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Effect of Post-Harvest Fungicides and Disinfestants on the Suppression of Silver Scurf on Potatoes in Storage

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Abstract Silver scurf of potato, caused by *Helminthosporium solani*, can be a serious problem of potato tubers sold for table stock. The fungus originates primarily on seed and infects the periderm of daughter tubers, causing unsightly blemishes that reduce tuber quality. Secondary spread occurs in potato storage facilities when spores produced on infected tubers are moved through the air system. Depending on storage conditions and time, even a low initial disease incidence can result in significant losses through quality reductions. In the past, thiabendazole has been the most effective post harvest treatment in controlling this disease, but the development of fungicide resistance has made this product unreliable. Because of the lack of consistent alternatives, studies were conducted from 2001 to 2003 to examine the efficacy of various products in suppressing silver scurf incidence and severity when applied to tubers following harvest and prior to storage. Daughter tubers from a seed lot with high incidence of silver scurf symptoms were grown and then harvested 1 month after vine kill. After harvest, tubers were treated with a post-harvest application of various products, stored, and then evaluated for disease incidence and severity each year at two locations (Washington or Oregon and Idaho) and at two time periods (2 or 3 months and 6 months following storage). When treated tubers were stored from the fall of 2002 to spring of 2003, potassium sorbate and *B. subtilis* reduced disease severity after 6 months in storage at location 1, while azoxystrobin reduced incidence after 6 months in location 2. During the 2003–2004 storage season, azoxystrobin reduced silver scurf at both locations after 2 months of storage. Most products currently labeled for post-harvest silver scurf management were ineffective. While not currently registered, azoxystrobin used as a post- harvest, pre- storage treatment may be a significant method for commercial potato growers to suppress silver scurf in potato storage.

Resumen La mancha plateada de la papa, causada por *Helminthosporium solani*, puede ser un problema serio de tubérculos de papa para el mercado en fresco. El hongo se origina primeramente en la semilla e infecta el peridermo de los tubérculos hijos, causando manchados desagradables que reducen la calidad del tubérculo. La dispersión secundaria se presenta en las instalaciones de almacenamiento de papa cuando las esporas producidas en tubérculos infectados se mueven a través del sistema de aire. Dependiendo de las condiciones de almacenamiento y del tiempo, aún una incidencia baja inicial de la enfermedad puede resultar en pérdidas significativas por reducción de la calidad. En el pasado, el thiabendazole ha sido el tratamiento más efectivo de postcosecha en el control de esta enfermedad, pero el desarrollo de resistencia a fungicidas ha hecho no confiable a este producto. Debido

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a la falta de alternativas consistentes, se hicieron estudios de 2001 a 2003 para examinar la eficacia de varios productos en la supresión de la incidencia y severidad de la mancha plateada cuando se aplica a los tubérculos después de la cosecha y antes del almacenamiento. Se sembraron tubérculos provenientes de un lote de semilla con alta incidencia de síntomas de la mancha plateada y después se cosecharon un mes después del secado del follaje. Después de la cosecha se trató a los tubérculos con una aplicación postcosecha de varios productos, se almacenaron y se evaluaron para la incidencia y severidad de la enfermedad cada año en dos localidades (Washington u Oregon y Idaho) y en dos períodos de tiempo (2 a 3 meses y 6 meses después del almacenamiento). Cuando los tubérculos tratados se almacenaron del otoño del 2002 a la primavera del 2003, el sorbato de potasio y *B. subtilis* redujeron la severidad de la enfermedad después de 6 meses en almacenamiento en la localidad 1, mientras que azoxystrobin redujo la incidencia después de 6 meses en la localidad 2. Durante el período de almacenamiento 2003–2004, azoxystrobin redujo la mancha plateada en ambas localidades después de dos meses de almacenamiento. La mayoría de los productos que normalmente están etiquetados para el manejo postcosecha de la mancha plateada no fueron efectivos. Aun cuando no está actualmente registrado, azoxystrobin usado como tratamiento post-cosecha, pre-almacenamiento, puede ser un método significativo para los productores comerciales de papa para suprimir la mancha plateada en almacenamiento de papa.

Keywords Silver scurf · Helminthosporium solani · Post-harvest disease management · Azoxystrobin · Thiabendazole · Hydrogen peroxide

Silver scurf, caused by *Helminthosporium solani* Durieu & Montagne, is an important disease of potato because of the occurrence of fungicide-resistant (benzimidazole) strains, increased disease severity, and increased financial losses from blemished tubers (Bain et al. 1996; Hide and Hall 1993; Kawchuk et al. 1994; Mérida and Loria 1994b). The fungus infects the periderm of tubers, and is particularly damaging on tubers sold in fresh markets because of the unsightly blemishes this pathogen produces. These blemishes consist of buff, brown, or gray lesions that develop on the tuber periderm and become silvery in appearance when wet. Severe infections completely obscure periderm pigmentation of red- or white-colored cultivars (Jellis and Taylor 1997). Increased water loss through infected areas on tubers can result in up to 13% less yield of marketable potatoes, which can also affect potatoes grown for processing (Jellis and Taylor 1997; Lennard 1980; Read and Hide 1984). An estimated $8.6 million US dollars were lost in the Idaho table stock industry in 1992–1993 due to tuber shipment rejections or price adjustments resulting from visible silver scurf (Shetty and Patterson 1993).

While primary inoculum for infection of daughter tubers can come from either seed (Burke 1938; Cayley et al. 1983; Miller et al. 2004) or soil (Bain et al. 1996; Firman and Allen 1995; Jellis and Taylor 1997; Mérida and Loria 1994b), seed is the most important source in the Pacific Northwest region (PNW=Idaho, Oregon, and Washington) of the United States (Miller et al. 2004). Daughter tubers grown from potato seed infected with *H. solani* become infected during the growing season. Seed treatments have been effective for reducing but not eliminating daughter tuber infection (Geary et al. 2007). Disease incidence and severity increase the longer tubers are left in the soil after potato vines have been killed (Burke 1938).

Silver scurf incidence and severity can increase in storage (Jellis and Taylor 1997; Rodriguez et al. 1996). Typical storage conditions for tubers destined for table stock are 7–9 C with relative humidity over 90% (Kleinkopf and Olsen 2003). These conditions are favorable for production of conidia from lesions produced on infected tubers (Mérida and Loria 1994b; Rodriguez et al. 1996). Conidia are then detached and moved throughout potato storage facilities by air currents produced by the ventilation system of the storage (Rodriguez et al. 1996). The spread of secondary inoculum causes an increase in silver scurf incidence and severity in storage, and as storage time increases, levels of infection also increases. As a result, post-harvest tuber treatments with either fungicides or disinfestants may be effective in managing the storage phase of silver scurf by reducing sporulation, killing spores, and/or protecting healthy tubers from infection.

There is a limited availability of products that can be applied to potato tubers for post harvest disease control. Current products utilized in the potato industry include the benzimidazole-based fungicide thiabendazole, disinfestants (chlorine dioxide, hydrogen peroxide, peroxyacetic acid, and mixtures of hydrogen peroxide and peroxyacetic acid—HPPA), a gas (ozone), and salts. In the past, thiabendazole was effective in reducing silver scurf when applied as a post-harvest spray (Cayley et al. 1983; Hide et al. 1980). However, benzimidazole resistance has developed in *H. solani* populations, substantially reducing the usefulness of this material (Hide et al. 1988; Mérida and Loria 1990).

Disinfestants, or general biocides, have also been evaluated for potato storage disease control. Olsen et al. (2003) reported limited efficacy with chlorine dioxide applications utilizing the rates and application methods labeled at the time the study was performed. Afek et al. (2001) showed the possibility of controlling silver scurf by applying an aerosol fog of stabilized hydrogen peroxide into a storage facility. Aerosol applications have not been universally accepted due to the corrosiveness of products on storage components and a lack of reliable product performance data.

Dipping a harvested crop in hydrogen peroxide alone or stabilized with silver ion, however, has been shown to be effective for specific disease control in agricultural crops such as eggplant and sweet red peppers (Fallik et al. 1994) and mushrooms (Brennan et al. 2000). Peroxyacetic acid, or peracetic acid, has been shown to be effective on brown rot when stone fruits are dipped for extended periods of time (Mari et al. 1999). The use of HPPA in storage was evaluated by Klimes (2002), but inconsistent disease control was reported.

Ozone, (O_3) has also been commonly recommended within the potato industry for the control of this disease. Produced by passing O_2 over hot elements, ozone is a strong oxidizer of organic materials and is injected from ozone generators into the air system of the storage. The effectiveness of this method has been questioned (Hamm 2005). A more recent use of ozone exposes the tubers on the conveyer belt before they enter the storage with high quantities of ozone for a brief period. Efficacy of this application method to reduce *H. solani* infection has not been proven. Application of 20 mg $O_3 kg^{-1}$ h^{-1} to tubers that were wounded and artificially inoculated with *H. solani* did not result in a reduction in silver scurf development (Spencer 2006).

Since some disinfectants are a risk to human health or can cause damage to equipment, other products have been suggested as possible means to control silver scurf in storage. These products have not been adequately tested. Post-harvest applications of salts such as potassium sorbate, calcium propionate, sodium carbonate, sodium bicarbonate, potassium carbonate, potassium bicarbonate, and ammonium bicarbonate have been effective in decreasing sporulation on tubers going into storage and can be used on tubers intended for consumer consumption or seed (Olivier et al. 1998). These salts also decreased disease severity on tubers after 15 weeks in storage, possibly due to the prevention of secondary infection cycles, but more work is needed to confirm the usefulness of certain salts to control this disease. The use of several biological control products have also been suggested but no work has been published to show their efficacy.

Safe post-harvest products that can provide consistent and effective control of silver scurf in a storage environment, where soil and debris are present, are needed in the potato industry. Any use of water during a pre-storage application must be limited to avoid development of bacterial soft rot (Powelson and Franc 2006), so a post-harvest product must be applied as a low-volume spray, most likely prior to storage. The purpose of this study was to evaluate various fungicides, disinfestants, and biological controls for their ability to suppress silver scurf in storage as a post-harvest pre-storage application.

Materials and Methods

Potato plants (cv. 'Russet Norkotah') were raised at the Hermiston Agricultural Research and Extension Center in Hermiston, OR during the potato growing seasons of 2001–2003. Potato seed tubers were planted in early to mid April and harvested in mid to late September. A seed lot was selected each year with high silver scurf incidence and severity (100% incidence with 30–50% of seed surface with silver scurf symptoms) and raised according to standard agricultural practices for potato crops in the southern Columbia Basin of Oregon. At the end of the growing season, vines were mechanically killed by chopping and flailing, and tubers were left in the ground for 4 weeks to promote daughter tuber infection by *H. solani* (Burke 1938; Mérida and Loria 1994a).

Tubers were lifted from the soil using a potato plot harvester, bagged by hand in the field, and then moved to the laboratory for treatment. With the exception of the ozone treatment, all products were mixed in water and applied at a rate of 2.08 L water/metric ton (MT) tubers (0.5 gal/ton tubers). This approach was designed to simulate a post-harvest liquid product application with a low-pressure boom sprayer as potato tubers are being loaded into storage. Each treatment was replicated 16 times and each replication contained 20 tubers. Tubers were treated at the University of Idaho Parma Research and Extension Center in Parma, ID (2001–2002) or the University of Idaho Potato Storage Research Facility located at the Kimberly Research and Extension Center in Kimberly, ID (2003). Treatments are listed in Table 1.

At Parma in 2001, treatments were applied to 20 tubers per replication using a CO_2–pressurized hand sprayer (R&D Sprayers, Opelousas, LA, 70570 USA) with a TeeJet 8001 flat fan nozzle (Teejet; Wheaton, IL, 60189 USA) on 23 October. At Parma in 2002, tubers were bulk loaded onto a conveyor leading to a roller table with three rollers. Two TeeJet ConeJet disc-core spray nozzles (D1, DC13; 2.81 kg/cm^2; Teejet; Wheaton, IL, 60189 USA) were positioned over the table and applications were made as tubers progressed across the rollers. In each year tubers were then placed into mesh onion bags and placed in paper bags for transport. At Kimberly in 2003, treatments were applied to tubers using a Research Track Spray Cabinet (Devries Manufacturing, Hollandale, MN 56045 USA) with a TeeJet™ 8001 EVS nozzle (TeeJet, Spraying Systems Co., Loveland, CO 80537 USA). Tubers were placed on plastic trays and treatments were applied. The tubers were then turned and the unsprayed side of the tuber was sprayed with a second pass of the nozzle. For tubers receiving the ozone treatment (2001–2003), tubers were shipped overnight to the University of Idaho Aberdeen Research and Extension Center. Upon receipt, tubers were placed in mesh bags and

Table 1 Products tested for efficacy in managing silver scurf in storage when applied to tubers going into storage

Common name (rate) [a]	Trade name	Manufacturer	2001	2002	2003
Thiabendazole (6.7)	Mertect® 340 F	Syngenta Crop Protection; Greensboro, NC	X	X	X
Azoxystrobin (4.9)	Quadris®	Syngenta Crop Protection; Greensboro, NC	X	X	X
Potassium sorbate (63.6)	–	Sigma Chemical Co; St. Louis, MO	X	X	
Aluminum chloride (5.2)	–	Sigma Chemical Co; St. Louis, MO		X	
Ozone[b]	–	O_3Co.; Aberdeen, ID	X	X	X
Hydrogen peroxide/peroxyacetic acid (9.0)	Oxidate®	BioSafe Systems; Glastonbury, CT		X	X
Bacillus subtilis QST 713 (7.3)	Serenade® WPO	Agra Quest; Davis, CA	X	X	X
Bacillus subtilis QST 713 (7.3)	Serenade® MAX	Agra Quest; Davis, CA			X
Harpin protein (1.9)	Messenger® STS	Eden Bioscience; Bothell, WA	X	X	
Acibenzolar-s-methyl (0.45)	Actigard® 50WG	Syngenta Crop Protection; Greensboro, NC	X		

[a] With the exception of ozone, products were applied using 2.08 L/mt tubers. Rate represents grams of active ingredient per metric ton of tubers treated

[b] Ozone applied as a gas in a hooded ozone tunnel. Tubers were exposed to 500 ppm for 30 s

passed through a commercial ozone tunnel (O3Co., Aberdeen, ID, 83210 USA). Ozone gas was applied at a rate of 500 parts per million over a 30 s time period. Tubers for the untreated control were not exposed to any post-harvest treatment.

For all treatments in all years, 20 tubers/replication were placed in large mesh onion bags and then into, brown grocery-style paper bags (17.8×30.5×43.2 cm) immediately after treatment. Paper bags were used in all years to prevent contamination of test products among treatments during transport to prevent conidia that may be produced on tubers of one treatment from transferring to tubers of another treatment. Eight replications of each treatment were sent to the Potato Storage Research Facility at Kimberly and eight replications were sent either to the Washington State University Prosser Irrigated Agriculture Research & Extension Center (2001) or to the Oregon State University Hermiston Agricultural Research and Extension Center (2002 and 2003). At Kimberly, the paper bags were removed and each mesh bag was placed into a sealed plastic box (76×51×38 cm). The enclosed treatment boxes contained filters to prevent spore transfer between treatment boxes and received air from the surrounding storage environment using a modified Dayton Shaded Pole Blower. The surrounding storage environment was 7.2°C and 95% relative humidity (RH). At Prosser in 2001, the tubers were stored at 10 C (50 F) at 95% RH. At Hermiston during both years (2002–2003), the storage was maintained at 7.2 C and 95% RH. At both Prosser and Hermiston, mesh bags were placed randomly into two wooden pallets, separated by sampling date.

Tubers were stored for two time periods (2–3 months and 6 months) at each storage location for each year of the trial. Following the appropriate storage time, four replications from each treatment were washed with water and then split into two subsamples. Subsample tubers were placed still damp into ventilated plastic potato bags and the bag tops were then closed. Each bag was placed into a fresh pack cardboard potato box (22.6 kg capacity) and stored in a dark room at 20°C for 3 weeks. Bags were opened weekly and tubers were lightly misted with distilled water. At the end of 3 weeks, tubers were removed from the plastic bags and allowed to air dry prior to scoring for silver scurf. Tubers in each replication were individually rated for incidence (percentage of tubers with silver scurf symptoms) and severity (visually estimated percentage of the tuber surface infected by the pathogen). Confirmation that symptoms were caused by *H. solani* and not *Colletotrichum coccodes* (which can cause similar symptoms on the tuber) was done by verifying the presence of *H. solani* conidia and conidiophores using a stereo microscope at 50× magnification.

Data were analyzed according to a split plot in time repeated measures analysis. Testing for significance of post-harvest treatment, storage time, and potential interactions between the two categories was done using the model statement $Y_{ijk}=\mu+\text{Replication}_i+\text{Treatment}_j+(\text{Replication}\times\text{Treatment})_{ij}$ (whole plot)+$\text{Time}_k+(\text{Time}\times\text{Treatment})_{jk}$ (sub-plot). Analysis of variance was performed using the PROC GLM procedure of SAS (SAS institute, Inc., Cary, NC). Mean separation was performed using the Fisher's protected least significant difference (LSD) test when the F test was significant ($P<0.05$) for a test factor. For disease severity data, values were transformed with the log(x+1) transformation prior to analysis and back transformed values were given in the tables.

Results

Post harvest treatments had a significant effect ($P<0.05$) on silver scurf incidence in all year×location combinations, and a significant effect on silver scurf severity in five of six year×location combinations (Table 2). Time in storage

Table 2 Significance (pr>F) of replication (Rep), post-harvest treatment (Trt), time in storage (Time) and associated interactions on silver scurf incidence and severity following storage from 2001 to 2003 at Kimberly, ID, Prosser, WA, and Hermiston, OR

Location; Variable					
Year	Replication (Rep)[a]	Treatment (Trt)	Rep×Trt	Time[b]	Trt×Time
Incidence[c]					
Kimberly, ID[d]					
2001	0.8827	**0.0025**[e]	0.0245	0.0750	**0.0186**
2002	0.8738	**0.0084**	0.0157	**0.0063**	0.1922
2003	0.1861	**<0.0001**	0.7479	0.2451	0.0992
Prosser, WA (2001) and Hermiston, OR (2002 and 2003)					
2001	0.5333	**<0.0001**	0.8851	0.8440	0.4070
2002	0.2036	**0.0139**	0.6771	**0.0500**	0.2738
2003	0.7603	**<0.0001**	0.7312	**0.0017**	0.1608
Severity[f]					
Kimberly, ID					
2001	0.8581	**0.0523**	0.0960	**0.0100**	0.0738
2002	0.9254	**0.0022**	0.3216	0.2805	0.8411
2003	0.2508	**<0.0001**	0.4308	**0.0212**	0.2098
Prosser, WA (2001); Hermiston, OR (2002 and 2003)					
2001	0.3668	**0.0229**	0.0309	**<0.0001**	**0.0210**
2002	0.5868	0.1313	0.2337	**0.0079**	0.3681
2003	0.3553	**<0.0001**	0.2786	**0.0324**	0.3464

[a] Each replicaiton consisted of 20 tubers

[b] Tubers were stored for two length of times (2–3 months and 6 months) before evaluating for silver scurf

[c] Incidence is the number (%) of 20 tubers/replication infected with silver scurf

[d] Two storage locations were utilized for all treatments each year

[e] Treatmemt, Time, and Treatment×Time interaction values in bold are significant at $P<0.05$

[f] Severity is the estimated percentage of the tuber surface with visible symptom of silver scurf

Severity data in 2002 and 2003 (both locations) were transformed by log(x+1) to satisfy the assumptions of ANOVA

significantly affected silver scurf incidence and severity in three of six and five of six year×location combinations, respectively. A significant interaction between post-harvest treatment and time in storage was only observed in 2001 at both study locations.

In 2001 at both locations, post harvest treatments had a significant effect on silver scurf incidence, but time in storage did not (Table 2). In Kimberly, none of the post-harvest treatments reduced silver scurf incidence compared to the untreated control, regardless of time (Fig. 1a, c), but potassium sorbate increased disease incidence after 2 months in storage (Fig. 1a). After 6 months in storage the ozone, thiabendazole, azoxystrobin, and *Bacillus subtilis* treatments reduced incidence compared to the harpin treatment (Fig. 1c). At the Prosser location, silver scurf incidence was reduced after 2 months in storage by azoxystrobin (Fig. 1b). After 6 months in storage, both azoxystrobin and *B. subtilis* significantly decreased disease incidence. Mean silver scurf incidence for both sampling times was greater at Prosser, WA (77%) than at Kimberly, ID (28%).

Differences among treatments for silver scurf severity (mean percentage of the tuber surface covered) were not observed at Kimberly following 2 months in storage (Fig. 2a) in 2001. However, significant differences were observed at Prosser, WA (Fig. 2b). As with incidence, none of the treatments reduced severity compared to the untreated control. However, tubers treated with azoxystrobin had significantly lower severity ratings than those treated with ozone. After 6 months in storage at Kimberly, none of treatments showed a significant reduction in severity compared to the untreated control (Fig. 2c). *B. subtilus* treatment did result in a severity rating significantly lower than the harpin treatment. Severity ratings were not recorded at Prosser, WA at the 6 month evaluation.

Significant interactions between treatment and time were not observed in 2002 or 2003 (Table 2). As a result, treatment means for 3 and 6 month evaluations were combined for presentation. At Kimberly in 2002, potassium sorbate, azoxystrobin, and *B. subtilus* reduced disease incidence compared to the untreated control (Fig. 3a). Conversely,

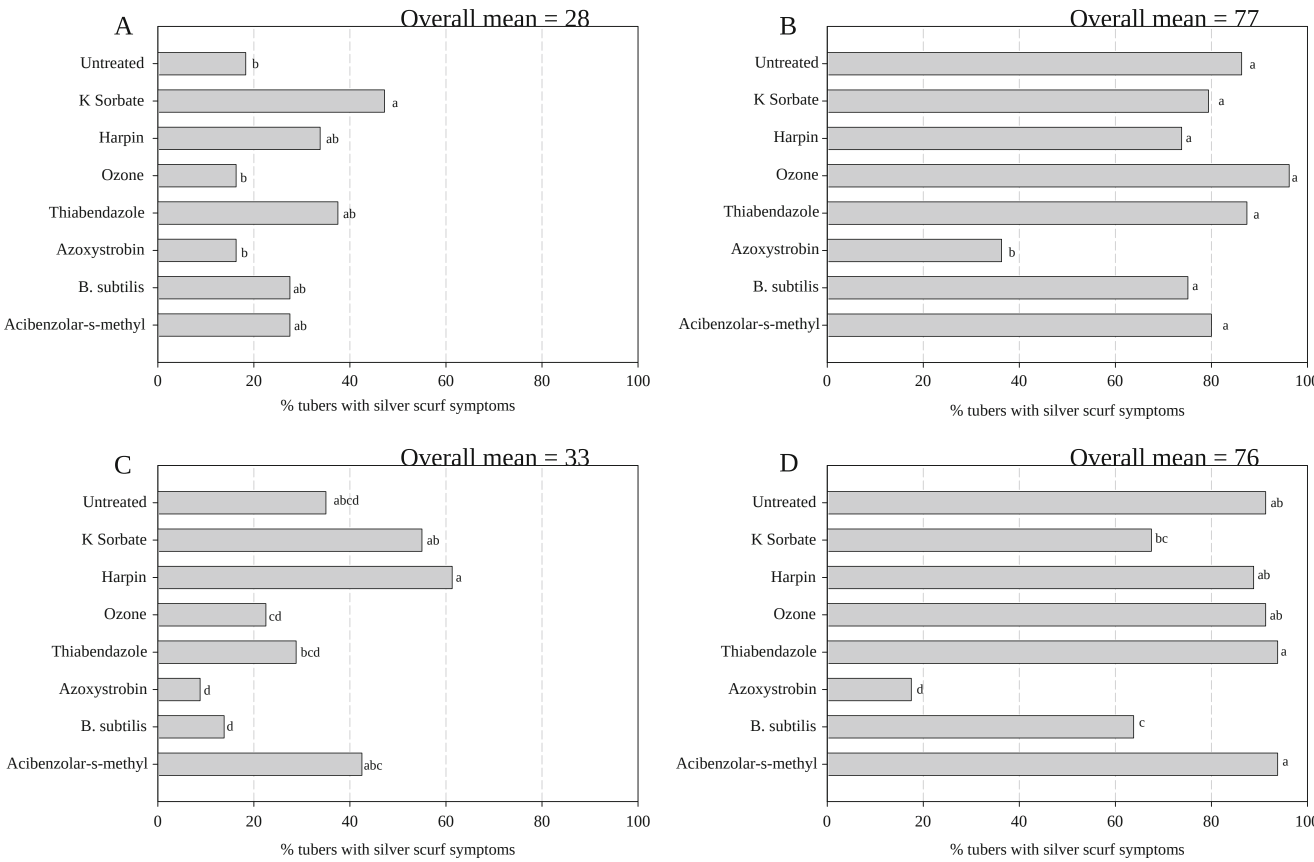

Fig. 1 Effect of post-harvest treatments on the incidence of silver scurf caused by *Helminthosporium solani* on potato tubers (cv. Russet Norkotah) in 2001. **a** Kimberly, ID location after 2 months in storage. **b** Prosser, WA location after 2 months in storage. **c** Kimberly, ID location after 6 months in storage. **d** Prosser, WA location after 6 months in storage. The mean for the time main effect (average of all treatments) is given in the upper right hand corner of each graph

ozone and harpin treatments increased incidence. A similar trend was also observed for tubers stored at Hermiston, OR, however, difference among treatments were not significant (Fig. 3b). At both locations, silver scurf incidence increased over time in storage and was significantly higher at the 6 month evaluation (increased from 13% to 22% at Kimberly and from 5.5% to 8.9% at Hermiston). Disease incidence was greater at Kimberly (average of 17.5%) than at Hermiston (average of 7.2%).

Disease severity in 2002 followed a trend similar with incidence. Potassium sorbate, azoxystrobin, and *B. subtilus* reduced disease severity compared to the untreated control at Kimberly (Fig. 3c). At Hermiston, all treatments were similar to the untreated control (Fig. 3d). None of the treatments at either location resulted in significantly greater severity than the untreated control. Increases in disease incidence (13 to 22 at Kimberly and 5.5 to 8.9 at Hermiston) and severity (0.60 to 0.88 at Kimberly and 0.14 to 0.44 at Hermiston) were observed with time in storage at both locations.

In 2003, thiabendazole, azoxystrobin, and hydrogen peroxide/peroxyacetic acid (HPPA) reduced disease incidence and severity at both Kimberly and Hermiston (Fig. 4). Ozone appeared to increase silver scurf incidence at Hermiston (Fig. 4b), but not at Kimberly (Fig. 4a). Treatment with *B. subtilus* decreased silver scurf severity at Kimberly (Fig. 4c), but not at Hermiston (Fig. 4d), even though the treatment did not decrease incidence. Disease incidence increased significantly with time in storage at Hermiston (40% to 54%), but not at Kimberly (49% to 54%).

Discussion

Managing silver scurf has become an important consideration for potato producers growing potatoes for fresh consumption. An integrated approach is required to best manage this disease. First, disease-free seed must be planted. Research has shown that the level of silver scurf on seed can be directly proportional to the amount of silver scurf that develops on daughter tubers (Firman and Allen 1995; Geary and Johnson 2006; Miller et al. 2004; Read and Hide 1984; Santerre 1972; Tsror (Lahkim) and Peretz-Alon 2002; Zimmerman-Gries and Blodgett 1974).

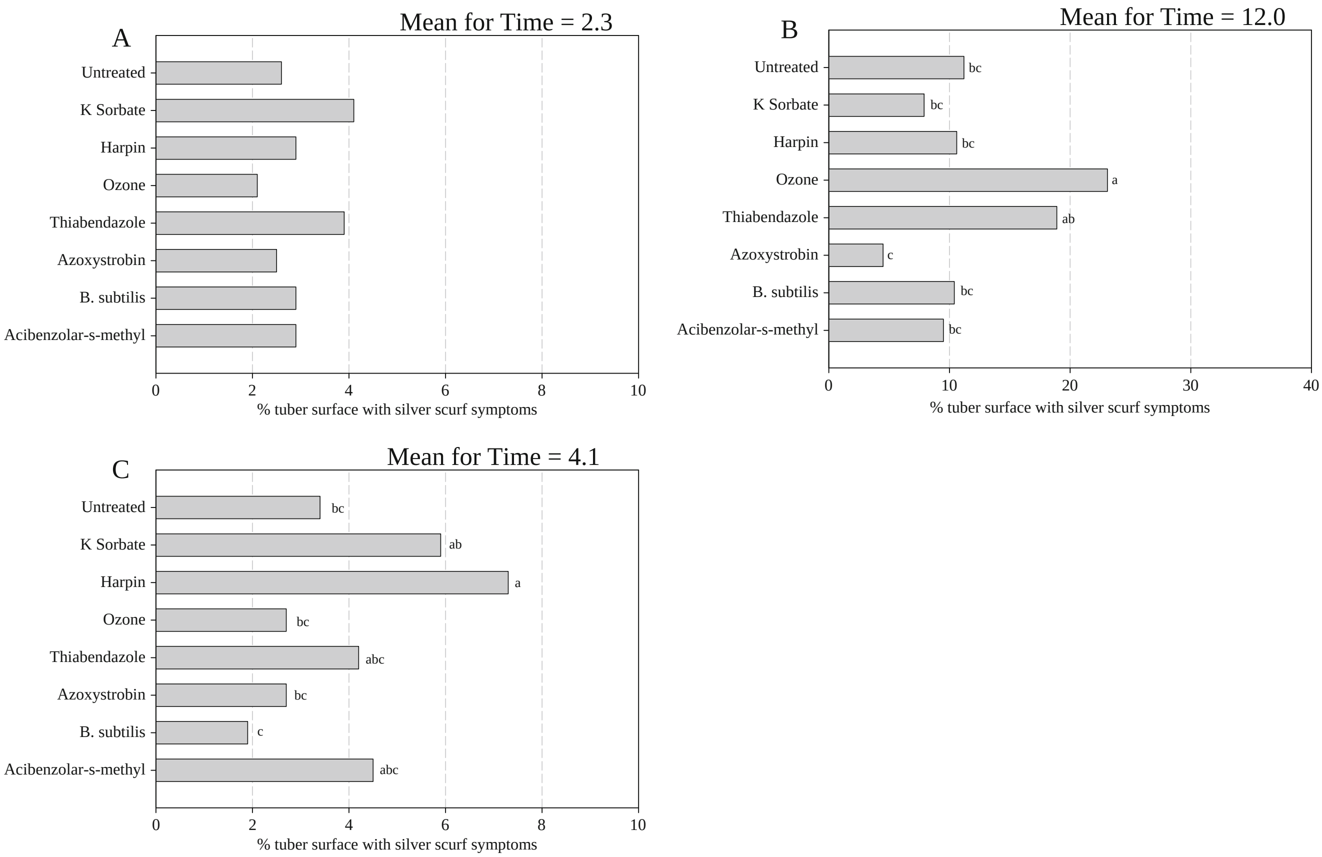

Fig. 2 Effect of post-harvest treatments on the severity of silver scurf caused by *Helminthosporium solani* on potato tubers (cv. Russet Norkotah) in 2001. **a** Kimberly, ID location after 2 months in storage. **b** Prosser, WA location after 2 months in storage. **c** Kimberly, ID location after 6 months in storage. Data were not collected on disease severity at Prosser, WA at the 6 month evaluation. The mean for the time main effect (average of all treatments) is given in the upper right hand corner of each graph

Second, seed lots must be isolated prior to planting. Storing different seed lots with a common air source can lead to contamination of a clean seed source by an infected seed source (Secor and Gudmestad 1999). Third, treating seed can limit spread of *H. solani* from seed pieces to daughter tubers (Denner et al. 1997; Errampalli et al. 2001; Frazier et al. 1998; Geary et al. 2007; Hall and Hide 1994; Hide et al. 1988; Miller et al. 2004; Tsror (Lahkim) and Peretz-Alon 2004). Effective fungicides cited in these articles that are used today in North America include fludioxonil, thiophanate-methyl+mancozeb, and azoxystrobin. Fourth, crop rotation can reduce the effect of soil-borne inoculum (Mérida and Loria 1994b). Finally, after vine kill tubers should be lifted from the soil as soon after skin set as possible since disease incidence increases the longer daughter tubers sit under dead vines (Firman and Allen 1995; Jellis and Taylor 1997; Mérida and Loria 1994a).

The use of a post harvest pre-storage fungicide would provide control in storage. Data provided in this study supports the use of azoxystrobin. Azoxystrobin was the most effective product applied in our trials. Azoxystrobin significantly reduced silver scurf incidence compared to the untreated control in five out of the eight location×time combinations presented in Figs. 1, 3, and 4. Azoxystrobin was the only product to significantly reduce silver scurf incidence compared to the untreated control at Prosser, WA at both 2 and 6 months in 2001. Commercially the product would be applied as a low pressure spray somewhere along the piling line.

The single use of azoxystrobin does have risks. Pathogens have shown the ability to develop resistance to azoxystrobin. Azoxystrobin (quinone outside inhibitor, or QoI) interferes with the mitochondrial electron transport chain. By disrupting this pathway, the target organism is inhibited in its ability to produce ATP. The F129L mutation in pathogen populations provides organisms with an alternative pathway. This mutation has been found in populations of *Alternaria solani* infecting potato (Pasche et al. 2004), *Pyricularia grisea* (Vincelli and Dixon 2002), *Pythium aphanadermatum* (Bartlett et al. 2002), and *Venturia inequalis* (Zheng et al. 2000). The potential exists

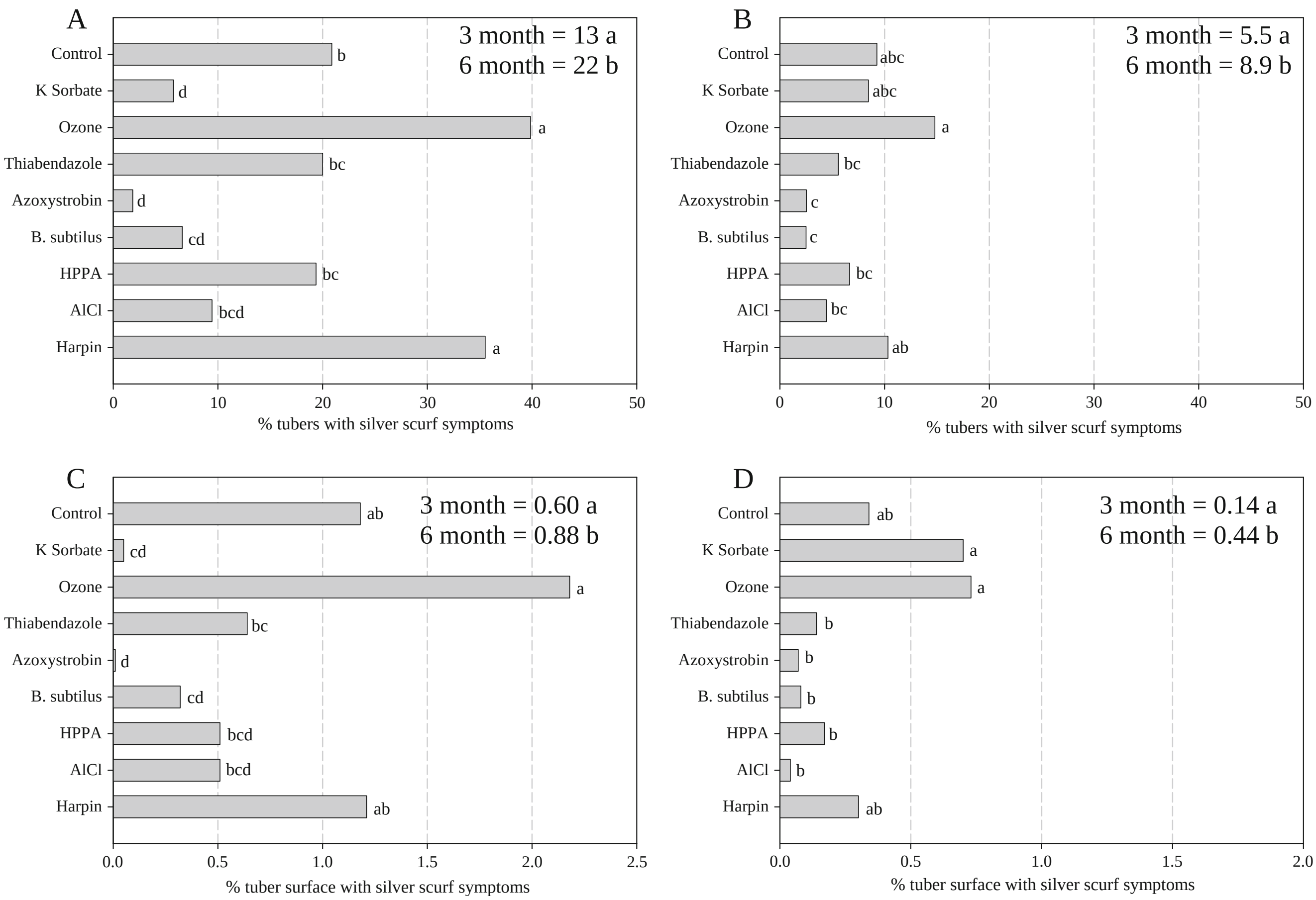

Fig. 3 Effect of post-harvest treatments on the incidence and severity of silver scurf caused by *Helminthosporium solani* on potato tubers (cv. Russet Norkotah) in 2002. **a** Incidence at Kimberly, ID. **b** Incidence at Hermiston, OR. **c** Severity at Kimberly, ID. **d** Severity at Hermiston, OR. The means for the time main effect (average of all treatments at 3 and 6 months) are given in the upper right hand corner of each graph

for selecting this mutation (or another resistance mechanism) in *H. solani* with improper use of QoI fungicides in potatoes similar to what happened with the benzimidazole fungicides (e.g. thiabendazole).

Azoxystrobin is currently labeled for use as a seed treatment and as an in-furrow spray to manage soil- and seed-borne diseases in potato such as silver scurf. Azoxystrobin is also applied as a foliar spray for the control of foliar diseases such as early blight and black dot. The additional use of this fungicide as a post-harvest use on seed potatoes could increase the likelihood for resistance development. A good resistance management guideline would be to limit the post-harvest application of azoxystrobin to tubers that are being removed from the production chain. Any tubers that would be replanted as seed should not be treated since that would create the possibility of multiple exposures of the same pathogen populations to the active ingredient.

Another resistance management strategy would be to combine azoxystrobin with one or more other effective products. Currently work is underway to compare other materials which may have activity against *H. solani* when applied to tubers immediately after harvest and prior to storage. However, none of the other products tested thus far reduced disease severity as consistently as azoxystrobin. In the trials reported here, *Bacillus subtilus* significantly reduced silver scurf incidence compared to the untreated control in two of the eight location×time combinations, while potassium sorbate was effective in one of six tests. Ozone was not effective in any of the experiments, and even resulted in a significant increase in silver scurf severity in Kimberly in 2003. This is in agreement with previous work on ozone for controlling silver scurf in storage (Hamm 2005). The significant increase in silver scurf incidence with ozone at Kimberly in 2002 could be explained by the ozone causing a reduction in other organisms on the tuber surface which could compete with *Helminthosporium* (Selma et al. 2006).

Hydrogen peroxide/peroxyacetic acid (HPPA) was effective in two of the four location×time combinations in which it was evaluated. However, in both cases where it was effective (Kimberly and Hermiston in 2003) disease

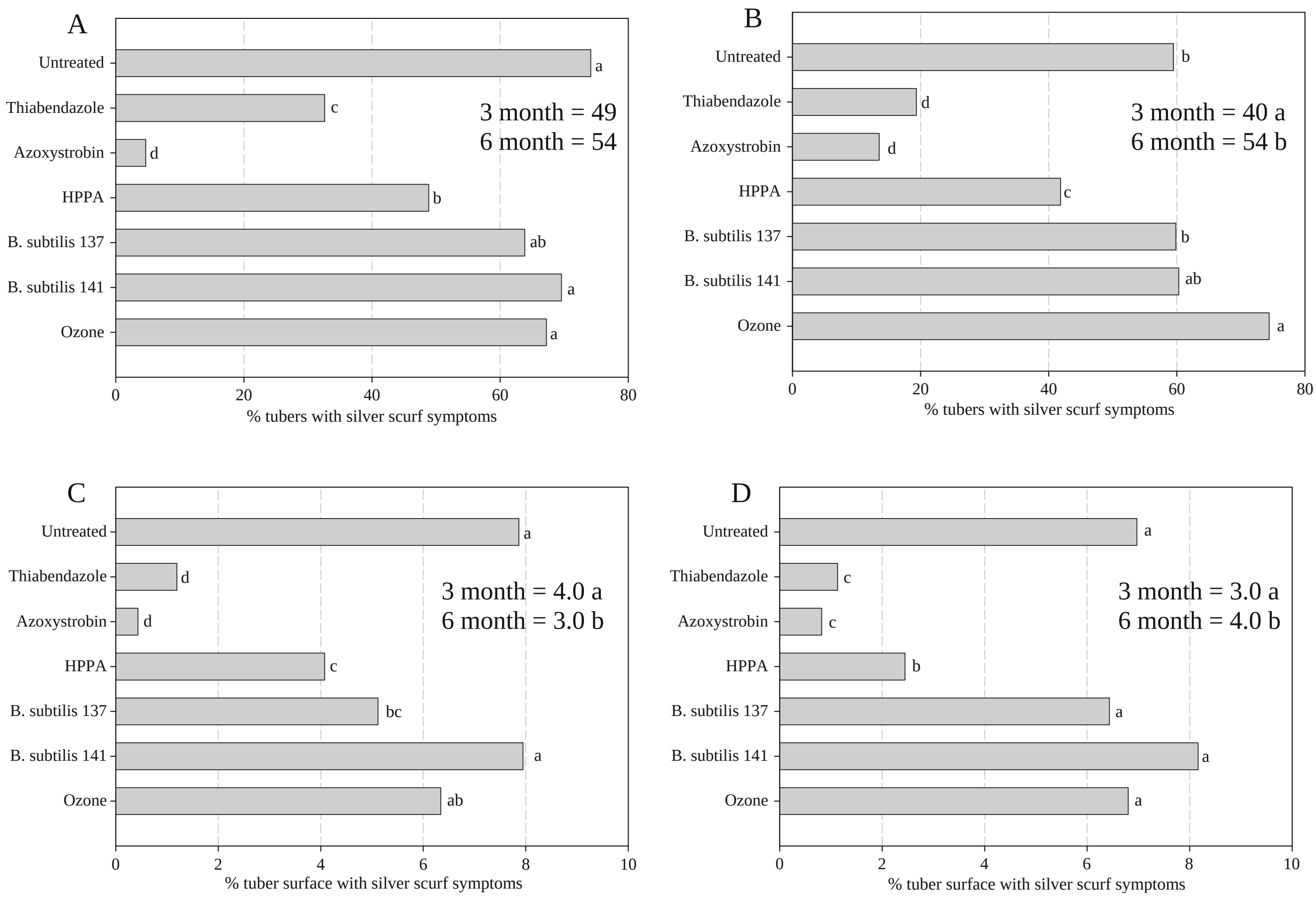

Fig. 4 Effect of post-harvest treatments on the incidence and severity of silver scurf caused by *Helminthosporium solani* on potato tubers (cv. Russet Norkotah) in 2003. **a** Incidence at Kimberly, ID. **b** Incidence at Hermiston, OR. **c** Severity at Kimberly, ID. **d** Severity at Hermiston, OR. The means for the time main effect (average of all treatments at 3 and 6 months) are given in the upper right hand corner of each graph

incidence was significantly greater than with the azoxystrobin treatment. HPPA-based products are relatively inexpensive and are used commonly to treat potatoes in storage. Hydrogen Peroxide Plus was successfully used to reduce silver scurf on potatoes with a single application in the ventilation system (Afek et al. 2001). This application was different than a spray application made to tubers being placed as they are being loaded into storage. Other research on HPPA efficacy has been mixed. Significant reduction in *H. solani* growth has been obtained in Petri dishes and on individual tubers (Klimes 2002). But Klimes also observed that movement of HPPA in a simulated potato storage was difficult to detect greater than 1 m above the storage floor (Klimes 2002). Hydrogen peroxide is a good, general disinfestant and in theory should provide some level of disease control when applied to tuber surfaces.

Thiabendazole did not significantly affect silver scurf in 2001 (Figs. 1 and 2) and 2002 (Fig. 3), but did result in a significant reduction in 2003 (Fig. 4). Thiabendazole use is not generally recommended due to presence of fungicide resistance in *H. solani* populations (Hide and Hall 1993; Mérida and Loria 1990). However, it is possible that some *H. solani* populations have shifted from being resistant to being sensitive. We did not evaluate isolate sensitivity in this trial and a recent survey of sensitivity in *H. solani* populations has not been published.

Fungicide applications at harvest prior to storage do present some challenges. It is difficult to maintain a consistent flow rate of tubers in a potato piling operation. Additionally, any application of water to tubers has the potential to increase soft rot (caused by *Pectobacterium carotovorum*) if the tubers get excessively wet and not allowed to thoroughly dry. All of our trials were conducted using 2.08 L water/metric ton (MT) tubers (0.5 gal/ton) in a semiarid environment. This is the rate that was originally developed for the application of thiabendazole to tubers at harvest. Improper calibration of the spray applicator may result in over-application resulting in tubers getting too wet, or in under application resulting in tubers receiving a dose too low for disease control. Similarly, poor control may result when tuber flow rate underneath the applicator changes. Poor training of applicators may result in poorly applied fungicides. These employees typically have multiple duties during the harvest and tuber piling operations and are not able to oversee the post-harvest application at all times.

The use of a post-harvest pre storage fungicide application is just one facet of an integrated disease management plan that should be used to manage silver scurf. Storage losses from silver scurf are usually not significant until after 3 months in storage. Previous work has shown that silver scurf can be decreased with a longer curing period (Hide et al. 1994). Also, conditions of low relative humidity (<85%) which can occur during the curing phase reduce silver scurf development (Frazier et al. 1998). Conditions which are optimal for potato storage (relatively humidity of 95%) favor the production of *H. solani* conidia (Errampalli et al. 2001) and large numbers of conidia (as much as 2.4×10^4 per day) can be detected in commercial potato storages (Rodriguez et al. 1996). As time in storage progresses, *H. solani* infections increase. Our data show that the use of an effective post-harvest application such as azoxystrobin can slow but not stop the increase of silver scurf on tubers in storage.

Managing silver scurf successfully will result from planting clean seed, utilizing effective seed and or in-furrow fungicide treatments, practicing crop rotation (at least 2 years between potato crops), harvesting tubers in a timely manner, and using an effective post-harvest treatment. The search for additional products that can be applied to tubers after harvest with activity against *H. solani* is critical for managing fungicide resistance. Using these tools will assist potato producers in reducing the loss of tubers to silver scurf during the storage period.

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