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Effect of Timing of Preharvest Fungicide Applications on Postharvest Botrytis Fruit Rot of Annual Strawberries in Florida

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Abstract

Preharvest fungicide applications for postharvest control of Botrytis fruit rot were evaluated over four seasons on annual strawberry in Florida. In the 2002-2003 season, applications of Switch or Elevate immediately prior to harvest were ineffective for controlling Botrytis fruit rot postharvest. In the 2003-2004 season, applications of Captevate or Switch made immediately prior to harvest reduced postharvest Botrytis fruit rot, but not as much as applications made during the flowering period. Similarly, in the 2004-2005 season, Captevate and Pristine provided some control of postharvest Botrytis fruit rot when applied immediately before harvest. In both the 2003-2004 and 2004-2005 seasons, applications made during the flowering period were more effective for postharvest Botrytis fruit rot control than those made prior to harvest. In the 2006-2007 season, applications of Captevate, Thiram, Scala plus Captan, or Switch alternated with Captan during the flowering period provided good control of postharvest Botrytis fruit rot. Although not as effective as bloom applications, fungicides applied immediately before harvest may have some benefit for controlling Botrytis fruit rot if the sprays during the bloom period were not made.

Introduction

Botrytis fruit rot of strawberry, also known as gray mold, is caused by the fungus *Botrytis cinerea* (13). It is a common disease of strawberry worldwide. The primary inoculum for Botrytis fruit rot epidemics is conidia produced on dead strawberry foliage in the field (3). Symptoms may develop on fruit either in the field or postharvest. Although symptoms are expressed on mature fruit, most Botrytis fruit rot infections occur at the flower stage of development (2,9,12). Mature fruit can also be infected by *B. cinerea* through wounds or by direct contact with a diseased fruit (1,5,13). This mechanism of infection may be important during storage and transport.

Transplants from northern nurseries are planted in fields from late September to mid-October for the annual strawberry production season in central Florida. Fruit from these plants are harvested from early December to late March. Although flowers are produced throughout the season, there is a peak bloom period that begins in late January and continues through February (8). This flowering period is responsible for a wave of fruit that lasts from late February until the season ends in March. Fenhexamid (Elevate) is one of the most effective systemic fungicides for controlling Botrytis fruit rot (11), but the number of applications that growers can use is limited to four per season (6).

Botrytis fruit rot is typically more severe late in the season (7) and numerous studies have shown that applying fungicides to flowers is the best way to control Botrytis fruit rot (6,9,14), since most infections occur at this stage of fruit development. The current recommendation for controlling Botrytis fruit rot in Florida is to apply fenhexamid or other effective systemic fungicides such as pyraclostrobin + boscalid (Pristine), cyprodinil + fludioxonil (Switch), and pyrimethanil (Scala) each week during the peak bloom period from late January to mid-February (6,10). At other times during the season, weekly applications of protectant fungicides such as captan or thiram are recommended (7,10).

Although there is good evidence that fungicide applications made at flowering help control Botrytis fruit rot at harvest (6,7,9), it is not clear if applications made just before harvest provide any additional benefit for control of postharvest Botrytis fruit rot. With raspberries, Ellis et al. (4) found that applications during flowering reduced Botrytis fruit rot, but pre-harvest applications were more effective. In Florida, strawberry fruit usually receive an application of a protectant fungicide prior to harvest if a weekly spray program is followed. The purpose of this study was to determine whether application of more effective systemic fungicides just prior to harvest would provide sufficient control of postharvest Botrytis fruit rot to justify their expense.

Fungicide Trials for Control of Postharvest Botrytis Fruit Rot

General methods. In all four seasons that experiments were conducted, bare-root runner plants from Canadian nurseries were transplanted into methyl-bromide:chloropicrin (98:2) fumigated soil in plastic-mulched raised beds in October at the Gulf Coast Research and Education Center in Dover, FL. The beds were 28 inches wide on 4-ft centers. In each case, beds contained two staggered rows of plants spaced 15 inches apart within rows and 12 inches between rows. The transplants were irrigated by overhead sprinklers for 9 to 12 days to facilitate establishment, then irrigated and fertilized through drip tape.

The experiments were conducted using 'Earlibrite' in the 2002-2003 season and 'Sweet Charlie' in the 2003-2004, 2004-2005, and 2006-2007 seasons. In all 4 years, treatments were arranged using a randomized complete block design. In 2002-2003, treatments were arranged in four blocks consisting of two beds each. In 2003-2004 and 2004-2005, individual plots were 3 beds wide and 32 ft long and contained 50 plants per bed. In 2006-2007, individual plots contained 14 plants in 9.4 ft of bed, separated by a 2.5-ft open space between plots. From 8 November 2002 to 7 February 2003, 7 November 2003 to 9 January 2004, from 8 November 2004 to 28 January 2005, and from 13 November 2006 to 10 January 2007, maintenance applications of captan were made weekly to the experimental area by a tractor-mounted sprayer, but were discontinued each year prior to initiation of the experiment to allow inoculum to increase. All fungicide treatments in the 2002-2003, 2003-2004, and 2004-2005 seasons were applied with a tractor-drawn sprayer delivering 100 gal/acre at 125 psi through a three-bed boom with three nozzles/bed. In the 2006-2007 season, experimental treatments were applied with a CO_2 back pack sprayer calibrated to deliver 100 gal/acre at 40 psi through a two-nozzle boom.

During the 2002-2003 season, the effect of fungicides applied just before harvest on postharvest Botrytis fruit rot incidence was tested. During the 2003-2004 and 2004-2005 seasons, both bloom applications and pre-harvest applications were tested for control of postharvest Botrytis fruit rot. In 2002-2003, a single application of Switch 62.5 WG (cyprodinil + fludioxonil) (Syngenta Crop Protection, Greensboro, NC) at 11 oz/acre, Switch 62.5 WG at 14 oz/acre or Elevate 50WDG (fenhexamid) (Arysta LifeScience, Cary, NC) at 1.5 lb/acre was applied on 3 March 2003 to flowering and fruiting plants. In 2003-2004, Captevate 68WDG (captan + fenhexamid) (Arysta LifeScience, Cary, NC) at 5.25 lb/acre or Switch 62.5 WG at 14 oz/acre was applied on 29 January, 3 February, and 10 February during a bloom period or on 20 February immediately before harvesting of fruit began. In 2004-2005, Captevate 68WDG at 5.25 lb/acre or Pristine 38WG (pyraclostrobin + boscalid) (BASF Corporation, Research Triangle Park, NC) at 23 oz/acre was applied on 2 and 9 February during a peak bloom period and on 25 February just before harvesting began. In 2006-2007, Captevate 68WDG at 4.38 lb/acre, Thiram Granuflo (thiram) (Chemtura Corporation, Middlebury, CT) at 3.2 lb/acre, Switch 62.5

WG at 14 oz/acre alternated with Captevate 68WDG at 4.38 lb/acre, Scala (pyrimethanil) (Bayer CropScince, Research Triangle Park, NC) at 9 fl oz/acre + Captan 80WDG at 3 lb/acre, and Pristine 38WG at 23 oz/acre were applied weekly during bloom from 17 January to 7 February 2007 for a total of four sprays. A nonsprayed control was included for comparison in all experiments.

Forty-eight fruit were harvested from the center bed in each plot on 4, 7, 10, and 13 March 2003 for the 2002-2003 season, on 21, 24, 27 February, and 1 March 2004 for the 2003-2004 season and on 26 February, 1, 4, and 7 March 2005 for the 2004-2005 season. These dates were 1, 4, 7, and 10 days after the last fungicide application in each season and included fruit from flowers receiving fungicide treatments over the bloom interval. In the 2006-2007 season, fruit were harvested on 20, 23, and 27 February and 2 March 2007 and the Botrytis fruit rot incidence was averaged over the four harvests. Harvested fruit were placed in cells of Styrofoam egg cartons, the cartons closed, and held at 2 to 4°C for 7 days. Fruit that developed lesions were transferred to humid chambers and incubated for 48 to 60 h at ambient temperature to allow symptoms to progress more rapidly. Incubated fruit were examined for sporulation of *B. cinerea* to verify that the lesions were attributable to this pathogen.

Data were analyzed using a mixed ANOVA model with treatment considered as a fixed effect and block as a random effect. For season-long means, a repeated-measures, mixed ANOVA model was used with treatment, date, and their interaction treated as fixed effects and block as a random effect. Incidence data were transformed to arcsine square roots prior to ANOVA. Means were separated using Fisher's protected LSD ($P \leq 0.05$) and nontransformed means are reported.

The 2002-2003 season. The incidence of postharvest Botrytis fruit rot was high on fruit harvested 1 day after treatment due to favorable conditions for infection when these fruit were at the flowering stage. Incidence declined at later harvest dates since conditions were less favorable for infection of the flowers that produced these fruit (Table 1). For fruit harvested 1, 4, or 7 days after fungicide application, there were no significant differences among treatments. There were some differences in the Botrytis fruit rot incidence in fruit harvested 10 days after treatment. Fruit sprayed with Elevate had a lower Botrytis fruit rot incidence than those fruit treated with Switch, but none of the treatments had significantly less disease than the control. There were no differences among treatments when averaged across all harvests. Overall, data from this season indicated that fungicide applications just before harvest provided no control of postharvest Botrytis fruit rot.

Table 1. Post-harvest incidence of Botrytis fruit rot (%) of strawberry harvested 1, 4, 7, or 10 days after a single fungicide application; and stored 7 days at 2 to 4°C in 2002-2003.

Treatment, rate/acre	Days after treatment[x]				
	1	4	7	10	Mean
Switch 62.5WG, 11 oz	30.2	7.3	4.2	8.9 a	12.6
Switch 62.5WG, 14 oz	27.1	7.3	4.2	8.3 a	11.7
Elevate 50 WDG, 1.5 lb	23.4	3.6	3.6	2.6 b	8.3
Control	36.5	7.8	4.2	5.7 ab[y]	13.5

[x] Fruit were harvested on 4, 7, 10, and 13 March, i.e., 1, 4, 7, and 10 days, respectively, after a single fungicide application of 3 March 2003.

[y] Means followed by the same letter are not significantly different ($P \leq 0.05$) according to Fisher's protected LSD.

The 2003-2004 season. Weather during bloom was not highly conducive to infection, although treatment effects were evident on two harvest dates. Very little postharvest Botrytis fruit rot developed in the treatments where three sprays of Captevate were applied during the bloom period. Differences from the control were significant for all treatments for the harvests made 1 and 7 days after the last fungicide application (Table 2). When averaged across all harvests, Captevate or Switch applied immediately before harvest reduced postharvest Botrytis fruit rot incidence somewhat, but these treatments were less effective than the bloom sprays of Captevate.

Table 2. Post-harvest incidence of Botrytis fruit rot (%) in strawberry fruit harvested 1, 4, 7, or 10 days after the last fungicide application; and stored 7 days at 2 to 4°C in 2003-2004.

Treatment, rate / acre	No. of appl., timing[y]	Days after the last fungicide application[x]				
		1	4	7	10	Mean
Captevate 68WDG, 5.25 lb	3, bloom	0.0 b[z]	0.0	1.0 b	2.6	0.9 c
Switch 62.5WG, 14 oz	1, pre-harvest	1.6 b	2.6	7.3 b	3.6	3.8 b
Captevate 68WDG, 5.25 lb	1, pre-harvest	1.6 b	1.6	6.8 b	7.8	4.4 ab
Control	–	5.2 a	1.0	15.6 a	6.8	7.2 a

[x] Fruit were harvested on 21, 24, 27 February, and on 1 March 2004, i.e., 1, 4, 7, and 10 days after the last fungicide application, respectively.

[y] Bloom treatments were applied on 29 January and 3 and 10 February 2004, and preharvest treatments were applied on 20 February 2004.

[z] Treatment means in columns followed by the same letter are not significantly different ($P \leq 0.05$) according to a Fisher's protected LSD.

The 2004-2005 season. Weather during the bloom period was generally conducive to Botrytis fruit rot and disease was moderate to severe (Table 3). Captevate or Pristine applied twice during the bloom period significantly reduced postharvest Botrytis fruit rot compared to the nonsprayed control on the harvests made 1 and 4 days after the last fungicide application. When overall averages were considered, Pristine, when applied during flowering, and preharvest applications of Captevate or Pristine reduced postharvest Botrytis fruit rot compared to the nonsprayed control, but were not as effective as applications of Captevate during bloom.

Table 3. Post-harvest incidence of Botrytis fruit rot (%) in strawberry fruit harvested 1, 4, 7, or 10 days after the last fungicide application; and stored 7 days at 2 to 4°C in 2004-2005.

Treatment, rate / acre	No. of applications, timing[y]	Days after the last fungicide application[x]				
		1	4	7	10	Mean
Captevate 68WDG, 5.25 lb	2, bloom	1.0 c[z]	1.0 c	1.0 b	3.1	1.6 c
Pristine 38WG, 23 oz	2, bloom	8.3 bc	4.2 bc	4.2 ab	2.6	4.8 b
Captevate 68WDG, 5.25 lb	1, pre-harvest	15.1 ab	4.7 bc	4.7 ab	4.2	7.2 b
Pristine 38WG, 23 oz	1, pre-harvest	20.3 a	8.9 ab	3.1 ab	2.1	8.6 b
Control	–	24.5 a	13.0 a	5.7 a	4.2	11.8 a

[x] Fruit were harvested on 26 February, 1 March, 4 March, and 7 March 2005, i.e., 1, 4, 7, and 10 days after the last fungicide application, respectively.

[y] Bloom treatments were applied on 2 and 9 February and preharvest treatments were applied on 25 February 2005.

[z] Treatment means in columns followed by the same letter are not significantly different ($P \leq 0.05$) according to a Fisher's protected LSD.

The 2006-2007 season. Conditions in this season were favorable for disease development and the incidence of Botrytis fruit rot was high (Table 4). Captevate applied during the bloom period was very effective again for control of postharvest Botrytis fruit rot. However, Thiram, Switch alternated with

Captevate, and Scala + Captan provided comparable control. Pristine was somewhat less effective, but still reduced disease incidence compared to the nontreated control.

Table 4. Post-harvest incidence of Botrytis fruit rot (BFR) (%) in strawberry fruit treated in the field during the bloom period; harvested when mature; and stored 7 days at 2 to 4°C in 2006-2007.

Treatment, rate / acre	No. of applications, timing[x]	BFR postharvest (%)[y]
Captevate 68 WDG, 4.38 lb	4, bloom	8.5 c
Thiram Granuflo 75 WDG, 3.2 lb	4, bloom	9.1 c
Switch 62.5WG, 14 oz. alt. Captevate 68 WDG, 4.38 lb	4, bloom	9.5 c
Scala SC, 9 fl oz. + Captan 80 WDG, 3 lb	4, bloom	10.3 bc
Pristine 38 WG, 23 oz	4, bloom	15.8 b
Control	0	26.9 a[z]

[x] Four weekly applications from 17 January to 7 February 2007

[y] Average of four harvests on 20, 23, and 27 February, and 2 March 2007.

[z] Treatment means in columns followed by the same letter are not significantly different ($P \leq 0.05$) according to a Fisher's protected LSD.

Considerations for Postharvest Botrytis Fruit Rot Control

The current study shows that, under certain conditions, there is a benefit to applications of effective systemic fungicides immediately prior to harvest for the control of postharvest Botrytis fruit rot. Earlier studies demonstrated that fungicide applications made during bloom are the most effective control for Botrytis fruit rot in the field (6,7,9). This study shows that applications at bloom are also effective for controlling the development of the disease after harvest. In the 2002-2003 trial, applications of Switch or Elevate immediately prior to harvest were ineffective in controlling postharvest Botrytis fruit rot. There were significant differences among treatments made 10 days before harvest, but those sprays were applied to green rather than to ripe fruit. In the 2003-2004 season, applications of Switch made immediately before harvest reduced postharvest Botrytis fruit rot, but not as much as bloom applications of Captevate. Similarly, in the 2004-2005 season, Captevate and Pristine provided some control of postharvest Botrytis fruit rot when applied immediately before harvest, but again, these treatments were less effective than bloom applications of Captevate. In the 2006-2007 season, Captevate applied at bloom was again highly effective for control of postharvest Botrytis fruit rot, but Thiram, Scala, and Switch also proved effective for control of this disease.

Strawberry growers in Florida are currently advised to apply captan weekly at the lowest recommended rate early in the season and to apply other more effective systemic products such as Switch, Elevate, Captevate or Pristine during the second major bloom period (6,10). That program is highly effective for control of Botrytis fruit rot during the season. However, excessive amounts of Botrytis fruit rot occasionally develop in storage or transit. This study indicates that some control of Botrytis fruit rot postharvest can be obtained by fungicide applications made immediately prior to harvest, but this benefit was seen only when fruit did not receive fungicide at bloom. With raspberries, Ellis et al. (4) found that applications made immediately prior to harvest provided better control of Botrytis fruit rot than applications made at bloom. A combined bloom and pre-harvest application did not improve control when compared to the pre-harvest application alone. In our studies, a bloom application plus a pre-harvest application was not tested to determine if postharvest Botrytis fruit rot would have been reduced further. Assuming a pre-harvest application would produce a similar and proportional decline in Botrytis fruit rot for fruit treated at bloom as it did for fruit not sprayed at bloom, the decrease in postharvest Botrytis fruit rot would be very small, difficult to detect, and of little benefit to the grower.

Strawberry growers must meet high quality standards in marketing their fruit and small amounts of decay can result in large financial losses. Thus, growers must take all necessary measures to avoid those losses. Under most circumstances in Florida, application of fungicides immediately before harvest is not advantageous if the recommended program has been followed. However, if for any reason, the standard program was not followed, an application of an appropriate fungicide just prior to harvest will moderately reduce postharvest Botrytis fruit rot losses.

Literature Cited

1. Blacharski, R. W., Bartz, J. A., Xiao, C. L., and Legard, D. E. 2001. Control of postharvest Botrytis fruit rot with preharvest fungicide applications in annual strawberry. Plant Dis. 85:597-602.
2. Bristow, P. R., McNicol, R. J., and Williamson, B. 1986. Infection of strawberry flowers by *Botrytis cinerea* and its relevance to grey mould development. Ann. Appl. Biol. 109:545-554.
3. Braun, P. G., and Sutton, J. C. 1987. Inoculum sources of *Botrytis cinerea* in fruit rot of strawberries in Ontario. Can. J. Plant Pathol. 9:1-5.
4. Ellis, M. A., Madden, L. V., Wright, S. R., and Wilson, L. L. 2008. Efficacy of pre-harvest applications and cold storage for postharvest control of Botrytis fruit rot (gray mold) on red raspberry. Online. Plant Health Progress doi:10.1094/PHP-2008-1015-01-RS.
5. Jarvis, W. R. 1962. The infection of strawberry and raspberry fruits by *Botrytis cinerea* Fr. Ann. Appl. Biol. 50:569-575.
6. Legard, D. E., MacKenzie, S. J., Mertely, J. C., Chandler, C. K., and Peres, N. A. 2005. Development of a reduced use fungicide program for control of Botrytis fruit rot on annual winter strawberry. Plant Dis. 89:1353-1358.
7. Legard, D. E., Xiao, C. L., Mertely, J. C., and Chandler, C. K. 2001. Management of Botrytis fruit rot in annual winter strawberry using captan, thiram and iprodione. Plant Dis. 85:31-39.
8. MacKenzie, S. J., and Chandler, C. K. 2009. A method to predict weekly strawberry fruit yields from extended season production systems. Agron. J. 1001:278-287.
9. Mertely, J. C., MacKenzie, S. J., and Legard, D. E. 2002. Timing of fungicide applications for *Botrytis cinerea* based on development stage of strawberry flowers and fruit. Online. Plant Dis. 86:1019-1024.
10. Mertely, J. C., and Peres, N. A. 2006. Botrytis fruit rot or gray mold of strawberry. Online. PP-230/PP152, Dept. of Plant Pathol., EDIS, Florida Coop. Ext. Service, Univ. of Florida-IFAS, Gainesville, FL.
11. Mertely, J. C., and Seijo, T. E. 2003. Evaluation of fungicides to control Botrytis fruit rot in annual strawberry, 2002-03. Fungic. Nematicide Tests. Online. Report 59:SMF020. DOI:10.1094/FN59. The American Phytopathological Society, St. Paul, MN.
12. Powelson, R. L. 1960. Initiation of strawberry fruit rot caused by *Botrytis cinerea*. Phytopathology 50:491-494.
13. Sutton, J. C. 1998. Botrytis fruit rot (gray mold) and blossom blight. Pages 28-31 in: Compendium of Strawberry Diseases, 3rd Edn. J. L. Maas, ed. American Phytopathological Society, St. Paul, MN.
14. Wilcox, W. F., and Seem, R. C. 1994. Relationship between strawberry gray mold incidence, environmental variables, and fungicide applications during different periods of the fruiting season. Phytopathology 84:264-270.