Research

Fungicide Rotation Programs for Managing *Phytophthora* Fruit Rot of Watermelon in Southeastern United States

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Abstract

About 50% of the watermelons in the United States are produced in the southeastern states, where optimal conditions for development of *Phytophthora* fruit rot prevail. *Phytophthora* fruit rot significantly limits watermelon production by causing serious yield losses before and after fruit harvest. Efficacy of fungicide rotation programs and Melcast-scheduled sprays for managing *Phytophthora* fruit rot was determined by conducting experiments in *Phytophthora capsici*-infested fields at three locations in southeastern United States (North Carolina, South Carolina, and Georgia). The mini seedless cultivar Wonder and seeded cultivar Mickey Lee (pollenizer) were used. Five weekly applications of fungicides were made at all locations. Significant fruit rot (53 to 91%, mean 68%) was observed in the nontreated control plots in all three years

(2013 to 2015) and across locations. All fungicide rotation programs significantly reduced *Phytophthora* fruit rot compared with non-treated controls. Overall, the rotation of Zampro alternated with Orondis was highly effective across three locations and two years. Rotations of Actigard followed by Ranman + Ridomil Gold, Presidio, V-10208, and Orondis, or rotation of Revus alternated with Presidio were similarly effective. Use of Melcast, a melon disease-forecasting tool, may occasionally enable savings of one spray application without significantly impacting control. Although many fungicides are available for use in rotations, under very heavy rain and pathogen pressure, the fungicides alone may not offer adequate protection; therefore, an integrated approach should be used with other management options including well-drained fields.

Phytophthora capsici, the causal agent of *Phytophthora* fruit rot of watermelon and other cucurbits, is responsible for serious pre- and postharvest yield and quality losses in the production of watermelon, as well as a number of other important vegetable crops in the United States (Kousik et al. 2014a, 2016). The pathogen causes crown and root rot, leaf blight, plant wilt, and fruit rot on various vegetable crops (Erwin and Riberio 1996; Granke et al. 2012; Hausbeck and Lamour 2004; Keinath et al. 2007). In watermelon, fruit rot is often the most damaging symptom. It begins as a dark, water-soaked, depressed lesion that expands quickly along with powdery, wet mold progressively developing over the infected area and eventually the entire fruit rots. The disease is very prevalent on watermelon crop in the southeastern states (Florida, Georgia, South Carolina, North Carolina, and Virginia) and more recently in other parts of the United States (e.g., Michigan, Delaware, Maryland, and Indiana) (Kousik et al. 2016). A significant portion of U.S. watermelon production occurs in the southeastern states where environmental conditions favorable for fruit rot development occur regularly during the growing season. In 2015, more than 21,853 ha (54,000 acres) of watermelon were planted in the southeast, with Florida (8,700 ha), Georgia (7,891 ha), South Carolina (3,116 ha) and North Carolina (2,387 ha) (USDA, NASS survey, 2015) being the leading states where *Phytophthora* fruit rot was an important concern for many growers. Identifying effective ways to manage *Phytophthora*

fruit rot has been considered a high priority since 2013 and before by the National Watermelon Association (NWA) (Kousik et al. 2014a; 2016; Morrissey 2006; B. Morrissey, 2013, 2014 and 2015, *personal communication*). Research conducted in North and South Carolina from 2006 to 2013 identified several fungicides (e.g., Revus, Presidio, Zampro, Orondis, and Forum) that are effective for managing pre- and postharvest phases of *Phytophthora* fruit rot of watermelon (Kousik et al. 2011, 2014a). However, the prevalence of pathogen resistance to chemicals such as Ridomil and Ranman has been well documented for *P. capsici* (Hausbeck and Lamour 2004; Jackson et al. 2012; Kousik and Keinath 2008; Lamour and Hausbeck 2000; Lamour and Keinath 2007; Parra and Ristaino 2001). Commercial watermelon cultivars with resistance to fruit rot are not yet available; but resistant germplasm lines have been identified and developed for use in breeding programs (Kousik et al. 2012, 2014c); therefore, application of effective fungicides continues to be a major component in developing effective programs for managing this disease.

The objectives of the present study were to compare and develop fungicide rotation programs that watermelon growers can adapt in their overall disease management plans especially in areas where *Phytophthora* fruit rot has been a severe problem year after year. In addition, Melcast, a melon disease forecaster that bases spray thresholds on environmental favorability index (EFI) was used as a tool to schedule spray applications. Melcast uses daily weather data for a given location using periods of temperature and humidity/leaf wetness that are favorable for development of foliar diseases on watermelon and melon (Latin and Egel 2001). The use Melcast as a specific treatments was included to determine if we could obtain improved control or reduce the number of sprays needed for managing *Phytophthora* fruit rot of watermelon.

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Planting and Fungicide Rotations

Experiments to evaluate the effect of fungicide rotations and Melcast-based spray applications on development of *Phytophthora* fruit rot of watermelon were conducted in *P. capsici*-infested fields at three locations in southeastern United States. The locations were: the U.S. Vegetable Laboratory farm in Charleston, SC; the University of Georgia, Coastal Plain Experiment Station farm in Tifton, GA; and the North Carolina State University, Horticultural Crops Research Station in Kinston, NC. Most of the techniques used to conduct these experiments have been described before (Kousik et al. 2011; 2014a).

The experimental design was a randomized complete block with 4 replications in all locations. Four- to five-week-old seedlings of the susceptible seedless (triploid) cultivar Wonder and the susceptible diploid (seeded, pollenizer) cultivar Mickey Lee were transplanted onto raised beds. There were 12 plants per plot with every fourth plant in the plot being Mickey Lee, which served as the pollenizer at all three locations. In South Carolina, the raised beds were 48 cm wide and 20 cm high. Beds were spaced 6.4 m (21 ft) apart and covered with silver plastic mulch. Plots were a single row of 12 plants spaced 46 cm apart with 4.6-m spacing between plots. Plants were irrigated as needed using drip irrigation with a drip tape placed 2.5 cm below the plastic mulch. After bedding but before planting, row middles were sprayed with Roundup Pro (1.17 liter/ha) and Strategy (2.24 liter/ha) for weed management. During the growing season, weeds between beds were controlled with spot application of Roundup or hand weeding. In Georgia, the raised plant beds were 76 cm (30 inches) wide and 15 cm (6 inches) high and were spaced 1.8 meters (6 ft) apart. The raised beds were covered with silver reflective mulch with a single drip tape installed 2.5 cm below the surface in the center of the beds for irrigation. Plants within a plot were spaced 0.9 m (3 ft) apart. In North Carolina, plots were bare-ground with double-row raised beds that were 20.3 cm (8 inches) high on 1.06 m (42-inch) centers with plots on 4.3-m (14-ft) centers. Each plot was 5.5 m (18 ft) long with 3 m (10 ft) between plots. Plants within a plot were spaced 0.9 m (3 ft) apart. Standard production practices for watermelon for the southeast were followed at all locations (Kemble 2015; Sanders 2006). Details of planting, inoculation, initiation of sprays, and observation dates are provided in Table 1.

The details of the fungicides applied at the three locations, their formulations, active ingredients, and rate are presented in Table 2. During each year and at each location, there were a total of five sprays per season. In 2013, trials were conducted in South Carolina and Georgia. Five simple rotation programs and a tank mix of Ranman and Ridomil were evaluated. In addition, Ridomil Gold was used as the standard treatment and nontreated plots as the controls. In 2014, the following fungicide rotations were evaluated in three states: (i) Actigard/K-Phite/Revus/Presidio/Zampro; (ii) Forum/Presidio/Phosphite/Ranman + Ridomil/Revus; (iii) Actigard/Ranman + Ridomil/Presidio/V10208/ Orondis; (iv) Forum/K-Phite /Presidio/Zampro/Ranman; (v) Zampro with Orondis; (vi) Melcast based spray of most effective fungicides in rotation (Presidio, Ranman + Ridomil, Revus, Zampro, Orondis); (vii) Ridomil Gold (standard treatment); and (viii) nontreated control. In addition, in South Carolina, Revus alternated with Presidio was included because of previous documented efficacy (Kousik et al. 2014a). Similarly, in North Carolina, Revus alternated with Ridomil Gold was included as a standard rotation scheme. In 2015, four of the most effective fungicide rotation programs from 2014, as well as nontreated control and the standard treatment (Ridomil Gold) were evaluated in Georgia. All the rotation programs from 2014 and the controls were evaluated in South Carolina in 2015.

Fungicide treatments were applied using a CO₂-pressurized backpack sprayer with a hand-held boom at all three locations. In South Carolina, the sprayer was equipped with 3 nozzles (flat fan, 8002VS; Teejet, Wheaton, IL) spaced 48 cm apart and calibrated to deliver 290 liters/ha. Similarly in North Carolina, the sprayer was equipped with 3 hollow-cone nozzles (TXVS-26) spaced 48 cm apart and calibrated to deliver 421 liters/ha. In Georgia, the sprayer was equipped with 2 nozzles (flat fan, Teejet 8005E SS) spaced 48 cm apart and calibrated to deliver 327 liters/ha. The first fungicide application was made when most of the watermelon fruit were about 8 to 10 cm in diameter. The first applications were started at this stage as this was when most fruit came in contact with the ground. In addition, watermelon fruit are susceptible to *P. capsici* at all developmental stages (Ando et al. 2009; Kousik et al. 2014b), hence subsequent applications were made at weekly intervals at all locations (Table 1). In South Carolina, the fungicide

TABLE 1
Transplant, start of spray, and inoculation dates; weather details; and observation dates for fungicide rotation studies conducted from 2013 to 2015 in southeastern United States (North Carolina, South Carolina, and Georgia)

Year and location	Transplant date	Spray start date ^x	Inoculation date	Rainfall from start of spray to observation (mm) ^y	Rainy days	Average temperature (°C) ^z	Final observation date
2013							
Charleston, SC	12 Jun	18 Jul	28 Jul	195.60	18	26.2	23 Aug
Tifton, GA	29 May	2 Jul	21 Jun	136.70	25	25.4	8 Aug
2014							
Clinton, NC	30 Jul	9 Sep	6 Oct	193.04	17	21.6	17 Oct
Charleston, SC	11 Jun	17 Jul	29 Jul	289.80	17	26.4	18 Aug
Tifton, GA	29 May	20 June	20 Jun	87.38	15	26.1	11 Aug
2015							
Charleston, SC	17 Jun	16 Jul	28 Jul	110.74	13	27.1	19 Aug
Tifton, GA	22 May	26 Jun	16 Jun	358.65	19	26.6	3 Aug

^x The date when spray applications for rotation programs were initiated at each location. There were a total of five spray applications at each location and each year.

^y Number of rainy days from start of spray treatments to observation date. Any precipitation recorded for the day during the period was considered as a rainy day.

^z Average temperature from start of spray treatments to observation date.

TABLE 2
Details of fungicides used in rotation programs for managing *Phytophthora* fruit rot of watermelon in North Carolina, South Carolina, and Georgia

Trade name and formulation ^x	Manufacturer	Active ingredient (a.i.) ^y	FRAC code ^z	Application rate (product/ha)
Orondis	Syngenta	oxathiapiprolin	U15	0.66 liter
V-10208	Valent	ethaboxam	U5	280 g a.i
Actigard 50WG	Syngenta	acibenzolar-S-methyl	P1	70 g
Zampro	BASF	ametoctradin/dimethomorph	45/40	1.02 liter
Forum 550SC	BASF	dimethomorph	40	0.43 liter
Ridomil Gold 4EC	Syngenta	mefenoaxam	4	1.17 liter
Revus 2.08SC	Syngenta	mandipropamid	40	0.59 liter
Ranman	FMC Corp.	cyazofamid	21	0.20 liter
Presidio 4FL	Valent	fluopicolide	43	0.29 liter
K-Phite 7LP	Plant Food Systems	Mono- and dipotassium salts of phosphorus acid	NC	2.34 liter

^x Activator 90 (0.1%) was added to all the Revus treatments and Silwett L-77 to Ranman treatments as per manufacturers instructions.

^y The details of the active ingredients including concentrations present in each of the fungicides can be obtained from the appropriate fungicide label.

^z FRAC = Fungicide Resistance Action Committee.

treatments were applied: in 2013 on 18 and 25 July, and 1, 8, and 19 August; in 2014 on 17, 24, and 31 July, and 7 and 14 August; and in 2015 on 16, 23, and 29 July, and 7 and 13 August. In Georgia, the fungicide applications were made: in 2013 on 2, 9, 16, 23, and 30 July; in 2014 on 30 June, and 7, 14, 21, and 28 July; and in 2015 on 26 June, and 2, 10, 17, and 24 July. In North Carolina, the fungicide treatments were applied: in 2014 on 9, 18, 23, and 30 September, and 7 October. In 2015 in North Carolina, the experiment was washed out due to severe rains and flooding.

Inoculation of Plots

Inoculation dates at each location and year are presented in Table 1. To enhance disease development, all the plots were inoculated about two weeks after the start of spray treatments in South Carolina. Each year, mefenoxam-sensitive and -insensitive isolates were grown for a month on rice grains soaked in V8 juice in wide-mouth mason jars. The isolates were grown individually and mixed prior to uniformly spreading them by hand-scattering (122 grams/plot) in each plot as described previously (Kousik et al. 2011, 2014a). Inoculations were done on days when rain was predicted and conditions were favorable for disease development. In Georgia, additional inoculum of *P. capsici* was applied by inoculating three squash seedlings (Ji et al. 2012) grown between each two watermelon plots on 21 June 2013, 19 June 2014, and 16 June 2015. In North Carolina, plots were inoculated one week after the first fungicide application in 2014 by scattering *P. capsici*-infested millet seed (150 g/plot) throughout each plot. Isolates used for inoculation were of different mating type (A1 and A2) and mefenoxam sensitivity (sensitive and insensitive). Overhead irrigation was used immediately before and after inoculation to promote infection in North Carolina. Local isolates were used at each location.

Melcast-Based Fungicide Treatments

Melcast is a melon-disease forecaster that bases spray applications on Environmental Favorability Indices (EFI) calculated from daily weather data for a given location using periods of temperature and humidity/leaf wetness that are favorable for development of foliar diseases on watermelon and melon (Latin and Egel 2001). Melcast has been used to reduce the number of fungicide applications for management of foliar diseases including gummy stem blight, anthracnose, and *Alternaria* blight on melon and watermelon (Everts and Shields 2000; Keinath et al. 2007; Latin and Egel 2001). In this study, our objective was to determine if Melcast would help reduce spray applications for management of

Phytophthora fruit rot of watermelon. Unlike the conventional calendar-based sprays, Melcast schedules spray applications based on forecasting for managing foliar diseases in melon and watermelon, such as anthracnose and gummy stem blight (Latin and Egel 2001). For our experiments, we made our first spray application after fruit formation as the watermelon fruit is highly susceptible to *P. capsici* at all stages (Ando et al. 2009; Kousik et. al. 2014b). The Melcast data on EFI for each of the three locations was obtained from the Purdue University website (<http://melcast.ceris.purdue.edu>). A Melcast threshold of 35 EFI units accumulated over time (days) was considered as the appropriate time to spray, similar to what is used for other foliar diseases including gummy stem blight on watermelon (Latin and Egel 2001). Details of weather conditions for each location and year are provided in Table 1.

Data Recording and Statistical Analysis

The total number of marketable watermelon fruit and the number of marketable-sized rotten fruit in each plot were recorded at end of the experiment. Details of the final observation dates at each location are presented in Table 1. Total number of fruits and number of rotted fruits per plot were recorded weekly by inserting a field flag through the rotting melon. Fruit rot incidence was calculated as the number of rotted fruit in a plot divided by the total number of fruits in the plot. If the assumptions of homogeneity of variance could not be met the (percent fruit rot) data were transformed to arcsine values and analyzed using Proc GLM procedure of SAS (SAS Institute Inc., Cary, NC). Means were separated using the Fisher's protected Least Significant Difference (LSD, $\alpha = 0.05$) procedure of SAS. Disease reduction (%) due to the various fungicide treatments was calculated relative to the mean disease in the nontreated control for each year at each location. Data points for each year and location were used to calculate the mean effectiveness of the various fungicide treatments across years and locations using the percent disease reduction data. Of the five evaluations across years and locations, only the treatments which were evaluated a minimum of four times were included. The two fungicide rotation programs evaluated only in South Carolina for two years were not included. The data was analyzed using the Proc GLIMMIX procedure of SAS and means were separated using the PDIF option ($\alpha = 0.05$). Location and year were considered as the random variable in the analysis.

Fungicide Rotation Programs and *Phytophthora* Fruit Rot

Substantial fruit rot was observed in the nontreated control plots in 2013 in South Carolina (63%) and Georgia (76%) (Table 3). All

TABLE 3
Simple fungicide rotation programs evaluated for managing *Phytophthora* fruit rot of watermelon in Charleston, SC, and Tifton, GA, in 2013

Week 1 ^w	Week 2	Week 3	Week 4	Week 5	Fruit rot SC (%) ^x	Disease reduction (%) ^y	Fruit rot GA (%)	Disease reduction (%)	Overall disease reduction (%)
nontreated	nontreated	nontreated	nontreated	nontreated	63 a ^z	–	76 a	–	–
Zampro	K-Phite	Zampro	K-Phite	Zampro	32 b	49	61 ab	20	35
Actigard	K-Phite	Revus	Presidio	Presidio	46 b	28	60 abc	22	25
Ridomil-Gold	Ridomil-Gold	Ridomil-Gold	Ridomil-Gold	Ridomil-Gold	40 b	37	52 bc	32	35
Ranman + Ridomil Gold	Ranman + Ridomil Gold	Ranman + Ridomil Gold	Ranman + Ridomil Gold	Ranman + Ridomil Gold	30 b	52	50 bc	34	43
Presidio	K-Phite	Presidio	Ranman + Ridomil Gold	Revus	35 b	44	46 bc	39	42
Presidio	V-10208	Presidio	V-10208	Presidio	36 b	44	40 bc	48	46
Presidio	Zampro	Presidio	Zampro	Presidio	32 b	50	37 c	51	50

^wAll sprays were applied using a CO₂-pressurized backpack sprayer on a weekly basis.

^x *Phytophthora* fruit rot incidence was calculated by dividing the number of rotten fruits by total fruits in a plot.

^y Disease reduction for each treatment was calculated based on mean disease for nontreated control plots for each location.

^z Means followed by the same letter within the column for fruit rot SC (%) and fruit GA (%) are not significantly different ($\alpha = 0.05$).

the fungicide treatments significantly reduced fruit rot compared with the nontreated control plots in South Carolina. In Georgia, Presidio alternated with Zampro was numerically the most effective treatment and had significantly less fruit rot compared with the nontreated control or Zampro alternated with K-Phite. Ridomil Gold or tank-mixing Ranman and Ridomil Gold also significantly reduced fruit rot compared with nontreated control. Similarly, the rotation of Presidio/K-Phite/Ranman + Ridomil Gold/Revus or Presidio alternated with V-10208 was also effective in reducing fruit rot. Overall, across the two locations in 2013, the maximum disease reduction compared with nontreated control was only 50%, and therefore we evaluated different fungicide rotation programs in 2014 and 2015 across three locations. Since tank-mixing of Ranman and Ridomil Gold did significantly reduce fruit rot compared with nontreated controls at both locations, we included this treatment as a part of fungicide rotation programs in 2014 and 2015.

Substantial fruit rot (mean = 75%) was observed in the nontreated control plots at all three locations in 2014 and ranged from 54 to 91% (Table 4). Across the three locations, the fungicide rotation programs had significantly lower *Phytophthora* fruit rot incidence compared with nontreated control. The rotation of Zampro alternated with Orondis was numerically the best based on the means across the locations. However, there were no significant differences among the various rotation programs suggesting that any of these rotations has equivalent potential for managing *Phytophthora* fruit rot. Significant fruit rot (91%) was observed in the nontreated control plots in South Carolina. Significant differences ($P \leq 0.0001$) were observed among the fungicide treatments. All the fungicide rotation programs significantly reduced fruit rot compared with the nontreated control. The standard fungicide treatment of Ridomil Gold was not as effective as some of the other treatments because of the presence of insensitive strains in the field in South Carolina in 2014. Melcast indicated no spray on 31 July, but it did suggest a spray on 1 August. However, we could not get back into the field to make an application until 7 August due to rainy and wet soil conditions for spray treatment. Despite having one less spray treatment, the Melcast scheduled treatments were not significantly different from the other effective fungicide rotations for managing fruit rot. Zampro alternated with Orondis, or Revus with Presidio were very effective in managing fruit rot. The rotation scheme of two sprays of Orondis

(17 July, 14 August) and one of Presidio (31 July) was as effective as other programs despite having two less sprays. Similarly, in North Carolina, severe fruit rot was observed in the nontreated control plots with an average of 80% of fruit rotten. All rotation programs performed better than the nontreated control. No significant differences among the various rotation programs were observed. In the plots with Actigard followed by Ranman + Ridomil, Presidio, V10208, and a final application of Orondis, no rotten fruit were detected. The standard treatment of Revus rotated with Ridomil Gold also was significantly better than the nontreated control, although not different from other rotation programs. Implementing Melcast did not result in fewer spray applications than a weekly schedule in North Carolina in 2014. The standard Ridomil Gold treatment was also very effective in reducing fruit rot in North Carolina. In Georgia, over 50% of the fruit were rotten in the nontreated control plots. All rotation programs performed better than the nontreated control. Zampro alternated with Orondis was numerically the best treatment. Melcast did not suggest fewer spray applications than a weekly schedule in Georgia in 2014 and was not significantly different in reducing fruit rot compared with other fungicide rotation programs (Table 4).

Similar trials were conducted at the three locations in 2015 (Table 5). In North Carolina, no data were obtained because the trials were washed out due to severe rains and flooding. The trials were successful in South Carolina and Georgia. Overall, significant fruit rot was observed across the two locations (mean = 58%). The simple rotation scheme of Zampro and Orondis was numerically the best treatment at both locations. Significant fruit rot (63%) was observed in the nontreated control plots in South Carolina (Table 5). Significant differences ($P \leq 0.0001$) were observed among the fungicide treatments. However, fruit rot in nontreated plots in South Carolina was less in 2015 (63%) compared with 2014 (91%). All the fungicide rotation programs significantly reduced fruit rot compared with the nontreated control. Ridomil Gold was not as effective as some of the other treatments likely because of the presence of insensitive strains of the pathogen in the field. Melcast indicated no spray on July 23 and none was applied for that one treatment. Despite one less spray the Melcast-scheduled treatment was not significantly different from the other effective fungicide rotations for managing fruit rot (Table 5). Zampro alternated with Orondis or Revus alternated with Presidio were numerically the

TABLE 4
Effect of fungicide rotation programs on development of Phytophthora fruit rot on watermelon at three locations
(South Carolina, North Carolina, and Georgia) in southeastern United States in 2014

Spray treatments each week ^u					Phytophthora fruit rot incidence (%) ^v			
Week 1	Week 2	Week 3	Week 4	Week 5	SC	NC	GA	Mean across locations (%)
nontreated	nontreated	nontreated	nontreated	nontreated	91 a ^w	80 a	54 a	75 a
Actigard	K-Phite	Revus	Presidio	Zampro	40 bc	30 b	27 bc	32 b
Forum	Presidio	K-Phite	Ranman + Ridomil	Revus	45 bc	26 b	25 bc	32 b
Actigard	Ranman + Ridomil	Presidio	V10208	Orondis	46 bc	0 b	27 bc	24 b
Forum	K-Phite	Presidio	Zampro	Ranman	45 bc	10 b	23 cd	26 b
Zampro	Orondis	Zampro	Orondis	Zampro	23 c	30 b	17 d	23 b
Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	64 b	16 b	31 b	37 b
Melcast	Melcast Ranman +	Melcast Revus	Melcast Zampro	Melcast	41 bc	36 b	22 cd	33 b
Presidio ^x	Ridomil	no spray in SC		Orondis				
Orondis ^y	no spray	Presidio	no spray	Orondis	24 c	–	–	–
Revus ^y	Presidio	Revus	Presidio	Revus	24 c	–	–	–
Revus ^z	Ridomil Gold	Revus	Ridomil Gold	Revus	–	26 b	–	–

^u All sprays were applied using a CO₂-pressurized backpack sprayer on a weekly basis.

^v Phytophthora fruit rot incidence was calculated by dividing the number of rotten fruits by total fruits in a plot.

^w Means followed by the same letter within a column are not significantly different ($\alpha = 0.05$).

^x Melcast sprays were based on predictions provided by Purdue University for each location in the study. In North Carolina and Georgia, all five sprays were made. However, in South Carolina Melcast indicated no spray on the spray day during the third week. However, it indicated spray for the next day. But this spray could not be made due to heavy rains.

^y In South Carolina, two extra fungicide rotation programs were evaluated.

^z A fungicide rotation program of Revus alternated with Ridomil Gold was also included in North Carolina.

TABLE 5
Effect of fungicide rotation programs on development of Phytophthora fruit rot on watermelon at two locations
(Charleston, SC, and Tifton, GA) in southeastern United States in 2015

Spray treatments each week in GA and SC ^v					Phytophthora fruit rot incidence (%) ^w		
Week 1	Week 2	Week 3	Week 4	Week 5	SC	GA	Mean across locations (%)
nontreated	nontreated	nontreated	nontreated	nontreated	63 ab ^x	53 a	58
Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	66 a	34 b	50
Forum ^z	Presidio	K-Phite	Ranman + Ridomil	Revus	44 bc	–	44
Actigard	K-Phite	Revus	Presidio	Zampro	37 cd	25 c	31
Orondis ^z	no-spray	Presidio	no-spray	Orondis	27 cde	–	27
Melcast ^y	Melcast	Melcast	Melcast	Melcast	25 cde	21 cd	23
	no spray SC		no spray GA				
Actigard ^z	Ranman + Ridomil	Presidio	V10208	Orondis	20 de	–	20
Forum	K-Phite	Presidio	Zampro	Revus	20 de	24 c	22
Zampro	Orondis	Zampro	Orondis	Zampro	12 e	14 d	13
Revus ^z	Presidio	Revus	Presidio	Revus	12 e	–	12

^v All sprays were applied using a CO₂-pressurized backpack sprayer on a weekly basis.

^w Phytophthora fruit rot incidence was calculated by dividing the number of rotten fruits by total fruits in a plot.

^x Means followed by the same letter within a column are not significantly different ($\alpha = 0.05$).

^y Melcast sprays were based on predictions provided by Purdue University for each location in the study. In South Carolina and Georgia, Melcast suggested one less spray. In South Carolina, Melcast sprays were Presidio, no spray, Revus, Zampro, and Orondis. In Georgia, the Melcast sprays were Zampro, Orondis, Presidio, no spray, and Revus.

^z In South Carolina, four extra fungicide rotation programs were evaluated similar to 2014.

most effective in managing fruit rot. The rotation program of two sprays of Orondis and one of Presidio was as effective as other programs despite two less sprays. However, this rotation scheme was not as effective in 2015 as it was in 2014. In Georgia, over 50% of the fruit were rotten in the nontreated control plots. All rotation programs performed better than the nontreated control. Zampro

alternated with Orondis was the best treatment. Ridomil Gold was significantly better than nontreated control in reducing Phytophthora fruit rot. However, Ridomil Gold was not as effective as Zampro rotated with Orondis or any other rotation programs (Table 5). Melcast indicated no spray application for the fourth week in Georgia and none was applied for that treatment. Despite

one less spray the fungicide rotation program used in Melcast in Georgia was as effective as the other rotation programs and was not significantly different from Zampro alternated with Orondis (Table 5).

Overall, across the three locations and two years, the fungicide rotation program of Zampro alternated with Orondis was numerically the most effective in reducing *Phytophthora* fruit rot (Table 6). The fungicide rotation program of Actigard/Ranman + Ridomil Gold/Presidio/V10208/Orondis was as effective as Zampro alternated with Orondis. Overall, the standard Ridomil Gold treatments were numerically the least effective in reducing *Phytophthora* fruit rot and this was partly due to the presence of insensitive strains. Overall the other rotation programs also reduced *Phytophthora* fruit rot by over 50% across years and locations (Table 6).

Using Melcast to determine when to apply fungicides did not significantly affect control in all three situations where one spray treatment was reduced. In these studies we used one threshold and started our spray applications on the same day as our other fungicide rotation programs, unlike what is recommended by Melcast for other diseases such as gummy stem blight and anthracnose of watermelon (Keinath et al. 2007; Latin and Egel 2001). Melcast suggested reducing one spray treatment in two out of the five trials: one in South Carolina and one in Georgia. In the third, Melcast suggested a spray the next day after the scheduled calendar-based spray date in South Carolina in 2014; however, a spray treatment was not applied owing to excessive rains that created difficult field conditions. Melcast-suggested sprays were not consistently effective in reducing spray applications and *Phytophthora* fruit rot across locations. Further studies to evaluate various Melcast EFI thresholds may make this disease-forecasting tool more suitable for reducing spray treatments for effective management of *Phytophthora* fruit rot of watermelon.

Conclusions and Management Implications

Development of pathogen resistance to fungicides is a major concern for manufacturers and growers and hence rotation programs or tank mixing of fungicides from different FRAC groups (Fungicide Resistance Action Committee) (Table 2) are recommended. Fungicides that were effective for managing *Phytophthora* fruit rot of watermelon have been identified in previous studies (Kousik et al. 2011, 2014a). The present study was undertaken in

three locations to evaluate fungicide rotation programs for managing *Phytophthora* fruit rot in the southeastern United States. The study has resulted in the identification of several fungicide rotation programs that significantly reduce *Phytophthora* fruit rot. Overall, the rotation of Zampro alternated with Orondis were numerically the most effective across locations and years. Similarly, the rotation of Revus alternated with Presidio in South Carolina was also effective and disease reduction was 78% over two years. However, both these were relatively simple programs and may lead to overuse of one of the fungicides. The rotation of Actigard/Ranman+ Ridomil Gold/Presidio/V10208/Orondis was equally effective and utilized fungicides from six different FRAC groups. Complex rotations utilizing fungicides from different FRAC groups has greatest potential to prevent resistance development in the pathogen. In addition, tank-mixing fungicides from two different groups for one of the spray applications can also be expected to be effective. Utilizing tank mixes with different FRAC groups in rotation programs with fungicides from other groups should also be an effective strategy. Application of the systemic resistance activator Actigard during early stages of plant growth may also be helpful. Similarly, Forum and K-Phite can be applied early in the rotation programs, as they are less expensive but not as effective as some of the other new fungicides. This study also demonstrates that fairly flexible fungicide rotation programs can be developed for use by growers, depending upon the availability of the fungicides.

Orondis (formerly known as DPX-QGU 42, OXTP, or Zorvec in Europe) is a relatively new fungicide in the U.S. market. However, Orondis has restrictions with respect to number of applications per season. Only two foliar applications per season are allowed. We found that the rotation of three applications of Zampro and two of Orondis was one of the most effective treatments and would be allowed per label directions. However, it will be prudent to continue to evaluate other rotation programs for effective management of *Phytophthora* fruit rot and for extending the usefulness of the fungicides. Growers should keep in mind that it is very important to rotate among the fungicides to prevent development of resistance in the pathogen population to these fungicides. Growers should not rotate Revus and Forum in sequence as they both belong to FRAC group 40 and have similar modes of fungicidal action. Similarly, Zampro also contains the same active ingredient (dimethomorph) as

TABLE 6
Phytophthora fruit rot reduction due to fungicide rotation programs across three locations (Georgia, South Carolina, and North Carolina) in southeastern United States in 2014 and 2015

Spray treatments each week in 2014 and 2015 ^x					Disease reduction compared with control (%) ^y					Mean across years and locations (%)
Week 1	Week 2	Week 3	Week 4	Week 5	SC14	SC15	GA14	GA15	NC14	
Zampro	Orondis	Zampro	Orondis	Zampro	75	81	69	73	63	75 a ^z
Actigard	Ranman + Ridomil Gold	Presidio	V10208	Orondis	50	68	50	–	100	69 ab
Forum	K-Phite	Presidio	Zampro	Revus	50	68	57	54	88	66 ab
Melcast	Melcast	Melcast	Melcast	Melcast	55	60	59	61	55	60 ab
Actigard	K-Phite	Revus	Presidio	Zampro	56	41	50	52	63	55 bc
Forum	Presidio	K-Phite	Ranman + Ridomil	Revus	50	29	54	–	68	52 bc
Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	Ridomil Gold	30	0	43	36	80	40 c
nontreated	nontreated	nontreated	nontreated	nontreated	0	0	0	0	0	0

^x All sprays were applied using a CO₂-pressurized backpack sprayer on a weekly basis.

^y Disease reduction for each treatment was calculated based on mean disease for nontreated control plots for each location.

^z Means followed by the same alphabet are not significantly different ($\alpha = 0.05$). LSmeans represented are those calculated using the Proc GLIMMIX procedure of SAS.

Forum. Hence, care should be taken while rotating these fungicides. We developed the above-described fungicide rotation programs with the intent of preventing or delaying development of resistance in the pathogen population. In addition, products such as Orondis (e.g., Orondis Ultra) may be combined with other fungicides, including Revus (mandipropamid, FRAC group 40), by the manufacturers. This should also be taken into account when selecting fungicides for a rotation.

Melcast has been used to reduce the number of fungicide applications for management of gummy stem blight on watermelon (Everts and Shields 2000; Keinath et al. 2007). In the present study, Melcast helped reduce one spray treatment in essentially three of the five experiments and the disease levels were not significantly different from other fungicide rotation programs. However, in this study, the first spray application was initiated after fruit formation, unlike conventional Melcast where initial sprays of a protectant fungicide are recommended early in the plant growth stages soon after planting. Melcast was initiated after fruit formation because the fruits are the part of the watermelon plant most susceptible to *P. capsici*. Further studies with modified Melcast thresholds and earlier sprays with systemic fungicides may be needed to effectively use Melcast recommendations for scheduling sprays to manage *Phytophthora* fruit rot.

In previous studies conducted in South Carolina, we have shown that some of the fungicides (e.g., Orondis, Zampro, Revus alternated with Presidio) were effective in reducing postharvest fruit rot by 80 to 92% for up to 9 days after the last spray in the field where the incidence ranged from 18 to 36% (Kousik et al. 2014a). Hence in these trials, for most of the rotation programs, the last spray was either Orondis, Zampro, Revus, or Presidio. However, we did not attempt to study effectiveness of the postharvest disease reduction due to the rotation programs as such facilities were not available at all the three locations. In the trials conducted at the three locations, the disease pressure was extreme because we had inoculated the plots to induce development of *Phytophthora* fruit rot. This was probably the reason for not achieving 100% reduction in disease. Fruit rot incidence in some of the numerically most effective fungicide rotation programs were fairly high (12 to 23%) and may not be acceptable to some growers. However, in many instances the growers may not face the extreme conditions created in our studies to generate disease and may get more effective disease management, especially if they use an integrated approach. As has been previously reported (Kousik et al. 2011, 2014a; McGrath 1996), under favorable weather conditions and severe disease pressure it can be extremely difficult to effectively manage *Phytophthora* fruit rot. Therefore, it is essential that growers use an integrated approach (Babadoost 2004; Ji et al. 2012; Ristaino and Johnston 1999), which includes proper site selection, well drained fields, crop rotation, and fungicides to effectively manage this disease.

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