Research

Management of Daylily Rust With Different Fungicides and Fungicide Combinations

Robert S. Emmitt and James W. Buck,[†] Department of Plant Pathology, University of Georgia, Griffin 30223

Accepted for publication 13 June 2017.

Abstract

Production nurseries and daylily hybridizers in the southeast United States rely on the use of fungicides to manage daylily rust, caused by the fungus *Puccinia hemerocallidis*. Foliar sprays of pyraclostrobin, flutolanil, tebuconazole, myclobutanil, chlorothalonil, mancozeb, pyraclostrobin + boscalid, flutolanil + tebuconazole, flutolanil + myclobutanil, flutolanil + chlorothalonil, and flutolanil + mancozeb applied on 14-day intervals, and a nontreated control, were evaluated under high disease pressure at three locations in Griffin, GA, in 2015. Tebuconazole or the

tebuconazole + flutolanil treatment consistently had the lowest area under the disease progress curve (AUDPC) of the treatments. The addition of flutolanil to chlorothalonil or mancozeb did not improve rust control and no difference in disease severity was observed in any treatment containing contact fungicides on all assessment dates. Single application costs ranged from \$10.21 to \$95.96 with tebuconazole providing excellent disease management at a relatively low cost per application (\$13.90).

Daylilies (*Hemerocallis* spp., Liliaceae) are one of the most widely cultivated plants in the world, with over 83,000 cultivars registered with the American Hemerocallis Society. It is an herbaceous perennial native to Asia and is used extensively in landscapes throughout the United States (Gatlin 1999). Daylily rust, caused by the basidiomycete fungus *Puccinia hemerocallidis* (Thum), has become a significant management problem for daylily growers in the southeastern United States (Buck and Ono 2012). Urediniospores produced on daylily can infect and reinfect the same and surrounding daylilies, which can result in destructive, localized disease epidemics if management steps are not implemented (Buck and Williams-Woodward 2003).

Growers rely heavily on fungicides, which remain the most effective tool for managing daylily rust. Many fungicides provide excellent rust management (Buck and Youmans 2009; Dong et al. 2013; Mueller et al. 2004). Azoxystrobin in particular has shown excellent efficacy against *P. hemerocallidis*. Foliar sprays of azoxystrobin at 14-, 21-, or 28-day intervals provided season-long management of daylily rust at three locations in Griffin, GA, in 2014 (Emmitt et al. 2016). One early-season drench application of azoxystrobin provided season-long reduction in daylily rust disease incidence (Dong et al. 2013). The efficacy of flutolanil against *P. hemerocallidis* has been mixed. Flutolanil reduced the total number of lesions on potted daylily in greenhouse trials (Buck and Williams-Woodward 2003) but only reduced disease on field-grown daylilies in one of two seasons (Dong et al. 2013) compared with the nontreated controls.

There is currently no specific chemical combination and spray interval recommended for the management of daylily rust. The objectives of this study were to determine effective fungicide active ingredients, other than azoxystrobin, and effective fungicide combina-

tions, and evaluate the costs of these fungicides when applied at 14-day intervals for managing daylily rust on field-grown daylily plants.

Field Experiments

Trials were conducted in 2015 at the Griffin campus of the University of Georgia in three separate fields. Each field had weed barrier fabric (Greenscapes Inc., Calhoun, GA) covered with 5 to 10 cm of pine bark mulch. Rust-susceptible ‘Pardon Me’ daylily plants, established in previous growing seasons (Dong et al. 2013; Emmitt et al. 2016), were irrigated as needed and fertilized with 10-10-10 soluble fertilizer (Farmer’s Favorite Fertilizer, Evergreen, AL) at 5.7 kg/ha every 2 months. Weeds were spot-treated with SedgeHammer (75% halosulfuron-methyl; Gowan Turf and Ornamental, Yuma, AZ) for sedges and grasses, and with Gly Star Plus (Albaugh LLC, St. Joseph, MS) nonselective glyphosate herbicide.

The experimental design was the same as outlined in Emmitt et al. (2016). Each experimental field had 144 plants, arranged in 12 rows of 12 plants each, spaced 0.6 m within rows and 1.0 m between rows. Each row was divided into four replications (experimental units) consisting of three adjacent plants. The experiment was a complete randomized design with 11 fungicide treatments and one nontreated control, each replicated 4 times. Treatments were randomly assigned to experimental units within each field using Agricultural Research Manager (ARM) 2016 software (Gylling Data Management Inc., Brookings SD).

Puccinia hemerocallidis Grif2 (Buck 2013) was maintained on ‘Pardon Me’ daylilies in a greenhouse. Fresh urediniospores were collected from sporulating lesions using a vacuum spore collector as described by Mueller et al. (2003). Urediniospores were suspended in sterile water amended with 0.05% Tween 20 (J. T. Baker Chemical Co., Phillipsburg, NJ) at a concentration of 1×10^5 urediniospores/ml and sprayed on spreader plants located between the experimental rows in all three fields in mid-June 2015 (Emmitt et al. 2016).

Fungicides at highest label rates were applied on 14-day intervals beginning on 7 July. Flutolanil was applied alone or in combination

[†]Corresponding author. E-mail: jwbuck@uga.edu

with tebuconazole, myclobutanil, chlorothalonil, or mancozeb. Pyraclostrobin (Insignia SC, BASF Corporation, Research Triangle Park, NC) at 0.48 ml/liter, flutolanil (Prostar 70 WP, Bayer CropScience LP, Research Triangle Park, NC) at 0.45 g/liter, tebuconazole (Torque, Cleary Chemicals LLC, Dayton, NJ) at 0.78 ml/liter, myclobutanil (Eagle 20 EW, Dow AgroSciences LLC, Indianapolis, IN) at 0.94 ml/liter, chlorothalonil (Daconil Ultrex 82.5 WDG, Syngenta Crop Protection Inc., Greensboro, NC) at 1.68 g liter, mancozeb (Dithane, Dow AgroSciences) at 1.80 g liter, and pyraclostrobin + boscalid (Pageant, BASF Corporation) at 0.90 g liter were applied as foliar sprays. Eight applications were made over the growing season. All fungicides were applied to runoff using a CO₂-pressurized (276 kPa) backpack sprayer using a single flat-fan air-induction nozzle (11002VS; TeeJet Technologies, Wheaton, IL).

Data Collection and Analysis

Rust disease was assessed on a 0 to 5 rating scale, where 0 = no lesions, 1 = 1 to 20 lesions per leaf on old leaves, 2 = >20 lesions per leaf on old leaves, 3 = 1 to 20 lesions per leaf on new leaves, 4 = >20 lesions per leaf on new leaves, 5 = >20 lesions on every leaf (Dong et al. 2013; Emmitt et al. 2016). The youngest third of leaves on the plant were considered new leaves. All remaining leaves were considered old leaves. Rust was assessed on individual plants weekly for 12 weeks starting from the first appearance of widespread symptoms on the nontreated controls (6 August), approximately 4 weeks after the first fungicide application.

For each location, disease ratings from all dates were used to calculate area under the disease progress curve (AUDPC) to examine treatment effects through the season. AUDPC values were calculated weekly and results are presented 4, 8, and 12 weeks after rust symptoms were first observed (Table 1). AUDPC values were analyzed using PROC MIXED of SAS, version 9.4 (SAS Institute Inc., Cary, NC). Means separation was performed using Fischer's LSD ($\alpha = 0.05$). Single-degree-of-freedom linear contrasts were

calculated to compare tebuconazole alone to the other single-product treatments, tebuconazole to the combination of tebuconazole and flutolanil, and to compare chlorothalonil to mancozeb ($\alpha = 0.05$).

Treatment Price Comparisons

To examine the relative costs associated with each fungicide treatment, prices for products used in this study were gathered from four online vendors and reflect the lowest price obtained in November 2016. Product costs were calculated based on low and high label rates for *Puccinia* sp. for an ornamental standard of 378.5 liters (100 gal).

Effect of Fungicide Treatments on Daylily Rust Development

Disease pressure was high in all three fields, with severity ratings on nontreated control plants reaching 5.0 (>20 lesions on all leaves) on 1 October in all three fields. Due to significant ($P < 0.05$) field-treatment interactions on AUDPC, data from individual fields are presented separately. All treatments were effective at reducing disease severity compared with the nontreated control in fields two and three, at 4, 8, and 12 weeks (26 August, 8 October, and 5 November) with the exceptions of 26 August in fields two (myclobutanil) and three (chlorothalonil) (Table 1). The 26 August assessment date in field one was compromised by deer herbivory and not included in analyses. AUDPC for all treatments containing tebuconazole was significantly lower than all other treatments on all but two assessment dates: 26 August and 5 November in field two. In addition, the flutolanil + tebuconazole combination had the lowest AUDPC on the final assessment date (5 November), in fields two and three (Table 1).

No significant differences were observed between pyraclostrobin alone and the combination of pyraclostrobin + boscalid on any assessment date. On all but one assessment date (5 November) in field three, flutolanil alone was not significantly different than the combination of flutolanil + myclobutanil (Table 1). In addition, no significant difference was observed between myclobutanil alone and

TABLE 1
Daylily rust area under the disease progress curves (AUDPC) for plants in fields 1, 2, and 3 treated at 14-day application intervals with different fungicides and fungicide combinations

Fungicide treatment ^x	AUDPC (date) ^y								
	Field 1			Field 2			Field 3		
	26 Aug ^z	8 Oct	5 Nov	26 Aug	8 Oct	5 Nov	26 Aug	8 Oct	5 Nov
Pyr	—	8.7 c	25.8 f	2.3 bcde	11.0 e	25.8 ef	3.1 cd	12.0 e	25.9 e
Flu		11.3 bc	28.3 def	2.6 bcd	12.8 de	30.4 cd	5.0 b	16.8 d	31.8 d
Teb		1.6 d	6.3 g	0.5 ef	4.5 f	21.8 f	0.9 ef	2.7 f	6.1 f
Myc		11.7 bc	31.5 bcd	4.3 ab	18.6 b	37.2 b	4.3 bc	17.5 cd	34.3 cd
Chl		11.9 bc	31.8 bc	3.4 bc	16.7 bc	35.5 b	5.6 ab	20.1 bc	37.2 bc
Man		12.0 bc	30.1 bcde	2.3 cdef	15.0 cd	33.7 bc	5.1 b	19.0 bcd	35.5 bc
Pyr+Bos		9.1 c	27.4 ef	1.3 def	10.3 e	27.9 de	2.2 de	13.7 e	27.8 e
Flu+Teb		1.1 d	5.0 g	0.3 f	3.4 f	13.6 g	0.0 f	0.7 f	2.9 g
Flu+Myc		10.4 bc	29.1 cdef	2.0 cdef	14.2 cd	33.3 bc	4.7 bc	18.0 bcd	35.0 c
Flu+Chl		13.5 b	33.0 b	2.8 bcd	16.0 bc	35.4 b	4.9 bc	20.3 b	38.3 b
Flu+Man		13.1 b	32.0 bc	3.1 bcd	16.3 bc	35.4 b	4.3 bc	19.2 bcd	36.4 bc
Nontreated control		17.8 a	37.8 a	5.6 a	23.6 a	42.4 a	7.3 a	25.9 a	44.7 a

^x Fungicide treatments included pyraclostrobin (Pyr), flutolanil (Flu), tebuconazole (Teb), myclobutanil (Myc), chlorothalonil (Chl), mancozeb (Man), and pyraclostrobin + boscalid (Pyr+Bos) applied every 14-days.

^y Disease was assessed on a 0 to 5 rating scale, where 0 = no lesions, 1 = 1 to 20 lesions per leaf on old leaves, 2 = >20 lesions per leaf on old leaves, 3 = 1 to 20 lesions per leaf on new leaves, 4 = >20 lesions per leaf on new leaves, 5 = >20 lesions on every leaf (Dong et al. 2013), and data were converted to area under the disease progress curves (AUDPC). Each datum set was analyzed using SAS PROC MIXED at $\alpha = 0.05$.

^z The first assessment date in field 1 was compromised by deer herbivory and not considered in analyses.

flutolanil + myclobutanil except on two assessment dates, 26 August and 8 October, in field two, when the combination product had significantly lower AUDPC. No significant difference was observed among chlorothalonil alone, mancozeb alone, flutolanil + chlorothalonil, or flutolanil + mancozeb in all fields. No significant difference was observed between chlorothalonil alone and mancozeb alone on all assessment dates at all locations (Table 1).

When specific groups of fungicides were compared using linear contrasts, the AUDPC of tebuconazole alone was significantly lower than all other treatments containing a single fungicide in all three fields ($P < 0.0001$). Tebuconazole alone was different than flutolanil + tebuconazole on all assessment dates at all locations ($P < 0.0001$). While AUDPC values of flutolanil + tebuconazole are lower than all other treatments, they are different from tebuconazole alone on only two assessment dates: 5 November in fields two and three (Table 1).

Costs of Fungicide Treatments

The fungicides used in our study range from \$10.21 to \$95.96 U.S. per application, when applied at the highest label rate (Table 2). The tebuconazole product (Torque) provided excellent rust management overall and had the lowest product cost of the systemic products when applied at highest label rate (\$13.90 per application). Pyraclostrobin (Insignia SC) and the combination product of pyraclostrobin + boscalid (Pageant) provided similar levels of rust management with application costs of \$95.96 and \$77.23 per application. Flutolanil (Prostar 70 WP) provided an intermediate level of rust management similar to that of myclobutanil (Eagle 20 EW). The costs were \$26.03 and \$20.94 per application for flutolanil and myclobutanil, respectively. The product application cost for the two contact fungicides was similar. Mancozeb (Dithane 75 DF) had a cost of \$10.21 per application which was similar to that of chlorothalonil (Daconil Ultrex) at \$14.61 per application. Both products provided the lowest levels of disease management.

Conclusions and Implications for Management

The use of fungicides is necessary for the effective management of daylily rust and fungicides remain the most consistent management tool available for growers, hybridizers, and homeowners. In the current study, treatments containing tebuconazole provided the highest level of season-long rust control at all three study locations. However, all fungicides reduced disease 8 and 12 weeks after rust symptoms were first observed compared with the nontreated control plants.

Disease managers choose fungicide combinations, fungicide rotations, and application intervals based on expected disease management outcomes and to manage fungicide resistance. In addition, product cost must also be considered. Typically, only low levels of disease will be tolerated at production nurseries and it is a common practice to spray large blocks of plants preventatively on 14- or 21-day intervals. The treated areas may include *Hemerocallis* cultivars that differ in rust susceptibility or even multiple plant species. Plants in nursery pots are often packed tightly together into groups of both resistant and susceptible cultivars (Buck and Ono 2012; Dreistadt 2001). *Hemerocallis* hybridizers have even less tolerance than production nurseries for disease symptoms and require an even higher level of rust management. Hybridizers are seeking to eradicate rust from their facilities and outgoing plant shipments must be free of all disease. Homeowners exhibit the greatest variability in regards to the level of disease that will be tolerated and low to medium levels of rust may not warrant fungicide application as rust is mainly a cosmetic problem at low levels.

Tebuconazole products are relatively inexpensive (Table 2) and readily available. Tebuconazole belongs to the demethylation inhibitor group of fungicides (DMI, FRAC group 3), which target sterol 14 α -demethylase. This P450 enzyme is essential to the biosynthesis of ergosterol, a prerequisite to fungal membrane integrity (Cools et al. 2013). The active ingredients in this group are broad spectrum and exhibit varying degrees of systemic activity. Tebuconazole applied every 14 days at the high label rate provided the best disease management in our study. However, Dong et al. (2013) observed intermediate efficacy against *P. hemerocallidis* in only one of two years using the lowest label rate. More research is necessary on potential rate effects with tebuconazole.

Myclobutanil, propiconazole, and triadimefon have all been shown to reduce lesion formation by *P. hemerocallidis* when applied as foliar sprays prior to inoculation (Buck and Williams-Woodward 2003; Mueller et al. 2004). Prior work has shown propiconazole to be ineffective at reducing disease severity when applied on a 21-day interval as a foliar spray to field-grown plants (Emmitt et al. 2016). In our current study, myclobutanil applied on a 14-day interval was effective at reducing disease severity and provided an intermediate level of rust management.

Pyraclostrobin and pyraclostrobin + boscalid provided excellent rust management in our current study. Boscalid is a succinate dehydrogenase inhibitor fungicide (SDHI, FRAC group 7) and pyraclostrobin is a member of the quinone outside inhibitors (QoI, FRAC group 11). Active ingredients in this group are systemic respiration inhibitors, broad spectrum, and used as protectants,

TABLE 2
Application costs of fungicides used in this study to manage daylily rust

Fungicide ^x	Active ingredient(s)	FRAC group	Spray interval (days) ^x	Rate ^x		Product cost ^y	Application cost ^z	
				low	high		low	high
Insignia SC	pyraclostrobin	11	7 - 14	88.7 ml	180.4 ml	\$0.532/ml	\$47.19	\$95.96
Prostar 70 WP	flutolanil	7	14 - 21	85.05 g	170.1 g	\$0.153/g	\$13.01	\$26.03
Torque	tebuconazole	3	14 - 21	118.3 ml	295.7 ml	\$0.047/ml	\$5.56	\$13.90
Eagle 20 EW	myclobutanil	3	10 - 14	177.4 ml	354.9 ml	\$0.059/ml	\$10.47	\$20.94
Pageant	pyraclostrobin + boscalid	11 + 7	7 - 14	170.1 g	340.2 g	\$0.227/g	\$38.61	\$77.23
Daconil Ultrex	chlorothalonil	M5	7 - 14	635.0 g		\$0.023/g	\$14.61	
Dithane 75DF	mancozeb	M3	7 - 10	680.4 g		\$0.015/g	\$10.21	

^x Recommended spray interval and rates (quantity fungicide per 378.5 liters water) are from manufacturer's product labels.

^y Product prices were collected from four online sources in November 2016. Prices reflect lowest product cost found.

^z Costs are for a single application.

curatives, and eradicants (Bartlett et al. 2002; Vincelli 2002). Azoxystrobin, another QoI fungicide, has been shown to be very effective at managing daylily rust when used as a foliar spray, soil drench, and root dip (Dong et al. 2013; Emmitt et al. 2016). This group of active ingredients has consistently provided a high level of efficacy against *P. hemerocallidis* and should be included in management programs for daylily rust.

Disease reduction has been inconsistent in prior studies with flutolanil (Dong et al. 2013). Flutolanil (FRAC group 7) was applied in our current study alone and in combination with both systemic and contact fungicides. Flutolanil alone significantly reduced rust compared with the nontreated control. However, AUDPC values for flutolanil treatments were greater than treatments containing tebuconazole and pyraclostrobin on all assessment dates. Combining flutolanil with myclobutanil (FRAC group 3), chlorothalonil (M5), or mancozeb (M3) did not improve efficacy.

Chlorothalonil and mancozeb are relatively inexpensive contact fungicides that exhibit no systemic activity and must be applied more frequently than systemic chemicals. Chlorothalonil was more effective for managing daylily rust than propiconazole when applied at 14-day intervals (Dong et al. 2013). Both chlorothalonil and mancozeb are commonly applied in combination and rotation with systemic fungicides and are important for fungicide resistance management. In our study, no difference was observed between chlorothalonil and mancozeb alone or in combination with the systemic fungicide flutolanil. In addition, prior work shows that chlorothalonil did not improve efficacy of azoxystrobin, propiconazole, or thiophanate-methyl (FRAC group 1) in management of daylily rust (Emmitt et al. 2016).

An integrated disease management (IPM) plan is needed for the control of daylily rust. The incorporation of monitoring, removal of infected plant material, and the use of resistant cultivars, are all key facets of an IPM program. Nonetheless, the use of fungicides remains the most consistent tool for maintaining low levels of daylily rust inoculum (Mueller et al. 2004). The decision-making process for applying foliar fungicides should include several considerations including fungicide efficacy, timing and frequency of applications, product cost, and acceptable level of disease. In addition, the mitigation of fungicide resistance must be considered in the choice of active ingredients and application schedule (FRAC 2017; Mueller et al. 2013). Growers can increase profits, streamline chemical inventories, and avoid unnecessary applications with a greater understanding of which active ingredients are most effective, when to apply them, and at what frequency. Tebuconazole provided the highest level of rust management and had the lowest product cost in the current study. Myclobutanil, another DMI fungicide, significantly reduced rust development at an intermediate product cost. The QoI fungicides such as pyraclostrobin (this study) and azoxystrobin

(Dong et al. 2013; Emmitt et al. 2016) provide excellent daylily rust management at a higher product cost. Contact fungicides are inexpensive and useful for reducing the potential for development of fungicide resistance to other active ingredients.

Acknowledgments

We thank J. Davis for assistance with statistical analyses and K. Stevenson and T. Brenneman for comments on earlier drafts. This work was partially funded by the American Hemerocallidis Society.

Literature Cited

- Bartlett, D. W., Clough, J. M., Godwin, J. R., Hall, A. A., Hamer, M., and Parr-Dobrzanski, B. 2002. The strobilurin fungicides. *Pest Manag. Sci.* 58: 649-662.
- Buck, J. W. 2013. Identification of pathotypes in the daylily rust pathogen *Puccinia hemerocallidis*. *J. Phytopathol.* 161:784-790.
- Buck, J. W., and Ono, Y. 2012. Daylily rust. *Plant Health Instruct.* American Phytopathological Society, St. Paul, MN. doi: 10.1094/PHI-I-2012-0516-01
- Buck, J. W., and Williams-Woodward, J. L. 2003. The effect of fungicides on urediniospore germination and disease development of daylily rust. *Crop Prot.* 22:135-140.
- Buck, J. W., and Youmans, J. 2009. Management of daylily rust with insignia, pageant or trinity, 2007. *Plant Dis. Manage. Rep.* 3:OT017.
- Cools, H. J., Hawkins, N. J., and Fraaije, B. A. 2013. Constraints on the evolution of azole resistance in plant pathogenic fungi. *Plant Pathol.* 62: 36-42.
- Dong, W. B., Jeffers, S. N., and Buck, J. W. 2013. Management of daylily rust with different fungicides and application methods. *Plant Dis.* 97: 921-926.
- Dreistadt, S. H. 2001. Integrated Pest Management for Floriculture and Nurseries. Publ. 3402. Div. of Agric. and Nat. Resources, Univ. of Calif., Oakland.
- Emmitt, R. S., Stevenson, K. L., Brenneman, T. B., and Buck, J. W. 2016. Management of daylily rust with different fungicide combinations and spray intervals. *Plant Dis.* 100:188-191.
- FRAC. 2017. FRAC Code List 2017: Fungicides sorted by mode of action (including FRAC Code numbering). Fungicide Resistance Action Committee (FRAC), CropLife Int., Brussels, Belgium <http://www.frac.info/docs/default-source/publications/frac-code-list/frac-code-list-2017-final.pdf>
- Gatlin, F. L. 1999. An Illustrated Guide to Daylilies, 2nd Ed. Am. Hemerocallis Soc., Kansas City, MO.
- Mueller, D. S., Jeffers, S. N., and Buck, J. W. 2004. Effect of timing of fungicide applications on development of rusts on daylily, geranium, and sunflower. *Plant Dis.* 88:657-661.
- Mueller, D. S., Williams-Woodward, J. L., and Buck, J. W. 2003. Resistance of daylily cultivars to the daylily rust pathogen, *Puccinia hemerocallidis*. *HortScience* 38:1137-1140.
- Mueller, D. S., Wise, K. A., Dufault, N. S., Bradley, C. A., and Chilvers, M. I. 2013. Decision making process for applying a foliar fungicide. Pages 16-21 in: *Fungicides for Field Crops*. D. S. Mueller, K. A. Wise, N. S. Dufault, C. A. Bradley, and M. I. Chilvers, eds. American Phytopathological Society, St. Paul, MN.
- Vincelli, P. 2002. QoI (strobilurin) fungicides: Benefits and risks. *Plant Health Instruct.* American Phytopathological Society, St. Paul, MN. doi:10.1094/PHI-I-2002-0809-02