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Evaluation of different fungicides applied as seed tuber treatments for the control of potato silver scurf

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Silver scurf of potatoes (*Solanum tuberosum*), caused by the fungus *Helminthosporium solani*, is an important surface-blemishing disease of potato tubers. The objective of the study was to evaluate the efficacy of different fungicides applied to potato seed tubers for control of silver scurf. Field trials were conducted in Québec province in 1998 and 1999. Potato seed tubers infected with *H. solani* were treated with either talc, fludioxonil, mancozeb, iprodione, thiabendazole, imazalil or azoxystrobin, and planted at three locations in 1998 and two locations in 1999. The results showed that, under our experimental conditions, the fungicides tested, applied as seed treatments, did not significantly influence total and marketable yields as well as silver scurf severity on daughter tubers at harvest and after different storage periods. In addition, this study showed the influence of the experimental locations on silver scurf development and suggests that soil inoculum plays a role in the epidemiology of the disease.

[Évaluation de différents fongicides appliqués en traitement de semence pour lutter contre la tache argentée de la pomme de terre]

La tache argentée de la pomme de terre (*Solanum tuberosum*), causée par le champignon *Helminthosporium solani*, est une maladie affectant la qualité du tubercule. L'objectif de cette étude était d'évaluer l'efficacité de différents fongicides, appliqués sur les tubercules de semence, à contrer le développement de la tache argentée. Pour ce faire, des tubercules de semence infectés par *H. solani* ont été traités avec l'un des fongicides suivants : talc, fludioxonil, mancozeb, iprodione, thiabendazole, imazalil et azoxystrobin. Ils ont, par la suite, été plantés au champ. Les essais ont été réalisés au Québec sur trois sites en 1998 et deux sites en 1999. Les résultats obtenus montrent que, sous nos conditions expérimentales, ces fongicides, appliqués en traitement de semence, n'ont pas affecté significativement les rendements totaux et vendables ainsi que la sévérité de la tache argentée sur les tubercules-fils au moment de la récolte et après différentes périodes d'entreposage. D'autre part, cette étude a permis de mettre en évidence l'influence des sites expérimentaux sur le développement de la tache argentée et suggère que l'inoculum du sol joue un rôle dans l'épidémiologie de cette maladie.

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INTRODUCTION

Silver scurf of potatoes (*Solanum tuberosum* L.), caused by the fungus *Helminthosporium solani* Durieu & Montagne, is a surface-blemishing disease of potato tubers (Read and Hide 1984). Silver scurf-diseased tubers show a metallic discoloration of the periderm in irregular patterns (Secor and Gudmestad 1999). Portions of tuber periderm may eventually slough off and cause fresh weight loss during storage (Olivier *et al.* 1998). Infection often takes place during the growing season (Heiny and McIntyre 1983) and lesions may be visible at harvest. Disease severity increases greatly during long-term storage of tubers.

Long recognized as a disease of minor importance, silver scurf, which is present in most potato-growing areas (Hooker 1981), has become in recent yr a leading cause of rejection of commercial potatoes (Secor *et al.* 1996). Some of the reasons explaining the dramatic increase in economic importance of silver scurf include (1) development of *H. solani* resistance to thiabendazole (2-(thiazol-4-yl)benzimidazole) which formerly provided control as post-harvest application (Mérida and Loria 1990, 1994; Platt 1997), (2) increased awareness by consumers, (3) stricter grading standards by the industry (Secor *et al.* 1996) and (4) the increasing market for washed potatoes in transparent plastic bags (Ogilvy 1992).

Silver scurf is primarily considered to be a seed-borne disease (Rodriguez *et al.* 1996; Secor and Gudmestad 1999) although soil-borne propagules of *H. solani* may be important in the epidemiology (Mérida and Loria 1994). Considering the importance of seed-borne inoculum in the disease cycle, several studies have dealt with the application of different fungicides on the seed tubers to control potato silver scurf. Indeed, different fungicides such as imazalil ((±)-allyl 1-(2,4-dichlorophenyl)-2-imidazol-1-ylethyl ether), iprodione (3-(3,5-dichlorophenyl)-*N*-isopropyl-2,4-dioxoimidazolidine-1-carboxamide), mancozeb (manganese ethylenebis (dithiocarbamate) (polymeric) complex with zinc salt), and thiabendazole have been evaluated for control of silver scurf. The results concerning their effectiveness are contradictory. Some studies have shown that imazalil (Bisht and Bains 1995; Hall and Hide 1992; Hide and Read 1985), iprodione (Le Corre *et al.* 1993), mancozeb (Gaucher 1998; Le Corre *et al.* 1993) and thiabendazole (Bisht and Bains 1995; Jellis and Taylor 1977) allow control of the disease whereas other studies performed in different experimental locations have shown that those fungicides are moderately effective or ineffective (Collet-Elimane and Jouan 1993; Le Corre *et al.* 1993; Shetty *et al.* 1994).

The objective of this study was to evaluate, under Québec agroenvironmental conditions, the effectiveness of different fungicides, applied as seed tuber treatments, for the control of potato silver scurf.

MATERIALS AND METHODS

Potato tubers

Red skinned potato seed tubers (cv. Norland) naturally infected with *H. solani* obtained from Propur Inc. (Saint-Ambroise, Canada) were used in this study. Tubers were sorted for size uniformity and disease severity. Tubers showing 20% or 80% of their surface covered with silver scurf lesions were selected for this study.

Chemicals

Thiabendazole (Mertect), mancozeb (Dithane M-45), azoxystrobin (Quadris; methyl (*E*)-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-=methoxyacrylate), fludioxonil (Maxim; 4-(2,2-difluoro-1,3-benzodioxol-4-yl)pyrrole-3-carbonitrile) and talc were purchased from Merck & Co (Rahway, NJ), Rohm and Haas Canada Inc. (West Hill, Canada), Zeneca Agro (Calgary, Canada), Novartis (Guelph, Canada) and Luzernac (Saint-Pierre-de-Broughton, Canada), respectively. Imazalil (Fungazil) and iprodione (Rovral) were purchased from Janssen (Beerse, Belgium) and Rhône-Poulenc (Monmouth Junction, NJ), respectively.

Treatments

The 11 treatments are fully described in Table 1. Potato seed tubers showing 80% of their surface covered with silver scurf lesions were treated according to the recommendations of the manufacturers with either imazalil (T7), azoxystrobin (T8) or fludioxonil (T9). Three rates of mancozeb application were tested : 0.8 (T5; recommendation of the manufacturer), 2.4 (T6) and 8.0 (T11) kg t^{-1} of potato. According to the recommendations of the manufacturer, Dithane M-45 (80% mancozeb) applied at a rate of 0.8 and 2.4 kg t^{-1} of potato was mixed with talc and then applied on potatoes, whereas for the treatment T11, Dithane M-45 was directly applied to potatoes. Talc (T3), thiabendazole (T4), and iprodione (T10) were applied as described in Table 1. Untreated potato tubers showing 20% (T1) and 80% (T2; control) of their surface covered with silver scurf lesions were included in the trials.

Field trials

Experimental plots were 3.64 m x 5.0 m (1998) or 3.64 m x 6.0 m (1999) and consisted of four rows separated by 91 cm. In 1998, field trials were established at three locations (Saint-Ubalde, Sainte-Croix-de-Lotbinière, Saint-Ambroise) in Québec province (Canada) using a randomised incomplete block design. For each location, the trials included four replications. Ten treatments (T1-T10) were conducted at Saint-Ubalde and Sainte-Croix-de-Lotbinière, whereas eight treatments (T1, T2, T4, T6, T7, T8, T9, T10) were conducted at Saint-Ambroise. Tubers were treated or not (T1 and T2), cut in half and hand-planted 25 cm apart on 27, 28 and 29 May at Saint-Ambroise, Sainte-Croix-de-Lotbinière and Saint-Ubalde, respectively. Experimental plots at Saint-Ubalde, Sainte-Croix-de-Lotbinière and Saint-Ambroise were established where soy, potatoes and barley had been cultivated the preceding yr, respectively.

In 1999, field trials were established at Saint-Ubalde and Sainte-Croix-de-Lotbinière where barley and a mix mil-lucerne had been cultivated the preceding yr, respectively. A completely randomised block design including 11 treatments (T1-T11) and four replications was used. On 17 and 18 May, cut tubers were treated or not (T1 and T2) and planted by hand as in 1998 at Sainte-Croix-de-Lotbinière and Saint-Ubalde, respectively.

Table 1. Seed treatments included in the trials

Seed treatment		Application rate (a.i. t^{-1} of potatoes)	Application method
(T1)	Untreated tubers (20%)[a]	—	—
(T2)	Untreated tubers (80%)[b]	—	—
(T3)	Talc	5.0 kg	Powdering
(T4)	Thiabendazole	[c]	Dipping
(T5)	Mancozeb	0.8 kg	Powdering
(T6)	Mancozeb	2.4 kg	Powdering
(T7)	Imazalil	15.0 g[d]	Spraying
(T8)	Azoxystrobin	66.0 g[e]	Spraying
(T9)	Fludioxonil	25.0 g	Powdering
(T10)	Iprodione	400.0 g[f]	Spraying
(T11)	Mancozeb	8.0 kg	Powdering

[a] Untreated tubers showing 20% of their surface covered with silver scurf lesions.
[b] Untreated tubers showing 80% of their surface covered with silver scurf lesions (control).
[c] Tubers (30 kg) were dipped (5 min) in water (30 L) containing thiabendazole (2.25%).
[d] Sprayed until run-off with a fungicide formulation (6.5 L t^{-1}) of imazalil (15 g a.i. t^{-1}).
[e] Sprayed until run-off with a fungicide formulation (6.5 L t^{-1}) of azoxystrobin (66 g a.i. t^{-1}).
[f] Sprayed until run-off with a fungicide formulation (6.5 L t^{-1}) of iprodione (400 g a.i. t^{-1}).

Evaluation of yields and silver scurf severity

In 1998, the two central rows of each plot were harvested on 22 September (Saint-Ubalde), 29 September (Sainte-Croix-de-Lotbinière) and 8 October (Saint-Ambroise). In 1999, central rows were harvested on 13 (Sainte-Croix-de-Lotbinière) and 15 September (Saint-Ubalde). Tubers were sorted at harvest for size and weighed to determine the total and marketable yields. Marketable yields (which include tubers from Canada #1, Canada #2 and Jumbo classes) and total yields were expressed in t ha^{-1}. For each plot, a 150-tuber sample was collected at harvest. Fifty tubers were assessed at harvest for disease severity; the other tubers were stored (7°C) at 95% relative humidity (RH) and assessed for disease severity after 3 (50 tubers) and 6 or 7 mo (50 tubers). All the tubers were stored in the same chamber. For each potato tuber, silver scurf severity was rated on a disease scale of 1 to 6 : class 1 (< 2% surface affected), class 2 (2-10%), class 3 (10-25%), class 4 (25-50%), class 5 (50-75%) and class 6 (75-100%). For each plot, the disease rating was calculated according to Bertrand and Gottwald (1986) :

$$\text{Disease rating :} \quad \frac{(N1 \times 1) + (N2 \times 2) + ... + (N6 \times 6)}{(N1 + N2 + ... + N6)}$$

Where N1, N2... and N6 represent the number of tubers belonging to classes 1, 2... and 6.

Data analysis

Analysis of variance (yields) and repeated measures analysis of variance (silver scurf severity) were carried out with the GLM procedure of SAS. When significant (P< 0.05), treatment means were compared using Fisher's protected LSD.

RESULTS

The mean total yields of potatoes were 39.3 and 37.8 t ha^{-1} in 1998 and 1999, respectively. The average potato marketable yields were 36.7 (1998) and 32.4 t ha^{-1} (1999). Seed tuber treatments and silver scurf severity on seed tubers did not significantly influence total and marketable yields (data not shown).

The results of the trials conducted in 1998 showed that, compared to the control (T2), the application of thiabendazole, imazalil, azoxystrobin, fludioxonil or iprodione on seed tubers did not significantly influence silver scurf severity at harvest and after 3 and 6 mo of storage (7°C, 95% RH) (Table 2). The application of either talc or a mixture of talc and mancozeb (0.8 and 2.4 kg t^{-1}), as for the other fungicides, did not significantly influence disease severity. At harvest, disease severity ranged from 2.22 to 2.86. Silver scurf severity increased during storage ranging from 3.93 to 4.60 after 6 mo (Table 2 and Fig. 1).

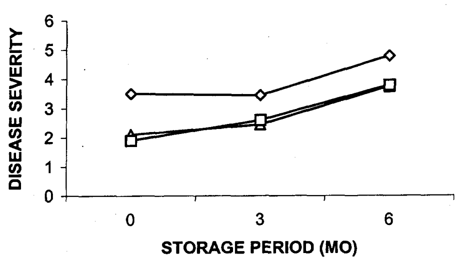

Figure 1. Effect of storage period on silver scurf severity on potato tubers harvested in 1998 at Sainte-Croix-de-Lotbinière (◇), Saint-Ambroise (□) and Saint-Ubalde (△). Disease severity was rated on 50 tubers at harvest (storage period = 0) and after 3 and 6 months of storage (7°C, 95% RH).

Trials conducted in 1999 also showed that the application of the different seed treatments did not significantly influence silver scurf severity at harvest and after 3 and 7 mo of storage (Table 3). In 1999, the disease severity at harvest was slightly lower than the previous yr. Indeed, silver scurf severity ranged from 1.62 to 2.06 at harvest and, as in 1998, increased during storage to reach values ranging from 3.51 to 3.91 after 7 mo of storage.

In both yr, the location significantly influenced disease severity (Tables 2 and 3). In 1998, the disease severity was higher at Sainte-Croix-de-Lotbinière (Fig. 1) at harvest and after storage. In

Table 2. Effect of seed treatments on the severity of silver scurf on potato tubers at harvest and after three and six months of storage in 1998[a]

Seed Treatment		Severity of silver scurf		
		Harvest	Storage period (mo)	
			3	6
T1	Untreated tubers (20%)[b]	2.85	3.44 a[d]	4.60
T2	Untreated tubers (80%)[c]	2.45	2.80 b	4.03
T3	Talc	2.79	2.88 b	4.12
T4	Thiabendazole	2.40	2.69 b	4.14
T5	Mancozeb (0.8 kg t^{-1})	2.86	2.89 b	4.16
T6	Mancozeb (2.4 kg t^{-1})	2.22	2.53 b	3.93
T7	Imazalil	2.29	2.72 b	4.23
T8	Azoxystrobin	2.48	2.93 b	4.11
T9	Fludioxonil	2.62	2.99 ab	4.14
T10	Iprodione	2.52	2.95 ab	4.10
Probability				
Treatment		NS	*	NS
Block		NS	NS	NS
Location		**	**	**
Location x Treatment		NS	NS	NS

[a] In the absence of a significant ($P < 0.05$) interaction between treatments and locations, data from the different locations (Saint-Ubalde, Saint-Ambroise and Sainte-Croix-de-Lotbinière) were pooled.

[b] Untreated tubers showing 20% of their surface covered with silver scurf lesions.

[c] Untreated tubers showing 80% of their surface covered with silver scurf lesions (control).

[d] Treatments followed by the same letter are not significantly different at the 0.05 level, according to Fisher's LSD.

*, ** Significantly different at $P < 0.05$ and $P < 0.01$ probability levels, respectively; NS, not significantly different.

Table 3. Effect of seed treatments on the severity of silver scurf on potato tubers at harvest and after three and seven months of storage in 1999[a]

Seed Treatment		Severity of silver scurf		
		Harvest	Storage period (mo)	
			3	7
T1	Untreated tubers (20%)[b]	1.76	1.88	3.72
T2	Untreated tubers (80%)[c]	1.97	2.33	3.59
T3	Talc	1.89	2.22	3.51
T4	Thiabendazole	1.90	2.35	3.61
T5	Mancozeb (0.8 kg t^{-1})	2.03	2.59	3.91
T6	Mancozeb (2.4 kg t^{-1})	1.99	2.45	3.84
T7	Imazalil	2.06	1.96	3.62
T8	Azoxystrobin	1.62	2.36	3.66
T9	Fludioxonil	1.72	2.51	3.60
T10	Iprodione	2.00	2.44	3.68
T11	Mancozeb (8.0 kg t^{-1})	1.83	2.12	3.75
Probability				
Treatment		NS	NS	NS
Block		NS	NS	NS
Location		**	**	**
Location x Treatment		NS	NS	NS

[a] In the absence of a significant ($P < 0.05$) interaction between treatments and locations, data from the different locations (Saint-Ubalde and Sainte-Croix-de-Lotbinière) were pooled.

[b] Untreated tubers showing 20% of their surface covered with silver scurf lesions.

[c] Untreated tubers showing 80% of their surface covered with silver scurf lesions (control).

** Significantly different at $P < 0.01$ probability level; NS, not significantly different.

1999, the disease severity at harvest and after 7 mo of storage was slightly higher at Saint-Ubalde (data not shown).

The seed tuber level of infection did not significantly influence silver scurf severity on progeny tubers at harvest and after 6 or 7 mo of storage (Tables 2 and 3). However, it was observed in 1998 that the use of seed tubers showing 20% of their surface covered with silver scurf lesions significantly increased disease severity, evaluated after 3 mo of storage, on progeny tubers (Table 2).

DISCUSSION

In the present study, none of the tested fungicides have significantly influenced silver scurf severity on progeny tubers at harvest and after different storage periods. The application of thia-bendazole on seed tubers did not decrease disease severity. The lack of efficacy of thiabendazole is possibly due to *H. solani* resistant isolates. Indeed, resistant strains have been isolated in the United States (Mérida and Loria 1990) and in Canada (Kawchuk *et al.* 1994) including the province of Québec (Platt 1997). Secor and Gudmestad (1999) report that thiabendazole is no longer effective because of the emergence of resistant strains.

Different studies have tested the efficacy of imazalil to control silver scurf. Bisht and Bains (1995) and Hall and Hide (1992) report that imazalil application provided good control of silver scurf, whereas imazalil efficacy is reported as irregular by Collet-Elimane and Jouan (1993). Our results show that imazalil application did not decrease silver scurf severity at harvest and during storage.

Very few studies have tested the control of silver scurf with the application of iprodione. Le Corre *et al.* (1993) observed that silver scurf control with iprodione was irregular, and varied among cultivars tested. Our results show, as reported by Gaucher (1998), that iprodione is not effective for silver scurf control.

The broad spectrum fungicide azoxystrobin has recently been reported to show efficacy against rhizoctonia (*Rhizoctonia solani* Kühn) disease of potato (Virgen-Calleros *et al.* 2000) and potato silver scurf (Geary *et al.* 2000). In this study, the application of azoxystrobin on potato seed tubers did not provide control against silver scurf.

This study shows that fludioxonil and mancozeb, at any application rate tested, did not effectively control the disease, although it is reported that the application, as seed treatment, of fludioxonil (Frazier *et al.* 1998; Geary *et al.* 2000; Secor *et al.* 1996; Shetty *et al.* 1994) or mancozeb (2.4 kg t^{-1} of potato) (Le Corre *et al.* 1993) provides protection against potato silver scurf. The presence of soil inoculum may explain the discrepancies of the findings. Long recognized as a seed-borne disease, recent studies have demonstrated that soil-borne inoculum may be important in the epidemiology of the disease and that silver scurf can be initiated by soil-borne inoculum (Bains *et al.* 1996; Mérida and Loria 1994). Considering that our experimental locations had a history of silver scurf, it may be hypothesised that soil inoculum infected progeny tubers which were not protected by the non-systemic fungicides fludioxonil and mancozeb applied on the seed tubers.

The experimental locations significantly influenced disease severity in both yr. Geary *et al.* (2000) also observed a significant effect of location on disease severity. The important influence of the locations on the disease severity suggests that soil and/or environmental conditions influence silver scurf severity. However, few studies have evaluated the effect of soil properties on silver scurf development. In 1998, disease severity was particularly high at Sainte-Croix-de-Lotbinière where potatoes had been cultivated the preceding yr; at Saint-Ubalde and Saint-Ambroise respectively, wheat and barley had been cultivated the preceding yr, and the disease was less severe. Although *H. solani* populations were not determined at the different locations, it may be hypothesised that cropping potatoes successively caused an increase in *H. solani* soil inoculum favouring disease development at Sainte-Croix-de-Lotbinière.

Different studies have examined the relationship between silver scurf severity on seed tubers and silver scurf severity on the progeny tubers. Lennard (1980) and Hide (1987) demonstrated that slightly affected seed tubers gave rise at harvest to more silver scurf in the subsequent crop than highly affected seeds. These authors attributed such results to the fact that young silver scurf lesions sporulate more profusely than old ones, and the degree of infection of the crop depends on the level of active spore production on seed rather than on the severity of the symptoms. However, Read and Hide (1984) observed, in 1 yr out of 3, a higher incidence of silver scurf on progeny tubers produced from more severely affected seeds (80-100% surface affected) than from slightly affected seed. Our experiments showed that silver scurf severity on seed tubers did not significantly influence the severity of the disease on progeny tubers at harvest or after 6 or 7 mo of storage. On the other hand, the results obtained in 1998 showing that, compared to highly affected seed tubers (80% of their surface covered), slightly affected seed tubers (20% of their surface covered) significantly increased the disease severity on progeny tubers after 3 mo of storage, is difficult to explain.

As reported (Ogilvy 1992; Secor and Gudmestad 1999), silver scurf lesions were evident at harvest and spread during storage. The increase in incidence and severity of silver scurf during long-term storage was attributed to lesion expansion and repeated cycles of sporulation and infection (Ogilvy 1992; Rodriguez *et al.* 1996).

The results gathered in this study show that, under our experimental conditions, fludioxonil, mancozeb, iprodione, thiabendazole, imazalil and azoxystrobin applied as seed tuber treatments do not provide protection against potato silver scurf. In addition, the results suggest, as reported by Mérida and Loria (1994), that soil inoculum may be important in the epidemiology of potato silver scurf.

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