Selection of Antagonist Microorganisms Against *Helminthosporium solani*, Causal Agent of Potato Silver Scurf

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ABSTRACT

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Silver scurf, caused by the fungus *Helminthosporium solani*, is an important disease affecting potato tubers. Control of the disease has been hampered by the development of *H. solani* strains resistant to thiabendazole, the only fungicide used in postharvest treatment. As a result, alternative control strategies are needed. In this study, 100 selected soil samples from the province of Québec were tested for their effect on silver scurf development on potato tubers. The results showed that 10 soils were able to decrease silver scurf development on tubers incubated at 10, 15, or 24°C. Many microorganisms were isolated from these soils and tested for their individual ability to reduce *H. solani* development using a whole-tuber assay. Several of them, including *Alcaligenes piechaudii*, *Aquaspirillum autotrophicum*, *Arcanobacterium haemolyticum*, *Arthrobacter oxydans*, *Bacillus mycoides*, *Kocuria rosea*, *Streptomyces griseus*, and a fungus of the class Zygomycetes displayed an ability to reduce the development of silver scurf on potato tubers at 10, 15, or 24°C. These results can find useful applications toward a biocontrol program of potato silver scurf as postharvest or seed tuber treatment.

Additional keywords: actinomycetes, bacteria, biocontrol, fungi

Silver scurf of potato (*Solanum tuberosum* L.) is a surface-blemishing disease spoiling the appearance of potato tubers (29). The disease is caused by the fungus *Helminthosporium solani* Durieu & Mont. (15). Infection often takes place during the growing season from infected seed tubers (14,31). Disease severity increases greatly during long-term storage of tubers due to lesion expansion and repeated cycles of sporulation and infection (26). Silver scurf-infected tubers are characterized by metallic discoloration of the periderm in irregular patterns (31). Portions of tuber periderm may eventually slough off and cause fresh weight loss during storage (26).

Long recognized as a disease of minor importance, silver scurf, which is present in most potato-growing areas (15), has become a leading cause of rejection of commercial potatoes in recent years (12,32). Some of the reasons explaining the dramatic increase in economic importance of silver scurf include: (i) development of *H. solani* resistance to thiabenda-

zole which formerly provided control as a postharvest treatment (21,22,28,31), (ii) the increasing market for washed potatoes in transparent plastic bags (25), and (iii) lowered tolerance for defects (31).

Potato cultivars resistant to *H. solani* do not exist (31) and cultural methods alone are not sufficient to effectively control the disease; therefore, biocontrol of this pathogen with antagonist microorganisms could become an interesting alternative or complement to thiabendazole application. To date, very little information pertains to the biocontrol of this pathogen, although the application on potato tubers of *Pseudomonas corrugata* (5), *P. putida*, *Xanthomonas campestris*, and *Nocardia globerula* (10) have been reported to limit silver scurf development. Secor and Gudmestad (31) identified a species of *Cephalosporium* as a mycoparasite of *H. solani* that may be useful as a biocontrol agent to reduce spread of disease during storage.

As a part of an ongoing research program on soils suppressive against potato silver scurf, the objective of this study was to characterize soil samples for their suppressiveness against silver scurf and to isolate from them microorganisms showing antagonism against *H. solani*.

MATERIALS AND METHODS

H. solani (strain ulaval-1), isolated from a potato tuber, was used in this study. The

fungus was grown at 24°C on V8 agar containing, per liter of distilled water, 200 ml of clarified V8 juice (Campbell's Soup Company Ltd, Toronto, Ontario), 3 g of CaCO₃, and 15 g of bacto agar (Difco Laboratories, Becton Dickinson, Sparks, MD). The pH was adjusted to 7.2. Stock cultures were maintained in slants at 4°C.

Potato tubers (cvs. Dark Red Norland, Red Ruby, and Cherry Red) were produced in sterile peat-vermiculite mix in a greenhouse (Semences Saguenois Inc., Petit Saguenay, Canada). Potato tubers were stored at 4°C in the dark. Selected tubers were gently washed with distilled water.

One hundred soils used for potato culture throughout the province of Québec (Canada) were selected. The selection was based on a survey suggesting that potato tubers produced in those fields showed fewer symptoms of silver scurf. Soils 1 to 8 (St-Ambroise area), 9 to 23 (Pérignonka), 50 to 54 (Ste-Brigitte), and 61 to 65 (St-Ubalde) were sandy loam. Soils 24 to 26 (Mistassini), 45 to 49 (Lyster), and 55 to 60 (Hérouxville) were fine sand. Soils 66 to 90 (St-Amable) were loamy fine sand. Soils 27 to 44 (St-Jean), 91 to 95 (St-Michel), and 96 to 100 (Rawdon) were sandy clay loam. From each field, several soil cores, at a 10- to 20-cm depth, were randomly collected, then mixed to have a representative sample. Soil samples were stored at 4°C in darkness in plastic bags.

Infection of potato tubers. Potato tubers were sprayed with 0.5 ml of an *H. solani* conidial suspension (5×10^4 conidia/ml) and air dried for 30 min. The conidial suspension was prepared by scraping the surface of 5-week-old mycelia of *H. solani* grown on petri dishes using a glass rod. The concentration of the conidial suspension was adjusted by dilution. A hemacytometer (Hausser Scientific Company, Horsham, PA) and a microscope ($\times 400$; Olympus Optical Company Ltd, Shinjuku-ku, Japan) were used for enumerating conidia in each suspension.

Suppressiveness of soil samples. Soil suppressiveness was evaluated according to the modified method of Elson et al. (10). Soil suspensions were prepared by placing 1 g of each soil in 10 ml of sterile distilled water containing peptone (10 g/liter; Sigma-Aldrich, Mississauga, Ontario). Each soil suspension (2 ml) was sprayed on infected tubers. Tubers then were placed

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individually in plastic chambers containing a moistened paper towel and incubated in the dark. After an incubation period of 45 (10°C), 30 (15°C), or 18 days (24°C), silver scurf severity was evaluated. These incubation temperatures were chosen based on observations that silver scurf spreads during the growing season, where soil temperatures vary generally between 15 and 24°C, and during storage, where potatoes are generally maintained between 5 and 12°C (30). Control tubers were sprayed with sterile distilled water (2 ml). A completely randomized design with two replicates was used.

Isolation of soil microorganisms. Microorganisms were isolated from soils that

suppressed disease on tubers using serial dilutions and spread on selective media in petri dishes. Fungi were isolated on malt agar (Difco Laboratories) containing streptomycin (0.3 g/liter; Sigma-Aldrich). Actinomycetes were isolated on actinomycete isolation agar (Difco Laboratories). Bacteria were isolated on the following media: tryptic soy agar 10% (TSA; Difco Laboratories), TSA 10% amended with crystal violet (0.002 g/liter; Sigma-Aldrich), and Pseudomonas agar F (Difco Laboratories) amended with glycerol (10 g/liter; Sigma-Aldrich), chloramphenicol (0.125 g/liter; Sigma-Aldrich), and ampicillin (0.5 g/liter; Sigma-Aldrich). After the spread of the different dilutions on the selective media,

petri dishes were incubated at 10, 15, or 24°C. Morphologically distinct microorganisms were isolated and grown in pure culture.

Effect of microorganisms on silver scurf severity. *H. solani*-infected potato tubers were sprayed with 0.5 ml of individual bacterial suspensions (optical density = 0.17 at 620 nm; 10) or with 0.5 ml of spore suspension (5×10^4 spores/ml) of each selected fungus. Triplicate tubers were incubated as previously described at 10, 15, or 24°C for 45, 30, and 18 days, respectively. Silver scurf severity then was evaluated. Control tubers were sprayed with distilled water (0.5 ml).

Silver scurf severity. On each tuber, 10 periderm discs (diameter 10 mm) were cut off with a cork borer and rated plus or minus for the presence of *H. solani* conidiophores using a stereomicroscope ($\times 25$; Olympus Optical Company). The disease severity was expressed as the percentage of potato tuber surface covered with *H. solani* conidiophores based on the number of infected periderm discs. Disease severity was calculated as follows: (surface covered with *H. solani* conidiophores [tuber sprayed with soil or microorganism suspension]/surface covered with *H. solani* conidiophores [control]) $\times$ 100.

Antagonist identification. Bacteria, actinomycetes, and fungi, which limited disease development by at least 50%, were identified. Bacteria were identified using phospholipid fatty acids gas-chromatographic analysis in Dr. Germida's laboratory (University of Saskatchewan, Saskatoon, Saskatchewan, Canada). An actinomycete was identified by analysis of 16S rRNA according to the method of Lane et al. (18) and Takeuchi et al. (33). Appropriate keys (1) were used for the identification of the fungus.

RESULTS

The effect of 100 different soils on *H. solani* development on potato tubers incubated at 10°C is presented in Table 1. Among the soils tested, only soils 5, 9, 19, 21, 50, and 79 decreased the disease severity by at least 50%. When soils were further analyzed for their microbiological content, 43 morphologically different microorganisms were isolated at 10°C. Each microorganism then was tested for its ability to decrease *H. solani* development on potato tubers (*data not shown*). Nine microorganisms, having displayed good biocontrol potential, were tested in three replicates (Table 2). Of the nine isolates tested, six reduced disease by 65% or more compared with the control (Table 2). Those isolates originated from soils 5, 21, 50, and 79. The microorganisms, isolated at 10°C, were identified as *Aquaspirillum autotrophicum* (21-14), *Arcanobacterium haemolyticum* (5-14), *Arthrobacter oxydans* (5-4A), *Bacillus mycoides* (50-12), *Kocuria rosea* (79-4), and a fungus (79-1) belong-

Table 1. Effect of different soils on silver scurf (*Helminthosporium solani*) development on potato tubers incubated at 10°C

Soil number	Disease severity (%) ^a	Soil number	Disease severity (%) ^a
1	71.5 $\pm$ 15.9	51	68.8 $\pm$ 6.3
2	77.7 $\pm$ 22.2	52	87.5 $\pm$ 0.0
3	66.0 $\pm$ 21.5	53	93.8 $\pm$ 6.3
4	66.6 $\pm$ 32.3	54	87.5 $\pm$ 12.5
5	42.3 $\pm$ 20.1	55	81.3 $\pm$ 30.3
6	101.4 $\pm$ 23.6	56	93.8 $\pm$ 18.8
7	75.7 $\pm$ 13.2	57	87.5 $\pm$ 0.0
8	84.0 $\pm$ 28.5	58	81.3 $\pm$ 6.3
9	40.3 $\pm$ 15.3	59	93.8 $\pm$ 30.3
10	100.0 $\pm$ 0.0	60	87.5 $\pm$ 0.0
11	82.6 $\pm$ 4.9	61	100.0 $\pm$ 25.0
12	78.5 $\pm$ 33.0	62	106.3 $\pm$ 6.3
13	75.0 $\pm$ 25.0	63	100.0 $\pm$ 12.5
14	88.2 $\pm$ 0.7	64	87.5 $\pm$ 12.5
15	93.7 $\pm$ 6.2	65	87.5 $\pm$ 12.5
16	88.9 $\pm$ 11.1	66	100.0 $\pm$ 0.0
17	66.7 $\pm$ 32.3	67	75.0 $\pm$ 0.0
18	64.6 $\pm$ 2.1	68	56.3 $\pm$ 6.3
19	46.5 $\pm$ 9.0	69	118.8 $\pm$ 6.3
20	65.3 $\pm$ 9.7	70	106.3 $\pm$ 6.3
21	40.3 $\pm$ 15.3	71	87.5 $\pm$ 25.0
22	82.6 $\pm$ 4.9	72	68.8 $\pm$ 18.8
23	75.0 $\pm$ 25.0	73	62.5 $\pm$ 25.0
24	105.6 $\pm$ 5.6	74	100.0 $\pm$ 12.5
25	100.7 $\pm$ 11.8	75	106.3 $\pm$ 6.3
26	100.7 $\pm$ 11.8	76	62.5 $\pm$ 12.5
27	93.8 $\pm$ 18.8	77	100.0 $\pm$ 12.5
28	100.0 $\pm$ 12.5	78	93.8 $\pm$ 6.3
29	75.0 $\pm$ 25.0	79	37.5 $\pm$ 0.0
30	87.5 $\pm$ 0.0	80	62.5 $\pm$ 37.5
31	81.3 $\pm$ 18.8	81	81.3 $\pm$ 6.3
32	81.3 $\pm$ 30.3	82	81.3 $\pm$ 30.3
33	75.0 $\pm$ 37.5	83	68.8 $\pm$ 6.3
34	100.0 $\pm$ 12.5	84	112.5 $\pm$ 12.5
35	68.8 $\pm$ 18.8	85	106.3 $\pm$ 6.3
36	87.5 $\pm$ 12.5	86	100.0 $\pm$ 25.0
37	68.8 $\pm$ 30.3	87	106.3 $\pm$ 18.8
38	106.3 $\pm$ 18.8	88	106.3 $\pm$ 6.3
39	100.0 $\pm$ 0.0	89	93.8 $\pm$ 6.3
40	93.8 $\pm$ 6.3	90	62.5 $\pm$ 12.5
41	100.0 $\pm$ 25.0	91	68.8 $\pm$ 6.3
42	87.5 $\pm$ 25.0	92	81.3 $\pm$ 18.8
43	100.0 $\pm$ 12.5	93	112.5 $\pm$ 12.5
44	93.8 $\pm$ 30.3	94	62.5 $\pm$ 0.0
45	100.0 $\pm$ 12.5	95	68.8 $\pm$ 30.3
46	106.3 $\pm$ 6.3	96	100.0 $\pm$ 12.5
47	56.3 $\pm$ 30.3	97	81.3 $\pm$ 30.3
48	81.3 $\pm$ 18.8	98	81.3 $\pm$ 43.8
49	106.3 $\pm$ 6.3	99	81.3 $\pm$ 18.8
50	50.0 $\pm$ 12.5	100	100.0 $\pm$ 25.0

^a Infected tubers were sprayed with different soil suspensions and incubated at 10°C in the dark. After 45 days of incubation, silver scurf severity was evaluated. Each value represents the mean of two replicates $\pm$ standard deviation.

ing to the class Zygomycetes. The isolates were further tested for their ability to control the disease on tubers incubated at either 15 or 24°C (Table 3). In these assays, the bacteria *Arcanobacterium haemolyticum* and *Arthrobacter oxydans* were the most effective at 15 and 24°C, respectively.

The effect of the application of the 100 selected soils to inoculated tubers on disease severity also was evaluated on potato tubers incubated at 15 and 24°C. Soils 13 and 18 were shown to decrease disease development at 15°C (*data not shown*). Twenty-two microorganisms showing distinct morphology were isolated at 15°C from those soils and were tested for their ability to reduce silver scurf development at this temperature (*data not shown*). After screening, five microorganisms showing the best potential were tested in three replicates (Table 4). The microorganism 13-1, identified as *Alcaligenes piechaudii*, caused a disease reduction of 51.3%. *A. piechaudii* also was shown to reduce disease development by $46.7 \pm 11.5\%$ and $80.0 \pm 0.0\%$ on tubers incubated at 10 and 24°C, respectively.

The application of soils 62 and 89 decreased silver scurf development on tubers incubated at 24°C (*data not shown*). Eleven microorganisms isolated at 24°C

from those soils then were tested in three replicates for their effect on disease development. The results showed that only isolate 89-22 reduced silver scurf severity (Table 5). This actinomycete, identified as *Streptomyces griseus*, reduced disease severity by 52.5% (Table 5), $86.7 \pm 5.8\%$, and $65.0 \pm 7.1\%$ on tubers incubated at 24, 15, and 10°C, respectively.

DISCUSSION

One hundred selected soil samples of the province of Québec were tested for their effect on silver scurf development on potato tubers. The results indicated that a number of soils decreased silver scurf severity at 10°C (soils 5, 9, 19, 21, 50, and 79), 15°C (soils 13 and 18), and 24°C (soils 62 and 89).

Several microorganisms were isolated from those soils and tested for their ability to reduce the disease. Each of the bacteria, *Aquaspirillum autotrophicum*, *Arcanobacterium haemolyticum*, *Arthrobacter oxydans*, *B. mycoides*, and *K. rosea*, which were isolated from the suppressive soils at 10°C, reduced disease at this temperature. Except for *Arcanobacterium haemolyticum*, which is reported to provoke haemolytic infection in humans (19,20,35), these bacteria may be of interest in the biocontrol of potato silver scurf during

storage. To our knowledge, this is the first report of the antagonistic activity of *Arthrobacter oxydans*, although another bacterium of the genus *Arthrobacter* was reported to provide protection of carnations against Fusarium stem rot (*Fusarium roseum*) (24). Considering that *A. oxydans* also was active at 24°C, this bacterium may be of interest as a seed tuber treatment for reducing disease development during the growing season. Similarly, *K. rosea* and *Aquaspirillum autotrophicum* also are identified here for the first time as potential antagonists of plant pathogens. Several studies have previously reported antagonism of *B. mycoides* against different plant pathogens, including *Pythium mamillatum* on cucumber (27), *Alternaria helianthi* on sunflower (17), and *F. oxysporum* on cu-

Table 2. Effect of microorganisms isolated at 10°C on silver scurf (*Helminthosporium solani*) development on potato tubers incubated at 10°C

Microorganism number	Disease reduction (%) ^a
5-4A (<i>Arthrobacter oxydans</i>)	66.7 ± 15.3
5-4B	28.6 ± 9.5
5-14 (<i>Arcanobacterium haemolyticum</i>)	66.7 ± 25.2
9-17	38.1 ± 22.2
21-14 (<i>Aquaspirillum autotrophicum</i>)	73.3 ± 5.7
50-12 (<i>Bacillus mycoides</i>)	73.3 ± 30.5
79-1 (Zygomycete)	80.0 ± 17.3
79-4 (<i>Kocuria rosea</i>)	76.7 ± 15.3
79-18	42.9 ± 38.1

^a Infected tubers were sprayed with different microorganism suspensions and incubated at 10°C. After 45 days of incubation, silver scurf severity was evaluated. Disease reduction was calculated as follows: (surface covered with *H. solani* conidiophores [control] – surface covered with *H. solani* conidiophores [tuber sprayed with microorganism suspension]/surface covered with *H. solani* conidiophores [control]) × 100. Each value represents the mean of three replicates ± standard deviation.

Table 3. Effect of microorganisms, isolated at 10°C, on silver scurf (*Helminthosporium solani*) development on potato tubers incubated at 15°C and 24°C

Microorganism (number)	Disease reduction (%) ^a	
	15°C	24°C
<i>Arthrobacter oxydans</i> (5-4A)	23.3 ± 5.8	76.7 ± 5.8
<i>Arcanobacterium haemolyticum</i> (5-14)	70.0 ± 0.0	10.0 ± 10.0
<i>Aquaspirillum autotrophicum</i> (21-14)	0.0 ± 0.0	40.0 ± 20.0
<i>Bacillus mycoides</i> (50-12)	35.7 ± 5.8	20.0 ± 10.0
Zygomycete (79-1)	–3.4 ± 6.7	–3.7 ± 6.4
<i>Kocuria rosea</i> (79-4)	30.0 ± 0.0	23.7 ± 5.8

^a Infected tubers were sprayed with different microorganism suspensions and incubated at either 15 or 24°C. After 30 days (15°C) and 18 days (24°C) of incubation, silver scurf severity was evaluated. Disease reduction was calculated as follows: (surface covered with *H. solani* conidiophores [control] – surface covered with *H. solani* conidiophores [tuber sprayed with microorganism suspension]/surface covered with *H. solani* conidiophores [control]) × 100. Each value represents the mean of three replicates ± standard deviation.

Table 4. Effect of microorganisms, isolated at 15°C, on silver scurf (*Helminthosporium solani*) development on potato tubers incubated at 15°C

Microorganism number	Disease reduction (%) ^a
13-1 (<i>Alcaligenes piechaudii</i>)	51.3 ± 20.8
13-17	43.3 ± 31.1
13-18	10.0 ± 10.0
13-53	3.3 ± 5.8
18-3	0.0 ± 0.0

^a Infected tubers were sprayed with different microorganism suspensions and incubated at 15°C. After 30 days of incubation, silver scurf severity was evaluated. Disease reduction was calculated as follows: (surface covered with *H. solani* conidiophores [control] – surface covered with *H. solani* conidiophores [tuber sprayed with microorganism suspension]/surface covered with *H. solani* conidiophores [control]) × 100. Each value represents the mean of three replicates ± standard deviation.

Table 5. Effect of microorganisms, isolated at 24°C, on silver scurf (*Helminthosporium solani*) development on potato tubers incubated at 24°C

Microorganism number	Disease reduction (%) ^a
62-2	10.0 ± 10.0
62-11	20.0 ± 17.3
62-12	6.7 ± 5.8
62-17	10.0 ± 10.0
89-8	0.0 ± 0.0
89-10	3.3 ± 5.8
89-11	10.0 ± 10.0
89-17	6.7 ± 11.5
89-20	13.3 ± 5.8
89-22 (<i>Streptomyces griseus</i>)	52.5 ± 12.6
89-23	10.0 ± 10.0

^a Infected tubers were sprayed with different microorganism suspensions and incubated at 24°C. After 18 days of incubation, silver scurf severity was evaluated. Disease reduction was calculated as follows: (surface covered with *H. solani* conidiophores [control] – surface covered with *H. solani* conidiophores [tuber sprayed with microorganism suspension]/surface covered with *H. solani* conidiophores [control]) × 100. Each value represents the mean of three replicates ± standard deviation.

cumber (13) and against potato pathogens (8). Finally, a fungus belonging to the class Zygomycetes also was effective at controlling silver scurf severity on potato tubers incubated at 10°C. Because of its activity at low temperature, this fungus may be of interest in the biocontrol of silver scurf during storage and its identification is ongoing.

In our trials, *Alcaligenes piechaudii* was very effective against *H. solani* on tubers incubated at 24°C, suggesting that this bacterium may be of interest in the biocontrol of potato silver scurf as seed tuber treatment. *A. piechaudii*, which is considered to be a plant-growth-promoting rhizobacterium (3), was described as acting by antibiosis against *X. campestris* pv. *campestris*, the causal agent of cabbage black rot (2). The same mechanism may be involved in the observed reduction of *H. solani* development.

S. griseus is another microorganism isolated in this study that caused a reduction of silver scurf on tubers. Several studies have reported *S. griseus* as an antagonist against different plant pathogens, such as *Rhizoctonia solani* on wheat (23); *Phomopsis sclerotoides* on cucumber (9); and *Phytophthora parasitica*, *Pythium debaryanum*, and *F. oxysporum* f. sp. *lycopersici* on tomato (4,36). *S. griseus* was found to produce chitinase (16) and antibiotics (6,11,34) that may be involved in the mechanisms by which it exerts its biocontrol activity. On the other hand, exploitation of this actinomycete should be viewed with caution because some strains of *S. griseus* have been reported as pathogens of potato tubers (7). In our trials, no symptoms were observed on the potato tubers sprayed with *S. griseus*.

For this study, a whole tuber assay (10) was used to select microorganisms displaying an ability to decrease silver scurf development. This bioassay was chosen for several reasons, including the fact that it selects microorganisms reducing silver scurf development by either inducing host resistance, reducing directly *H. solani* growth and development, or affecting potato periderm penetration. The results obtained have led to the identification of several organisms, including first reports of *Arthrobacter oxydans*, *Aquaspirillum autotrophicum*, and *K. rosea* as potential biocontrol agents and have suggested that the use of a combination of selected organisms may be of interest for silver scurf biocontrol, considering that potato tubers are exposed to a temperature range during production and storage. These findings open the way to new avenues of investigation toward achieving biological control of potato silver scurf.

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