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Research

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Efficacy of Biological and Conventional Fungicide Programs for Foliar Disease Management on Pomegranate (*Punica granatum*) in Florida

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Abstract

Pomegranate (*Punica granatum* L.) is an emerging alternative perennial crop in the southeastern United States. However, foliar diseases are present across this production area, causing almost 100% premature defoliation. A series of fungicide efficacy trials were conducted to evaluate biological, systemic, and contact fungicides at two locations in Florida, Plant City (cv. Angel Red) and Parrish (cvs. Christina, Azadi, Vikusnyi, Alsirinnar, Sakerdze, and Wonderful), for foliar disease management. Based on AUDPC, the fungicides Captan 80 WDG (captan, 78.2%), Penncozeb 75DF (mancozeb, 75%), Merivon (pyraclostrobin, 21.3% + fluxapyroxad, 21.3%), and Topsin 4.5 FL (thiophanate methyl, 45%) significantly reduced the percentage of foliar disease severity compared with biologicals consisting of Serenade OPTI and Tenet WP (Plant City) and the nontreated control (Plant City and Parrish cv. Wonderful). All treatments applied in a rotational program three times at bloom significantly reduced disease severity compared with the nontreated control in both locations. Rotational programs applied throughout the season also reduced disease severity compared with nontreated controls and repeated applications of neem oil. Foliar disease management is critical for long-term establishment of pomegranate as a viable economic crop in the southeastern United States.

Keywords: pesticides, integrated pest management, chemical control, biocontrol

California is the largest producer of pomegranate in the United States (U.S.) (NASS 2012). In the southeastern U.S., pomegranate has emerged as an alternative crop for growers dealing with devastating disease and pests on citrus and avocado (Castle et al. 2011). However, diseases are also limiting factors on pomegranate production. Leaf spots and blight, caused by *Colletotrichum* spp., *Dwiroopa punicae*, and *Pseudocercospora punicae*, are important foliar diseases occurring on pomegranate across the southeastern U.S. (Xavier et al. 2019a, 2019b). Together these pathogens can cause complete defoliation and fruit loss in the absence of an effective management strategy.

Integrated management strategies are recommended to reduce disease levels in the major pomegranate production areas (Jadhav and Sharma 2009). Cultural practices play an important role in disease management. The recommended field sanitation measures are pruning of suckers and infected plant parts followed by removal of infected material, as well as plant debris, from the orchard (Munhuweyi et al. 2016).

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There is limited information on the use of chemical and biological controls for the management of pomegranate diseases in the U.S. However, in subtropical and tropical countries where pomegranate is well adapted, more studies have been performed. For example, in India, where climatic conditions are similar to those in Florida, integrated management strategies include the application of chemical and biological controls (Munhuweyi et al. 2016; Thomidis 2014).

The use of preharvest chemical fungicides is especially important in areas with high relative humidity. In southwestern India the use of preharvest fungicides was reported to reduce the incidence of pomegranate fruit rot by more than 90% after the application of either the systemic fungicide propiconazole or a mixture of a systemic fungicide, carbendazim, and the contact fungicide mancozeb (Nargund et al. 2012). In another study conducted in India, the fungicides carbendazim, difenoconazole, captan, chlorothalonil, hexaconazole, iprobenfos, mancozeb, thiophanate-methyl, propineb, and propiconazole were effective in reducing disease levels when applied alone or in rotational programs in the field (Jadhav and Sharma 2009). Under field conditions, Ridomil Gold 68% WP (mefenoxam) was reported to reduce *Alternaria alternata* leaf spot by 90% compared with the nontreated control (Muthukumar and Udhayakumar 2015). Although fungicides are commonly used to control diseases of pomegranate worldwide, there are currently no conventional fungicides registered for preharvest disease control in the U.S.

Most of the studies to evaluate the efficacy of biocontrol agents and plant extracts have been performed in vitro. For instance, eight fungal species were tested as potential biopesticides against *A. alternata*, and results indicated that *Trichoderma viride*, *T. hamatum*, and *Aspergillus niger* showed the highest level of mycelial growth inhibition (Kadam et al. 2018). In addition, extracts of *Allium sativum*, *Zingiber officinale*, and *Azadirachta indica* showed the highest mycelial growth inhibition among 11 plant extracts tested (Kadam et al. 2018). The efficacy of biopesticides was also tested in vitro against *Colletotrichum gloeosporioides*. Once again, *T. viride* was the best in inhibiting mycelial growth, followed by *T. harzianum* and *Pseudomonas fluorescens*. The plant extracts from *Datura stramonium* and *A. sativum* showed more than 50% mycelial growth inhibition. In the same study, *Bacillus subtilis* showed the least inhibition of mycelial growth (Nargund et al. 2012). However, when *Bacillus* spp. were tested on fruits, it effectively retarded and controlled pomegranate fruit rot (Gajbhiye et al. 2013). Although multiple biopesticides are registered for use on pomegranate against foliar diseases in the U.S. (CDMS 2019), no information regarding their effectiveness in controlling preharvest diseases is available.

Recently, we reported the effect of three fungicide programs, Merivon (pyraclostrobin + fluxapyroxad), Luna Experience (fluopyram + tebuconazole), and a rotational program consisting of these two fungicides as well as Penncozeb 75DF (mancozeb), to control foliar and fruit diseases of pomegranate across the southeastern U.S. (Xavier et al. 2020). A request to expand the label of Merivon to include pomegranate is currently under consideration by the U.S. Environmental Protection Agency. The evaluation of additional fungicides will potentially help growers to develop an alternative fungicide program to control diseases on pomegranate across the southeastern U.S. Furthermore, the use of multiple fungicide chemistries in pomegranate can be essential in the management of fungicide resistance. Therefore, the objective of this work was to evaluate several biological and conventional fungicides in order to develop effective programs for disease management on pomegranate. This information is important in supporting labeling efforts necessary to provide the pomegranate industry in the southeastern U.S. with effective fungicide options for commercial production.

Fungicide Applications

Fungicide trials were established in 2017 at two pomegranate orchard sites in Florida. Tested biopesticides included Serenade OPTI (Bayer CropScience, Research Triangle Park, NC), containing the QST 713 strain of *B. subtilis* (26.2%); Tenet WP (Isagro USA, Morrisville, NC), containing *Trichoderma asperellum* (ICC 012) (2%) and *T. gamsii* (ICC 080) (2%); and neem oil (Lawn and Garden Products, Fresno, CA), containing clarified hydrophobic extract of neem oil (70%). Tested conventional fungicides included Merivon SC (BASF, Research Triangle Park, NC), containing pyraclostrobin (21.3%) + fluxapyroxad (21.3%); Luna Experience SC (Bayer CropScience), containing fluopyram (17.6%) + tebuconazole (17.6%); Topsin 4.5 FL (United Phosphorus, King of Prussia, PA), containing thiophanate-methyl (45%); Penncozeb 75DF (United Phosphorus), containing mancozeb (75%); and Captan 80 WDG (Drexel Chemical Company, Memphis, TN), containing captan (80%) (Table 1). In addition, a nontreated control was included in each trial.

Fungicides were applied alone or within a series of rotational programs (Tables 2, 3, and 4) with a CO_2 backpack sprayer calibrated to deliver 46 liters/ha at 275.8 kPa. The first set of trials evaluated two consecutive foliar applications, 14 days apart, of Penncozeb 75DF, Captan 80 WDG, Topsin 4.5 FL, Serenade OPTI, Tenet WP, and Merivon treatments at bloom (Table 2). The second set of trials evaluated four at-bloom fungicide programs, consisting of three consecutive applications of Merivon, Topsin 4.5 FL, or Captan 80 WDG in different combinations and a seasonal program of Luna Experience (Table 3). The third set of trials evaluated a series of seasonal fungicide rotations beginning with at-bloom application of Merivon, followed by three applications of either Captan 80 WDG, Topsin 4.5 FL, neem oil, Serenade OPTI, or Tenet WP (Table 4).

Trials were initiated when pomegranate trees showed at least 20% flower bud break, on April 5 and 6 in Parrish and Plant City, respectively. In Plant City all the trials consisted of pomegranate cultivar Angel Red, with three replicate trees per treatment. In Parrish, due to a limit in available trees, each trial consisted of two separate cultivars with three replicate trees per cultivar for each treatment. Treatments, including a nontreated control, were arranged in a randomized complete block design. All trees used in this study were cultivated in a row spacing of 5.8 m and tree spacing of 2.7 m. Each orchard site had a history of high disease pressure, so trials relied on natural inoculum prevalent in the area.

Foliar Disease Assessment and Data Analysis

The most prevalent foliar diseases of pomegranate consist of leaf spots and blight caused by *Colletotrichum* spp., *D. punicae*, and *P. punicae*, as previously described (Xavier et al. 2019a, 2019b, 2019c). Foliar disease severity (leaf spotting and blighting) was assessed on each tree using the Horsfall–Barratt rating (Horsfall and Barratt 1945) every 2 weeks starting on April 19 and 20 in Parrish and Plant City, respectively. The Horsfall–Barratt rating was converted to a midpoint percentage for data analysis. Area under disease progress curve (AUDPC) was calculated based on foliar disease severity using the following formula: $\Sigma\{[(x_i + x_{i-1})/2](t_i - t_{i-1})\}$,

TABLE 1
Fungicides used in this study

Product	Rate/ha	Active ingredient	Source	FRAC code[z]
Merivon Xemium	83.8 ml	Fluxapyroxad + pyraclostrobin	BASF Ag Products, Research Triangle Park, NC	7 and 11
Penncozeb 75DF	0.7 kg	Mancozeb	United Phosphorus, King of Prussia, PA	M3
Captan 80 WDG	0.9 kg	Captan	Drexel Chemical Company, Memphis, TN	M3
Topsin 4.5 FL	359 ml	Thiophanate-methyl	United Phosphorus, King of Prussia, PA	1
Luna Experience	203.5 ml	Fluopyram + tebuconazole	Bayer CropScience LP, Research Triangle Park, NC	7 and 3
Neem oil	622.3 ml	Neem oil	Lawn and Garden Products, Fresno, CA	NA
Serenade OPTI	0.23 kg	*Bacillus subtilis*	Bayer CropScience LP, Research Triangle Park, NC	BM 02
Tenet WP	0.55 kg	*Trichoderma asperellum* + *Trichoderma gamsii*	Isagro USA, Morrisville, NC	44

[z] FRAC codes from the Fungicide Resistance Action Committee (https://www.frac.info/docs/default-source/publications/frac-code-list/frac-code-list-2020-finalb16c2b2c512362eb9a1eff00004acf5d.pdf?sfvrsn=54f499a_2). NA = not applicable.

in which x_i is the rating at the time of evaluation and $(t_i - t_{i-1})$ is the time between evaluations; the values are estimates of least squares means for treatments. AUDPC was calculated from midpoint percentages using the trapezoidal method (Jeger 2004).

The effect of the treatments on foliar disease severity and AUDPC was analyzed using a generalized linear mixed model (PROC GLIMMIX, SAS, version 9.4, SAS Institute, Cary, NC) with blocking as a random effect and fungicide program as a fixed effect in the model. Values of disease severity and AUDPC were log-normal transformed for statistical analyses but presented as actual means in the results and tables. Degrees of freedom were calculated using the Kenward–Roger method (Kenward and Roger 1997) and mean separation performed with Fisher's least square difference (LSD) method at the 95.0% level of confidence.

Effect of At-Bloom Fungicide Treatments

Based on foliar disease severity, significant differences were detected among the treatments beginning in May (week 4) and June (week 5) at Plant City and Parrish, respectively (Supplementary Table S1). Based on final disease severity and AUDPC, differences were observed among treatments applied on 'Christina' ($P = 0.0206$ and $P = 0.0483$, respectively), 'Wonderful' ($P = 0.0027$ and $P = 0.0088$, respectively), and 'Angel Red' ($P < 0.0001$ and $P < 0.0001$, respectively) (Table 2).

Based on final disease severity and AUDPC, the systemic fungicides, Merivon and Topsin 4.5 FL, provided the highest level of disease control in comparison with the nontreated control in both locations (Table 2). When applied on Wonderful, Angel Red, and Christina, the systemic fungicides provided up to 64, 92, and 92% disease control in comparison with the nontreated control, respectively, based on final disease severity (Table 2).

The contact fungicides, Captan 80 WDG and Penncozeb 75DF, provided 46 and 57% disease control, respectively, when applied on Angel Red (Table 2). On Wonderful, Penncozeb 75DF provided 75% disease control, based on the final disease severity; however, Captan 80 WDG was not effective in comparison with the nontreated control (Table 2). When applied on Christina, the contact fungicides were not effective in reducing foliar disease severity in comparison with the nontreated control (Table 2).

The biological fungicides, Tenet WP and Serenade OPTI, were not effective in reducing foliar disease severity in comparison with the nontreated control when applied on Angel Red, Wonderful, or Christina (Tenet WP only) (Table 2).

Effect of At-Bloom, Rotational Fungicide Programs

Significant differences in foliar disease severity were detected among fungicide treatments beginning in June (week 5) at both trial locations (Supplementary Table S2). Based on final disease severity and AUDPC, all treatments applied on Angel Red ($P = 0.0001$ and $P < 0.0001$, respectively) and 'Sakerdze' ($P < 0.0001$ and $P < 0.0001$, respectively) had significant effects on foliar disease severity in comparison with the nontreated control (Table 3). Similar trends were observed when treatments were applied on 'Alsirinnar', based on final disease severity and AUDPC; however, due to the high variability there were no significant differences among the treatments ($P > 0.1919$ and $P > 0.1039$, respectively). Treatments including the three at-bloom fungicide rotation programs, the seasonal application of Luna Experience, and Merivon applied twice at bloom provided disease control that ranged from 84 to 92% and from 61 to 85% in Plant City and Parrish, respectively, in comparison with the nontreated control (Table 3).

Based on final disease severity, all treatments consisting of a rotational program among three fungicides were not significantly different from two at-bloom applications with Merivon or a seasonal application with Luna Experience (Table 3).

Effect of Postbloom Fungicide Applications with an At-Bloom Merivon Program

Based on foliar disease severity, significant differences were detected among the treatments beginning in June (weeks 4 and 5) at Plant City and Parrish (Supplementary Table S3). In Plant City, final disease severity ranged from 4.5 to 91.5%. All treatments significantly reduced disease severity compared with the nontreated control except for the neem oil program (Table 4). However, based on AUDPC, the season-long neem oil program significantly reduced foliar disease severity in comparison with the nontreated control when applied on Angel Red, with similar numerical trends, but not significant, observed on 'Azadi' and 'Vikusnyi' (Table 4).

TABLE 2
Effect of rotational programs applied twice at bloom on disease severity and area under the disease progress curve (AUDPC) in field trials performed at pomegranate orchards in Plant City and Parrish[w]

Treatments, rate (application)[x]	DS_f [y]			AUDPC[z]		
	Plant City	Parrish		Plant City	Parrish	
	Angel Red	Christina	Wonderful	Angel Red	Christina	Wonderful
Merivon, 83.8 ml/ha (1, 2)	7.5 c	4.5 b	21.7 dc	607 c	558 b	1,040 bc
Topsin 4.5 FL, 359 ml/ha (1, 2)	7.5 c	4.5 b	31.2 bc	565 c	558 b	1,015 bc
Captan 80 WDG, 0.9 kg/ha (1, 2)	49.0 ab	21.7 a	45.8 ab	1,279 b	1,000 ab	1,463 ab
Penncozeb 75DF, 0.7 kg/ha (1,2)	39.5 b	28.5 a	15.3 d	1,039 b	963 ab	852 c
Serenade OPTI, 0.23 kg/ha (1, 2)	89.7 a	9.0 ab	45.8 ab	2,837 a	706 b	1,379 ab
Tenet WP, 0.55 kg/ha (1, 2)	86.5 a	36.3 a	62.5 a	2,389 a	1,067 ab	2,080 a
Nontreated	91.5 a	42.7 a	60.5 ab	3,174 a	1,557 a	2,088 a
P > F	<0.0001	0.0206	0.0027	<0.0001	0.0483	0.0088

[w] Means followed by the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).

[x] Treatments were applied on April 5 and 6 (application 1) and April 19 and 20 (application 2) in Parrish and Plant City, respectively (corresponding with applications 1 and 2 shown in the table).

[y] Final disease severity (DS_f) was evaluated on August 24.

[z] AUDPC was calculated using the following formula: $\Sigma\{[(x_i + x_{i-1})/2](t_i - t_{i-1})\}$, where x_i is the midpoint percentage of the Horsfall–Barratt rating at each evaluation time and $(t_i - t_{i-1})$ is the time between evaluations.

In Parrish, based on the final disease severity, significant differences among the treatments were observed on the cultivars Azadi ($P = 0.0082$) and Vikusnyi ($P = 0.0598$) (Table 4). In both locations, up to 90% disease control was obtained by two at-bloom applications of Merivon followed by three seasonal applications of either a contact or systemic fungicide, in comparison with the nontreated control. Based on the AUDPC, the seasonal inclusion of Captan 80 WDG, Topsin 4.5 FL, Serenade OPTI, or Tenet WP with Merivon did not significantly improve disease control compared with the two at-bloom applications of Merivon alone (Table 4).

Conclusions and Implications

Although federal registration for the use of Merivon on pomegranate is under consideration, there are no chemical fungicides labeled for foliar disease control on pomegranate in the U.S. Furthermore, little information is available for biopesticides currently registered on pomegranate. Our prior research demonstrated the efficacy of at-bloom applications of Merivon for disease control on pomegranate (Xavier et al. 2020). Although Merivon is a formulation of two fungicides with different modes of action, additional fungicidal materials with differing modes of action are essential for managing the risk of fungicide resistance within pathogen populations. Results from this study indicate that fungicides such as Captan 80 WDG, Penncozeb 75DF, and Topsin 4.5 FL would be ideal rotational partners or alternatives to Merivon, whereas the biopesticides Tenet WP, Serenade OPTI, and neem oil were ineffective in reducing disease.

The contact fungicides, captan and mancozeb, have shown promise in reducing disease levels of pomegranate in India, which has the largest pomegranate production area in the world, comprising 143,000 ha in 2014 to 2015 (Chandra et al. 2010; Jain and Desai 2018). In the same study, thiophanate methyl, a single-site systemic fungicide from Fungicide Resistance Action Committee group 1, showed significant disease control, similar to our findings in Florida (Jadhav and Sharma 2009).

The use of biopesticides has shown promise in controlling fungal diseases on other fruit crop systems (Borges et al. 2018; Gurjar et al. 2012; Howell 2003). For example, *T. harzianum* was effective against the pathogen *Botrytis cinerea* on apple (Tronsmo 1991) and grape (Harman et al. 1996). *B. subtilis* (ACB-69) applied weekly reduced the amount of sweet orange postbloom fruit drop caused by *C. acutatum* by 47%, whereas the conventional fungicide applications of mancozeb + famoxadone followed by two applications of carbendazim at 15-day intervals showed reduction in fruit drop of only 28.7% (Kupper et al. 2012). The plant extract neem oil significantly reduced disease incidence of rusty spot, caused by *Podosphaera leucotricha*, on peach. However, the amount of disease control ranged from 24 to 34%, which is relatively low compared with 94% control for the systemic fungicide myclobutanil (Lalancette et al. 2013). In our study we also obtained relatively low foliar disease control using biopesticides in comparison with conventional fungicides. However, because the evaluated biopesticides consistently provided some level of control at the two locations, they have the potential to be used in an integrated program with conventional fungicides, or as an option for organic production.

Resistant populations of *C. acutatum* to quinone outside inhibitors have recently been reported in strawberry in Florida (Forcelini and Peres 2018). Because populations of *C. acutatum* from pomegranate and strawberry can cross-infect (Xavier et al. 2019b), there is a potential risk for the population from pomegranate to become resistant to pyraclostrobin, one of the active ingredients in Merivon. To minimize the risk of *C. acutatum* from pomegranate developing resistance to pyraclostrobin, it is important to include other effective fungicides with different modes of action within a rotational program. In this work the rotational programs with three fungicide applications at bloom or throughout the season were statistically the same as two at-bloom applications of Merivon. Despite the potential cost increase to growers, the rotational program, which requires the use of more fungicides, may effectively manage pathogen resistance.

Previously, we demonstrated that Merivon (pyraclostrobin + fluxapyroxad), Luna Experience (fluopyram + tebuconazole), and a rotational program consisting of these two fungicides as well as Penncozeb 75DF (mancozeb) were effective at controlling pomegranate

TABLE 3
Effect of rotational programs applied three times at bloom on disease severity and area under the disease progress curve (AUDPC) in field trials performed at pomegranate orchards in Plant City and Parrish[w]

	DS_f [y]			AUDPC[z]		
	Plant City	Parrish		Plant City	Parrish	
Treatments, rate (application)[x]	Angel Red	Alsirinnar	Sakerdze	Angel Red	Alsirinnar	Sakerdze
Merivon, 83.8 ml/ha (1, 2)	7.5 b	15.3	4.5 b	614 c	662	614 b
Merivon, 83.8 ml/ha (1); Captan 80 WDG, 0.9 kg/ha (2); Topsin 4.5 FL, 359 ml/ha (3)	12.2 b	21.2	6.0 b	661 c	859	601 b
Merivon, 83.8 ml/ha (1); Captan 80 WDG, 0.9 kg/ha (2); Merivon, 83.8 ml/ha (3)	13.8 b	24.8	6.0 b	752 bc	876	600 b
Merivon, 83.8 ml/ha (1); Topsin 4.5 FL, 359 ml/ha (2); Merivon, 83.8 ml/ha (3)	9.0 b	10.7	4.5 b	677 c	604	614 b
Luna Experience, 203.5 ml/ha (1, 4, 6)	15.3 b	15.3	4.5 b	886 b	762	530 b
Nontreated	94.7 a	33.2	31.2 a	4,084 a	1,466	1,185 a
P > F	0.0001	0.1919	<0.0001	<0.0001	0.1039	<0.0001

[w] Means followed by the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).

[x] Treatments were applied on April 5 and 6 (application 1), April 19 and 20 (application 2), May 3 and 4 (application 3), May 17 and 18 (application 4), and July 12 and 13 (application 6) in Parrish and Plant City, respectively (corresponding with applications 1 to 4 and 6 shown in the table).

[y] Final disease severity (DS_f) was evaluated on August 24.

[z] AUDPC was calculated using the following formula: $\Sigma\{[(x_i + x_{i-1})/2](t_i - t_{i-1})\}$, where x_i is the midpoint percentage of the Horsfall–Barratt rating at each evaluation time and $(t_i - t_{i-1})$ is the time between evaluations.

TABLE 4
Effect of rotational programs applied throughout the season, starting at bloom, on disease severity and area under the disease progress curve (AUDPC) in field trials performed at pomegranate orchards in Plant City and Parrish[w]

Treatments, rate (application)[x]	DS_f [y]			AUDPC[z]		
	Plant City	Parrish		Plant City	Parrish	
	Angel Red	Azadi	Vikusnyi	Angel Red	Azadi	Vikusnyi
Merivon, 83.8 ml/ha (1, 2)	7.5 bc	31.2 ab	12.2 bc	656 c	1,253 bc	701 bc
Merivon, 83.8 ml/ha (1, 2); Captan 80 WDG, 0.9 kg/ha (4, 5, 6)	7.5 bc	21.7 bc	7.5 bc	719 c	968 c	607 c
Merivon, 83.8 ml/ha (1, 2); Topsin 4.5 FL, 359 ml/ha (4, 5, 6)	4.5 c	10.7 c	6.0 c	551 c	888 c	608 c
Merivon, 83.8 ml/ha (1, 2); Serenade OPTI, 0.23 kg/ha (4, 5, 6)	9.0 b	37.5 ab	12.2 bc	686 c	1,489 bc	659 bc
Merivon, 83.8 ml/ha (1, 2); Tenet WP, 0.55 kg/ha (4, 5, 6)	9.0 b	26.8 bc	15.3 abc	656 c	1,453 bc	782 bc
Neem oil, 622.3 ml (1, 2, 4, 5, 6)	63.7 a	54.2 a	34.8 ab	1,984 b	2,112 ab	1,485 ab
Nontreated	91.5 a	75.2 a	58.0 a	3,174 a	3,090 a	2,422 a
P > F	<0.0001	0.0082	0.0598	<0.0001	0.0217	0.0201

[w] Means followed by the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).
[x] Treatments were applied on April 5 and 6 (application 1), April 19 and 20 (application 2), May 17 and 18 (application 4), June 14 and 15 (application 5), and July 12 and 13 (application 6) in Parrish and Plant City, respectively (corresponding with applications 1 to 2 and 4 to 6 shown in the table).
[y] Final disease severity (DS_f) was evaluated on August 24.
[z] AUDPC was calculated using the following formula: $\Sigma\{[(x_i + x_{i-1})/2](t_i - t_{i-1})\}$, where x_i is the midpoint percentage of the Horsfall–Barratt rating at each evaluation time and $(t_i - t_{i-1})$ is the time between evaluations.

fruit and foliar diseases. Furthermore, we demonstrated the importance of at-bloom fungicide applications for disease management on pomegranate (Xavier et al. 2020). In this study we are reporting the effect of other conventional fungicides as alternatives in fungicide programs to manage pomegranate diseases across the southeastern U.S. The use of multiple fungicide chemistries will be essential for the management of fungicide resistance in this region, especially if pomegranate is to be planted on a commercial scale in the future. Results from the current study further emphasize the importance of at-bloom applications for effective disease control, which were similar to the two rotational programs beginning at bloom, based on final disease severity. These results are in agreement with our previous study (Xavier et al. 2020).

In previous studies we reported that the most common foliar diseases, including leaf spots and blight, are caused by *Colletotrichum* spp., *D. punicae*, and *P. punicae*. In the present study we demonstrated the efficacy of several fungicides for the management of these three foliar diseases of pomegranate. In order to minimize the threat of developing fungicide-resistant pathogen populations, we recommend that growers apply these products within a rotational program beginning at bloom, and in conjunction with other integrated practices to reduce inoculum levels within the orchard. The registration of Merivon on pomegranate is expected in 2020, but the registration of additional conventional fungicides will take time. Although the evaluated biopesticides performed poorly, relative to conventional fungicides, their performance may be improved with increased application frequency, rates, and other integrated disease management practices. We have reported that fungal diseases are limiting factors to pomegranate production in the southeastern U.S. when control strategies are not applied (Xavier et al. 2020). Thus, similar to other tropical and subtropical regions where pomegranate is widely grown, an integrated approach incorporating cultural practices and the use of conventional fungicides could be an effective disease management program for commercial production in the southeastern U.S.

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