Efficacy of Azoxystrobin, Pyraclostrobin, Potassium Phosphite, and Mefenoxam for Control of Strawberry Leather Rot Caused by *Phytophthora cactorum*

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Abstract

Efficacy of azoxystrobin, pyraclostrobin, mefenoxam, and potassium phosphite for control of strawberry leather rot, caused by *Phytophthora cactorum*, was evaluated on a commercial farm. Foliar sprays of azoxystrobin, pyraclostrobin, and potassium phosphite were applied weekly from bloom through harvest and mefenoxam was applied twice as a soil drench at early plant growth and at fruit set. All fungicide treatments had significantly less leather rot than the untreated control and there were no significant differences in leather rot incidence between any fungicide treatment during both years of testing. Mefenoxam (Ridomil Gold) and potassium phosphite (ProPhyt) are currently registered for control of strawberry leather rot in the U.S. Although they are registered for use on strawberry, leather rot is not on the azoxystrobin (Abound) or pyraclostrobin (Cabrio) labels. Results from these studies indicate that both of these strobilurin fungicides provide excellent control of strawberry leather rot.

Introduction

Leather rot of strawberry is caused by the oomycete *Phytophthora cactorum* (Lebert and Cohn) J. Schröt (17). Since the first report of the disease in the southern United States in 1924, leather rot has been reported in a number of different states and is an important disease in Europe and parts of Asia (15). Leather rot is normally sporadic in occurrence and is associated with excessively wet weather (flooding or saturated soils). When the disease occurs, losses are generally severe. Fruit losses of 20 to 30% were common in many commercial fields during a 1981 epidemic in Ohio, and some growers experienced a 50% crop loss (8). *P. cactorum* can infect fruit at any stage of development (15). Infected green fruit become dark brown and appear leathery (Fig. 1). On mature berries, infection may result in little color change or discoloration ranging whitish-gray to purple (Fig. 2). In addition to direct losses from fruit rot, the disease can also cause indirect losses related to the pungent, unpleasant taste and odor of infected fruit. Unlike most other fruit rot diseases, symptoms of leather rot may be subtle on ripe fruit, which thus can be picked and consumed along with healthy fruit. Growers have experienced complaints from customers about off-flavored jams and jellies after processing fruit from fields where leather rot was a problem (M. A. Ellis, unpublished data). Therefore, the tolerable incidence of leather rot is near zero, and some Midwestern growers have reported closing plantings to pick-your-own customers as soon as leather rot was detected.
At present, mefenoxam (Ridomil Gold EC) and fosetyl-aluminum (Aliette) are registered in the United States for leather rot control and both materials are effective (6,10). In Ohio, both materials are used to some extent by strawberry growers annually. Due to the development of fungicide resistance, the continued utility of these materials is in question. Resistance to the phenylamide fungicides (Metalaxyl) was detected soon after their introduction in the early 1980s (14), and resistance to mefenoxam in \textit{P. cactorum} was recently reported (13). Resistance to fosetyl-aluminum has also been reported in oomycete plant pathogens (5,16). New fungicide chemistry with efficacy against \textit{P. cactorum} and a different chemical mode of action than mefenoxam and fosetyl-aluminum should be useful in fungicide resistance management programs.

The strobilurin fungicides represent a new, important class of chemicals for the management of a broad range of diseases caused by fungi and oomycetes. At present, two strobilurin fungicides are registered for use on strawberries in the United States. They are azoxystrobin (Abound), previously Quadris, and pyraclostrobin (Cabrio). Although both fungicides are registered for control of several strawberry diseases, leather rot is not included on the label of either material. The strobilurin fungicides are unique because they are the first synthetic, site-specific materials that provide significant control of both fungi in the Ascomycota and Basidiomycota as well as oomycetes (1,2,11,12,19). Although leather rot is not on the strawberry label for Abound or Cabrio, it is probable that these materials would provide some level of control of \textit{P. cactorum}.

Several foliar nutrient supplements containing phosphonic acid (also called phosphorous acid) are currently marketed within the U.S. These products are marketed as a source of phosphorous and are used on a large number of commercial crops. In the plant, they are converted to phosphite (phosphonate, \( \text{PO}_3^{2-} \)). Phosphite is also the active ingredient in the fungicide fosetyl-aluminum and related fungicides (7). At present, several systemic fungicides with phosphorous acid as their active ingredient are being registered and marketed for use on strawberry within the U.S. Although they have the same active ingredient as fosetyl-aluminum, their efficacy against strawberry leather rot has not been evaluated.

The purpose of this study was to determine the efficacy of azoxystrobin, pyraclostrobin, and potassium phosphite (ProPhyt) for control of strawberry leather rot under field conditions and to compare their efficacy with mefenoxam.

**Fungicide Evaluations**

In 2003, research plots were established in a 2-year-old (first bearing year) commercial planting of the cultivar "Honeoye" near Wooster, OH. Plots (replications) consisted of three adjacent, 3-m-long rows with 0.9 m between rows. Treatments were replicated four times in a randomized complete block
design. Plants were maintained in a matted-row system that was renovated annually (9). For winter protection, the planting was covered with approximately 9 tons/ha of wheat straw in late November 2002. On 10 April, plants were uncovered and straw was moved to the area between the rows. On 12 May (initiation of bloom), straw was removed from between the rows of all plots leaving bare soil only to enhance disease development (10). To further enhance disease development, all plots were flooded until water puddled on the soil surface using an overhead sprinkler every other day (unless rain occurred), from 26 May (5 days after first application) through 22 June (3 days after second harvest). Irrigation provided water at approximately 0.64 cm/h and plots were watered for 2 h each time. The following fungicides were evaluated: azoxystrobin (as Quadris 2.08F); pyroclostrobin (as Cabrio 20EG); mefenoxam (as Ridomil Gold EC 4L); and potassium phosphite (as ProPhyt, 54.5% potassium phosphate, 34.3% phosphorous acid equivalent, 4.2L). Treatments were applied using a hand-held CO\textsubscript{2} sprayer with a pressure of 276 kPa and a water volume of 935 liters/ha. Mefenoxam was applied two times in accordance with current label recommendations. Mefenoxam was applied to the entire area of each treated plot at 0.56 kg a.i./ha on 26 April, then 13 mm of water was applied immediately afterwards through overhead irrigation (spring drench treatment). This application was repeated on 2 June (green fruit present). Pyraclostrobin, azoxystrobin, and potassium phosphite were applied as foliar applications at the rates of 0.20, 0.28, and 2.35 kg ai/ha, respectively. Foliar applications were applied to the center row of each plot on a 7-day interval on 21 May (late bloom), 28 May (green fruit present), 4 June (green fruit present), and 11 June (fruit turning red). All ripe and diseased fruit were harvested from the center row of each plot on 16, 19, and 24 June. The number of diseased and marketable fruit, and the total yield (weight) were recorded for each replication and harvest date.

The experiment was repeated in 2004 in the same commercial planting used in 2003. Winter straw cover was removed 15 April and straw was removed from between the rows, as previously described, on 12 May (5 days prior to first application, 75% bloom). Plots were flooded every other day as previously described from 20 May (3 days after first fungicide application) through 6 June (3 days after first harvest). All treatments were applied at the same rates as previously described. Mefenoxam was applied on 27 April (spring drench) and 19 May (green fruit present). Due to abnormally warm weather during late April and May in 2004, the strawberry season was approximately 2 weeks shorter than in 2003. The condensed growing season resulted in only three applications of foliar fungicides in 2004. Foliar applications were applied on 17 May (late bloom, green fruit present), 24 May (post bloom, green fruit), and 30 May (fruit turning red, four days before first harvest). All ripe and diseased fruit were harvested from the center row of each plot on 3, 7, and 10 June. The number of diseased and marketable fruit, and the total yield (weight) were recorded for each replication and harvest date.

Analysis of variance (ANOVA) was used to determine the effects of treatment on the percentage of fruit with leather rot symptoms, percentage of marketable fruit, total number of fruits, and total yield. The angular transformation was used to stabilize variances. Duncan’s modified (Bayesian) least significant difference test was used to separate means after ANOVA at $P = 0.05$.

**Fungicide Efficacy**

Removing straw from between the rows and repeatedly flooding test plots resulted in a mean percentage leather rot incidence over all harvest dates of 67 and 58% in 2003 and 2004, respectively (Tables 1 and 2), when no fungicides were applied. All fungicide treatments had significantly less leather rot than the untreated control and there were no significant differences in leather rot incidence between any fungicide treatments during both years of testing (Tables 1 and 2). In 2003, the percent disease control provided by pyraclostrobin, azoxystrobin, potassium phosphite, and mefenoxam was 95, 91, 89, and 84, respectively, compared to the untreated control (Table 1). In 2004, percentage disease control for the same treatments was nearly 100% (Table 2).
Table 1. Effect of fungicides on control of strawberry leather rot, 2003.

<table>
<thead>
<tr>
<th>Treatment and rate (a.i/ha)</th>
<th>Leather rot (%)\textsuperscript{w}</th>
<th>Marketable fruit (%)\textsuperscript{x}</th>
<th>Total no. of fruits</th>
<th>Total yield (kg)\textsuperscript{y}</th>
<th>Percent disease control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyraclostrobin (0.20 kg)</td>
<td>3.6 b\textsuperscript{z}</td>
<td>90.3 a</td>
<td>850 a</td>
<td>10.7 a</td>
<td>95</td>
</tr>
<tr>
<td>Azoxystrobin (0.28 kg)</td>
<td>6.3 b</td>
<td>89.8 a</td>
<td>732 a</td>
<td>9.9 a</td>
<td>91</td>
</tr>
<tr>
<td>Phosphorous acid (2.35 kg)</td>
<td>7.4 b</td>
<td>85.8 ab</td>
<td>823 a</td>
<td>9.3 a</td>
<td>89</td>
</tr>
<tr>
<td>Mefenoxam (0.56 kg)</td>
<td>11.0 b</td>
<td>80.0 b</td>
<td>829 a</td>
<td>9.5 a</td>
<td>84</td>
</tr>
<tr>
<td>Untreated control</td>
<td>67.3 a</td>
<td>29.1 c</td>
<td>885 a</td>
<td>7.7 b</td>
<td>--</td>
</tr>
</tbody>
</table>

\textsuperscript{w} Mean percentage of *Phytophthora cactorum*-infected fruit from three harvest dates (16, 19, and 24 June).

\textsuperscript{x} Mean percentage of marketable fruit from the above three harvest dates.

\textsuperscript{y} Total yield from the above three harvest dates for 3 m of crop row per replication.

\textsuperscript{z} For percentages, the analysis was based on the angular transformation. Numbers followed by the same letter within columns do not differ significantly according to Duncan’s modified (Bayesian) LSD test ($P = 0.05$).

Table 2. Effect of fungicides on control of strawberry leather rot, 2004.

<table>
<thead>
<tr>
<th>Treatment and rate (a.i/ha)</th>
<th>Leather rot (%)\textsuperscript{w}</th>
<th>Marketable fruit (%)\textsuperscript{x}</th>
<th>Total no. of fruits</th>
<th>Total yield (kg)\textsuperscript{y}</th>
<th>Percent disease control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyraclostrobin (0.20 kg)</td>
<td>0.5 a\textsuperscript{z}</td>
<td>96.8 a</td>
<td>1080 a</td>
<td>10.8 a</td>
<td>99</td>
</tr>
<tr>
<td>Azoxystrobin (0.28 kg)</td>
<td>0.4 a</td>
<td>97.8 a</td>
<td>1054 a</td>
<td>10.9 a</td>
<td>99</td>
</tr>
<tr>
<td>Phosphorous acid (2.35 kg)</td>
<td>0.8 a</td>
<td>96.8 a</td>
<td>1065 a</td>
<td>10.4 a</td>
<td>98</td>
</tr>
<tr>
<td>Mefenoxam (0.56 kg)</td>
<td>0.3 a</td>
<td>97.9 a</td>
<td>1080 a</td>
<td>9.6 a</td>
<td>99</td>
</tr>
<tr>
<td>Untreated control</td>
<td>58.1 b</td>
<td>35.9 b</td>
<td>1144 a</td>
<td>7.7 b</td>
<td>--</td>
</tr>
</tbody>
</table>

\textsuperscript{w} Mean percentage of *Phytophthora cactorum*-infected fruit from three harvest dates (3, 7, and 10 June).

\textsuperscript{x} Mean percentage of marketable fruit from the above three harvest dates.

\textsuperscript{y} Total yield from the above three harvest dates for 3 m of crop row per replication.

\textsuperscript{z} For percentages, the analysis was based on the angular transformation. Numbers followed by the same letter within columns do not differ significantly according to Duncan’s modified (Bayesian) LSD test ($P = 0.05$).

All fungicide treatments had significantly ($P < 0.05$) more marketable fruit than the untreated control in both years of testing. In 2003, mefenoxam had significantly less marketable fruit than pyraclostrobin or azoxystrobin, but was not significantly different from potassium phosphate (Table 1). There were no significant differences in marketable fruit between pyraclostrobin, azoxystrobin, and potassium phosphate. In 2004, there were no significant differences in percentage marketable fruit between any of the fungicide treatments, with all treatments providing over 96% marketable fruit, compared to 36% for the untreated control (Table 2).

All fungicide treatments had significantly ($P < 0.05$) higher yield (total weight) than the untreated control for both years of testing, and there were no differences in yield between any of the fungicide treatments (Tables 1 and 2). Although yield was significantly lower in the untreated control, there were no significant differences in total number of fruits harvested between any of the treatments (Tables 1 and 2). Total yield effects probably resulted from the failure of infected immature fruit to increase in size. Although it was not recorded, a high percentage of green fruit were infected during both years of testing. Fruit are susceptible to infection by *P. cactorum* at all stages of development (15).
Summary

All of the fungicides tested in these studies provided excellent control of leather rot. Mefenoxam, fosetyl-aluminum, and potassium phosphite are all currently registered for control of strawberry leather rot in the United States. Metalaxyl and fosetyl-aluminum have been reported to be effective for control of leather rot (10). Mefenoxam has the same mode of action as metalaxyl and potassium phosphite has the same mode of action as fosetyl-aluminum (7); therefore, it is not surprising that they are effective against leather rot. At present, mefenoxam, fosetyl-aluminum, and potassium phosphite are all registered and used in Ohio for control of the disease and they appear to be providing excellent control in commercial plantings (M. A. Ellis, unpublished data). Although mefenoxam and potassium phosphite are highly effective for controlling leather rot, both are at risk for resistance development in *P. cactorum* (5,13,14). Fungicide chemistry different from that of mefenoxam and the phosphite fungicides with activity against *P. cactorum* would therefore be beneficial in resistance management programs. In addition, both of these fungicides only provide control of *P. cactorum* on strawberry and have no efficacy against other strawberry fruit rot diseases such as gray mold, caused by *Botrytis cinerea*, and anthracnose, caused by *Colletotrichum acutatum*. Therefore, these materials generally should be used in combination with other fungicides in a comprehensive disease management program.

The strobilurin fungicides are a welcome addition to the fungicides currently registered on strawberry. Pyraclostrobin is registered for control of anthracnose, caused by *Colletotrichum* spp.; leaf spot, caused by *Mycosphaerella fragariae*; and powdery mildew, caused by *Sphaerotheca macularis*. It also provides suppression of gray mold. Azoxystrobin is registered for control of anthracnose and powdery mildew. Neither fungicide is registered for control of leather rot. Our data indicates that both materials provide excellent control of leather rot under highly adverse (i.e., high moisture) conditions in the field. Although leather rot is not on the label, both fungicides can be used for leather rot control in the United States as long as current label recommendations are followed.

Incidence of anthracnose fruit rot appears to be increasing in Ohio and across the Midwest (M. A. Ellis, unpublished data). Prior to the registration of the strobilurin fungicides, there were no highly effective materials available for control of anthracnose fruit rot. In warm, wet growing seasons when anthracnose is generally a problem, leather rot is also a problem and both diseases commonly occur simultaneously in the same field. The use of a strobilurin fungicide discussed herein during such seasons should provide simultaneous control of both anthracnose and leather rot, as well as suppression of *Botrytis*. This is the first class of fungicide chemistry to provide some level of disease control for all of the major fruit rot pathogens in Ohio.

Due to their highly specific mode of action, the strobilurin fungicides are at high risk for resistance development in fungi and oomycetes (3,4,18). For this reason, their current labels restrict the maximum number of applications per season (four for azoxystrobin and five for pyraclostrobin) and states that no more than two sequential applications can be made without alternating to a non-strobilurin fungicide with a different mode of action. It should be noted that in our studies, however, we applied four and three sequential sprays in 2003 and 2004, respectively, without alteration with a non-strobilurin fungicide. Our objective was to evaluate the materials for efficacy; therefore, we applied them throughout the critical period for leather rot control (late bloom through harvest). The high level of control provided by the strobilurins in our studies, indicate that they should be good materials to alternate with phosphite fungicides or mefenoxam applications in a fungicide resistance management program for *P. cactorum* on strawberry.

In summary, the fungicides pyraclostrobin and azoxystrobin are highly effective for control of strawberry leather rot. Their use in one or two spray block programs, alternated with other materials such as potassium phosphite or mefenoxam should provide effective control of leather rot as well as reduce the risk of fungicide resistance development in *P. cactorum*. 
**Acknowledgment**

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**Literature Cited**


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