Yield of Cucumber Infected with *Pythium aphanidermatum* when Grown with Soluble Silicon

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Abstract. Two experiments were conducted in separate locations, one at Université Laval in eastern Canada (Québec) and one at the Agassiz Research Station in western Canada (British Columbia), in an attempt to determine the effectiveness of soluble silicon (Si) against cucumber root disease caused by *Pythium aphanidermatum* Edson. Long English cucumber (*Cucumis sativus* L. cv. Corona) plants were grown either in a standard nutrient solution or in nutrient solutions supplemented with 1.7 mM (100 ppm) Si and inoculated or not with the pathogen. Supplying the solutions with 1.7 mM Si significantly reduced mortality and disease symptoms attributed to infection by *P. aphanidermatum*. Grown in presence of Si, plants infected with *P. aphanidermatum* showed a significant increase in yield, marketable fruit, and plant dry weight compared to Si-nonamended and infected plants. These beneficial effects were observed under both experimental conditions. The fruit yield of noninoculated plants was not affected by the presence of Si in the Agassiz experiment. However, Si-amended control plants were more productive in the experiment conducted at Laval, apparently because of contamination problems, which indicates that Si beneficial effects are most likely related to disease management.

Root diseases, caused by agents such as *Pythium* spp., are a particularly acute problem in recirculating nutrient systems because these systems offer an ideal environment for root pathogens to infect and spread (Gold and Stanghellini, 1985). Recently, Chérif and Bélanger (1992) have shown that amendment of the nutrient solution with soluble Si could prevent and reduce losses attributable to *P. ultimum* Trow on long English cucumber. *Pythium aphanidermatum* (Edson) Fitzp., the predominant species on cucumber cultures (Favrin et al., 1988), can spread rapidly by means of zoospores and has been reported to be extremely virulent under hydroponic conditions, potentially destroying a crop within days. In this context, it was pertinent to evalu-

ate the potential of soluble Si amendments against *P. aphanidermatum* on long English cucumber. To address this objective, collaborative experiments between Université Laval in eastern Canada (Québec) and Agassiz Research Station in western Canada (British Columbia) were conducted where the effects of a Si treatment could be evaluated under different growing conditions.

Materials and Methods

At both locations, the long English cucumber cultivar Corona was used. Seeds were sown in either cubes of rockwool (Grodan, Roermond, Holland) or in LC-1 Horticultubes (Smithes-Oasis, Kent, Ohio) and fertilized daily with a 7N–11P–27K nutrient solution for 3 to 4 weeks under greenhouse conditions. After transplanting into hydroponic systems, the plants were grown in a base nutrient solution that contained (in mM) 13.0 NO₃⁻, 1.5 H₂PO₄⁻, 7.0 K, 3.5 Ca, 1.0 Mg, and 1.0–1.5 SO₄⁻ and (in µM) 18.8 Fe, 5.5 Mn, 0.9 Zn, 0.2 Cu, 18.1 B, and 1.0 Mo. Soluble Si was fed to the plants by amending the nutrient solution with 1.7 mM (100 ppm) Si in the form of potassium silicate (Kasil no. 6, 23.6% SiO₂; PQ Corp., Toronto, Ont.) for the duration of the experiment. Proper adjustments were made to the nutrient solutions to compensate for the additional input of K. The nutrient solutions were prepared with

tap water (<0.05 mM Si), and final pH was adjusted to 5.8 with nitric acid. The pH and the electrical conductivity (EC) were continually monitored. The air was maintained between 17 and 27°C.

Inoculum was prepared from one isolate of *P. aphanidermatum*, isolated by J. Menzies from greenhouse-grown cucumber, which was grown on potato dextrose agar (PDA) on 9-cm petri dishes for 5 days. For each 100 liters of nutrient solution to be inoculated, the equivalent of one petri dish culture was blended in 100 ml of distilled water and added directly into the appropriate tank. Sterile PDA was used for the controls.

The first experiment was undertaken at Agassiz Research Station, Agriculture Canada, where 12 recirculating systems were built in a greenhouse. The greenhouse was divided into three blocks. Half of the recirculating systems were supplied with the standard nutrient solution (Si⁻) and the other half with the Si-amended solution (Si⁺). Five plants were transplanted into each system. Ten days later, pairs of Si⁺ and Si⁻ systems, within each of the three blocks, were inoculated with *P. aphanidermatum*. The two remaining non-treated Si⁺ and Si⁻ systems within each block were controls. Thus, the trial was comprised of four treatments: *P. aphanidermatum* inoculation with (Si⁺+P⁺) or without silicate amendments (Si⁻+P⁺) and two controls with (Si⁺+P⁻) and without silicate amendments (Si⁻+P⁻).

The plants were trained to a wire 1.2 m above the trough using the "umbrella" system (Klieber et al., 1993), and one lateral was allowed to grow down from the top. Cucumber fruit growing below the sixth node were removed. Marketable fruit (weighing 250 g or more) were harvested three times per week and weighed. Then, at the final harvest, 7 weeks after transferring seedlings to the troughs, all fruit, marketable or not, were counted (number of fruit per plant). Each plant was then cut off at the crown, dried, and weighed. For plants that died before the final harvest, the date was noted and the above procedure was followed.

A second experiment was undertaken at Université Laval using the same hydroponic system as described by Chérif and Bélanger (1992). Plants were transferred to troughs in which the nutrient solution was pumped from 500-liter tanks and constantly circulated. The design was comprised of eight recirculating systems with each tank feeding two randomly selected troughs. Six plants, spaced at 0.75-m intervals, were placed in each trough for a total of 96 plants for the experiment. A guard row was placed at each extremity of the experimental area. Each tank contained 300 liters of nutrient solution that was replaced every 3 weeks. The volume of the nutrient solution was maintained constant throughout the experiment by automatically adding tap water. Treatments were the same as in Expt. 1. The experiment was maintained for 10 weeks following the transfer of the seedlings to the troughs. The same cultural practices as in the previous experiment were used, and the same variables were measured throughout the ex-

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periment. In both experiments, weekly samples of the roots and the nutrient solutions were analyzed for *Pythium* propagules using a dilution plate technique with a *Pythium*-selective medium (PSM; Jeffers and Martin, 1986).

Data were analyzed by analysis of variance, and means were separated by Duncan's multiple range test ($P \leq 0.05$). The software SuperANOVA (Abacus Concepts, Berkeley, Calif.) and SAS (SAS Institute, Cary, N.C.) were used for statistical analysis.

Results and Discussion

In both experiments, *P. aphanidermatum*-treated plants started showing typical symptoms of infection within 1 week after inoculation. For instance, in the experiment conducted at Université Laval (Fig. 1), Si- plants were rapidly affected by *P. aphanidermatum*, and only 10 days after inoculation, 50% of those plants (Si-P+) were dead. In contrast, the Si+ system reduced the impact of *P. aphanidermatum* infection by keeping close to 60% of the infected plants alive by the end of the experiment, while all Si- plants were dead (Fig. 1). Nonetheless, *P. aphanidermatum* induced important yield reductions when compared to controls. Average plant dry weight was reduced by >50%, and the same pattern of results held true for fruit set and marketable fruit at both locations (Table 1).

The Si+ treatment consistently resulted in higher productivity for all variables measured 7 to 10 weeks after the plants were infected with *P. aphanidermatum* (Table 1). Within that treatment, a Si+ amendment improved plant dry weight by 35%, cucumber fruit set by 58%, and the number of marketable fruit by 57% in the experiment conducted at Agassiz (Table 1). At Laval, the Si+ plants outyielded the Si- plants by 62% and 72% in terms of dry weight and fruit, respectively, and the Si amendment showed also a significant effect on the number of marketable fruit produced (Table 1). While the beneficial effects of soluble Si were believed to be confined to foliar patho-

Table 1. Average plant dry weight, number of fruit, and number of marketable fruit per plant of long English cucumber ('Corona') grown at the Agassiz Research Station (British Columbia) for 7 weeks or at Université Laval (Québec) for 10 weeks in a recirculating nutrient solution with or without potassium silicate and noninoculated or inoculated with *Pythium aphanidermatum*.

Treatment ^z	Plant dry wt (g)	No. fruit/plant	No. marketable fruit/plant
Agassiz ^y			
Si-P-	69.6 c ^x	9.1 c	4.1 c
Si+P-	72.4 c	8.7 c	4.7 c
Si-P+	31.5 a	2.9 a	1.9 a
Si+P+	39.2 b	4.4 b	2.7 b
Laval ^w			
Si-P-	136.7 b	7.5 b	2.8 b
Si+P-	257.1 c	15.8 c	5.0 c
Si-P+	69.6 a	2.6 a	0.8 a
Si+P+	119.5 b	6.9 b	2.7 b

^zSi- = 0 and Si+ = 1.7 mM; P- = noninoculated and P+ = inoculated.

^yEach treatment represents an average of 15 plants.

^wMean separation in columns for a given location by Duncan's multiple range test ($P \leq 0.05$).

^xEach treatment represents an average of 24 plants.

gens such as powdery mildews (Menzies et al., 1991), recent studies have shown that soluble Si can also be effective at repressing the root pathogen *P. ultimum* (Chérif and Bélanger, 1992), and this study constitutes the first report that Si is effective against the important and more destructive species *P. aphanidermatum*.

Interestingly, for control plants (not inoculated with *P. aphanidermatum*), the Si+ and Si- treatments resulted in similar levels of productivity of all variables measured at Agassiz (Table 1). Similar results were obtained in an earlier study (Chérif and Bélanger, 1992). However, the presence of Si increased the yield of noninoculated plants (Si+P-) compared to Si-P- plants (Table 1) in the Laval experiment. In this experiment, control plants treated with 1.7 mM Si gave a significantly higher dry weight and number of fruit. However, sampling the nutrient solutions and roots revealed that both Si+ and Si- systems had been contaminated with *P. aphanidermatum*, a phenomenon only too frequently encountered in hydroponic systems. These results indicate that the amendment of Si alone did not influence the productivity of the plants, which

is in line with the idea that the beneficial effect of Si is most likely related to better disease management. Nonetheless, this treatment should not be regarded as a miracle solution against pathogens, but as a prophylactic measure that can reduce and prevent losses against many pathogens and thus limit dependency on fungicides. Several other reports have associated the beneficial effects of Si with a decreased receptivity of some plants to fungal pathogens (Menzies et al., 1991). The exact mechanisms by which Si can provide protection against pathogens are still not fully understood, but there is accumulating evidence that induced resistance would play a major role (Chérif et al., 1992a, 1992b).

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Fig. 1. Percent mortality over time of long English cucumber ('Corona') plants grown at Université Laval (Québec) for 10 weeks in a standard nutrient solution (Si-) or in a solution amended with 1.7 mM soluble Si (Si+) and inoculated with *P. aphanidermatum* (P+) or sterile PDA (P-).