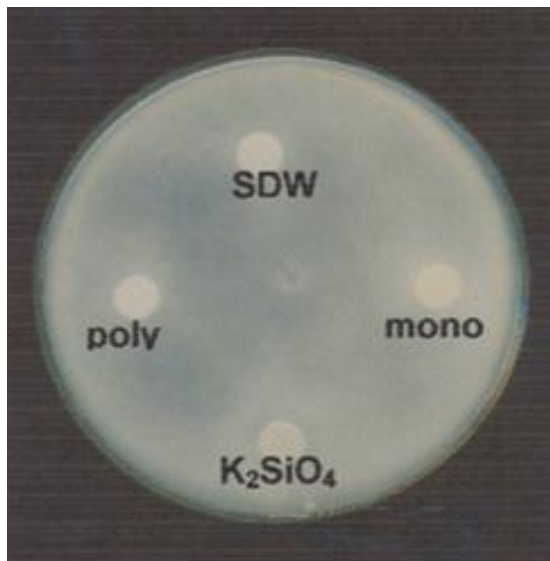


Figure 7. Confirmation of direct inhibition effects of monomer and polymer sodium silicate and potassium silicate on the growth of *Pythium helicoides*. Above: sterile distilled water (SDW), center left: polymer sodium silicate (poly), center right: monomer sodium silicate (mono) and under: potassium silicate (K_2SiO_4).

2014). IPM programs use pest and environmental information with the most economical pest control means and with the least possible hazard to human health and the environment (Elsharkawy and El-Sawy, 2015; Hassan et al., 2014a). An integrated approach to disease control aims to reduce the frequency and the amount of pesticides used. This can be achieved in part by using alternative products when appropriate. Si is known to reduce the severity of a number of plant diseases. This study was performed using both forms (polymer and monomer) of an aqueous sodium silicate solution. The results of the two experiments showed that high inhibitory effects were found against powdery mildew and root rot diseases of miniature roses in polymer sodium silicate treated plants when compared to plants treated with monomer sodium silicate. These results may be because polymers are large-sized molecules or macromolecules, and in select cases, the polymeric phase is more stable than the monomeric (Currie and Perry, 2007). Similarly, cucumber root rot caused by *Pythium* spp. was suppressed by the application of Si in cucumber plants. The pathogenic fungus attacks the root and hypocotyl (Belanger et al., 1995). Although, the roles of providing a physical and/or biochemical defense system have been proposed, the protective effect of Si has yet to be fully

elucidated. The role of Si deposition as a physical barrier to pathogen penetration has been examined (Yoshida et al., 1962). The results show that polymer sodium silicate treated plants recorded higher silicon contents in the roots when compared to monomer sodium silicate treated plants.

Additionally, no antimicrobial effect was found in polymer sodium silicate against *P. helicooides*. Debate remains as to whether this increased physical strength is sufficient in explaining the observed protective effects (Fauteux et al., 2005). Another explanation is the emerging role of Si as a biologically active element capable of enhancing the natural defense response of the plant. Si-treated plants exhibited increased activity of peroxidases, chitinases, polyphenol oxidases and flavonoid phytoalexins, which play an important role in plant resistance against fungal pathogens (Chérif et al., 1994; Fawe et al., 1998). Additionally, increased production of glycosylated phenolics, antimicrobial products such as diterpenoid phytoalexins and a proline-rich protein in Si-treated plants indicated the role of these products in the protection effects of Si against plant diseases (Belanger et al., 2003; Kauss et al., 2003; Rodriques et al., 2003). The bioactivity of Si as a regulator of plant defense mechanisms may be explained through the biochemical properties. Si can bind to hydroxyl groups of proteins strategically involved in signal transduction. Si also may interfere with cationic co-factors of enzymes influencing pathogenesis-related events. Therefore, Si may interact with several key components of plant stress signaling systems leading to induced resistance. In this study, the ability of different concentrations of both polymer and monomer sodium silicate to reduce the severity of the powdery mildew disease of miniature rose has been tested. No significant differences were found in the severity of powdery mildew and root rot diseases between the two concentrations of silicate aqueous solution treated plants.

Cherif et al. (1992) found that the Si application was not physically blocking the entry site of the *Pythium* spp. and that the Si was not accumulating in the entry site. The disease suppression by Si against root rot is not only associated with lignin and the strengthening of physical barrier against infection, but it is associated with the accumulation of phenolic substances (Cherif et al., 1994). The activity of disease resistance related enzymes, peroxidases and polyphenols oxidases, quickly increased after the infection with *Pythium ultimum* in silicon treated cucumber plants compared with the non-treated cucumber (Cherif et al., 1994). Rhamnetin, an O-methylated flavonol, is a phytoalexin and was reported in cucumber plants treated with Si, suggesting the possible role of Si in physiological resistance reactions (Fawe et al., 1998). The size and structure of the elicitors has been reported in disease resistance. Silicic acid was involved in the physiological resistance reaction in cucumbers and could be involved against rose powdery mildew and the

root rot disease that has been reported in this study through the silicic acid application. Physiological disease resistance could be considered as a possible mechanism other than the production of antibacterial substances such as phytoalexin.

In conclusion, the inhibitory effects of polymer sodium silicate were significantly higher than monomer sodium silicate. Therefore, according to the results obtained in the present study, polymer sodium silicate can play a role in controlling powdery mildew and root rot infection in rose plants.

Conflict of interests

The author(s) did not declare any conflict of interest.

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