Article

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Resistance to thiabendazole in *Fusarium* species and *Helminthosporium solani* in potato tubers treated commercially in eastern Canada

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During the 1992-1993 and 1994-1995 winter storage period for potatoes (*Solanum tuberosum*) in Quebec, New Brunswick, and Prince Edward Island, tubers were collected which had symptoms of fusarium tuber rot and silver scurf and which had been treated commercially after harvest with thiabendazole. Resistance to thiabendazole was detected in isolates of *Fusarium sambucinum* and *Helminthosporium solani* but not in isolates of *F. avenaceum* and *F. oxysporum*. However, the majority of those farms surveyed (64%) had adequate disease control with no pathogen isolated from the diseased tubers. Incidence and EC_{50} values of resistant isolates were lower than found elsewhere and the occurrence of farms with resistant isolates of *F. sambucinum* (18%) was greater than for *H. solani* (7%). For *H. solani*, EC_{50} values of resistant isolates were substantially less than those found in Alberta. While the study investigated commercial operations employing a wide range of thiabendazole rates (6-42 g a.i. t^{-1}), no specific trends were detected between the occurrence of resistant isolates and cultivar or thiabendazole application rate.

[Résistance au thiabendazole par des espèces de *Fusarium* et par *Helminthosporium solani* chez des tubercules de pommes de terre traités commercialement dans l'est du Canada]

Pendant les périodes d'entreposage hivernal 1992-1993 et 1994-1995 au Québec, au Nouveau-Brunswick et à l'Île-du-Prince-Édouard, des tubercules de pommes de terre (*Solanum tuberosum*) présentant des symptômes de pourriture fusarienne et de gale argentée ont été sélectionnés, ces tubercules ayant été traités commercialement au thiabendazole après la récolte. La résistance au thiabendazole a été détectée dans les isolats de *Fusarium sambucinum* et d'*Helminthosporium solani* mais elle ne l'a pas été dans les isolats de *F. avenaceum* et de *F. oxysporum*. Cependant la plupart des fermes étudiées (64 %) luttaient adéquatement contre les maladies, aucun agent pathogène n'ayant été isolé des tubercules affectés. L'incidence et la « EC_{50} » étaient inférieures à celles trouvées ailleurs et le nombre de fermes avec des isolats résistants de *F. sambucinum* (18 %) était supérieur à celui de *H. solani* (7 %). Pour *H. solani*, les valeurs de « EC_{50} » des isolats résistants étaient substantiellement moindres que celles trouvées en Alberta. Bien que l'étude se soit concentrée sur les opérations commerciales faisant appel à une large gamme de doses de thiabendazole, aucune tendance spécifique n'a été détectée entre la présence d'isolats résistants, le cultivar ou la dose de thiabendazole.

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INTRODUCTION

Most potato (*Solanum tuberosum* L.) production areas have problems due to fusarium tuber rot (caused by *Fusarium* species) and silver scurf (caused by *Helminthosporium solani* Dur. & Mont. (Boyd 1972)). While disease incidence and severity vary from year to year and site to site, these diseases continue to reduce tuber quality and marketability. Thiabendazole (2-(4-thiazolyl)-benzimidazole), sold as Mertect® (MSD AgVet Canada Ltd.), is used in Canada as a post-harvest tuber treatment to control these tuber-borne diseases. Unfortunately, resistance to thiabendazole has been reported for *Fusarium sambucinum* Fckl. and *H. solani* in Europe (Langerfeld 1986; Tivoli *et al.* 1986), the United Kingdom (Hide *et al.* 1988, 1992) and the U.S.A. (Desjardins *et al.* 1993; Merida and Loria 1990). Recently, isolates of *F. sambucinum* and *H. solani* resistant to thiabendazole have also been found in Alberta (Desjardins 1995; Kawchuk *et al.* 1994).

In eastern Canada, thiabendazole has been used primarily to control fusarium tuber rots as silver scurf occurs infrequently in this region and resistance to thiabendazole was not detected in any isolates collected during the 1980's (Desjardins 1995). However, the increasing occurrence of silver scurf and a report of thiabendazole resistant isolates of these pathogens in some Canadian production areas in the 1990's (Desjardins 1995; Kawchuk *et al.* 1994) is cause for concern within the potato industry. It is important to prevent or minimize the occurrence of resistance to thiabendazole as it is the only registered product in Canada for use as a post-harvest treatment and at the present time, no other replacement fungicidal materials are in the registration process. The objectives of the present study were to determine the occurrence of thiabendazole-resistant isolates of these pathogens in eastern Canada and to assess the role of thiabendazole application rate in the occurrence of resistance to the fungicide.

MATERIALS AND METHODS

Following the potato storage period during the 1992-1993 winter seasons, potato tuber samples were collected at random from within commercial potato storages in three provinces of Canada : Quebec, New Brunswick and Prince Edward Island. From Quebec in 1992-1993, tubers of the Superior cultivar were collected from the Saint-Arsène, Kamouraska and Notre-Dame-du-Portage areas while for farms from New Brunswick (Florenceville to Grand Falls area) and from across all production areas of Prince Edward Island (P.E.I.), the cultivar was Russet Burbank. During the 1994-1995 potato storage period, tuber samples were collected at random from farms across P.E.I. but samples were not available from Quebec and New Brunswick.

Fifteen to twenty-five tubers were obtained for each cultivar, potato storage and post-harvest treatment rate of thiabendazole. The collected tubers had been treated after harvest as the potatoes were put into the storages with thiabendazole at rates of 6, 12, 15, 21 or 42 g a.i. per tonne of tubers. They had been in storage for more than 100 d (approx. 5°C) and had clearly recognizable symptoms of fusarium tuber rot or silver scurf.

Tuber slices (3-5 mm deep and approx. 5 cm wide x 7 cm long) from regions with moderate to severe disease symptoms were placed separately on moist filter paper in a plastic petri dish. After 1, 2 and 3 d incubation at 25 ± 1°C (12 h light), spores and/or mycelium were transferred from fungal growth areas on the tuber sections to culture plates containing 20 mL of potato dextrose agar (PDA). These isolates were maintained on PDA with single spore or hyphal tip transfer to establish pure cultures of all isolates obtained and to identify the fungal type. *Fusarium* species identification was determined according to Nelson *et al.* (1983). Pure cultures of the fungal isolates obtained from each potato storage sample were sectioned into small agar blocks

(3 mm x 3 mm). To test the level of resistance to thiabendazole in the *Fusarium* and *Helminthosporium* isolates, the agar blocks of the pure cultures were placed in the centre of petri dishes (90 mm x 15 mm) containing 15 mL of PDA amended with technical grade thiabendazole at rates of 0, 10, 20, 50 or 100 µL L^{-1} of thiabendazole (added to the cooling media prior to pouring the plates). Four replicate inoculated dishes were incubated at 25 ± 1°C in the dark and the colony diameters were measured (in two directions per dish) after 7-10 d. The effective concentration of thiabendazole inhibiting colony growth by 50% relative to the growth without thiabendazole treatment (EC_{50}) was determined using linear regression analysis (Genstat Analysis Program, Rothamsted, U.K., 1993 version).

Data summary also involved calculating the thiabendazole sensitivity responses of isolates. These categories include: a) sensitive isolates which have fungal growth completely inhibited on agar amended with thiabendazole at rates equal to or less than 40 µL L^{-1} ; b) intermediate isolates that have some growth at thiabendazole rates greater than 40 µL L^{-1} but less than 50 µL L^{-1}; and resistant isolates which had growth at thiabendazole rates greater than 50 µL L^{-1}. These categories were established on the basis that commercial use of the fungicide involves an application rate of about 40 µL L^{-1}. The isolates were categorized on the basis of the mycelial growth at 50 µL L^{-1} and by estimating the growth at 40 µL L^{-1} based on the actual growth at 20 and 50 µL L^{-1}.

RESULTS

For the 1992-1993 sampling period, 29 tubers with fusarium tuber rot symptoms and 24 with silver scurf symptoms from 24 farms in three provinces (Quebec, New Brunswick and P.E.I.) yielded 13 and 19 isolates of *F. sambucinum* and *H. solani*, respectively (Table 1). These tubers had been treated after harvest with thiabendazole at rates of 6, 12, 15, 21 or 42 g a.i. t^{-1} of tubers. For the 1994-1995 sampling period, 53 tubers of a total of 18 cultivars with fusarium tuber rot and silver scurf symptoms were obtained from 32 farms on P.E.I. (Table 2). These provided a total of 30 isolates of three *Fusarium* spp. (*F. avenaceum* (Corda ex Fr.), *F. oxysporum* Schlecht. and *F. sambucinum*) and four isolates of *H. solani*.

The majority of the *F. sambucinum* isolated in the 1992-1993 samples had EC_{50} values less than 50 µL L^{-1} but five isolates had EC_{50} values greater than 50 µL L^{-1} (Table 1). While one isolate of *H. solani* also had EC_{50} values greater than 50 µL L^{-1}, most of the isolates had EC_{50} values of about 20 µL L^{-1} or less. Similar results were obtained during the 1994-1995 study but three isolates each of *F. sambucinum* and of *H. solani* had EC_{50} values equal to or greater than 50 µL L^{-1} (Table 2). In both studies, some isolates had EC_{50} values greater than 100 µL L^{-1}.

For the tubers treated with thiabendazole (6 g a.i. t^{-1}) from Quebec in the 1992-1993 study, 33% of the isolates of *F. sambucinum* from tubers with symptoms of fusarium tuber rot were resistant to thiabendazole while 67% of the isolates were sensitive (Table 3). In New Brunswick, tubers treated with the 6 or 21 g rates of thiabendazole, respectively, had 50 or 33% of the *F. sambucinum* isolates sensitive to thiabendazole and 50 or 67% resistant. In P.E.I., tubers treated at the 21 g rate also had 33% sensitive and 33% resistant to *F. sambucinum* isolates while at the 6 g rate more sensitive isolates (67%) were found than resistant ones (33%). No isolates of *F. sambucinum* were obtained for testing at the 12 and 42 g rates. Averaging the four thiabendazole postharvest treatment rates applied to the tubers with fusarium tuber rot symptoms on P.E.I. demonstrated that 50% of the *F. sambucinum* isolates were sensitive and 33% were resistant.

Of the isolates of *H. solani* from the 1992-1993 study in Quebec, 33% tested resistant and none were assessed as sensitive (Table 3). For New Brunswick isolates, none were found to be sensitive or resistant; all had an intermediate thiabendazole sensitivity rating. In P.E.I., tubers treated with the 6, 12 and 21 g rates of thiabendazole had 33, 100 and 20% sensitive isolates, respectively, and over all rates the mean occurrence of sensitive isolates was 30%. None of the isolates from P.E.I. were resistant to thiabendazole.

Table 1. Concentration of thiabendazole in culture media to inhibit by 50% growth of *Fusarium sambucinum* and *Helminthosporium solani* isolates obtained in May 1993 from stored potato tubers treated with thiabendazole after harvest in 1992

Farm[a] – Tuber No.	*F. sambucinum* TBZ[b] (g a.i. t^{-1})	*F. sambucinum* EC_{50}[c] (µL L^{-1})	Farm[a] – Tuber No.	*H. solani* TBZ[b] (g a.i. t^{-1})	*H. solani* EC_{50}[c] (µL L^{-1})
1 - 1	6	Na[d]	1 - 2	6	54.0
2 - 1	6	< 0.5	– –	– –	– –
2 - 2	6	< 0.5	– –	– –	– –
2 - 3	6	62.5	2 - 4	6	48.5
3 - 1	6	Na	3 - 2	6	20.0
4 - 1	21	< 0.5	4 - 2	21	Na
5 - 1	6	Na	5 - 2	6	7.7
6 - 1	6	< 0.5	6 - 2	6	7.4
7 - 1	21	Na	7 - 2	21	20.0
8 - 1	21	36.5	– –	– –	– –
8 - 2	21	> 100	8 - 3	21	11.5
9 - 1	6	> 100	9 - 2	6	20.0
10 - 1	21	< 0.5	10 - 2	21	< 0.5
11 - 1	42	Na	11 - 2	42	21.0
12 - 1	21	60.0	– –	– –	– –
12 - 2	21	Na	12 - 3	21	7.2
13 - 1	6	5.5	13 - 2	6	Na
14 - 1	12	Na	14 - 2	12	Na
15 - 1	12	Na	15 - 2	12	< 0.5
16 - 1	21	Na	16 - 2	21	19.5
17 - 1	6	Na	17 - 2	6	Na
18 - 1	6	63.5	– –	– –	– –
18 - 2	6	< 0.5	18 - 3	6	19.0
19 - 1	6	Na	19 - 2	6	< 0.5
20 - 1	21	Na	20 - 2	21	20.0
21 - 1	6	Na	21 - 2	6	8.5
22 - 1	21	Na	22 - 2	21	8.0
23 - 1	15	Na	23 - 2	15	Na
24 - 1	21	Na	24 - 2	21	23.5

[a] Quebec (cv. Superior) : farm numbers 1-3; New Brunswick (cv. Russet Burbank) : farm numbers 4-9; Prince Edward Island (cv. Russet Burbank) : farm numbers 10-24.
[b] TBZ = thiabendazole rate.
[c] Rate of thiabendazole to inhibit fungal growth by 50% in amended media; values are means of four replications.
[d] Na = no *Fusarium* species and *H. solani* isolated from tubers with disease symptoms.

Overall provinces and post-harvest treatment rates of thiabendazole in the 1992-1993 study, 47% of all *F. sambucinum* isolates were categorized as sensitive and 33% were resistant to thiabendazole (Table 3). Similarly, 17% of the *H. solani* isolates were sensitive and 6% were resistant. However, viable pathogen isolations were not obtained from 67% of the farms and 25% of the tubers with disease symptoms in Quebec. For New Brunswick, 33 or 67% of the farms with the 6 or 21 g thiabendazole rates, respectively, had no pathogens isolated but only 17 and 29% of the tubers had no pathogen at the 6 and 21 g rates, respectively. The provincial average for the occurrence of disease symptoms but absence of viable pathogens for isolation was 50% based on the number of farms and 23% based on the number of tubers. On P.E.I., no pathogens were obtained from diseased tubers on 80-100% of the farms for the various post-harvest thiabendazole treatment rates. However, based on the number of tubers tested, the inability to obtain viable pathogens ranged from 38 to 83% depending on thiabendazole treatment rate. For all provinces and all post-harvest treatment rates of thiabendazole in the 1992-1993 study, 75% of the farms and 40% of the tubers had no pathogens obtained from the diseased tuber samples.

Table 2. Concentration of thiabendazole in culture media to inhibit by 50% growth of fungal species isolated in May 1995 from stored potato tubers treated with thiabendazole after harvest in 1994

Farm - Tuber No.	Cultivar - Fungus[a]	TBZ[b] (g a.i. t^{-1})	EC_{50}[c] (µL L^{-1})	Farm - Tuber No.	Cultivar - Fungus[a]	TBZ[b] (g a.i. t^{-1})	EC_{50}[c] (µL L^{-1})
1 - 1	KE-NF	12	Na[d]	15 - 1	YU-NF	12	Na
1 - 2	RB-FA	12	< 0.5	16 - 1	SH-FA	12	< 0.5
2 - 1	NI-NF	12	Na	16 - 2	SH-HS	12	< 0.5
3 - 1	RB-NF	21	Na	17 - 1	SU-FA	6	5.0
3 - 2	SU-NF	21	Na	17 - 2	SU-FA	6	< 0.5
4 - 1	RB-NF	21	Na	18 - 1	CK-FA	21	< 0.5
5 - 1	SN-FA	12	5.5	18 - 2	SN-HS	21	> 100
6 - 1	CR-FO	21	< 0.5	19 - 1	SU-NF	21	Na
6 - 2	GM-FO	21	< 0.5	20 - 1	FR-NF	21	Na
7 - 1	RB-FA	21	6.5	21 - 1	NO-FO	21	< 0.5
8 - 1	RR-FO	42	< 0.5	22 - 1	SU-NF	21	Na
9 - 1	RB-NF	21	Na	22 - 2	NO-HS	42	> 100
9 - 2	YU-FS	21	50.0	23 - 1	SU-NF	6	Na
9 - 3	YU-FS	21	60.0	24 - 1	SU-NF	21	Na
9 - 4	YU-FS	21	49.0	25 - 1	RI-NF	21	Na
10 - 1	RR-FA	6	7.5	25 - 2	SN-NF	21	Na
10 - 2	RR-FA	6	< 0.5	26 - 1	AT-FS	21	12.0
10 - 3	RR-FS	6	46.5	27 - 1	AT-NF	6	Na
11 - 1	AT-FS	21	18.5	28 - 1	RR-NF	21	Na
11 - 2	AT-FS	21	49.0	29 - 1	YU-HS	21	60.5
11 - 3	AT-FA	21	< 0.5	29 - 2	NW-NF	21	Na
11 - 4	AT-FA	21	< 0.5	30 - 1	RR-NF	21	Na
12 - 1	SH-FA	12	< 0.5	31 - 1	AT-FS	21	19.5
13 - 1	CH-FA	21	< 0.5	31 - 2	AT-FS	21	50.0
13 - 2	RB-FA	21	6.5	32 - 1	YU-FS	21	46.0
14 - 1	MC-FO	12	< 0.5	32 - 2	YU-NF	21	Na
– –	– –	– –	– –	32 - 3	YU-FS	21	35.0

[a] Potato cultivars : AT = Atlantic; CH = Chieftain; CK = Cherokee; CR = Century Russet; FR = Frontier Russet; GM = Green Mountain; KE = Kennebec; MC = McIntrye; NI = Niska; NO = Novachip; NW = Norwis; RB = Russet Burbank; RI = Rideau; RR = Ranger Russet; SH = Shepody; SN = Snowden; SU = Superior; and YU = Yukon Gold; Fungal species isolated from diseased tuber tissues: HS = *Helminthosporium solani*; FA = *Fusarium avenaceum*; FO = *F. oxysporum;* FS = *F. sambucinum;* and NF = no *H. solani* and *Fusarium* species isolated.

[b] TBZ = thiabendazole rate.

[c] Rate of thiabendazole to inhibit fungal growth by 50% in amended media; values are means of four replications.

[d] Na = no *Fusarium* species and *H. solani* isolated from tubers with disease symptoms.

For all cultivars and pathogens in the 1994-1995 study, 4, 7, 19, 2 and 32 farms or 7, 8, 36, 2, and 53 tubers, respectively, had been treated with 6, 12, 21, 42 g or any rate of thiabendazole after harvest (Table 4). For all cultivars, all isolates of *F. avenaceum* and *F. oxysporum* from tubers treated with any rate of thiabendazole after harvest had thiabendazole sensitive responses. None of the isolates were resistant. Isolates of *F. sambucinum* from tubers treated with 6, 21 g or any rate of thiabendazole after harvest had no thiabendazole sensitive responses and 0, 60 and 55%, thiabendazole resistant responses, respectively. For isolates of *H. solani*, 100% of those treated with 12 g or 25% of all rates of thiabendazole used were sensitive to the fungicide while 100% of the isolates from tubers treated with 21 and 42 g and 75% of those from all treated tubers were resistant. No pathogens were obtained from the diseased samples at the 6, 12, 21, 42 g or any rate of thiabendazole for 50, 43, 63, 0 and 53% of the farms, respectively or 29, 38, 39, 0, and 36% of the tubers, respectively.

In the 1994-1995 study, tubers of 18 cultivars were tested (Table 5). The occurrence of pathogens from diseased samples ranged from 0 to 100% but not

Table 3. Occurrence and sensitivity to thiabendazole of fungal species isolated in May 1993 from stored potato tubers treated with thiabendazole after harvest in 1992

Province - TBZ [a]	Farms (No.)	Tubers (No.)	Occurrence: No pathogen[b] Farms (%)	No pathogen[b] Tubers (%)	Fusarium rot Sen[c] (%)	Fusarium rot Res[c] (%)	Silver scurf Sen[c] (%)	Silver scurf Res[c] (%)
Que. - 6 g	3	8	67	25	67 (3)	33 (3)	0 (3)	33 (3)
N.B. - 6 g	3	6	33	17	50 (2)	50 (2)	0 (3)	0 (3)
N.B. - 21 g	3	7	67	29	33 (3)	67 (3)	0 (2)	0 (2)
N.B. - all	6	13	50	23	40 (5)	60 (5)	0 (5)	0 (5)
P.E.I. - 6 g	5	11	80	45	67 (3)	33 (3)	33 (3)	0 (3)
P.E.I. - 12 or 15 g	3	6	100	83	— (0)	— (0)	100 (1)	0 (1)
P.E.I. - 21 g	6	13	83	38	33 (3)	33 (3)	20 (5)	0 (5)
P.E.I. - 42 g	1	2	100	50	— (0)	— (0)	0 (1)	0 (1)
P.E.I. - all	15	32	87	50	50 (6)	33 (6)	30 (10)	0 (10)
Total	24	53						
Mean			75	40	47 (14)	40(14)	17 (18)	6 (18)

[a] Provinces: Que. = Quebec; N.B. = New Brunswick; P.E.I. = Prince Edward Island. TBZ = thiabendazole rate (active ingredient per metric tonne of harvested potatoes) applied with a Brooks applicator on the grader or binpiller.

[b] Occurrence based on the number of farms and tubers tested and from which no pathogen was successfully isolated.

[c] Values indicate occurrence of isolate sensitivity to thiabendazole based on the number of isolates tested as shown in parentheses. Sensitive (Sen) isolates are those with fungal growth inhibited by thiabendazole rates of 40 $\mu L\ L^{-1}$ or less. Resistant (Res) isolates are those with fungal growth inhibited by rates greater than 50 $\mu L\ L^{-1}$.

Table 4. Occurrence and sensitivity to thiabendazole of fungal species isolated in May 1995 from stored potato tubers treated with thiabendazole after harvest in 1994

	Thiabendazole treatment rates (g a.i. t^{-1}) 6	12	21	42	All
Number of farms	4	7	19	2	32
Number of tubers[a]	7 (3)	8 (7)	36 (16)	2 (2)	53 (28)
Fusarium avenaceum[b]					
% Sen	100 (4)	100 (4)	100 (6)	Nt[c]	100 (14)
% Res	0 (4)	0 (4)	0 (6)	Nt	0 (14)
Fusarium oxysporum[b]					
% Sen	Nt	100 (1)	100 (3)	100 (1)	100 (5)
% Res	Nt	0 (1)	0 (3)	0 (1)	0 (5)
Fusarium sambucinum[b]					
% Sen	0 (1)	Nt	0 (10)	Nt	0 (11)
% Res	0 (1)	Nt	60 (10)	Nt	55 (11)
Helminthosporium solani[b]					
% Sen	Nt	100 (1)	0 (2)	0 (1)	25 (4)
% Res	Nt	0 (1)	100 (2)	100 (1)	75 (4)
No Pathogen isolated					
% By number of farms	50	43	63	0	53
% By number of tubers	29	38	39	0	36

[a] Values in parentheses indicate the number of cultivars for which tubers were tested.

[b] Occurrence based on the number of tubers tested as shown in parentheses, of sensitive (Sen) and resistant (Res) isolates. Sensitive isolates had fungal growth inhibited by thiabendazole rates of 40 $\mu L\ L^{-1}$ or less. Resistant isolates had fungal growth inhibited at rates greater than 50 $\mu L\ L^{-1}$.

[c] Nt = No fungus obtained for testing.

all cultivars were treated with the same rate of thiabendazole after harvest. Seven cultivars had at least one pathogen isolated from the diseased samples. For the four pathogens isolated from the diseased samples, the occurrence of isolates sensitive and resistant to thiabendazole also ranged from 0 to 100% but not all pathogens were obtained from all cultivars. All isolates of *F. avenaceum* and *F. oxysporum* tested were found to be 100% sensitive. 'Atlantic' (21 g rate) and 'Ranger Russet' (6 g) had some isolates of *F. sambucinum* with intermediate responses to thiabendazole. For *H. solani,* isolates from 'Shepody' (12 g) were 100% sensitive while those from 'Novachip' (42 g), 'Snowden' (12 g) and 'Yukon Gold' (21 g) were 100% resistant.

DISCUSSION

Thiabendazole is registered in Canada for the post-harvest treatment of potato tubers for the control of several diseases including fusarium tuber rot and silver scurf. While the former has been controlled by fungicide rates of 6 g (rate in U.S.A.) to 21 g a.i. t^{-1} of potatoes, the manufacturer recommends a 42 g a.i. t^{-1} rate to control all tuber-borne diseases

Table 5. Potato cultivar role in the occurrence and sensitivity to thiabendazole of fungal species isolated in May 1995 from stored potato tubers treated with thiabendazole after harvest in 1994

Potato cultivar[a]	No pathogen[b] isolated (%)	FA		FO		FS		HS	
		Sen[c] (%)	Res[c] (%)	Sen[c] (%)	Res[c] (%)	Sen[c] (%)	Res[c] (%)	Sen[c] (%)	Res[c] (%)
AT	25 (6)	100 (21)	0 (21)	Ni	Ni	0 (21)	60 (21)	Ni	Ni
CH	0	100 (21)	0 (21)	Ni	Ni	Ni	Ni	Ni	Ni
CK	0	100 (21)	0 (21)	Ni	Ni	Ni	Ni	Ni	Ni
CR	0	Ni	Ni	100 (21)	0 (21)	Ni	Ni	Ni	Ni
FR	100 (21)	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
GM	0	Ni	Ni	100 (21)	0 (21)	Ni	Ni	Ni	Ni
KE	100 (12)	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
MC	0	Ni	Ni	100 (12)	0 (12)	Ni	Ni	Ni	Ni
NI	100 (12)	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
NO	0	Ni	Ni	100 (21)	0 (21)	Ni	Ni	0 (42)	100 (42)
NW	100 (21)	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
RB	100 (21)	100 (21)	0 (21)	Ni	Ni	Ni	Ni	Ni	Ni
RI	100 (21)	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
RR	100 (21)	100 (6)	0 (6)	100 (42)	0 (42)	0 (6)	0 (6)	Ni	Ni
SH	0	100 (12)	0 (12)	Ni	Ni	Ni	Ni	100 (12)	0 (12)
SN	100 (21)	100 (12)	0 (12)	Ni	Ni	Ni	Ni	0 (12)	100 (12)
SU	100 (6,21)	100 (6)	0 (6)	Ni	Ni	Ni	Ni	Ni	Ni
YU	100 (12,21)	Ni	Ni	Ni	Ni	Ni	Ni	0 (21)	100 (21)
Mean[d]		100 (6, 12, 21)	0	100 (12, 21, 42)	0	0	55 (6, 21)	25 (12, 21, 42)	75

[a] Potato cultivars : AT = Atlantic; CH = Chieftain; CK = Cherokee; CR = Century Russet; FR = Frontier Russet; GM = Green Mountain; KE = Kennebec; MC = McIntrye; NI = Niska; NO = Novachip; NW = Norwis; RB = Russet Burbank; RI = Rideau; RR = Ranger Russet; SH = Shepody; SN = Snowden; SU = Superior; and YU = Yukon Gold.

[b] Occurrence based on the number of farms sampled from which no pathogen was successfully isolated from at least one tuber. Values in parentheses indicate postharvest thiabendazole application rate (g a.i. t^{-1} of tubers).

[c] Isolate occurrence based the number of isolates tested at the different postharvest thiabendazole application rates (g a. i. t^{-1} of tubers as shown in parentheses) for two sensitivity responses : sensitive isolates (Sen) are those with fungal growth inhibited by thiabendazole rates of 40 $\mu L\ L^{-1}$ or less; resistant isolates (Res) are those with fungal growth inhibited by thiabendazole rates greater than 50 $\mu L\ L^{-1}$. Ni = pathogen not isolated; FA = *Fusarium avenaceum*; FO = *F. oxysporum*; FS = *F. sambucinum;* HS = *Helminthosporium solani.*

[d] Average for all cultivars with values in parentheses indicating postharvest thiabendazole application rate (g a.i. t^{-1} of tubers).

including silver scurf. In both the 1992-1993 and 1994-1995 sampling periods, isolates of *Fusarium* were found with resistance to thiabendazole in Quebec, New Brunswick and P.E.I. similar to previous reports on samples from New Brunswick and P.E.I. (Desjardins 1995; Desjardins *et al.* 1993). However, the occurrence of resistant isolates of *H. solani* in Quebec during the 1992-1993 study and P.E.I. in 1994-1995 is a new finding.

The EC_{50} values for resistant isolates of *Fusarium* spp. in the present study ranged from about 50 to 150 $\mu L\ L^{-1}$ of thiabendazole which is similar to those reported elsewhere (Desjardins *et al.* 1993; Hide *et al.* 1992; Kawchuk *et al.* 1994). Meanwhile, the EC_{50} values for *H. solani* (about 50 to 150 $\mu L\ L^{-1}$) were substantially less than the 50 to > 500 $\mu L\ L^{-1}$ found in Alberta (Kawchuk *et al.* 1994) but similar to those in Europe (Hide *et al.* 1988) and the U.S.A. (Merida and Loria 1990). However, the overall occurrence of resistant isolates of *F. sambucinum* and *H. solani* based on the number of farms in the three provinces (21 and 4%, respectively in 1992-1993 and 6 and 9%, respectively, in 1994-1995) were less than those found elsewhere. In Alberta (Kawchuk *et al.* 1994), Europe (Hide *et al.* 1992; Langerfeld 1986; Tivoli *et al.* 1986) and the U.S.A. (Desjardins *et al.* 1993) incidence of resistance in *Fusarium* spp. on potato farms were 40, 100 and 96%, respectively. For *H. solani*, about 45% of the isolates in the U.K. (Hide *et al.* 1988) were resistant while only 20% were in New York State (Merida and Loria 1990).

Three *Fusarium* spp. were isolated during the studies from diseased tubers with symptoms of fusarium rot but only *F. sambucinum* had isolates resistant to thiabendazole. This is similar to reports from Europe and U.S.A., but resistance in *F. culmorum* was found in the U.K. (Hide *et al.* 1992). Although *F. avenaceum* and *F. oxysporum* isolates were obtained, these were all sensitive to thiabendazole. However, some isolates of *F. sambucinum* and *H. solani* were detected with intermediate responses to thiabendazole as some fungal growth was observed on agar amended with 40 but not 50 or 100 $\mu L\ L^{-1}$ of thiabendazole. For example, 33% in New Brunswick and 17% in P.E.I. in 1992-1993 and 45% in P.E.I. in 1994-1995 of the *F. sambucinum* isolates tested were intermediate. For *H. solani*, 67% in Quebec in 1992-1993 had intermediate responses. While this may reflect the natural response range of the isolates, it may also be indicative of a trend towards resistance within the population. Further study with a larger number of isolates is required to elucidate this phenomenon.

During the two study periods, diseased tubers from 18 different cultivars were evaluated. Some of the cultivars are known to be quite sensitive to fusarium rots (*e.g.* 'Shepody') and silver scurf (*e.g.* 'Russet Burbank') but not all pathogens were isolated for testing from all cultivars. Resistant isolates of *F. sambucinum* were obtained from 'Atlantic' but not from 'Ranger Russet'. Similarly, isolates of *H. solani* from 'Shepody' were all sensitive while those from 'Novachip', 'Snowden' and 'Yukon Gold' were all resistant. The occurrence of resistant isolates did not appear related to specific cultivars or farming area although the three cultivars with resistant isolates of *H. solani* all have early to mid-season crop maturities.

Sampled farms had post-harvest thiabendazole treatment rates ranging from 6 to 42 g a.i. t^{-1} of tubers. This seemed to be more a result of tradition and costs of application than a lack of awareness about the potential for resistance; most farmers were attempting to control fusarium rots. Although the manufacturer recommends the 42 g rate for adequate control of five diseases, many producers recognize that fusarium rots can be controlled by lower rates. In fact, a low rate (6 g a.i. t^{-1}) is recommended for the control of fusarium rots in the U.S.A. In the 1992-1993 study, resistant isolates of *F. sambucinum* were obtained from tubers (33 to 67% incidence) treated with 6 and 21 g rates but not from those treated with 12 and 42 g rates (based on 45 and 8 tubers, respectively). Similarly, in 1994-1995, resistant isolates were found in 60% of the tubers treated at the 21 g rate but not in tubers at the other rates. Resistant isolates of *H. solani* only occurred on one farm (33% incidence) which involved the 6 g rate in 1992-1993 but in 1994-1995, resistant isolates were detected in all

tubers (100%) treated at 21 and 42 g rates but not in tubers at the 12 g rate. While the occurrence of resistant isolates of the two species does not seem to be strongly related to the application rate, it is generally recognized that sublethal doses of pesticides may enhance the potential for resistance. For example, utilizing a low rate for control of fusarium rots (*e.g.,* 6 to 21 g rates) could increase the potential for resistance in populations of *H. solani* which requires a 42 g rate for control according to the manufacturer. The inability of the two studies to detect this phenomenon may be related to the relatively low incidences (8-9%) and EC_{50} values detected in these production areas of eastern Canada. It may also be related to the fact that the pathogen may not be uniformly found throughout a field and hence a lot of potatoes. In addition, adequate tuber coverage with the fungicide, and therefore control success or potential for development of resistant strains, is related to the variation in the amount of soil on the tubers as well as the physical setup of the fungicide application apparatus. Thus, to accurately determine the role of application rate on development of resistant strains, a more detailed study that accounts for use factors would seem to be needed.

The relatively high incidences where no pathogens were detected (75 and 40% of the farms and tubers, respectively in 1992-1993 and 53 and 36%, respectively in 1994-1995) indicate that thiabendazole is still providing control of these pathogens. In addition, the relatively low EC_{50} values for *H. solani* resistant isolates demonstrates that this may be a fairly recent phenomenon. However, the occurrence of isolates with intermediate responses to thiabendazole should not be ignored as they may represent the continued potential for resistance. Furthermore, cross-resistance to another fungicide (thiophanate-methyl) used as a pre-planting seed treatment has been reported (Kawchuk *et al.* 1994) which could also become a problem if the current practises are not modified to prevent or reduce the development of resistance to thiabendazole in pathogen populations. These might include : utilizing thiabendazole only at the recommended rate (42 g); avoiding the use of thiabendazole and/or thiophanate-methyl where resistant isolates are a problem; developing new fungicide combination products for treatment of tubers; increasing crop rotation periods to prevent buildup of the pathogens in the soil; and adjusting crop management and storage sanitation and management practises to reduce disease risk.

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