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Evaluation of Silicon Fertilizers and a Resistance Inducing Agent for Control of Apple and Pear Scab under Field Conditions

Glynn C. Percival

Abstract. Two field trials were conducted using established apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien') to assess the efficacy of a range of silicon (Si) fertilizers, a resistance-inducing (IR) agent based on salicylic acid and a combination of Si + IR when applied at four growth stages of tree development (i.e., bud break, green cluster, 90% petal fall, early fruitlet) against the foliar pathogens apple (*Venturia inaequalis*) and pear (*V. pirina*) scab. In addition, a comparative evaluation of a conventional synthetic fungicide (penconazole) used within the UK for apple and pear scab control was performed. Greatest protection against apple and pear scab was provided by a combination of a Si fertilizer + IR agent and the synthetic fungicide penconazole in both the 2014 and 2015 field trials where statistically comparable degrees of control were achieved. Efficacy as scab protectant compounds (i.e., reduced scab severity of leaves and fruit) enhanced leaf chlorophyll content and fruit yield, and was confirmed when each Si fertilizer was applied at four growth stages during two growing seasons; however, there was little difference in the degree of control conferred by each Si fertilizer. The IR agent used alone proved the least effective scab protectant compound.

Key Words. Apple Scab; Fungicide; Integrated Disease Management; Orchard Management; Pathogen Control; Pear Scab; Plant Health Care; Urban Landscapes.

Apple and pear scab caused by the fungal pathogens *Venturia inaequalis* and *V. pirina* respectively can be devastating to apples (*Malus* spp.) and pears (*Pyrus* spp.), reducing fruit quality, marketable yield, and aesthetics (Cuthbertson and Murchie 2003; Jamar et al. 2010; Hailey and Percival 2014). The scab fungi infect leaves, petioles, and fruit, with initial symptoms appearing as olive-green spots on the leaf or leaf petiole. As infection develops, leaves turn yellow and drop prematurely, while infected fruit becomes deformed, scabby, and can drop before maturity (Jamar et al. 2010). Within Europe, suppliers, vendors and growers of apples and pears adopt a zero-tolerance policy toward scab. As a result, the economics of fruit production require frequent application of synthetic fungicides throughout the growing season. Increased pathogen insensitivity to synthetic fungicides coupled with public demands to reduce use, stimulated by greater awareness of environmental and health issues has placed emphasis on the development of alternative control strategies (Gozzo 2003; Villalta et al. 2004; Percival and Haynes 2008; Hailey and Percival 2014).

The potential benefits of silicon (Si) nutrition in plants include enhancement of growth and yield; improvement of mechanical properties (soil penetration by roots, resistance to lodging); reduced transpiration; and resistance to drought, salt, and heavy metal toxicities (Fauteux et al. 2005). In addition, Si-based soil fertilizers and sprays have proved effective in controlling soilborne and foliar fungal pathogens of several plant species (Ma 2004). In rice, for example, Si has been demonstrated to control rice blast, (*Magnaporthe grisea*, anamorph = *Pyricularia grisea*), as effectively as commercially available fungicides as well as reduce the number of fungicide applications (Datnoff et al. 2001; Seebold et al. 2004). Studies of the influence of Si fertilizers on gray leaf spot development in St Augustine grass under greenhouse conditions demonstrated that Si significantly reduced disease progress by 44% to 78%, and whole-plant infection by 2.5% to 50.5%.

(Datnoff and Nagata 1999). Si fertilizers also have been shown to reduce the incidence of powdery mildew in Kentucky bluegrass (Hamel and Heckman 2000), improve disease resistance in zoysia grass to *Rhizoctonia solani* (Saigusa et al. 2000) and creeping bentgrass to *Pythium aphanidermatum*, *Sclerotinia homoeocarpa* and *R. solani* (Schmidt et al. 1999; Rondeau 200l; Uriarte et al. 2004).

Induced resistance (IR) is the phenomenon whereby a plant's own defense mechanisms are induced by treatment with a biological (i.e., weakened or attenuated fungal pathogen) or chemical agent (i.e., inorganic potassium and phosphate salts, low molecular weight proteins, unsaturated fatty acids; (Bécot 2000; Fobert and Després 2005; Percival et al. 2009). Developments in plant protection technology have led to the formulation of a range of commercially available IR compounds such as harpin protein, potassium phosphite, and a range of salicylic acid analogs that are registered for commercial use within the horticultural industry, although their availability differs between countries (Percival and Haynes 2008). Studies show that IR compounds can reduce disease severity of fungal pathogens such as *Venturia inaequalis* and *V. pirina* with the level of pathogen suppression, on occasion, comparable with synthetic fungicides (Christiansen et al. 1999; Bernards and Bastrup-Spohr 2008; Percival et al. 2009). The potential of Si fertilizers singly and in combination with an inducing agent to manage scab diseases of trees has received little study. The majority of studies investigating the efficacy of IR agents on pathogen suppression were conducted under controlled laboratory and glasshouse conditions that do not reflect field environments (Agnostini et al. 2003; Percival et al. 2009). The purpose of this study was to investigate the association of Si fertilizers singly and in combination with an IR agent as scab-protective compounds, using scab-sensitive species of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien').

MATERIALS AND METHODS

Field Trials

The apple trial site consisted of a 0.75 ha block of apple (*Malus* cv. Golden Delicious) interspersed with individual trees of *Malus* Red Delicious and Gala as pollinators. The pear trial site consisted of a 0.90 ha block of *Pyrus communis* 'Williams' Bon Chrétien' interspersed with individual trees of *Pyrus communis* Beth and Concorde. Planting distances were 2 m × 2 m spacing. Trees were planted in 2003 and trained under a central-leader system to an average height of 2.5 m ± 0.25 m with mean trunk diameters of 12 cm ± 1.4 cm at 45 cm above the soil level. The trial sites were located at the University of Reading Shinfield Experimental Site, Berkshire, UK (51°43N, -1°08W).

The soil was a sandy loam containing 4%–6% organic matter; pH of 6.2; and available P, K, Mg, Na, and Ca were 52.0, 659.1, 175.2, 49.4, and 2,188 mg l^{-1}, respectively. Weeds were controlled using glyphosate (Roundup®; Green-Tech, Sweethills Park, Nun Monkton, York, UK). No watering or fertilization was applied during the two-year trial. *Venturia inaequalis* and *V. pirina* occur every year due to monocultures in the experimental area where the experiments were carried out. Prior to studies commencing in 2014 and 2015, trees were inspected in September 2013 and 2014, and only those trees with >50% of leaves affected with severe foliar discoloration, and scab infection were used. A minimal insecticide program, based on deltamethrin (Bandu, Headland Agrochemicals Ltd, Saffron Walden, Essex, UK), was applied every two months from May 2014 to September 2015. All sprays were applied using a Tom Wanner Spray Rig sprayer at 40 ml deltamethrin per 100 l^{-1} of water. Trees were sprayed until runoff, 0.30 l^{-1} insecticide per tree.

Silicon and IR Treatments

Treatments were applied at four distinct growth stages (Bevan and Knight 2001), namely: bud break (07 March 2014, 18 March 2015), green cluster (01 April 2014, 06 April 2015), 90% petal fall (08 May 2014, 21 May 2015), and early fruitlet (03 June 2014, 14 June 2015). Prior to each treatment, trees were inspected and no symptoms of apple or pear scab were apparent. During spray treatments, polythene screens 2.5 m high were erected around each tree to prevent spray drift and cross contact with other trees. The base of the tree was covered with a 0.5 m × 0.5 m polythene mulch to prevent potential soil percolation. The treatments, 1 IR compound, 1 fungicide, 4 silicon fertilizers × 4 spray times were applied in 10 randomized complete blocks plus a water control with a single tree as the experimental unit, giving a total of 60 observations per response variable. Foliar sprays of each Si fertilizer, IR agent, and penconazole were applied until runoff using a 10 liter knapsack sprayer (Cooper Pedlar, Agratech NW Ltd, Waterfoot, Rossendale, UK) at:

- Topas (a.i. penconazole): 1.5 ml l^{-1} of water (Syngenta Crop Protection UK Ltd, Whittlesford, Cambridge, UK).
- Rigel (a.i. Polyether modified trisiloxane + Salicylaldehyde): 3 ml l^{-1} of water (Orion Future Technology Ltd, Henwood House, Henwood, Ashford, Kent, UK).
  - ► Equivalent to 7 g Si per liter of water
- Sirius (Tetraethyl orthosilicate [Si $(OC_2H_5)_4$]): 10 ml l^{-1} of water (Orion Future Technology Ltd, Henwood House, Henwood, Ashford, Kent, UK).
  - ► Equivalent to 7 g Si per liter of water
- Fossil (polyether modified trisiloxane): 10 ml l^{-1} of water (Orion Future Technology Ltd, Henwood House, Henwood, Ashford, Kent, UK).
  - ► Equivalent to 7 g Si per liter of water
- Salicylaldehyde (Sigma-Aldrich, Gillingham, Dorset, UK)
- Sil-MATRIX (Potassium silicate) 10 ml l^{-1} of water (Certis Granta Park, Riverside, Great Abington, Cambridge, UK)

Tree Vitality

Leaf chlorophyll measurements

To keep the age of the leaves comparable throughout the experiment, measurements of chlorophyll content (SPAD) were made only on fully expanded mature leaves. In all cases measurements were taken from six leaves (two from the top of the crown, two in the center, and two at the base) per tree. A chlorophyll meter was used (SPAD-502 Chlorophyll Meter, Konica Minolta Sensing Europe B.V.). Chlorophyll was measured at the midpoint of the leaf next to the main leaf vein. Calibration was obtained by measurement of absorbance at 663 and 645 nm in a spectrophotometer (PU8800 Pye Unicam) after extraction with 80% v/v aqueous acetone (regr. eq. = 5.75 + 0.055x; r^2 adj = 0.96, $P \leq 0.001$) (Lichtenthaler and Wellburn 1983).

Scab severity

Scab severity of leaves and fruit was assessed 28 September 2014 and 28 September 2015. Leaf scab severity of each tree was rated using a visual indexing technique and ratings on the scale: 0 = No scab observed; 1 = less than 5% of leaves affected and no aesthetic impact; 2 = 5%–20% of leaves affected with some yellowing but little or no defoliation; 3 = 21%–50% of leaves affected, significant defoliation and/or leaf yellowing; 4 = 51%–80% of leaves affected, severe foliar discoloration; 5 = 81%–100% of leaves affected with 90%–100% defoliation. Scab severity on fruit was calculated on the scale: 0 = no visible lesions; 1 = <10% fruit surface infected; 2 = 10%–25% fruit surface infected; 3 = 25%–50% fruit surface infected; 4 = >50% fruit surface infected. The individual ratings for each tree in each treatment were used as a measure of scab severity for statistical analysis. Leaf scab severity ratings used in this study was based on UK and Ireland market standards for fungicide evaluation of scab control (Butt et al. 1990; Swait and Butt 1990). Fruit scab severity was based a scale used by Ilhan et al. (2006).

Fruit Yield

Yield per tree was determined by weighing all fruit on each tree at harvest and dividing by the number of trees per treatment.

Silicon Analysis

Ten leaves and three fruits per tree were collected for tissue Si analysis. The leaves and fruit per tree were pooled for randomization purposes, washed with deionized water, and then placed in an oven for three days at 70°C. Dried leaves and fruit were then ground to pass through a 40-mesh screen. Leaf tissue Si concentration was determined following the method of Elliott and Snyder (1991). Leaves were ashed on platinum dishes and ash mixed with Na_2CO_3 and H_3BO_3 (5:1) to melt. Aliquot product was dissolved in HCl solution and transferred to a volumetric flask. Ammonium molybdate, tartaric acid, and ascorbic acid were added to this solution, and the absorbance of the solution measured at 420 and 655 nm using a spectrophotometer (UV-1600; SHIMAZDU Co., Kyoto, Japan). The silica content was calculated per unit area and on a dry weight basis by comparing the absorbance with standard silicon solutions (10–1000 ppm).

Statistical Analysis

Mean pathogen severity values for all treatments were transformed using the Arcsin (sine $^{-1}$) transformation. All data were analyzed using ANOVA and the differences between means were determined using Tukey *w* procedure (P = 0.05), Genstat® for Windows® program. Back transformed pathogen severity values are presented here to ease interpretation of data (Blaedow et al. 2006).

RESULTS

Damaging outbreaks of apple and pear scab were recorded on foliage of control trees in both the 2014 and 2015 trials as indicated by leaf scab severity ratings of 4.8 and 5.0 on *Malus* cv. Golden Delicious, and 3.4 and 3.4 on *Pyrus communis* 'Williams' Bon Chrétien' at the end of the 2014 and 2015 growing season, respectively (Table 1; Table 2). None of the treated or control trees died as a result of scab attack during the course of the two-year study (data not shown).

Efficacy as scab-protectant compounds (i.e., reduced scab severity of leaves and fruit) enhanced leaf chlorophyll content and fruit yield was confirmed when penconazole (synthetic fungicide), salicylaldehyde (IR agent), Sil-MATRIX, Fossil, Sirius (Si fertilizers), and Rigel (Si fertilizer + IR agent) were applied at four growth stages during two growing seasons (Table 1; Table 2; Table 3; Table 4). In most instances, these effects were statistically significant (P < 0.05; Table 1; Table 2; Table 3; Table 4). Maximal reductions in apple and pear scab severity on leaves and fruit was recorded following application of the synthetic fungicide penconazole and a combination of a polyether modified trisiloxane (Si fertilizer) + salicylaldehyde (IR agent; Trade name Rigel) (Tables 1 and 2). In all cases there was no sta-

Table 1. Selected silicon fertilizers and inducing agents applied by foliar sprays compared for the control of *Venturia inaequalis* and *V. pirina* on leaves of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien'), respectively, as measured by an observed leaf scab severity index[z].

Treatment	Apple scab severity on leaves[y]		Pear scab severity on leaves[y]	
	2014	2015	2014	2015
Water (control)	4.8a	5.0a	3.4a	3.4a
Sil-MATRIX (10 ml liter of water)	2.7bc	3.0bc	2.4b	2.4b
Salicylaldehyde	3.0b	3.2b	2.2b	2.4b
Fossil (10 ml liter of water)	2.3bc	2.2bcd	1.9b	2.0bc
Sirius (10 ml liter of water)	2.3bc	2.4bcd	1.8b	2.0bc
Rigel (3 ml liter of water)	1.6cd	1.8de	1.6bc	1.4cd
Topas (1.5 ml liter of water)	0.4d	0.8e	0.8c	1.0d
Treatment	<0.001	<0.001	<0.001	<0.001

[z] Scab severity index: 0 = no scab observed; 1 = less than 5% of leaves affected and no aesthetic impact; 2 = 5%–20% of leaves affected with some yellowing but little or no defoliation; 3 = 21%–50% of leaves affected, significant defoliation, and/or leaf yellowing; 4 = 51%–80% of leaves affected, severe foliar discoloration; 5 = 81%–100% of foliage affected with 90%–100% defoliation.
[y] Mean of ten randomized complete blocks with one tree per block.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test (P = 0.05).

Table 2. Selected silicon fertilizers and inducing agents applied by foliar sprays compared for the control of *Venturia inaequalis* and *V. pirina* on fruit of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien'), respectively, as measured by an observed scab severity index[z].

Treatment	Apple scab severity on fruit[y]		Pear scab severity on fruit[y]	
	2014	2015	2014	2015
Water (control)	2.3a	2.5a	2.1a	1.8a
Sil-MATRIX (10 ml liter of water)	1.9ab	1.8ab	1.5b	1.3b
Salicylaldehyde	1.4bc	1.6b	1.4bc	1.4ab
Fossil (10 ml liter of water)	1.5bc	1.2bc	1.2bc	1.0bc
Sirius (10 ml liter of water)	1.2cd	1.5bc	0.9cd	1.1bc
Rigel (3 ml liter of water)	0.7de	0.9cd	0.6d	0.7c
Topas (1.5 ml liter of water)	0.2e	0.4d	0.4d	1.0c
Treatment	<0.001	<0.001	<0.001	0.001

[z] Scab severity index: 0 = no scab observed; 1 = less than 5% of leaves affected and no aesthetic impact; 2 = 5%–20% of leaves affected with some yellowing but little or no defoliation; 3 = 21%–50% of leaves affected, significant defoliation, and/or leaf yellowing; 4 = 51%–80% of leaves affected, severe foliar discoloration; 5 = 81%–100% of foliage affected with 90%–100% defoliation.
[y] Mean of ten randomized complete blocks with one tree per block.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test (P = 0.05).

tistically significant ($P < 0.05$) differences between these two treatments. The mean over two growing seasons reductions in leaf and fruit scab severity ranged from 62.5%–91.6% and 60.8%–91.3% (*Malus* cv. Golden Delicious) and from 52.9%–76.4% and 52.4%–81.0% (*P. communis* 'Williams' Bon Chrétien' respectively (Table 1; Table 2). The mean over two growing seasons increased in leaf chlorophyll content (SPAD values) and fruit yield per tree (kg), and ranged from 47.3%–64.1% and 46.1%–65.4% (*Malus* cv. Golden Delicious) and from 36.6%–53.4% and 40.0%–53.3% (*P. communis* 'Williams' Bon Chrétien', respectively (Table 3; Table 4).

Applications of each Si fertilizer namely; tetraethyl orthosilicate $[Si (OC_2H_5)_4]$ (Trade name Sirius), polyether modified trisiloxane (Trade name Fossil), potassium silicate (Trade name Sil-MATRIX) reduced leaf and fruit scab severity by 37.5%–54.1% and 20.8%–50.0% (*Malus* cv. Golden Delicious) and by 29.4%–47.1% and 23.1%–53.8% (*Pyrus communis* 'Williams' Bon Chrétien'), respectively, when averaged over both growing seasons (Table 1; Table 2). Improvements in leaf chlorophyll content SPAD values ranged from 15.4%–49.2% (*Malus* cv. Golden Delicious) and 9.0%–21.0% (*Pyrus communis* 'Williams' Bon Chrétien') (Table 3), while improvements in *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien' fruit yield (kg per tree) ranged from 5.5%–27.3% and 17.3%–34.5%, respectively, compared to water-treated control trees when averaged over two growing seasons (Table 4). Of all the products evaluated, the IR agent salicylaldehyde proved the least effective scab-protectant compound reducing leaf and fruit scab severity by 36.7% and 37.5% (*Malus* cv. Golden Delicious) and 32.4% and 28.2% (*Pyrus communis* 'Williams' Bon Chrétien'), respectively, when averaged over two growing seasons (Table 1; Table 2). Improvements in leaf chlorophyll content SPAD values and fruit yield (kg per tree) were, however, comparable with all Si treatments with values of 23.1% (*Malus* cv. Golden Delicious) and 12.9% (*Pyrus communis* 'Williams' Bon Chrétien') and 10.9% and 18.1%, respectively, recorded com-

Table 3. Selected silicon fertilizers and inducing agents applied by foliar sprays compared for the control of *Venturia inaequalis* and *V. pirina* on fruit of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien') respectively as measured by leaf chlorophyll content SPAD values.

Treatment	Apple scab SPAD[z]		Pear scab SPAD[z]	
	2014	2015	2014	2015
Water (control)	24.5a	27.3a	29.2a	32.2a
Sil-MATRIX (10ml liter of water)	30.0ab	32.4ab	33.8ab	37.5ab
Salicylaldehyde	31.8b	33.2abc	34.1abc	36.4ab
Fossil (10 ml liter of water)	34.0b	37.1bcd	35.5abc	34.9a
Sirius (10 ml liter of water)	31.2a	38.8bcd	36.9bc	37.2ab
Rigel (3 ml liter of water)	36.1b	39.4cd	39.9bc	42.6bc
Topas (1.5 ml liter of water)	36.4b	40.2d	41.4c	44.8c
Treatment	0.035	0.044	0.031	0.050

[z] Mean of ten randomized complete blocks with one tree per block. Ten leaves per tree were randomly selected throughout the crown for chlorophyll content measurements, and the mean calculated per tree for statistical purposes.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test ($P = 0.05$).

Table 4. Selected silicon fertilizers and inducing agents applied by foliar sprays compared for the control of Venturia inaequalis and *V. pirina* on mean fruit yield of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien'), respectively.

Treatment	Apple scab yield/tree (kg)[z]		Pear scab yield/tree (kg)[z]	
	2014	2015	2014	2015
Water (control)	5.2a	5.9a	6.0a	5.6a
Sil-MATRIX (10 ml liter of water)	5.8ab	7.0ab	7.2ab	6.8ab
Salicylaldehyde	6.0ab	6.2a	6.8a	6.9ab
Fossil (10 ml liter of water)	5.8ab	6.6ab	7.4abc	7.4bc
Sirius (10 ml liter of water)	6.4b	6.7ab	7.3ab	7.8bcd
Rigel (3 ml liter of water)	7.9c	7.6b	8.8c	9.2d
Topas (1.5 ml liter of water)	8.6c	7.8b	8.4c	8.4cd
Treatment	0.030	0.045	0.050	<0.022

[z] Mean of ten randomized complete blocks with one tree per block.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test ($P = 0.05$).

pared to water-treated control trees when averaged over two growing seasons (Table 3; Table 4).

In all cases, application of a Si fertilizer (i.e., Sil-MATRIX, Fossil, Sirius, Rigel) significantly ($P < 0.05$) increased leaf and fruit Si content in both *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien' compared to water treated controls. However, there was no major difference in the level of Si content recorded between each Si fertilizer (Table 5; Table 6). Within leaf tissue of *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien', Si content increased by 36.2%–58.5% and 34.5%–53.4%, respectively (Table 5). Within fruit tissue of *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien', Si content increased by 57.0%–104.2% and 76.9%–107.4%, respectively (Table 6). Application of penconazole or salicylaldehyde had no significant effect on leaf and fruit Si content of both *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien' where values were statistically comparable to controls. (Table 5; Table 6).

DISCUSSION

A significant body of literature exists that describes Si nutrition as reducing the intensity of fungal diseases in peach, grape, barley, corn, rice, rye, strawberry, and wheat (Datnoff et al. 2007; Resende et al. 2012). However, few studies have investigated increased host resistance to scab epidemics promoted by Si under field conditions. Some authors suggest that mechanical or physical barriers promoted by Si deposition in cell walls contributes to enhanced resistance (Kim et al. 2002; Hayasaka et al. 2008). For example, Si application led to a pronounced cell silicification in rice leaves and more elaborate and larger papillae, with the authors concluding that the elaborate papillae formed in Si-treated leaf epidermal surface might increase host resistance to fungal penetration (Zhang et al. 2006; Cai et al. 2008). In addition, enhanced Si layers were observed in Si-treated plant epidermal cell walls, increasing wall thickness and conferring enhanced host resistance. Further studies have shown enhanced cuticular Si layer development on plants supplemented with Si fertilizers constituted a phys-

Table 5. The influence of silicon fertilizers and inducing agents applied by foliar sprays on silicon content (mg/kg) of leaves of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien').

Treatment	Apple[z]		Pear[z]	
	2014	2015	2014	2015
Water (control)	22.8a	26.4a	26.2a	20.1a
Sil-MATRIX (10 ml liter of water)	35.3b	38.1b	34.8b	31.2b
Salicylaldehyde	23.7a	23.9a	24.2a	18.7a
Fossil (10 ml liter of water)	36.0b	35.2b	35.0b	32.8bc
Sirius (10 ml liter of water)	36.5b	39.0b	35.6b	34.6bc
Rigel (3 ml liter of water)	33.5b	37.2b	33.3b	35.5c
Topas (1.5 ml liter of water)	20.1a	24.1a	22.8a	19.5a
Treatment	0.001	0.001	0.001	0.001

[z] Mean of ten randomized complete blocks with one tree per block. Ten leaves per tree were randomly selected throughout the crown for Si analysis.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test ($P = 0.05$).

Table 6. The influence of silicon fertilizers and inducing agents applied by foliar sprays on silicon content (mg/kg) of fruit of apple (*Malus* cv. Golden Delicious) and pear (*Pyrus communis* 'Williams' Bon Chrétien').

Treatment	Apple[z]		Pear[z]	
	2014	2015	2014	2015
Water (control)	15.0a	13.4a	14.6a	12.3a
Sil-MATRIX (10 ml liter of water)	26.1bc	24.8b	27.9b	23.8b
Salicylaldehyde	16.8a	15.3a	13.9a	14.6a
Fossil (10 ml liter of water)	22.3b	27.0b	25.0b	25.0bc
Sirius (10 ml liter of water)	26.5bc	25.8b	24.3b	27.1bc
Rigel (3 ml liter of water)	29.0c	26.1b	27.2b	27.5c
Topas (1.5 ml liter of water)	17.4a	12.4a	14.0a	14.1a
Treatment	0.001	0.001	0.001	0.001

[z] Mean of ten randomized complete blocks with one tree per block. Three fruits per tree were randomly selected throughout the crown for Si analysis.
Note: Lowercase letters indicate significant differences between means for each evaluation date by Tukey highly significance test ($P = 0.05$).

ical barrier to impede fungal penetration and colonization (Kim et al. 2002; Hayasaka et al. 2008). Other studies, suggest that Si plays a biochemical role (i.e., Si-induced accumulation of phenolic compounds, phytoalexins, lignin, and peroxidase) in mediating plant resistance to pathogens (Rodrigues et al. 2003; Liang et al. 2005; Sun et al. 2010). In the current study, a significant increase in leaf and fruit Si content was recorded in both *Malus* cv. Golden Delicious and *Pyrus communis* 'Williams' Bon Chrétien' following application of any of the Si fertilizers. Such a response is consistent with other findings following application of Si fertilizers to peach, grape, kiwi, as well as several economically important grain and grass crops (Catherine Keller and Meunier 2012). Enhanced Si content in leaves and fruit suggests that Si-enhanced scab resistance maybe partially caused by the role of Si as a physical barrier (Sun et al. 2010), coupled with promotion of inherent biochemical plant defense systems in apple and pear not investigated here.

Penconazole applied at bud break, green cluster, petal fall, and early fruitlet formation was highly effective in reducing apple and pear scab severity of fruit and leaves. The effectiveness of penconazole against apple and pear scab under laboratory and field conditions has been confirmed elsewhere (Schnabel and Parisi 1997; Percival et al. 2009). However, due to the development of triazole-insensitive strains of scab, greater emphasis on alternative scab management strategies is now warranted (Gozzo 2003; Vallad and Goodman 2004; Fobert and Després 2005; Witzell and Martin 2008). The phenomenon of inducing resistance in plants by biological, natural, and/or inorganic compounds potentially offers an alternate approach to scab management (Hammerschmidt 2003; Percival and Haynes 2008; Percival et al. 2009; Hailey and Percival 2014). Consequently, developments in plant protection technology have focused on the production of commercially available IR agents. In this study, the IR agent salicylaldehyde reduced leaf and fruit scab severity by ca. 37.0% (*Malus* cv. Golden Delicious) and 30% (*Pyrus communis* 'Williams' Bon Chrétien'). Salicylic acid (SA) and SA derivatives are phenolic-based compounds found in a wide range of plant species that directly or indirectly influence plant metabolism. Application of SA to plants induces synthesis of low-molecular-weight (LMW) compounds (phenolics, terpenoids, alkaloids) that possess toxic, antimicrobial, anti-nutritive, and anti-digestive activity (Facchini 2001; Vallad and Goodman 2004; Fauteux et al. 2005; Keeling and Bohlmann 2006; Bernards and Bastrup-Spohr 2008; Witzell and Martin 2008). Consequently, stimulation and elevated concentrations of these compounds within plant tissue can significantly contribute to reduced severity of fungal, bacterial, and viral pathogens (Bokshi et al. 2003; Sparla et al. 2004).

Results of this study demonstrate that the commercially available Si fertilizer Rigel (a.i. Polyether modified trisiloxane + Salicylaldehyde) was as effective a scab protectant product as penconazole. In all cases, reductions in scab leaf and fruit severity and enhancement of leaf color and fruit yield were statistically comparable to penconazole when applied four times from bud break to early fruitlet formation. In comparison to all other Si fertilizers evaluated in this study and the IR agent salicylaldehyde alone, a combination of Si + IR proved superior to Si or IR applied individually. Consequently, this indicates additive and/or synergistic effects when combining an Si fertilizer with an IR agent. From a commercial aspect, producers, suppliers, and vendors of apples generally adopt a low-tolerance policy toward apple and pear scab on fruit (Butt et al. 1990). Combining a Si + IR agent reduced scab levels to those achieved using penconazole, a synthetic fungicide. Such a result would prove of interest to professionals involved in the production, supply, and/or consumption of apple and pear especially where fruit produce is sold under an organic or naturally produced label, as scab severity levels tend to be less stringent (Bevan and Knight 2001) while ornamental apples planted for aesthetic reasons within town and city landscape industry, lower scab levels are also acceptable (Percival et al. 2009). Because of their mode of action, aimed at enhancing the physical and biochemical defense mechanisms of treated host plants rather than at directly arresting or killing a fungal disease agent, an Si fertilizer + IR agent potentially offers opportunities for the control of other fungal pathogens in natural ecosystems. As effects are mostly on the plant itself, unlike with a synthetic fungicide, little, if any, consequences on the existing tree microbial community exist.

In addition, Si fertilizers and/or IR agents are potential candidates for treatment in natural ecosystems because they have extremely low toxicity to invertebrates, aquatic organisms, or animals, including humans, compared to synthetic fungicides (Vlad and Goodman 2004; Garbelotto et al. 2007). Finally, Si fertilizers and/or IR agents can be incorporated into an integrated pest management system and/or be used preventatively to bolster general plant health (Sparla et al. 2004; Walters 2009; Percival 2016). In these instances, the reductions in scab severity recorded in this investigation may warrant the use of an Si fertilizer and/or IR agents as an alternative or compliment to conventional synthetic fungicides.

In conclusion, the results of this study provide some evidence that Si fertilizers and/or IR agents individually or in combination could potentially play a useful role as an alternative and/or supplementary method of apple and pear scab management under field and/or landscape conditions, provided four sprays are applied from bud break to early fruitlet formation.

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Glynn C. Percival
R.A. Bartlett Tree Research Laboratory
Cutbush Lane
Shinfield, University of Reading
Reading, RG2 9AF UK
gpercival@bartlettuk.com