Management of Silver Scurf (*Helminthosporium solani*) with Fungicide Seed Treatments and Storage Practices[1]

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ABSTRACT

Thiabendazole insensitive strains of *Helminthosporium solani*, the causal agent of silver scurf, make controlling the disease with seed treatment difficult. Potato tuber seed treatments and environmental storage management practices were investigated as means to minimize silver scurf. Fungicide seed treatments were evaluated for control of *H. solani*; disease was evaluated during the growing season, at harvest, and after 5 months of storage. Silver scurf was observed on progeny tubers eleven weeks after planting. Fungicides that reduced silver scurf incidence and severity on the seed resulted in reduced incidence and severity of the disease in the progeny tubers at harvest and significantly lower disease ratings after storage. Only small increases in disease incidence (0-8%) were seen after storage. Thiophanate-methyl with mancozeb, Captan with mancozeb, and fludioxonil were among the most effective in reducing the incidence and severity of silver scurf on seed and in progeny tubers (Incidence on progeny tubers at harvest for these three treatments were 3%, 9%, and 8% respectively). Thiophanate-methyl alone was not effective for control of silver scurf (48% incidence compared to 43% incidence for the untreated control).

Environmental conditions in storage affected disease development. Reduced humidity (85%) during the curing period (0-3 weeks after harvest) significantly reduced (11%) the surface area of tubers infected with silver scurf. Free moisture on the tuber surfaces during storage significantly increased (15%) tuber surface area infection. *H. solani* was shown to survive in soil and on some potato storage building materials for up to 9 months. The silver scurf disease of potatoes can be suppressed using effective seed treatment and storage management.

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INTRODUCTION

The silver scurf disease of potatoes, caused by *Helminthosporium solani* Durieu & Montagne, occurs in most potato-growing areas and has recently become a significant problem in the fresh market potato industry of Idaho. An economic analysis estimated an annual loss of $8.6 million to the Idaho table stock industry during 1992/93 (Shetty and Patterson, 1993).

The fungus can infect potato tubers during the growing season and in storage. Seed tubers are the primary source of inoculum (Burke, 1937) and infection can occur in the field when progeny tubers have direct contact with the seed tuber or develop in close proximity to it. Initial infection can occur shortly after tuber initiation and is most often located at the stem end of the tuber (Jellis and Taylor, 1977a). In some cases, severe infection of seed tubers retards sprout emergence and canopy development (Read and Hide, 1984). Research conducted to relate the severity of seed tuber infection and the severity of the disease on progeny tubers has produced conflicting results. Perhaps these discrepancies may have been seen because older lesions produce fewer conidia and may lose their ability to sporulate (Jellis and Taylor, 1977a).

Seed-borne inoculum is important in the disease cycle and severity of silver scurf in progeny tubers has been reduced by treating seed tubers with fungicide (Jellis and Taylor, 1977b). Some seed treatments currently registered are not effective for control of silver scurf on seed. Although thiophanate-methyl (TPM) and thiabendazole (TBZ) compounds have been used in the past with good results (Cayley *et al.*, 1979), recent research has shown that many isolates of *H. solani* have become insensitive to benzimidazole fungi-

cides (Mérida and Loria, 1990). In studying the development of benzimidazole resistance, Hide and Hall (1993) have shown that the population of insensitive isolates increases and the population of sensitive isolates decreases when TBZ is applied to a seed lot. TBZ insensitive isolates were found on progeny tubers after one application of TBZ to seed infected with sensitive isolates. The application of TBZ to seed infected with an insensitive isolate of *H. solani* increased the incidence of disease in progeny tubers compared to untreated seed (Hide and Hall, 1993). Mérida and Loria (1994a) studied the virulence of TBZ-sensitive and TBZ-insensitive isolates and found no differences. This suggests sensitive and insensitive isolates do not differ in fitness and insensitive isolates may persist in the population even if benzimidazoles are no longer used.

Although initial infection of progeny tubers occurs during the growing season, much of the actual increase in the disease and the resulting quality problems takes place in storage. *H. solani* sporulates on potatoes in storage and, as a result, spreads to healthy tubers (Rodriguez *et al.*, 1996). Recent reports have demonstrated that conidia of *H. solani* are airborne in storages and are dispersed in the storage ventilation system (Rodriguez *et al.*, 1993). New infection may occur when warm and humid conditions favor germination of the conidia (Rodriguez *et al.*, 1996). *H. solani* infects healthy intact tuber periderm, but causes more severe infection in wounded tubers (Hide, 1994). As infection progresses, periderm cells collapse. The disruption and subsequent collapse of the phellem layer causes a significant increase in shrinkage in infected tubers (Hunger and McIntyre, 1979). The desiccation of cells and the deposition of suberin in the affected area gives the potato the characteristic silvery appearance and degrades color pigments in red varieties. Infection in russet cultivars is usually not visible at the time of harvest, but symptoms begin to appear 3 to 4 months after storage begins. Temperature and relative humidity in storage influence disease severity (Hide and Boorer, 1991). Curing potatoes at 80% relative humidity (RH) decreased disease severity relative to that in potatoes cured at 95% RH (Hide *et al.*, 1994a). When airborne spores of *H. solani* in a commercial storage were trapped and counted, the number of spores in the air was shown to increase with time in storage and significantly increased when potatoes were handled or transported out of storage (Rodriguez *et al.*, 1993). Rodriguez *et al.* (1995) found tubers could be naturally inoculated by exposing them to the air circulated in a commercial potato storage.

Our objective was to evaluate the efficacy of several new fungicide seed treatments for control of silver scurf. The relative effectiveness of fungicide seed treatments was determined by evaluating the incidence and severity of silver scurf on the seed, in progeny tubers during growth, at harvest, and after long-term storage. Additional studies evaluated storage environmental factors that affect pathogen infection and severity.

MATERIALS AND METHODS

Seed Treatment

Solanum tuberosum cv Russet Burbank potatoes were used throughout this study. In 1993, Generation 2 (G2) seed from the University of Idaho foundation seed program at Tetonia, Idaho, that showed a low level (incidence <5%) of silver scurf infection was used. In early April, this seed lot was inoculated with *H. solani* conidia. Single spore isolates of *H. solani* collected from tubers in southern Idaho were grown on V-8 juice agar (Tuite, 1969) for 4 weeks. Conidia were harvested from culture using a sterile glass rod and sterile distilled water. Inoculum was adjusted to approximately 10,000 conidia ml^{-1} in sterile water. Seed tubers were sprayed with this inoculum at the rate of 12.5 ml kg^{-1}; the tubers were completely wetted with the inoculum. The tubers were held at 20 C and 95% RH for three weeks to allow infection to occur. A second portion of this seed lot was not inoculated and will be referred to as the noninoculated control. Seed was treated with fungicides immediately prior to planting at Kimberly, Idaho. Materials tested included TPM (2.5%), TPM (2.5%) combined with manganese/zinc ethylene bis dithiocarbamate (6%) (TPM-MZ), TBZ (0.5%) combined with manganese/zinc ethylene bis dithiocarbamate (6%) (TBZ-MZ), Captan (5%) combined with manganese/zinc ethylene bis dithiocarbamate (6%) (Captan-MZ), and fludioxonil (0.33%). The rate of application was 10 g product kg^{-1} seed tubers except for fludioxonil. Fludioxonil was tested in 1993 as a flowable formulation (0.05 ml kg^{-1}) and in 1994 and 1995 as a dust formulation (7.5 g kg^{-1}).

In 1994, a G2 seed lot was inoculated in the manner outlined above, except that the inoculation was done in early December in an attempt to mimic natural infection in storage. The seed was then stored at 7.2 C and 95% RH for 4 months. The storage temperature was raised to 15 C for three weeks prior to planting. For the 1995 test, a G2 seed lot was inoculated three weeks prior to planting in the same manner as the inoculated seed lot in 1993. Fungicides were applied as previously described.

Test plots constituted a single row 15.2 meters in length

and treatments were replicated in five blocks. Herbicide, nematicide, insecticide, and fertilizer were applied to the plots in a manner consistent with University of Idaho recommendations (University of Idaho Cooperative Extension System, 1993). Irrigation was applied at 100% of estimated/calculated evapotranspiration or as needed through solid set sprinklers. Starting approximately one month after planting, the emergence of plants was counted twice weekly until approximately 95% of the stand had emerged. Analysis of variance (SAS Institute, 1990) was used to compare the emergence and the final stand establishment of seed treated with various fungicides.

Eleven weeks after planting, five plant samples were dug from each plot. Cross contamination between samples was avoided by disinfecting digging forks and the use of clean gloves. Seed pieces were evaluated within 1 day of digging. Progeny tubers were incubated in plastic bags with holes (5 mm) for gas exchange and wet paper towels for high RH. Samples were held in a dark incubation chamber at 21 C and approximately 95% RH for three weeks. Samples were evaluated by examining the seed piece or tuber under a stereoscopic microscope (10X magnification) to confirm the presence of conidiophores and conidia characteristic of the pathogen (Heiny and McIntyre, 1983). Tubers were subjectively rated on a disease scale of 1 to 4: 1= no silver scurf infection present; 2= a tuber with a single sporulating lesion less than 1 cm in diameter, considered a slight infection; 3= moderate infection, a tuber with 1 or more sporulating lesions covering 1 to 3 cm in diameter; 4= a tuber with sporulating lesions of more than 3 cm in diameter and considered a heavy infection. The mean of five seed pieces or ten progeny tubers was calculated to determine the disease rating for each plot. Data analysis was performed using analysis of variance and means were compared using LSD in pair-wise comparisons. Ranking and selection were used to determine the three most effective seed treatments (Lund *et al.*, 1991).

The plots were harvested during the first week in October with a single-row potato digger. The lifter and other equipment used to collect the potatoes were disinfested between treatments with a 5% Clorox® bleach (NaOCl) solution to prevent contamination. Yield (1993, 1994, and 1995) and grade (1994 and 1995) were determined in the field. Samples were collected at harvest, incubated and rated for disease as previously described. Progeny tubers from the treatments which were ranked with the lowest disease rating in the early season evaluation, plus the untreated and healthy controls were put in storage. Forty-five kilogram samples were placed in individual storage containers. These containers included an evenly distributed air supply to simulate bulk potato storage conditions. Containers were sealed and vents filtered to prevent cross-contamination while in storage. Potatoes were cured at 12.8 C for three weeks. The temperature was decreased at the rate of 0.3 C day^{-1} to 7.2 C and then held constant for the six month storage period. A high level of RH (90-98%) was maintained. At the end of 6 months in storage the temperature was increased to 21 C for three weeks to allow conidiophore development. Twenty tuber samples representing each field plot were rated for disease in the same manner as the early-harvest evaluations. Incidence of disease was calculated. A general linear model analysis was performed for treatments and years.

Relative Humidity and Free Moisture

The effect of two RH levels, 85% and 95%, during the curing period was evaluated on the severity of silver scurf in stored Russet Burbank potatoes. In the same study, the influence of free moisture after the curing period on silver scurf severity was also examined. Potatoes were stored in two one-ton bins, one each for the two RH levels. Both bins were held at 12.8 C for 3 weeks and subsequently reduced to 7.2 C for the remaining 5 months. Each bin was divided in half with a wooden barrier then sealed to prevent moisture movement from one side to the other.

Potatoes were harvested using a single row digger and bagged carefully in open mesh bags. The initial weight of each bag (approximately 20 kg) was recorded. Conidia of *H. solani* were harvested from 12 week old cultures and suspended in sterile distilled water (approximately 10,000 conidia ml^{-1}). Bagged potatoes were sprayed with inoculum suspension (approximately 25,000 conidia kg^{-1} potatoes) or with sterile water. The bins were first filled with a 15 cm layer of unbagged potatoes at the bottom of each bin to ensure even airflow through the bagged potatoes above them. In one side of each bin, water nozzles were placed above the bags as a means of mimicking condensation. Each bin was provided with an independent air supply with velocity comparable to standard ventilation used in commercial storages and which ran in a 2 hours on / 6 hours off cycle. One hundred milliliters of distilled water was injected through the nozzles into each bin, at weekly intervals, throughout the 5 month storage. This procedure was done to mimic condensation in one half of each bin. At the end of 5 months the bin temperature was raised to 21 C for three weeks to enhance sporulation of the fungus as an aid in evaluating the potatoes. Disease ratings were based on a subjective scale of 0 to 10 with zero representing no visible

symptoms of the disease and 10 representing 100% infection of the tuber surface area. General linear model analysis for shrinkage or analysis of variance for disease rating was conducted. Means were compared using LSM_{05} or LSD_{05}.

Spore Survivability

H. solani was cultured on V-8 juice agar medium (Tuite, 1969) and maintained from single spore isolations from infected potatoes. The culture was incubated at 22.2 C with no exposure to light. Abundant conidia were harvested after 12 weeks of incubation and the conidial suspension was adjusted to approximately 10,000 conidia ml^{-1} of sterile water. Three different structural materials commonly found in potato storages, viz. galvanized sheet metal, foam insulating sealant (FastFoam™), and plywood, were sized to fit within a 100 mm X 20 mm Petri plate. A cylindrical plastic cup measuring 18 mm X 15 mm was filled with soil collected from a storage. Structural materials and the soil-filled cups were autoclaved. Subsequently, a 500 µl spore suspension was pipetted on the surfaces of the sterilized materials and the soil. These materials were placed inside Petri plates with a wet, 9 cm #2 filter paper. The Petri plates were sealed with parafilm and incubated at 22.2 C without exposure to light. There were 30 replicate plates for each material tested. At the end of 3, 6, and 9 months, 10 plates with each material were opened, and the area where the spore culture was placed was scraped and transferred to sterile V-8 medium. The streaked plates were then incubated for 12 weeks at 22.2 C and examined for surviving cultures of *H. solani*. Viable cultures showed regrowth of hyphae producing mycelia and conidiophores. After confirming the identity of surviving cultures, the materials were observed under the microscope and photographed.

RESULTS AND DISCUSSION

Seed Treatment

At full stand establishment, no significant differences in plant populations were seen for any treatment. Plant emergence when compared over the three years of the study showed no significant effects due to seed treatment.

TPM-MZ, Captan-MZ and Fludioxonil seed treatments provided good control of *H. solani* on the seed (Table 1). The noninoculated control showed a low level of infection, probably due to a low level of natural infection in the seed or to soil-borne inoculum. Silver scurf was observed on the progeny tubers eleven weeks after planting. The fungicide treatments which showed good control on the seed piece resulted in significantly less disease in the progeny tubers. The same trend was evident for the harvest evaluation, but there was an increase in the incidence and severity of the disease. This is consistent with previous research that showed increasing disease severity the longer the tubers remain in the field (Wilcockson *et al.*, 1985). The post-storage evaluations showed only a slight increase in silver scurf severity after 5 months of storage. Other researchers have reported a significant increase in silver scurf after storage (Adams and Hide, 1980). The incubation of samples prior to disease evaluation made detection of all infection sites possible regardless of size. Factors that may have limited both spread and increase in severity of disease while in storage are relatively cool storage temperature, adequate humidity control (which eliminated free moisture on the tubers), and the filtering of the air supply to prevent contamination of samples. Treatment differences were consistent in all three years, however yearly differences varied, perhaps due to environmental factors (Hide and Adams, 1980).

The use of effective seed treatments significantly reduced the incidence and severity of silver scurf in progeny tubers. Reducing the severity of the disease at harvest with the use of seed treatments may limit the amount of disease development in storage. The development of resistance to TPM and TBZ in isolates of *H. solani* has become a serious problem. Resistance may develop to other seed treatment chemicals with single site modes of action if used in a widespread and exclusive manner. This tendency toward fungicide resistance may be combated by combining single site action fungicides with multi-site activity partners such as TPM-MZ. Alternatively, rotating the use of fungicides among different chemical classes in successive generations will help slow the build up of fungicide resistance (Hide and Hall, 1993). Control of silver scurf was superior when fungicide combinations were used. TPM-MZ, Captan-MZ, and fludioxonil are effective for control of silver scurf and provide alternatives to benzimidazoles alone.

Relative Humidity and Free Moisture

Silver scurf developed well at both RH levels. The infection readily spread from inoculated to noninoculated tubers, confirming that the disease can move from tuber to tuber within a storage. Curing potatoes at 12.8 C and 85% relative humidity reduced disease development (Table 2) compared to curing at 95% RH. This result is similar to that reported by Hide and Boorer (1991). The addition of free moisture

TABLE 1.—*Effect of fungicide seed treatments on silver scurf disease rating and incidence. Values are means of three years (1993, 1994, and 1995) combined analysis.*

Seed Treatment	Seed 11 weeks after planting		Progeny 11 weeks after planting		Progeny at harvest		Progeny after 6 months storage[z]	
	Disease rating[x]	Incidence (%)	Disease rating	Incidence (%)	Disease rating	Incidence (%)	Disease rating	Incidence (%)
TPM	3.0 c[y]	80 d	1.3 c	20 b	1.8 c	48 c	*	*
TPM-MZ	1.4 a	32 b	1.0 a	1 a	1.0 a	3 a	1.1 a	5 a
TBZ-MZ	2.1 b	54 c	1.1 ab	7 a	1.5 b	23 b	*	*
Captan-MZ	1.2 a	9 a	1.0 a	1 a	1.1 a	9 a	1.2 a	10 a
Fludioxonil	1.1 a	11 a	1.0 a	0 a	1.1 a	8 a	1.1 a	3 a
Untreated	3.4 c	88 d	1.2 bc	15 b	1.8 c	43 c	1.9 b	35 b
Noninoculated/Untreated	1.3 a	20 ab	1.0 a	2 a	1.0 a	3 a	1.3 a	11 b

[x]Disease rating based on scale 1-4, 1 = no disease; 2 = slight infection; 3 = moderate infection; 4 = heavy infection. All treatments were inoculated except the noninoculated control.
[y]Values followed by the same letter are not significantly different according to a protected LSD ($\alpha = 0.05$).
[z]Potatoes stored at 7.2 C and 95% relative humidity.
*No data taken

resulted in a higher disease rating but significantly decreased shrinkage (Table 2). Inoculation increased the level of infection, but potatoes did not show significant shrinkage loss under these experimental conditions.

Current recommendations on curing suggest that potatoes should be cured at 12.8 C and 95% relative humidity for 2 to 3 weeks (University of Idaho Cooperative Extension System, 1993). This study demonstrates that the silver scurf development on stored potatoes can be reduced significantly when cured at 85%, but this technique may increase the risk of shrinkage loss from the potatoes (Table 2). Perhaps, the most important management issue is maintaining uniform temperature and relative humidity without free moisture formation. Free moisture will increase the incidence and spread of silver scurf on stored potatoes (Table 2). Recent ventilation recommendations call for short intermittent cycles or continuous but reduced velocity ventilation. These procedures have been reported to effectively equilibrate the pile temperatures (Hellevang, 1995). Although, a comparison of different ventilation cycles was not conducted in this study, an intermittent 2 hour run time and 6 hour shut down of the fans maintained the required temperature of the potatoes within the 1 ton bins. The influence of higher levels of silver scurf on shrinkage was not significantly different between the inoculated and the noninoculated potatoes. This result may vary with different varieties, length of storage, and the physiological condition of the potatoes.

Spore Survivability

Reisolation of the conidia from soil and foam insulation showed that the fungus remained viable after 3, 6, and 9 months. No reisolation of viable *H. solani* conidia was pos-

TABLE 2.—*Effect of relative humidity, free moisture, and inoculation with conidia of* Helminthosporium solani *on shrinkage and silver scurf severity after 5 months storage.*[x]

Storage treatment[w]	Shrinkage %	Silver scurf disease rating[y]
Relative humidity		
85%	2.6 b[z]	5.2 a
95%	1.9 a	6.3 b
Free moisture		
Added	1.8 a	6.5 b
None added	2.7 b	5.0 a
Spores		
Inoculated	2.4 a	7.4 b
Noninoculated	2.1 a	4.0 a

[w]Treatment interactions were nonsignificant.
[x]Potatoes stored at 7.2 C and 95% relative humidity after a three week curing period with 85% or 95% relative humidity.
[y]Disease rating based on scale 0-10 where 1 = approximately 10% of the surface area infected and 10 = 100% surface area infected.
[z]Numbers in columns followed by a different letter, within each storage treatment, differ significantly according to a protected LSD ($\alpha = 0.05$).

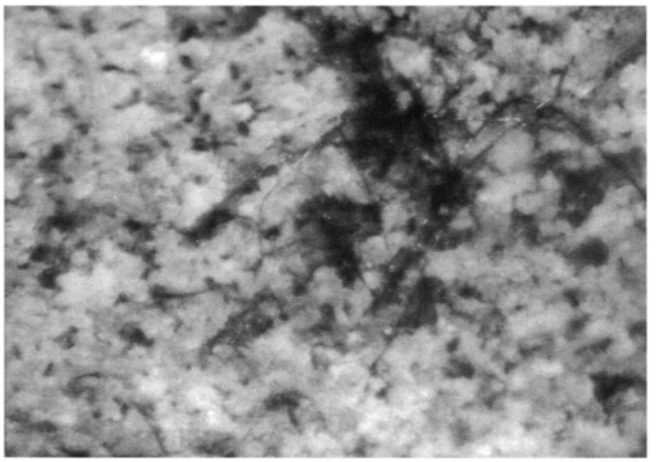

FIGURE 1
Micrograph (30X) showing conidiophores of *H. solani* growing on soil after 9 months incubation.

sible from inoculated plywood or sheet metal after 3 months. A 30x magnified photograph of the soil surface showed evidence of active sporulation 6 months after incubation (Figure 1). Conidia remained viable on the foam insulation but no sporulation was seen. There was growth of the fungus observed on the plywood after 6 months but attempts to reisolate were not successful. Commercial plywood may be impregnated with antimicrobial substances which affected spore viability. Recent reports have shown that the fungus has saprophytic capabilities (Mérida and Loria, 1994b). Therefore, silver scurf may survive between storage seasons inside potato storages, on potato waste and other organic substances. This may a pose an increased risk of infecting new potatoes brought in to storage. Potato storages that have had a recurring problem with silver scurf need to be periodically cleaned and sanitized.

An integrated approach to control of silver scurf may be necessary for long term control. Such practices as crop rotation, bruise prevention, storage temperature and relative humidity management as well as the use of combination seed treatments may be used in an integrated manner to control silver scurf. Storage sanitation procedures to eliminate or minimize the carry-over potential of *H. solani* should also be considered as an integral component of the management strategies to reduce the silver scurf disease of potato.

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