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Pre- and post-inoculation activity of a protectant and a systemic fungicide for control of anthracnose fruit rot of strawberry under different wetness durations

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A protectant fungicide (Captan, a.i. captan) and a systemic fungicide (Switch, a.i. fludioxonil + cyprodinil) were evaluated as pre- and post-inoculation applications for control of anthracnose fruit rot (AFR), caused by *Colletotrichum acutatum*, under a short (6 or 8 h) or long (18 or 24 h) wetting period. Evaluations were conducted for two seasons in Maryland and for two seasons in Florida. Both Captan and Switch were very effective for control of AFR when applied prior to inoculation, but control was more effective under the shorter wetting period. Switch was as effective when applied 4, 8, or 24 h post-inoculation as when applied before inoculation, but control was better under the short wetting period. Captan was effective when applied 4 or 8 h after inoculation under the short wetting period, but was ineffective at 24 h post-inoculation. Post-inoculation sprays of Captan were ineffective at any time under the long wetting period. The post-infection activity of Switch allows greater flexibility for managing AFR when fungicide applications are scheduled based on weather-based decision-support systems.

1. Introduction

Anthracnose fruit rot (AFR), caused by *Colletotrichum acutatum* Simmonds, is an important disease of strawberries worldwide (Maas, 1998). *C. acutatum* attacks nearly all tissues of the plant, including mature and immature fruit, petioles, flowers, crowns and roots. Although plants may be weakened or killed by crown infections (Peres et al., 2005), fruit infections are the target of most disease control programs. Lesions on mature fruit range from 5 to 15 mm in diameter and are dark brown, sunken and firm. On green fruit, lesions are black but are smaller than they are on mature fruit. Fruit losses in the field are common but post-harvest damage is minimal if fruits are refrigerated promptly after harvest. Other species of *Colletotrichum* may cause fruit rots, but *C. acutatum* is by far the most important causal agent in the eastern USA (Smith and Black, 1990; Maas, 1998).

The pathogen is often introduced into new plantings on infected transplants. Transplants may show symptoms on petioles or other tissues, but *C. acutatum* typically forms quiescent infections on vegetative tissues that are not visible with the naked eye. The fungus also produces secondary conidia on asymptomatic vegetative tissues (Leandro et al., 2001, 2004). On symptomatic vegetative tissues and on fruit, conidia are formed in acervuli that typically appear as pink to orange slimy masses. Secondary spread of conidia to healthy tissues occurs by rain splash and the disease may be severe after extended rainy periods (Yang et al., 1990). The optimum temperature range for infection is between 25 and 30 °C, with very limited infection occurring below 4 or above 35 °C (Wilson et al., 1990). The wetness duration necessary for infection varies with temperature, but at least 4–6 h of wetness is necessary for significant damage even at optimal temperatures (Wilson et al., 1990; Turechek et al., 2006).

Exclusion of the pathogen through the use of transplants free of *C. acutatum* provides the best control of AFR (Wise et al., 2003). However, because *C. acutatum* forms quiescent infections, visual inspection is not reliable for detecting all infected transplants. Selection of tolerant cultivars such as Sweet Charlie, Carmine, Florida Radiance, and Florida Elyana can also be useful for controlling the disease, but tolerant cultivars may lack desirable horticultural characteristics (e.g., fruit quality, flowering time and duration, and yield) and suitable cultivars may not be available in all growing regions (Chandler et al., 2006; Seijo et al., 2008). Thus, control of AFR is often dependent on routine, preventive applications of fungicides during the season. In Florida, protectant fungicides, such as captan (Captan, Arysta LifeScience, Cary, NC) or thiram (Thiram, Chemtura, Middlebury, CT), are usually applied

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weekly during the growing season for control of AFR (Mertely et al., 2009). In addition, strobilurin or quinone outside inhibitor (QoI) fungicides, such as pyraclostrobin (Cabrio, BASF Corporation, Research Triangle Park, NC) or azoxystrobin (Abound, Syngenta Crop Protection, Greensboro, NC), or other systemic products, such as the pre-formulated mixture of cyprodinil and fludioxonil (Switch, Syngenta Crop Protection, Greensboro, NC), may be substituted when conditions are especially favorable for disease development. Programs incorporating these fungicides at various application timings have provided effective control of AFR in Florida (Mertely et al., 2005, 2006, 2008a, 2008b). In the Mid-Atlantic and Midwestern States, tank mixtures of captan with systemic fungicides such as the pre-formulated mixture of boscalid and pyraclostrobin (Pristine, BASF Corporation, Research Triangle Park, NC), other QoI fungicide, or Switch are recommended for AFR control (Ellis et al., 2004; Ernest et al., 2010).

Equations to predict AFR disease incidence using temperature and wetness duration as input variables (Wilson et al., 1990) along with knowledge of the post-infection activity of the systemic fungicide Cabrio (Turechek et al., 2006) have been used to time applications of protectant and systemic fungicides in strawberries (Peres et al., 2009). Timing applications in response to weather conditions reduced the number of fungicide applications needed compared to calendar-based programs, and timed applications of fungicides with post-infection activity performed better than programs that relied strictly on preventive applications. However, data on the post-infection activity of fungicides other than Cabrio for managing AFR are limited. This not only impedes our ability to design management programs that utilize the post-infection activity of other fungicides, but also places at risk the current program because relying on a single product for post-infection activity increases the potential for the development of fungicide resistance. Thus, the purpose of the present study was to evaluate the pre- and post-infection activity of the fungicides-Switch and Captan-under different levels of disease pressure, which was accomplished by altering the periods of leaf wetness in the field.

2. Materials and methods

2.1. Planting sites

Annual plantings of strawberry were established at the USDA–ARS Beltsville Agricultural Research Center (BARC) in Beltsville, MD in 2005 and 2006 and at the University of Florida's Gulf Coast Research and Education Center (GCREC) in Wimauma, FL in 2007 and 2008. We chose to run trials in these two regions to encompass diversity in environmental conditions and production practices as a means of ensuring that results generated as part of this study would be broadly applicable. In Maryland, plug plants (cv. Chandler [Shade Hollow Nursery, Salisbury, PA]) were transplanted into glyphosate-treated soil in 1.2-m-wide plastic-mulched, raised beds in August 2004 and 2005. In Florida, bare-root runner plants (cv. Strawberry Festival [Blue Sky Nursery, CO]) were transplanted into methyl-bromide:chloropicrin (98:2)-fumigated soil in 71-cm-wide, plastic-mulched, raised beds in October 2006 and 2007. As alluded to above, cultivars were chosen because of their susceptibility to anthracnose and their suitability for production in the region. In all four plantings, the beds were on 1.2-m centers, the plants were planted in two staggered rows spaced ~0.4 m apart within rows and ~0.3 m between rows, and transplants were irrigated by overhead sprinklers for 10–12 days to aid establishment. Once established, the plants were irrigated and fertilized through drip tape. In Maryland, 12-plant plots (two rows of six plants each) with a one-plant border between plots were established within the planting. In Florida, 14-plant plots (two rows of seven plants each) with three non-planted holes between plots were established.

Environmental parameters in Florida were measured and recorded by an automated weather station located at the GCREC. The station is operated and maintained by the Florida Automated Weather Network (FAWN). Environmental parameters in Maryland were measured and recorded with weather station #2 located on BARC's North Farm. This station is operated and maintained by the Farm Operations Unit at BARC.

2.2. Experimental design and treatment application

Each planting was bisected to allow two separate wetting regimes designated as 'short' and 'long' based on the results of Turechek et al. (2006). Except in 2005, the short wetting period was defined as 8 h of overhead irrigation and the long wetting period as 24 h of overhead irrigation. In 2005, the short and long periods of wetting were 6 and 18 h, respectively. The following fungicides were evaluated for their efficacy against anthracnose fruit rot when applied singly as either a protectant (i.e., prior to infection) or at pre-determined intervals after the imposed infection event (i.e., post-inoculation): Switch 62.5WG (cyprodinil + fludioxonil) at

Table 1
Temperature and rainfall statistics during the inoculation and evaluation periods in fungicide-treated plots of strawberry artificially inoculated with *Colletotrichum acutatum* and subjected to either a short or long wetting period in field trials conducted in 2005 and 2006 in Beltsville, Maryland and in 2007 and 2008 in Wimauma, Florida.

Site	Year	Statistic	Temperature (°C)[a]			Rain during evaluation period[c]	
			Short wetting[b]	Long wetting[b]	Evaluation period[c]		
Maryland	2005	Minimum	17.3	7.9	8.5	Number of days with rain	5
		Average	22.4	18.0	17.6	Total rainfall (mm)	46
		Maximum	26.2	28.3	27.2	Maximum daily value (mm)	16
	2006	Minimum	16.2	9.2	4.9	Number of days with rain	3
		Average	21.4	16.6	18.8	Total rainfall (mm)	5
		Maximum	25.5	25.5	35.1	Maximum daily value (mm)	2
Florida	2007	Minimum	14.2	14.2	11.9	Number of days with rain	2
		Average	15.2	20.6	19.4	Total rainfall (mm)	12
		Maximum	17.1	28.6	27.5	Maximum daily value (mm)	11
	2008	Minimum	12.6	10.8	10.8	Number of days with rain	6
		Average	22.2	17.3	19.9	Total rainfall (mm)	64
		Maximum	25.4	25.4	29.6	Maximum daily value (mm)	22

[a] Temperature data reflect the minimum, average, and maximum temperatures during the actual wetting event specified.
[b] The short and the long wetting periods were produced by application of overhead irrigation for 8 (short) and 24 h (long) immediately after inoculation, except in 2005 where the short and long wetting periods were 6 and 18 h, respectively.
[c] The evaluation period is defined from the time of inoculation through the last harvest period.