Application of Organic and Inorganic Salts to Field-Grown Potato Tubers Can Suppress Silver Scurf During Potato Storage

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ABSTRACT

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Silver scurf, caused by *Helminthosporium solani*, is an economically important postharvest disease of potato tubers. Organic and inorganic salts were evaluated for their ability to suppress silver scurf lesion development and sporulation of *H. solani* on potato tubers. Tubers were treated immediately after harvest with 0.2-M solutions of potassium sorbate, calcium propionate, sodium bicarbonate, sodium carbonate, ammonium bicarbonate, or water. Tween 20 was added as a surfactant to most treatments. Potassium sorbate (0.1 M), acidified potassium sorbate and calcium propionate treatments (0.2 M), and calcium chloride treatments (0.136 M) were included in additional experiments. Tubers were stored under commercial storage conditions for 4 to 6 months prior to disease evaluation. The extent of disease suppression varied among experiments; however, some treatments consistently reduced disease. Lesion formation on the tuber surface was reduced by 26 to 60% using potassium sorbate (in three of four experiments) compared to water-treated or untreated tubers. Sporulation was suppressed by 0.2 M potassium sorbate (78 to 99% reduction) in all four experiments. Sodium carbonate reduced lesion formation in two experiments and sporulation in three of four experiments. Other treatments inconsistently suppressed lesion formation or sporulation, or did not reduce disease. Addition of Tween or acidification of organic salt solutions did not improve silver scurf suppression in most cases. Potassium sorbate has very low mammalian toxicity and great potential as an innocuous and inexpensive postharvest fungicide for suppression of silver scurf during potato storage.

Silver scurf, caused by *Helminthosporium solani* Durieu & Mont., is a postharvest disease affecting the periderm of potato tubers. The disease is characterized by tan to gray circular lesions which may coalesce with increased disease severity. Lesions are often clustered at the stolon end of the tuber and have a silvery sheen attributed to air pockets that develop in the periderm as a result of the cellulolytic activity of *H. solani* (6). Infection can occur during the growing season and lesions may be visible at the time of harvest (23). Disease symptoms increase greatly during long-term storage of tubers as a result of lesion expansion and repeated cycles of sporulation and reinfection (6,11,13).

The ecology of *H. solani* is not well understood due to difficulties in isolating this slow-growing pathogen from soil. Although the seed tuber is considered the major source of inoculum, survival of *H. solani* in soil has been demonstrated

(14,24). The saprophytic potential of *H. solani* was shown in vitro by colonization of senescing or dried plant tissue of a range of crops (24; C. Olivier, unpublished).

Silver scurf is of great economic importance (30). Losses result from reduction in tuber fresh weight during storage and from discoloration of the tuber periderm (11,13), which greatly reduces tuber marketability. Economic losses have increased in Europe and North America since *H. solani* has developed resistance to thiabendazole (TBZ), which is frequently applied to potatoes as a postharvest and seed-piece treatment (12,15,22). TBZ has been used for many years in the United States for control of Fusarium dry rot on potato tubers; it is likely that the fungicide concomitantly controlled silver scurf, until resistance developed. At present, no fungicide is registered for postharvest control of silver scurf in the United States, and alternative control strategies are needed.

Selected organic and inorganic salts are active antimicrobial agents and have been widely used in the food industry. Many of these salts are effective against a range of microorganisms; most have low mammalian toxicity and therefore have potential for postharvest disease control. Salt treatments can inhibit plant pathogens or suppress mycotoxin production (26,31,37,39,44). Sodium and ammonium bicarbonate were shown to inhibit fungal pathogens of fruits,

field crops, vegetables, and ornamentals (9,32,33,35,46). Sodium carbonate effectively suppressed green mold of citrus fruits caused by *Penicillium digitatum* (Pers.:Fr.) Sacc. (40,41) and reduced growth of storage fungi (1). Salts of sorbic and propionic acid are the most commonly used preservatives in the food industry and reduce growth of molds, yeast, or bacteria in food and feed products (16,19,25,43). They can also inhibit pathogens that cause postharvest plant diseases (2,31,33). Calcium salts, including calcium propionate and calcium chloride, were shown to reduce brown rot of peach and green mold of citrus. These salts also reduced tissue maceration of potato tubers caused by *Erwinia carotovora* (4,10,20). The efficacy of salt treatments depends on the concentration, the target organism, and the method of application (21,25,31,33,42); dip treatments of whole fruits or vegetables, misting, or dusting of plants and plant products are the commonly used application methods. Addition of surfactants may increase the efficacy of salt treatments (2,45,46).

We previously demonstrated that sodium- and potassium carbonate and bicarbonate, ammonium bicarbonate, potassium sorbate, and calcium propionate inhibited growth of *H. solani* in vitro (31). Under controlled experimental conditions, sporulation of *H. solani* and silver scurf lesion development were inhibited by dip treatments of whole potato tubers. In this article, we describe the application of several salts and a surfactant for postharvest control of silver scurf. Salt solutions were applied by dipping or misting naturally infected tubers harvested from commercial fields. Tubers were stored for at least 4 months under conditions simulating potato storage or directly in commercial storage facilities.

MATERIALS AND METHODS

Experimental design. For all experiments, potato tubers were harvested when physiologically mature. Tubers were grown in 1996 for experiments 1 and 2 and in 1997 for experiments 3 and 4. Potatoes were grown by farmers in field sites to which potatoes had been planted previously as part of a crop rotation; these fields likely contained soilborne inoculum of *H. solani*. After harvest, tubers were sorted for size uniformity and randomly assigned to treatments. The surfactant Tween 20

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(polyoxyethylene sorbitan monolaurate) was added to most treatments in 1996 at a concentration of 0.25%. Control treatments (water with and without Tween 20) were included. In all experiments, tubers were evaluated individually for silver scurf lesions (percentage of tuber surface with lesions) immediately after storage. From each treatment, 12 tubers (in 1996) or 20 tubers (in 1997) with visible lesions were selected for spore counts. Tubers used in experiments 1 and 2 had already developed visible silver scurf lesions at the time of harvest. All chemicals used in this study were obtained from Sigma-Aldrich, St. Louis.

Experiment 1. Potato tubers (cv. Chieftain) were grown on a mineral soil in Freeville, New York. Tubers were stored for 10 days at 15 to 20°C before treatments. A total of 48 tubers per treatment were washed, air dried overnight, and dipped for 1 min in one of the following eight solutions: 0.2 M potassium sorbate ($C_6H_7O_2K$), 0.2 M potassium sorbate with Tween, 0.2 M calcium propionate ($C_3H_5O_2 \cdot \frac{1}{2}Ca$) with Tween, 0.2 M sodium bicarbonate ($NaHCO_3$) with Tween, 0.2 M ammonium bicarbonate (NH_4HCO_3) with Tween, 0.2 M sodium carbonate (Na_2CO_3) with Tween, 0.25% Tween 20, and water. Treated tubers were placed into plastic mesh bags, air-dried for 6 h, and stored at 15°C and high relative humidity in growth

chambers for 4 months before disease evaluation.

Experiment 2. Potato tubers (cv. Chieftain) were grown on a muck soil in Wayne County, New York, and stored for 10 days before treatment. The experiment was performed with 48 tubers per treatment as described for experiment 1, but included the following three additional treatments: 0.2 M potassium sorbate (pH 5.7; adjusted with sorbic acid), 0.2 M calcium propionate (pH 5.2; adjusted with propionic acid), and untreated, unwashed tubers.

Experiment 3. Potato tubers (cv. Monona) were grown on a muck soil in Wayne County, New York. Tubers (105 tubers/treatment) were treated immediately after harvest and were not washed prior to treatment. Treatments consisted of 0.2 M potassium sorbate, 0.1 M potassium sorbate, 0.2 M potassium sorbate (pH 6; adjusted with sorbic acid), 0.2 M sodium carbonate, 0.2 M sodium bicarbonate, 0.1 M calcium propionate, 0.2 M calcium propionate (pH 6; adjusted with propionic acid), 0.136 M (2%) calcium chloride, water, and untreated, unwashed tubers. Each tuber was individually misted with a hand-held sprayer until the entire tuber surface was moistened. Tubers were placed in mesh bags, air dried, and placed in a commercial potato storage facility (at 4°C) for 20 weeks. Immediately before disease evaluation, tubers were washed.

Experiment 4. Tubers (cv. Chieftain) were grown in Wayne County, New York, and washed and air dried prior to treatments. Treatments consisted of 0.2 M potassium sorbate, 0.1 M potassium sorbate, 0.2 M sodium bicarbonate, 0.2 M sodium carbonate, 0.136 M calcium chloride, water, and untreated potato tubers. Tubers (100 tubers/treatment) were misted as described above, placed in mesh bags, air-dried, and stored under commercial potato storage conditions at 5°C for 6 months before disease evaluation.

Evaluation of sporulation. Tubers selected for sporulation assessment were stored for another 3 weeks at 21 to 23°C in moist chambers to encourage sporulation. Spore production was evaluated by removing circular slices (7 mm in diameter, 2 to 4 mm thick) from lesions, using a cork borer and a scalpel. Tuber periderm disks (15/tuber) were placed in a 2-ml Eppendorf tube and vortexed with 1 ml of distilled water for 8 min to dislodge spores. The suspension was centrifuged at $5,000 \times g$ for 10 min, tuber disks were removed, the volume reduced to 200 μ l, and spore suspensions were stored at -10°C. Spores (for 12 or 20 individual potato tubers per treatment) were counted using a hemacytometer. Spore counts were repeated at least two times for each spore suspension. All statistical analyses (18,29) were performed with SAS (SAS Institute, Cary, NC). Lesion development and sporulation data were analyzed with analysis of variance (general linear model), and treatment means were compared with Tukey's Studentized Range Test. Sporulation data were log-transformed prior to statistical analysis. Graphical presentations include original data.

RESULTS

Lesion development. None of the treatments significantly reduced lesion surface area in experiment 1 compared to the water or surfactant controls (Fig. 1A). Average tuber surface area with silver scurf lesions across all treatments was 17%. In experiment 2, all three potassium sorbate treatments and ammonium bicarbonate with Tween significantly ($P < 0.01$) reduced the lesion surface area compared to untreated controls, water, or Tween control treatments (Fig. 2A). In this experiment, water treatment alone significantly reduced lesion surface area compared to the untreated control tubers. Tween alone did not reduce lesion surface area in experiments 1 or 2 (Figs. 1A and 2A). In experiment 3 (Fig. 3A), all three potassium sorbate treatments, sodium bicarbonate, and calcium chloride significantly ($P < 0.01$) reduced lesion surface area compared to water-treated or untreated controls. In this experiment, calcium propionate (pH 6) treatments suppressed silver scurf at 0.2 M, but not at 0.1 M, when compared to control treatments. Sodium carbonate significantly ($P < 0.01$) reduced lesions compared to

Fig. 1. (A) Lesion surface area and (B) sporulation of *Helminthosporium solani* on silver scurf-infected potato tubers treated with salt solutions (experiment 1). Graphs represent means of untransformed data with standard error bars. In B (spores per mm² tuber surface), letters correspond with statistical analyses performed on log-transformed data. Mean values followed by the same letter do not differ significantly.

Fig. 2. (A) Lesion surface area and (B) sporulation of *Helminthosporium solani* on silver scurf-infected potato tubers treated with salt solutions (experiment 2). Graphs represent means of untransformed data with standard error bars. In B (spores per mm² tuber surface), letters correspond with statistical analyses performed on log-transformed data. Mean values followed by the same letter do not differ significantly.

water-treated tubers, but not compared to untreated tubers. The percentage of lesion area did not differ between water-treated and untreated tubers. In experiment 4, results of lesion evaluation were similar to those in experiment 3 for all seven treatments (Fig. 4A). Potassium sorbate treatments, sodium bicarbonate, and calcium chloride significantly ($P < 0.01$) reduced the surface area with lesions compared to water-treated or untreated controls. The percentage of lesion area did not differ between water-treated and untreated tubers.

Sporulation. Treatments differed in their ability to suppress sporulation in all experiments. Potassium sorbate at 0.2 M (at all pH values) significantly ($P < 0.01$) reduced sporulation in all four experiments. Suppression of sporulation ranged from 78 to 99% (Figs. 1B to 4B) among the four experiments. In three out of four experiments, sporulation was almost completely suppressed (0.02 to 0.05 spores/mm² tuber) after potassium sorbate treatments. Potassium sorbate at a lower concentration (0.1 M) similarly reduced spore formation compared to water-treated tubers in experiments 3 and 4 (Figs. 3B and 4B), but not compared to untreated tubers in experiment 4 (Fig. 4B). Sodium carbonate (0.2 M) suppressed sporulation of *H. solani*, although results were less consistent than with potassium sorbate.

Sodium carbonate significantly ($P < 0.01$) reduced spore numbers in experiments 1 to 3 (Figs. 1B to 3B) and significantly ($P < 0.01$) reduced spore development compared to water-treated tubers, but not to untreated tubers in experiment 4 (Fig. 4B). Calcium propionate with Tween suppressed sporulation in experiment 1 compared to all controls and in experiment 2 compared to the untreated control (Figs. 1B and 2B). Acidified calcium propionate (pH 5.2) significantly ($P < 0.01$) reduced sporulation compared to all control treatments in experiment 2 (Fig. 2B). However, no effect on sporulation was observed by any calcium propionate treatment in experiment 3 (Fig. 3B). Ammonium bicarbonate, calcium chloride, and Tween 20 did not reduce sporulation (Figs. 1B to 4B).

DISCUSSION

We have evaluated postharvest applications of organic and inorganic salts for their ability to suppress silver scurf on naturally infected, field-grown potato tubers stored under commercial conditions. Because of the importance of sporulation and reinfection during storage in the epidemiology of this disease, we evaluated the effects of postharvest treatments on both lesion surface area and sporulation. In a previous study, we demonstrated a significant and similar reduction of silver scurf with several organic and inorganic salts

under controlled conditions (31). The present study allowed us to identify the most efficacious treatments. In this study, tubers were severely infected with silver scurf before treatment application and were stored under commercial potato storage conditions where sporulation and reinfection could occur (36). Potassium sorbate was the most efficacious treatment, which reduced the silver scurf lesion area by 26 to 60% in three out of four experiments and significantly reduced sporulation in all four experiments. Potassium sorbate (0.2 M) almost completely (96 to 99%) eliminated sporulation in experiments 1, 3, and 4. Two of the four experiments included 0.2 M acidified potassium sorbate (pH ≤ 6) in addition to unadjusted 0.2 M potassium sorbate (pH 8.3). Several studies describe that sorbic acid and its salts are more effective in suppression of microorganisms at acidic pH (5,33). However, in our study, no differences were detected in lesion surface area or sporulation as a result of acidification. A reduced concentration of potassium sorbate (0.1 M) was insufficient for consistent disease suppression.

Sodium carbonate was the second most efficacious treatment. This treatment did not consistently result in lesion reduction, but inhibited sporulation in most experiments. Although pathogen inhibition by carbonate salts is primarily due to the production of the carbonate anion (7,34), suppression of fungi by 0.2 M sodium carbonate is likely also related to the alkaline pH (pH > 11), which is detrimental to most microorganisms. Sodium carbonate was shown to be more effective against green mold of citrus fruits (*P. digitatum*) when applied at concentrations of 4 or 6% than at 2% (40). We treated tubers with only 2.1% (equals 0.2 M) solutions of sodium carbonate. In our studies, sodium carbonate caused a slight discoloration (darkening) of the tuber periderm when applied at a concentration of 0.2 M. Although an increased concentration of sodium carbonate would likely result in better control of silver scurf (40), this discoloration could decrease the market value of the tubers. In contrast to sodium carbonate, potassium sorbate resulted in a desirable light coloration of the tuber periderm, and the red coloration of potato cv. Chieftain was especially pronounced after storage. All other treatments did not affect periderm pigmentation.

Sodium bicarbonate has been reported to be an efficient antifungal compound on ornamentals, cucurbits, and against postharvest pathogens (3,7,8,27,32,35,46). In our study, 0.2 M sodium bicarbonate resulted in inconsistent disease suppression. Likewise, ammonium bicarbonate has the potential to suppress plant pathogens (32,46), but did not reduce silver scurf lesions or *H. solani* sporulation. Other in vivo studies reported that sodium- and ammonium bicarbonate were much less efficient in postharvest disease suppression

Fig. 3. (A) Lesion surface area and (B) sporulation of *Helminthosporium solani* on silver scurf-infected potato tubers treated with salt solutions (experiment 3). Graphs represent means of untransformed data with standard error bars. In B (spores per mm² tuber surface), letters correspond with statistical analyses performed on log-transformed data. Mean values followed by the same letter do not differ significantly.

Fig. 4. (A) Lesion surface area and (B) sporulation of *Helminthosporium solani* on silver scurf-infected potato tubers treated with salt solutions (experiment 4). Graphs represent means of untransformed data with standard error bars. In B (spores per mm² tuber surface), letters correspond with statistical analyses performed on log-transformed data. Mean values followed by the same letter do not differ significantly.

on carrots than potassium sorbate and acidified calcium propionate (33). The effectiveness of bicarbonate salts against plant pathogens may depend on the addition of oil to the treatments (45,46).

Calcium propionate reduced the growth of *Monilinia fructicola* (Wint.) Honey in vitro and on inoculated peach fruits (4). It is also applied as an antifungal compound against storage molds (25). In our study, suppression of silver scurf by calcium propionate was inconsistent. Reduction of *H. solani* sporulation by acidified calcium propionate in 1996 could not be repeated in the following year. Our previous study and those of others (38) had demonstrated that calcium propionate is less effective than potassium sorbate, although both compounds are common antimicrobial agents in the food industry.

In 1997, a calcium chloride treatment was included in both experiments at a concentration (0.136 M) reported to suppress growth of the citrus mold pathogen *P. digitatum* (10). Calcium chloride effectively reduced silver scurf lesions on potato tubers, but not sporulation of *H. solani*. It is known that addition of calcium chloride can also improve the activity of biocontrol agents (10,21).

Several reports describe an increased efficacy of salt treatments when combined with surfactants (2,45,46). In our study, Tween 20 was included in most treatments in 1996 (experiments 1 and 2). Treatment with the surfactant alone did not reduce lesion development or sporulation. Improvements in treatment efficacy did not result from addition of Tween; therefore, it was not included in the 1997 experiments.

Two control treatments were included in experiments 2 to 4, because it is common practice on potato farms to either wash the tubers at the time of harvest prior to long-term storage or immediately after storage. The effect of water control treatments on the development of silver scurf lesions and sporulation of *H. solani* compared to unwashed tubers varied among experiments. However, no significant differences were detected between water-treated and untreated tubers, except in experiment 2, where less sporulation was observed on water-treated tubers. This result could be due to a relatively small sample size for sporulation studies in experiment 2, which was increased in the following year. Water treatment (followed by air-drying of the tubers) never resulted in a significant disease increase.

Sorbic acid and its salts alter cell membranes and cell transport functions, and inhibit RNA, DNA, and protein synthesis and enzymes involved in the tricarboxylic acid cycle. Sorbic acid may also uncouple oxidative phosphorylation reactions in mitochondria (16,42,43). Whereas inhibition of spoilage fungi and bacteria with potassium sorbate has been frequently demonstrated (5,17,28,38), only a few

studies assessed the potential of potassium sorbate to control fungi causing plant diseases (2,34). Our study demonstrates that potassium sorbate at a concentration of 0.2 M consistently reduced silver scurf lesion development on previously infected potato tubers; (tubers are commonly infected with silver scurf at the time of harvest). This treatment effectively suppressed disease for a period of up to 6 months. Potassium sorbate also inhibited sporulation to 78 to 99% and improved the appearance of red- and white-skinned potato tubers. Postharvest application of potassium sorbate equally suppressed disease on washed and unwashed tubers and was independent of the application method (dip treatment or misting of tubers). Potassium sorbate is contained as a preservative in most perishable foods and is considered nontoxic, with a 50% lethal dose equivalent of 500 g for an adult human (42). It is therefore well suited as an innocuous fungicide against silver scurf. Although no negative effect on wound healing of potassium sorbate-treated tubers was observed in any experiment, further studies are needed to confirm this result. Postharvest applications of potassium sorbate could be combined with seed treatments of potatoes and cultural practices to minimize losses to silver scurf.

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