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Silicon and increased electrical conductivity reduce downy mildew of soilless grown lettuce

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Abstract Downy mildew of lettuce, caused by *Bremia lactucae*, is difficult to control in soilless systems by using conventional methods of disease management because few chemicals are registered, while resistant cultivars face the problem of resistance break down; therefore other methods for disease control need to be investigated. The effect of silicon salt as well as increased electrical conductivities against downy mildew was evaluated in four experiments carried out in hydroponically systems, using the cultivar of lettuce "Cobham Green", known for its susceptibility to the pathogen. Silicon, as potassium silicate, was added at 100 mg l^{-1} of nutrient solution at three levels of electrical conductivity: 1.5–1.6 mS cm^{-1} (EC1), 3.0–3.5 $mScm^{-1}$ (EC2, 0.70 g l^{-1} NaCl) and 4.0–4.5 mS cm^{-1} (EC3, 0.95 g l^{-1} NaCl) respectively. Lettuce plants, grown for 14–20 (trials 1 and 2) and 36–45 (trials 3 and 4) days in the different nutrient solutions tested, were inoculated with *B. lactucae* conidia with a maximum of two inoculations before final disease assessment carried out 14–21 days after the inoculation able to give symptoms. EC and potassium silicate significantly influenced downy mildew incidence and severity, while their interaction was not a significant factor. The addition to the standard nutrient solution (EC1) of potassium silicate resulted in a significant reduction of downy mildew severity in trials 1 and 2 where plants were artificially inoculated 15 and 20 days after transplanting. This efficacy was slight on plants grown for 36 and 45 days before inoculation in a soil drenched with EC1 amended with potassium silicate. EC2 gave a significantly similar downy mildew reduction than EC2 added with potassium silicate in trial 3. Plants grown for 36 and 45 days at the highest electrical conductivity (EC3) showed a significant reduction in severity of downy mildew compared with that observed at EC2 level. The best results, in terms of disease control, were given by the addition of potassium silicate to the EC3 solution. This combination also led to a significantly increased plant biomass. The possibility and benefits of applying potassium silicate and increased EC amendments in practice is discussed.

Keywords *Bremia lactucae* · Potassium silicate · Electrical conductivity · Disease management

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Introduction

In the absence of control strategies, downy mildew, incited by *Bremia lactucae*, causes severe economic losses in cooler regions where lettuce is grown (Blancard et al. 2003; Lebeda et al. 2007). Among foliar diseases of lettuce, downy mildew is important enough to be considered in crop protection and resistance breeding programmes (Lebeda et al. 2007). Downy mildew management relies on the use of chemicals and/or resistant cultivars. Both strategies can be complicated by the development of strains of the pathogen resistant to fungicides (Crute et al. 1987; Cobelli et al. 1998); as well as by the presence of several races of the pathogen in different geographical areas, that limits the durability of host-specific resistance (Lebeda et al. 2007).

Most of the lettuce cultivars available for commercial cultivation are susceptible to downy mildew or are resistant only to some of the races present in a country despite considerable effort spent in the search for resistance to *B. lactucae*, particularly focusing on field resistance and on new sources of resistance in wild *Lactuca* species (Crute 1992; Lebeda et al. 2007). Use of fungicides face the problem that few chemicals are registered in soilless cropping systems, therefore other methods for disease control need to be investigated.

Silicon (Si) amendments have proved effective in suppressing soil-borne, foliar and post-harvest pathogens on several crops, including turfgrass. Recently, researches demonstrated that application of various Si sources to rice plants increased resistance to blast, incited by *Pyricularia oryzae* (Ishiguro 2001). Silicon-mediated resistance to plant pathogens has also been demonstrated in several pathosystems, such as cucumber-*Podosphaera fuliginea* (Fawe et al. 1998; Liang et al. 2005), zucchini-*P. xanthii* (Savvas et al. 2009), wheat-*Blumeria graminis* (Bélanger et al. 2003), *Lolium perenne-Magnaporthe oryzae* (Nanayakkara et al. 2008), bell pepper-*Phytophthora capsici* (Lee et al. 2004). In the case of the pathosystem strawberry-*Sphaerotheca fuliginea*, Kanto et al. (2004) reported a suppressive effect of potassium silicate on powdery mildew of strawberry grown in hydroponic systems. Very recently, the reduction of tomato powdery mildew, incited by *Oidium neolycopersici* by potassium silicate has been reported on hydroponically grown tomato (Garibaldi et al. 2011). Si salt has been associated with disease resistance through its role in inducing the production and accumulation of antifungal low-molecular weight metabolites during pathogenesis (Fawe et al. 1998). Si induces the chemical defence of cucumber, similarly to systemic acquired resistance (SAR). In both cases, the defence potential of the plant is increased and maximally expressed following infection. However, Si-induced resistance is quickly lost, when the Si source is removed, while SAR is characterised by a long-lasting effect (Dalisay and Kuc' 1995).

To expand the use of Si to soilless crops other than those already studied in order to evaluate its effect on quality, specific information regarding the response, in terms of disease suppression, to the supply of this element via the nutrient solution is needed.

Lettuce is a major crop in most vegetable production areas of Italy, increasingly grown in soilless systems and downy mildew incited by *B. lactucae* is one of the most important diseases of this crop.

The objective of this work was to evaluate the effect of potassium silicate amendments to nutrient solution, of the increased EC and of the combination of both this factors for their effect on downy mildew incidence and severity in soilless lettuce. The efficacy of silicon amendments was tested under varying levels of electrical conductivity (EC) of the nutrient solutions.

Materials and methods

Growth and experimental conditions

Four trials (Table 1) were carried out at at Grugliasco (Torino), in a glasshouse belonging to Agroinnova. Potted lettuce plants cv. Cobham Green were maintained on benches in a glasshouse at temperatures ranging between 18 and 22°C. Details about irrigation delivery system and nutrient solutions used are described in Tables 1 and 2. The pots were placed over 6 channels of 6 m in length and 25 cm in width. Each hydroponic unit consisted of one channel connected to a storage tank (300 l) filled with the nutrient solution, automatically delivered to the plants with the aid of an electronic control unit program (Idromat 2, Calpeda S.p.a., Vicenza, Italy), at the timing, duration and volumes indicated under Table 1. In the standard nutrient solution (EC1), the components were added to the irrigation water obtained by reverse osmosis (model HIFLO2HB90, Culligan) at the concentrations reported in Table 2.

A closed soilless system with a slow sand filtration of nutrient solution was adopted in all the trials. In this fully automated system, the nutrient solution was

Table 1 Summary of the layout and operations of the different trials

	Trial			
	1	2	3	4
Location of the trial	Grugliasco (TO)	Grugliasco (TO)	Grugliasco (TO)	Grugliasco (TO)
Lettuce cultivar	Cobham Green	Cobham Green	Cobham Green	Cobham Green
Date of sowing	December 10, 2009	February 15, 2010	September 21, 2010	November 15, 2010
Date of transplant	December 24, 2009	February 24, 2010	October 1, 2010	December 1, 2010
Substrate	PerliteAgrilit3: peat Tecno 2 (Perlite Italiana, Milano, Italy; Turco srl, Savona, Italy) (1:1 v/v)	PerliteAgrilit3: peat Tecno 2 (Perlite Italiana, Milano, Italy; Turco srl, Savona, Italy (1:1 v/v)	PerliteAgrilit3: peat Tecno 2 (Perlite Italiana, Milano, Italy; Turco srl, Savona, Italy) (1:1 v/v)	PerliteAgrilit3: peat Tecno 2 (Perlite Italiana, Milano, Italy; Turco srl, Savona, Italy) (1:1 v/v)
Irrigation method	Drip	Drip	Drip	Drip
Irrigation time (hours of the day) and duration				
4 -7 -9 -11 a.m.	2 min	2 min	2 min	2 min
1 -3 -5 p.m.	3 min	3 min	3 min	3 min
8 - 12 p.m.	2 min	2 min	2 min	2 min
Temperature (°C) and RH%	18–22	20–24	21–24	19–22
	85–95	85–95	85–95	85–95
Nutrient solution tested [a]	EC1, EC2, EC1+ K_2SiO_3	EC1, EC2, EC1+ K_2SiO_3	EC1, EC2, EC3; EC1+ K_2SiO_3 EC2+ K_2SiO_3; EC3+ K_2SiO_3	EC1, EC2, EC3; EC1+ K_2SiO_3; EC2+ K_2SiO_3; EC3+ K_2SiO_3
Plants per replicate (Number replicate)	20 (3)	20 (3)	14 (4)	14 (4)
Date of artificial inoculation (and conidial concentration conidia ml^{-1})	January, 7, 2010 (1×10^5)	March 15, 2010 (1×10^5)	November 5, 2010; November 15, 2010 ($1–2\times10^5$)	January 14, 2011 (7×10^4)
End of trial	January 26, 2010	March 29, 2010	November 24, 2010	February 4, 2011

Table 2 Composition of the different nutrient solutions used

Nutrient solution tested	Component	mM	Electrical conductivity ($mScm^{-1}$)
EC1	NO_3^-	11.24	1.5–1.6
	NH_4^+	4.80	
	KH_2PO_4	0.75	
	K_2SO_4	0.75	
	Iron chelate EDTA	0.012	
	MgO	2.0	
	SO_3	2.0	
	B	0.20	
	Mo	0.001	
	Zn	0.15	
	CaO	3.1	
	Cu^{++}	0.05	
	Mn	0.25	
	K	12.20	
EC1+ K_2SiO_3	K_2SiO_3 (100 mg l^{-1})		1.5–1.6
EC2	EC1+NaCl (0.70 gl^{-1})		3.0–3.5
EC2+ K_2SiO_3	EC1+NaCl (0.70 gl^{-1})+ K_2SiO_3 (100 mg L^{-1})		3.0–3.5
EC3	EC 1+NaCl (0.95 gl^{-1})		4.0–4.5
EC3+ K_2SiO_3	EC1+ NaCl (0.95 gl^{-1})+ K_2SiO_3 (100 mg l^{-1})		4.0–4.5

pumped from the water storage tank, fed to the plants and left to drain back to the storage tank by gravity. The excess of nutrient solution was filtered with the slow sand method before being used for fertilization.

Three nutrient solutions, with different electrical conductivity (EC1 and EC2) and with the addition of potassium silicate (EC1+ K_2SiO_3) were applied starting from the transplant in trials 1 and 2. Three more nutrient solutions (EC2+ K_2SiO_3, EC3 and EC3+ K_2SiO_3) were applied in trials 3 and 4. The nutrient solutions were delivered by drip irrigation, by means of emitters (one per pot) at a flow rate of 6 l h^{-1}. The irrigation plan was revised according to the environmental conditions, mainly temperature.

The electrical conductivity in the low salinity nutrient solution (EC1), considered standard for lettuce grown hydroponically, was 1.5–1.6 mS cm^{-1}. The concentration of nutrients for EC2 and EC3 was identical to EC1, except that NaCl was added at rates of 0. 70 and 0.95 g l^{-1} to achieve electrical conductivities of 3.0–3.5 and 4.0–4.5 mS cm^{-1}, respectively. The nutrient solutions EC1+ K_2SiO_3, EC2+ K_2SiO_3, EC3+ K_2SiO_3 were prepared with 100 mg l^{-1} of potassium silicate (K_2SiO_3, 33.7–34.7%, Andrea Gallo S.r.l., Genoa, Italy). Since potassium silicate salt has a strong alkaline reaction, it was delivered to the nutrient solutions from a separate stock solution tank. The characteristics of the different nutrient solutions are summarized under Table 2.

The pH and EC values were regularly checked by means of portable instruments, pH meter and conductivimeter SevenGo DUO TM SG23 (Tettler, Toledo, Spain). The pH of all nutrient solutions was adjusted to 6.0 by using citric acid (Greengeo,Cuneo, Italy) (Table 2).

Fourteen-twenty plants per replicate respectively with three or four replicates per treatment were used. All replicates of the same treatment were managed similarly in terms of delivery, storage and disinfestation of drained nutrient solutions.

Two lettuce plants, cv. Cobham Green, were transplanted in each 18 cm-diam. plastic pots filled with a mix 50:50 v/v of perlite and peat (Tecno 2, Turco s.r.l., Albenga, Italy), pH 5.2–5.7.

Plants received standard agronomic treatments used by growers for pest management.

Inoculum preparation and artificial inoculation

Bremia lactucae conidia were sampled from young downy mildew colonies of naturally infected leaves of lettuce plants. Immediately before inoculation, infected leaves were shaken in 200 ml of sterile water containing 5 μl of Tween 20 and the obtained conidial suspension were adjusted with the aid of a haemocytometer to 7.0×10^4 to 2.0×10^5 conidia ml^{-1}. Inoculation was carried out by spraying the conidial suspension, with a laboratory spray bottle (20 ml of capacity), onto all the leaves of lettuce plants 14 to 45 days after the transplant, 0.5 ml of conidial suspension was applied to each plant. After the artificial inoculation, plants were kept covered with plastic, in order to maintain very high levels of relative humidity. A plastic sheet was placed over all the plants by using three iron supports (1.0 m high, 3.0 m wide and 6.0 m long) for each trial. The plastic sheets were placed on the iron support immediately after each artificial inoculation and maintained until the last assessment. The artificial inoculation was carried out once in trials 1 and 2, three times in trial 3 and two times in trial 4 (Table 1). In trial 3 and 4 the first inoculation, carried out 25 and 38 days after transplanting respectively, did not give symptoms within 7–11 days. For this reason a second inoculation was carried out in both trials on the same plants at 36 and 45 days from transplanting, respectively. The third inoculation was performed in trial 3, 46 days after transplant to increase disease severity.

Data collection and analysis

Plants were checked weekly for disease development. The percentage of lettuce leaves affected by *B. lactucae* (disease incidence) was evaluated. The evaluations were carried out by scoring 100 lettuce leaves per replicate. Disease severity was evaluated by using a disease index ranging from 0 to 5 (EPPO 2004), were 0 = healthy plant; 1 = 5% leaf area affected; 2 = 10.0% leaf area affected; 3 = 25% leaf area affected; 4 = 50% leaf area affected; 5 = >75% leaf area affected. The final disease rating took place 14–21 days after the artificial inoculation of the pathogen that was able to give symptoms, when plants were at the marketable stage and ready for harvest. Data were expressed as percentage of leaves infected (disease incidence) and percentage of leaf area with the signs of downy mildew (disease severity) by using the EPPO rating method (EPPO 2004).

Biomass, expressed as fresh weight, was evaluated at the end of trials 3 and 4 by weighting plants.

The data were analysed by univariate ANOVA with Tukey's multiple range test ($p=0.05$) using SPSS software 18.0. The General Linear Model was used to investigate the effect of each factor (EC and potassium silicate) and their interactions in each trial.

Results

Signs of downy mildew were first observed 10, 7 days after the artificial inoculation in trials 1, 2 and 6–7 days after the inoculations able to give disease in trials 3 and 4. Control lettuce plants, grown with EC1 standard nutrient solution, showed a final mean disease severity ranging from 15.8 to 21.8% in trials 1 and 2, with one single artificial inoculation with the pathogen (Tables 3 and 4). In trial 3, despite two artificial inoculations with the pathogen able to give symptoms, a lower disease severity (12.4%) was observed (Table 5). In trial 4, downy mildew symptoms were observed 7 days from the second inoculation, with a disease severity reaching 15.6% in plants grown with EC1 control nutrient solution (Table 6).

Table 3 Effect of the electrical conductivity (EC) and of potassium silicate on the incidence and severity of lettuce downy mildew, incited by *Bremia lactucae* expressed respectively as percentage of leaves infected and as percentage of leaf area affected (cv. Cobham green, trial 1, 2009)

EC	Silicate[a]	% infected leaves		% leaf area affected	
		26/01/10		26/01/10	
EC1[b]	No	52.0[c]	a	15.8	b
EC2	No	45.5	a	13.6	ab
EC1	Yes	28.0	a	7.0	a

[a] Potassium silicate at 100 mg l^{-1}

[b] EC1 Nutrient standard solution (See tables 1 and 2).

[c] The values of the same column, followed by the same letter do not differ significantly according to Tukey's test ($p=0.05$). According to the general linear model, EC was not a significant factor influencing disease incidence ($p=0.484$) and severity ($p=0.186$), while potassium silicate was significant for disease incidence ($p=0.033$) and severity ($p=0.002$).

Effect of the electrical conductivity on downy mildew development

The general linear model analysis confirmed for trial 1 that the addition of the NaCl salt to the control

Table 4 Effect of the electrical conductivity (EC) and of potassium silicate on the incidence and severity of lettuce downy mildew, incited by *Bremia lactucae* expressed respectively as percentage of leaves infected and as percentage of leaf area affected (cv. Cobham green, Trial 2)

EC	Silicate[a]	% infected leaves		% leaf area affected	
		29/03/2010		29/03/2010	
EC1[b]	No	46.7[c]	b	21.8	b
EC2	No	29.0	a	5.8	a
EC1	Yes	19.0	a	4.6	a

[a] Potassium silicate at 100 mg l^{-1}

[b] EC1 Nutrient standard solution (See Tables 1 and 2).

[c] The values of the same column, followed by the same letter do not differ significantly according to Tukey's test ($p=0.05$). According to the general linear model, EC and potassium silicate were a significant factor influencing disease incidence ($p=0.012$ and $p=0.001$) and severity ($p<0.0001$ and $p<0.0001$).

Table 5 Effect of electrical conductivity (EC) and of potassium silicate on the incidence and severity of lettuce downy mildew, incited by *Bremia lactucae* expressed respectively as percentage of leaves infected and as percentage of leaf area affected (cv. Cobham green, trial 3)

EC	Silicate[a]	% infected leaves		% leaf area affected	
		24/11/2010		24/11/2010	
EC1[b]	No	39.0[c]	b	12.4	bc
EC1	Yes	29.0[c]	ab	8.2	abc
EC2	No	51.0[c]	b	16.5	c
EC2	Yes	37.0[c]	b	10.4	bc
EC3	No	29.5[c]	ab	7.8	ab
EC3	Yes	6.5[c]	a	1.0	a

[a] Potassium silicate at 100 mg l^{-1}

[b] EC1 Nutrient standard solution (See Tables 1 and 2).

[c] The values of the same column, followed by the same letter do not differ significantly according to Tukey's test (p=0.05). According to the general linear model, EC and potassium silicate were a significant factor influencing disease incidence (p<0.0001 and p=0.002) and severity (p=0.001 and p=0.002), while their interaction was not significant for disease index (p=0.465) and severity (p=0.788).

nutrient solution EC1 was not a significant factor influencing disease incidence (p=0.484) and severity

Table 6 Effect of electrical conductivity (EC) and of potassium silicate on the incidence and severity of lettuce downy mildew, incited by *Bremia lactucae* expressed respectively as percentage of leaves infected and as percentage of leaf area affected (cv. Cobham green, trial 4)

EC	Silicate[a]	% infected leaves		% leaf area affected	
		04/02/2011		04/02/2011	
EC1[b]	No	45.5[c]	e	15.6	e
EC1	Yes	38.0	de	13.7	de
EC2	No	30[c]	cd	10.5	cd
EC2	Yes	21.5	bc	6.8	bc
EC3	No	14.5	ab	2.6	ab
EC3	Yes	10.0	a	1.3	a

[a] Potassium silicate at 100 mg l^{-1}

[b] EC1 Nutrient standard solution (See Tables 1 and 2).

[c] The values of the same column, followed by the same letter do not differ significantly according to Tukey's test (p=0.05). According to the general lineal model, EC and potassium silicate were a significant factor influencing disease incidence (p<0.0001 and p=0.01) and severity (p<0.0001 and p=0.014), while their interaction was not significant for disease index (p=0.592) and severity (p=0.490).

(p=0.186) (Table 3). The same analysis confirmed that the use of NaCl to increase EC at EC2 and EC3 levels was a significant factor (p<0.05) influencing disease spread and the percentage of leaf area affected by *B. lactucae* in trials 2, 3 and 4. In particular, downy mildew severity reduction was significant in trial 2, where it changed from 21.8% at EC1 control nutrient solution to 5.8% at EC2 level (Table 4). In trial 3, the reduction of leaf area affected from *B. lactucae* was significant only at the highest electrical conductivity tested and changed from 16.5% observed at EC2 level to 7.8% of the EC3 treatment, while no significant differences in disease severity were observed among EC1 and EC2 (Table 5). In trial 4, the reduction of disease severity compared with the EC1 control nutrient solution was partial but significant with EC2 (from 15.6 to 10.5%) and very good (from 15.6 to 2.6%) with EC3 (Table 6).

Effect of potassium silicate on downy mildew development

The general linear model analysis confirmed for all the trials that the addition of potassium silicate to the nutrient solutions EC1, EC2 and EC3 was a significant factor (p<0.05) influencing disease index and severity.

The addition of potassium silicate to the standard nutrient solution (EC1) resulted in trials 1 and 2 in significantly improved downy mildew management, in comparison to what observed for trials 3 and 4 (Tables 3, 4, 5 and 6). In trial 1, the addition of potassium silicate to EC1 nutrient solution significantly reduced disease severity at the last assessment from 15.8 to 7.0% (Table 3), while in trial 2 the reduction was from 21.8 to 4.6% (Table 4). In trial 2, when plants were artificially inoculated 20 days after transplant, the effect of adding potassium silicate to the control nutrient solution was the same as adding NaCl at 0.70 g l^{-1} to change the EC value (Table 4). The positive effect of potassium silicate was improved by adding the salt to the nutrient solutions having higher conductivity values (Tables 5 and 6). In the case of EC3 nutrient solution, the inclusion of potassium silicate significantly reduced disease severity at the final evaluation, from 12.4 to 1.0% in trial 3 and from 15.6 to 1.3% in trial 4, when compared with the EC1 control without NaCl and potassium silicate (Tables 5 and 6). A statistically similar disease control was given by EC3 amended with potassium silicate, or without the silicate salt, compared with EC1 control solution, when plants were artificially inoculated 45 days after transplant (Table 6).

Effect on biomass

In trials 3 and 4, when biomass was evaluated at the end of the trials, a significant increase of fresh weight was observed at EC 2 and EC3 values in the presence of potassium silicate. The highest biomass production was achieved in trial 3 (Table 7). Under increased EC level, yield of lettuce plants was not significantly different from what observed at EC1 control nutrient solution.

Discussion

In this work, the effect of increasing the value of electrical conductivity of the nutrient solution in soilless systems, of potassium silicate amendments and of the combination of both was evaluated against downy mildew of lettuce.

According to the general lineal model, EC was a significant factor influencing disease incidence and severity in trials 2, 3 and 4, while all the trials were significantly affected by the use of potassium silicate amendments. No interaction was found between these two factors. However, in the presence of an average to high downy mildew incidence, NaCl added at 0.70 g l^{-1} to EC1 provided a significant reduction in disease incidence and severity compared with the EC1 control solution in trial 2 and 4. In trial 4, where a long-term treatment before the artificial inoculation of lettuce plants was adopted, disease severity was significantly reduced from 15.6% recorded at EC1 to 10.5% (EC2) and 2.6% (EC3). The same trend was not observed in trial 3, probably because of the high disease pressure caused by the two artificial inoculations carried out. In trial 1, the EC factor was not significant probably because of a short-term of treatment of lettuce plants artificially inoculated 14 days after transplanting. The nutrient solution EC3, having a higher value of NaCl, tested in trials 3 and 4, resulted in a significant reduction of downy mildew incidence and severity.

Table 7 Effect of electrical conductivity (EC) and of potassium silicate on the yield at the end of the trial (cv. Cobham green, at the end of the trials)

EC	Silicate[a]	Fresh weight (g) in			
		Trial 3		Trial 4	
EC1[b]	No	677.0	b[c]	623.5	b
EC1	Yes	942.3	ab	726.3	ab
EC2	No	633.0	b	725.3	ab
EC2	Yes	787.0	b	841.8	a
EC3	No	749.3	b	783.0	ab
EC3	Yes	1181.8	a	771.5	ab

[a] Potassium silicate at 100 mg l^{-1}

[b] EC1 Nutrient standard solution (See Tables 1 and 2).

[c] The values of the same column, followed by the same letter do not differ significantly according to Tukey's test ($p=0.05$).

A higher reduction in disease incidence and severity was obtained with the simple addition to the nutrient solution EC1 of 100 mg l^{-1} of potassium silicate on lettuce plants artificially inoculated 14–20 days after transplanting. Disease suppression persisted over 15 days after inoculation. The level of disease control achieved by adding potassium silicate to the control nutrient solution (EC1) was higher in the short-term with treatment of lettuce plants artificially inoculated 14–20 days after transplanting and lower when a long-term treatment (38 and 45 days before the artificial inoculation of lettuce) was used. The addition of 100 mg potassium silicate l^{-1} to nutrient solution resulted in a significant and consistent reduction of downy mildew incidence and severity at EC2 and EC3 values.

Potassium silicate supplied via nutrient solution, at a concentration corresponding to 100 mg l^{-1}, to hydroponically grown lettuce, effectively reduced the incidence of downy mildew, incited by *B. lactucae*, in the presence of an average disease pressure on a variety susceptible to the disease.

The effects of Si salt in reducing the incidence and severity of several plant diseases on a number of crops have been known for some time (Fauteaux et al. 2005). Its ability to reduce the severity of powdery mildew has been demonstrated for a number of crops such as cucumber (Adatia and Besford 1986), strawberry (Kanto et al. 2004), barley (Wiese et al. 2005), wheat (Bélanger et al. 2003; Chain et al. 2009), zucchini (Savvas et al. 2009), muskmelon (Menzies et al. 1992), rose (Voogt 1992), dandelion (Bélanger et al. 1995) and tomato (Garibaldi et al. 2011). This study is the first one dealing with the management of a causal agent of downy mildew by potassium silicate amendments and increased EC nutrient solution.

Cherif et al. (1992) showed that cucumber was protected against fungal diseases by silicon provided in solution, not by polymerised or solid silicon. Many types of organic compounds and complexes show affinity to silicon (Epstein 2009). Fauteaux et al. (2006) examined the role of silicon in *Arabidopsis thaliana*: in plants affected with powdery mildew, numerous genes were differentially expressed, and silicon promoted that response.

Si is not usually classified as an essential element of higher plants (Epstein 1995). Many plant species accumulate Si in their tissues and its beneficial role in the nutrition of higher plants is well established (Epstein 2009). Si has been applied as an important fertilizer for rice crops (Ma et al. 2001). Many dicotyledonous plants seem to respond positively to an enhanced Si supply, especially when they are exposed to both abiotic and biotic stress conditions (Ma 2004; Fauteaux et al. 2005).

Si is currently applied to rice and other Poaceae crops as a fertilizer especially in Si-depleted soils (Epstein 2009). Silicon is generally abundant in soil, a sub-optimal supply of this element is more likely in soilless cultivation rather than in soil-grown crops. Therefore, Sonneveld and Straver (1994) have already recommended the inclusion of Si in nutrient solutions supplied to cucumber, melon and lettuce grown in water or substrates. The protective effect of Si against diseases as well as its positive effect on quality in saline conditions has been well documented for various plant species, including cucumber (Zhu et al. 2004), tomato (Al-Aghabary et al. 2004) and zucchini (Savvas et al. 2009). At high salinity, silicon increases both the fresh and dry mass of all plant parts, specifically roots, shoots, and fruits, thus implying a positive effect on whole-plant photosynthesis. Lettuce grown with high salinity level of nutrient solution showed an improvement in green colour with increased phenolics accumulation (Kim et al. 2008).

While there is evidences of the promoting effect of Si on the growth of monocotyledonous plants (Epstein 1995), a direct role of Si in the growth of horticultural crops is much less clearly established (Bélanger et al. 1995). Interpretation of data may be confounded by the fact that Si reduces the incidence of diseases such as powdery mildew, which would improve crop growth irrespective of any direct effect of Si on the crop. Further research is needed to determine whether a physiological role for Si exists in commercially important horticultural crops, particularly since most of these crops are grown soilless in presence of a concentration of Si usually lower than 10 mg l^{-1}. The nature of the production system is especially important in recirculating nutrient solution systems, where Si levels in the nutrient solution can become extremely low because of uptake by the crop (Bélanger et al. 1995).

In this study, the content of Si in treated lettuce plants was not evaluated. On other crops, when applied to cucumber via recirculating nutrient solution, Si accumulated in leaves (Adatia and Besford 1986) and improved water use efficiency as well as the Si content in fruit in the cv. Carosello (Buttaro et al. 2009). Si and lignin content were also significantly increased in Si-treated rice seedlings, inoculated with *Magnaporthe grisea* (Cai et al. 2008).

The cost of the Si treatment has been calculated as 0.09 Euro per 100 l^{-1} of nutrient solution. The addition of Si to the control nutrient solution appears a simple method and could be handled by growers.

The results of this study provide new, previously not exploited, insights for the control of a new class of foliar diseases of soilless grown crops. Simply increasing electrical conductivity is already permitted to achieve a partial control of lettuce downy mildew, particularly at the highest (EC 3) level. Even better results are provided by amendments of the nutrient solution with potassium silicate. At present, under practical conditions, growers adopt electrical conductivity levels corresponding to EC 1. Values corresponding to EC 2 and EC 3 adopted in this study could be easily implemented under commercial conditions on crops grown at temperatures between 18 and 24°C. Higher levels of NaCl also improve the quality of produce, as shown with Romain lettuce (Kim et al. 2008).

In our study, the effect of potassium silicate on lettuce yield, evaluated in two out of 4 trials, showed that the combination of increased values of electrical conductivity and amendments with potassium silicate led to an increased plant biomass.

Studies carried out on zucchini (Savvas et al. 2009) did not show a stimulatory effect of Si on plant growth. On roses, an increased supply of Si significantly enhanced the vegetative growth at different salinity levels, improving yield and quality (Savvas et al. 2007)

In conclusion, on lettuce the combination of nutrient solutions with increased electrical conductivity and amendments with potassium silicate permitted to achieve a very satisfactory control of downy mildew. The possibility of applying silicon to vegetable and ornamental crops grown hydroponically is of particular interest as the use of soilless systems is increasing and there is a scarcity of registered fungicides. Supplemented via nutrient solution, silicon may permit a reduction in the number of chemical sprays, being also compatible with an integrated disease management approach.

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