Research

Fungicides for Control of Downy Mildew on Pickling Cucumber in Michigan

Katelyn E. Goldenhar and Mary K. Hausbeck[†]

Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI 48824

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Abstract

Michigan growers rely on fungicides to limit cucurbit downy mildew (CDM), incited by *Pseudoperonospora cubensis*; resistance of the pathogen to fungicides is a concern. We evaluated fungicides against CDM in Michigan field studies from 2015 to 2017. According to the relative area under the disease progress curve (rAUDPC), in 2015, mandipropamid, propamocarb, fluxapyroxad/pyraclostrobin, copper octanoate, and dimethomorph resulted in disease levels similar to the control. These treatments, along with cymoxanil, were similar to the control in 2016. Fungicides that were ineffective during 2015 and 2016 did not limit CDM in 2017. Famoxadone/cymoxanil and fluopicolide did not limit CDM in 2017. Each year, the following treatments were similar for disease based on rAUDPC data: oxathiapiprolin applied alone or premixed with chlorothalonil or

mandipropamid, ametoctradin/dimethomorph, fluazinam, mancozeb/zoxamide, cyazofamid, and ethaboxam. An exception occurred in 2017, when ethaboxam was less effective than fluazinam, oxathiapiprolin/chlorothalonil, and oxathiapiprolin/mandipropamid. Mancozeb and chlorothalonil treatments were similar in 2015 and 2017, according to rAUDPC data. In 2017, yields were increased for oxathiapiprolin/chlorothalonil, oxathiapiprolin/mandipropamid, mancozeb, ametoctradin/dimethomorph, mancozeb/zoxamide, ethaboxam, cyazofamid, chlorothalonil, and fluazinam compared with the untreated control.

Keywords: *Pseudoperonospora cubensis*, *Cucumis sativus* L., cucumber, Michigan, fungicide

Michigan is the top producer of pickling cucumbers in the United States. In 2018, 14,164 ha of cucumbers (fresh and pickling) were planted in the state, with a value of \$22.5 million for fresh market and \$32.9 million for pickling cucumbers (USDA 2019). *Pseudoperonospora cubensis* (Berk. & M. A. Curtis) Rostovzev, the causal agent of cucurbit downy mildew (CDM), is especially destructive on pickling cucumber (*Cucumis sativus* L.) (Cespedes-Sanchez et al. 2015). Lesions are restricted by the leaf veins and appear as chlorotic necrotic spots on the upper surface with pathogen sporulation underneath (Holmes et al. 2015; Savory et al. 2011).

Although the pathogen cannot overwinter in northern climates such as Michigan (Holmes et al. 2015), *P. cubensis* has reoccurred yearly in the state since 2005, costing pickling cucumber growers an estimated \$6 million or more annually in fungicide sprays to protect their crop (Granke et al. 2014; Savory et al. 2011). Today, these growers apply fungicides frequently to limit CDM (Savory et al. 2011), timing sprays to coincide with an observed influx of *P. cubensis* sporangia into the growing region (Hausbeck 2018) or initial disease symptoms in the crop detected through intensive scouting.

P. cubensis is a pathogen at high risk for developing fungicide resistance (FRAC 2013). Resistance has been documented for

certain fungicides including those in the Fungicide Resistance Action Committee (FRAC) groups 4 (phenylamides), 11 (quinone outside inhibitors), and 40 (carboxylic acid amides) (Gisi and Sierotzki 2015; Holmes et al. 2015). Fluopicolide and propamocarb were effective against CDM when introduced commercially in 2008 and 2006, respectively (Hausbeck and Cortright 2012a; Ojiambo et al. 2010; Raid 2013; Wyenandt 2013), but since 2013 their efficacy appears to be reduced in Michigan CDM trials (Goldenhar and Hausbeck 2016; Hausbeck and Linderman 2014). Mandipropamid was registered in 2008 but was determined to be ineffective against CDM in Michigan by 2010 (Hausbeck and Cortright 2012b). Cymoxanil showed reduced efficacy against CDM according to a bioassay in South Carolina (Keinath 2016) and Michigan field studies (Hausbeck and Cortright 2012a). Oxathiapiprolin, registered in late 2015, inhibits *P. cubensis* and has been effective in Michigan studies (Goldenhar and Hausbeck 2016; Hausbeck et al. 2016). Ethaboxam was registered in 2017 and has demonstrated efficacy against CDM (Adams et al. 2012; Adams and Quesada-Ocampo 2014; Gugino and Grove 2015; Hausbeck et al. 2015; Miller et al. 2011; Trueman 2014).

Each year, fungicides are recommended to protect Michigan's pickling cucumber crop based on local trial data to ensure that this destructive pathogen is effectively managed. The objective of this study was to evaluate fungicides in field studies over three seasons for their ability to protect a susceptible pickling cucumber cultivar against *P. cubensis* in Michigan.

Fungicides Applied Preventively to Pickling Cucumbers

Field experiments were conducted during July to September in 2015, 2016, and 2017 at the Michigan State University (MSU) Plant

[†]Corresponding author: M. K. Hausbeck; E-mail: hausbec1@msu.edu

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Pathology Farm in Lansing, Michigan. Temperature and precipitation variables were recorded from July to October using the Michigan Automated Weather Network approximately 3 km from the Plant Pathology Farm. The 2015 and 2017 trials were planted in Capac loam soil, previously cropped to cucumber. The 2016 trial was established in Houghton muck soil, previously planted to carrots. Glyphosate (Roundup PowerMax at 2.34 liters/ha, Monsanto Company, St. Louis, MO) was applied prior to planting for weed control. Soil was plowed, cultivated, and fertilized with ammonium nitrate (112 kg/ha).

Plots were prepared as raised plant beds (15 cm high by 60 cm wide) covered with black plastic with drip tape down the center. Single rows, spaced 1.68 m center to center, were seeded with the CDM-susceptible 'Vlaspik' pickling cucumber (Seminis Vegetable Seeds, St. Louis, MO) on 24, 19, and 14 July for 2015, 2016, and 2017, respectively. Seed was commercially treated with azoxystrobin/fludioxonil/mefenoxam/thiamethoxam (Farmore FI400, Syngenta Crop Protection, Greensboro, NC) to protect against seedling pathogens and insects. Throughout the growing season, fertilizer (20-20-20 at 2.8 kg/ha) was applied weekly via drip tape, weeds were managed by hand, and insects were controlled with imidacloprid (Admire Pro at 0.58 liter/ha, Bayer CropScience, Research Triangle Park, NC) applied through the drip tape 4 weeks after seedling emergence. Cucumbers were irrigated via trickle as needed.

Fungicide treatments and a control (untreated) were arranged in a randomized complete block design with four replicates. Each treatment replicate consisted of a 6.1-m plant bed with a 0.61-m buffer between beds within a plant row. Fungicides (Table 1) were

applied as sprays to the foliage using a CO₂ backpack boom sprayer (Bellspray R & D Sprayers, Opelousas, LA) equipped with XR8003 flat-fan nozzles spaced 45.7 cm apart, operating at 275.8 kPa (2016) or 344.7 kPa (2015 and 2017 trials), delivering 467.7 liters/ha. Two nozzles were used to apply the fungicide at the onset of the trial, with a third nozzle added once the plants grew to the edges of the plant bed.

Disease Assessments

CDM symptoms were first identified on 27 July 2015, 9 August 2016, and 3 August 2017, on earlier planted, untreated cucumbers not in the trial area but located at the MSU Plant Pathology Farm. Fungicide treatments were applied to the plots as follows: 7, 14, 21, and 28 August and 4 September 2015; 10, 17, 24, and 31 August and 7 and 14 September 2016; and 2, 9, 18, and 25 August and 2, 9, and 16 September 2017. Although treatments were applied on each date in each year, some treatments were adjusted during the course of the study. Fluxapyroxad/pyraclostrobin was applied only in August 2016 owing to product availability. Owing to a change in registration, oxathiapiprolin was tested in 2015, whereas newly available prepacks of oxathiapiprolin/mandipropamid and oxathiapiprolin/chlorothalonil were tested in 2016 and 2017.

Disease was visually assessed on the following dates: 19 and 31 August and 4 September 2015; 6, 9, 14, 19, and 22 September 2016; and 18, 24, and 31 August and 6, 11, 18, and 26 September 2017. The percentage of foliar plant area diseased with CDM was assessed for each treatment plot using the Horsfall–Barratt scale (Horsfall and Barratt 1945) (1 = 0%, 2 = 0 to 3%, 3 = 3 to 6%, 4 = 6 to 12%,

TABLE 1
Fungicide treatments applied to 'Vlaspik' pickling cucumber to control *Pseudoperonospora cubensis* in field trials established from 2015 to 2017 at the Michigan State University Plant Pathology Research Farm

Active ingredient	Product name	Registrant ^v	FRAC ^w		Rate/ha
			Chemical group ^x	Code ^y	
Ametoctradin/dimethomorph	Zampro SC	BASF	QoSI/CAA	45/40	1.03 liters
Chlorothalonil	Bravo WeatherStik SC	Syngenta	M	M05	2.34 liters
Copper octanoate	Cueva SC	Certis	M	M01	4.68 liters
Cyazofamid	Ranman SC	FMC	QiI	21	0.2 liter
Cymoxanil	Curzate DG	DuPont	CO	27	0.35 kg
Dimethomorph	Forum SC	BASF	CAA	40	0.44 liter
Ethaboxam	Elumin SC	Valent	Thiazole carboxamide	22	0.58 liter
Famoxadone/cymoxanil	Tanos DF	DuPont	QoI/CO	11/27	0.56 kg
Fluazinam	Omega SC	Syngenta	Phenyl-pyridinamine	29	1.17 liters
Fluopicolide	Presidio SC	Valent	Benzamide	43	0.29 liter
Fluxapyroxad/pyraclostrobin	Priaxor SC	BASF	SDHI/QoI	7/11	0.58 liter
Mancozeb	Koverall DG	Cheminova	M	M03	2.24 kg
Mancozeb/zoxamide	Gavel DF	Gowan	M/Benzamide	M03/22	2.24 kg
Mandipropamid	Revus SC	Syngenta	CAA	40	0.58 liter
Oxathiapiprolin	Orondis OD ^z	Syngenta	OSBPI	49	0.12 liter
Oxathiapiprolin/chlorothalonil	Orondis Opti SC ^z	Syngenta	OSBPI/M	49/M05	2.5 liters
Oxathiapiprolin/mandipropamid	Orondis Ultra SC ^z	Syngenta	OSBPI/CAA	49/40	0.7 liter
Propamocarb	Previcur Flex SL	Bayer	Carbamate	28	1.4 liters

^v Certis USA (Colombia, MD); Syngenta Crop Protection (Greensboro, NC); Valent USA (Walnut Creek, CA); Bayer CropScience (Research Triangle Park, NC); FMC Corporation (Philadelphia, PA); BASF Corporation (Research Triangle Park, NC); DuPont Crop Protection (Wilmington, DE); Gowan Company (Yuma, AZ); and Cheminova (Research Triangle Park, NC).

^w Fungicide Resistance Action Committee. <http://www.frac.info>.

^x CAA = carboxylic acid amide; CO = cyanoacetamide-oxime; M = multisite inhibitor; OSBPI = oxysterol-binding protein homolog inhibitor; QiI = quinone inside inhibitor; QoI = quinone outside inhibitor; QoSI = quinone outside inhibitor, stigmatellin binding type; and SDHI = succinate dehydrogenase inhibitor.

^y Codes given to fungicides based on their activity on pathogens.

^z Orondis OD was tested in 2015 only; Orondis Ultra SC and Orondis Opti SC were tested in 2016 and 2017.

5 = 12 to 25%, 6 = 25 to 50%, 7 = 50 to 75%, 8 = 75 to 87%, 9 = 87 to 94%, 10 = 94 to 97%, 11 = 97 to <100%, and 12 = 100%). The area under the disease progress curve (AUDPC) was used to represent the disease severity progression throughout the disease epidemic. AUDPC values were calculated as described by Madden et al. (2007), where y_i is the assessment of the disease (using the midpoint percentage from the Horsfall–Barratt scale) at the i th observation, t_i is time (days) at the i th observation, and n is the total number of ratings. To compare among sites or years, the relative or absolute AUDPC (rAUDPC) has been useful (Fry 1978). This is calculated by dividing each AUDPC value by the maximum potential AUDPC for that specific trial. Plots were hand harvested on 10 September 2015 and on 1, 12, and 20 September 2017. Fruit larger than 7.5 cm in length were collected from each plot and weighed. The 2016 trial was not harvested owing to an uneven plant stand.

Statistical Analyses

Statistical analyses were performed using SAS software, version 9.4 of the SAS System for Windows (SAS Institute, Cary, NC). A global analysis of variance (ANOVA) F test was calculated (using PROC MIXED) for each trial, to determine significant differences among treatments. Fungicide treatments were considered as fixed effects and blocks as a random effect. The treatment by year interaction was significant for the calculated rAUDPC values, and therefore years could not be combined. Years were then analyzed individually using the PROC GLIMMIX in SAS version 9.4. Normality was checked using residual plots, and Levene's test was performed to test homogeneity of the variances for each trial. No trials violated the ANOVA test. If the F test was significant, all

pairwise comparisons were assessed with Tukey's honestly significant difference test.

Fungicide Efficacy Can Vary Annually

In Michigan, the importance of fungicides for CDM protection was established after the pathogen reemerged and host resistance was no longer adequate (Holmes et al. 2006). Michigan growers now manage CDM at significant cost and rely on fungicide recommendations based on local data to reduce the risk posed by CDM. Results from this 3-year field study identified the following treatments as effective against CDM: ethaboxam, cyazofamid, ametoctradin/dimethomorph, mancozeb/zoxamide, mancozeb, chlorothalonil, and oxathiapiprolin alone or premixed with either chlorothalonil or mandipropamid. Resistance management is key to maintaining efficacy of single-site fungicides, and growers are encouraged to rotate among fungicides from different FRAC groups (FRAC 2018). Mixing high-risk fungicides with low-risk protectant fungicides is also recommended to delay resistance (Hobbelen et al. 2011).

The broad-spectrum fungicides mancozeb and chlorothalonil consistently controlled CDM in this study. They are considered to be at low risk for resistance (FRAC 2018; Gisi and Sierotzki 2015); tank mixing them with high-risk fungicides is an important resistance management approach (Hobbelen et al. 2011). In 2016, when rainfall in August was high, chlorothalonil reduced CDM based on rAUDPC data compared with mancozeb (Table 2). Plots treated with chlorothalonil or mancozeb produced similar yields in 2017 (Table 3). However, the yield for mancozeb was similar to

Treatment	rAUDPC		
	2015	2016	2017
Untreated control	0.41 a ^y	0.59 a	0.57 a
Oxathiapiprolin	0.00 g	NT	NT
Oxathiapiprolin/chlorothalonil	NT ^z	0.01 d	0.01 d
Oxathiapiprolin/mandipropamid	NT	0.01 d	0.01 d
Ethaboxam	0.02 g	0.15 d	0.29 bc
Ametoctradin/dimethomorph	0.04 g	0.14 d	0.14 cd
Fluazinam	0.04 g	0.07 d	0.02 d
Mancozeb	0.05 fg	0.40 b	0.22 c
Mancozeb/zoxamide	0.05 fg	0.18 cd	0.16 cd
Cyazofamid	0.11 e–g	0.07 d	0.11 cd
Chlorothalonil	0.19 ef	0.20 cd	0.14 cd
Cymoxanil	0.21 de	0.46 ab	0.49 a
Famoxadone/cymoxanil	0.24 c–e	0.36 bc	0.50 a
Fluopicolide	0.25 b–e	0.36 bc	0.45 ab
Mandipropamid	0.34 a–d	0.62 a	0.56 a
Propamocarb	0.36 a–c	0.51 ab	0.52 a
Fluxapyroxad/pyraclostrobin	0.37 a–c	0.45 ab	0.45 ab
Copper octanoate	0.38 a–c	0.45 ab	0.44 ab
Dimethomorph	0.41 a	0.50 ab	0.45 ab

^y Means within a column with the same letter are not significantly different (Tukey's honestly significant difference, $\alpha = 0.05$).

^z NT = not tested in column year.

Treatment	Marketable ^v yield (kg/plot)	
	2015 ^w	2017 ^x
Untreated control	4.75 a ^y	22.30 ef
Oxathiapiprolin/chlorothalonil	NT ^z	55.27 a
Oxathiapiprolin/mandipropamid	NT	54.96 a
Mancozeb	8.91 a	48.68 a–d
Fluopicolide	8.88 ab	36.94 b–e
Ametoctradin/dimethomorph	7.42 a–c	53.10 a
Ethaboxam	7.30 a–c	46.04 a–d
Fluxapyroxad/pyraclostrobin	7.13 a–c	33.56 d–f
Mancozeb/zoxamide	7.10 a–c	53.65 a
Cyazofamid	7.04 a–c	49.23 a–c
Chlorothalonil	6.78 a–c	53.35 a
Fluazinam	6.76 a–c	50.85 ab
Cymoxanil	6.68 a–c	28.97 ef
Famoxadone/cymoxanil	6.43 a–c	25.47 ef
Dimethomorph	6.41 a–c	30.44 ef
Propamocarb	6.15 a–c	26.68 ef
Oxathiapiprolin	5.92 a–c	NT
Copper octanoate	5.73 a–c	35.10 c–f
Mandipropamid	4.89 c	19.77 f

^v Marketable yield was composed of fruit >7.5 cm in length.

^w Harvested on 10 September 2015.

^x Harvested on 1, 12, and 20 September 2017.

^y Means within a column with the same letter are not significantly different (Tukey's honestly significant difference, $\alpha = 0.05$).

^z NT = not tested in column year.

fluopicolide, fluxapyroxad/pyraclostrobin, and copper octanoate, whereas the yield for chlorothalonil was greater than the yields for these three fungicides.

For each year of this 3-year study, several fungicides were similar to the control for CDM and included mandipropamid, propamocarb, fluxapyroxad/pyraclostrobin, copper octanoate, and dimethomorph. Cymoxanil was added to the list of treatments that was similar to the control in years 2 and 3 of the study. For year 3, two additional fungicides were similar to the control and included famoxadone/cymoxanil and fluopicolide (Table 2). Prior to the completion of this study, growers had routinely used fungicides containing cymoxanil, propamocarb, and fluopicolide. Mandipropamid was not effective when used alone, and thus the oxathiapiprolin/mandipropamid treatment is effective owing to the inclusion of oxathiapiprolin.

Oxathiapiprolin is a relatively new active ingredient that became available to Michigan growers in 2016 and has proven efficacy against *P. cubensis* (Cohen 2015; Goldenhar and Hausbeck 2016). This active ingredient works by targeting oxysterol-binding proteins, is in the novel FRAC group 49, and is considered at high risk of pathogen resistance (Cohen 2015; FRAC 2018); thus, resistance management is important. Although both oxathiapiprolin-based treatments performed similarly for CDM control and yield in this study, oxathiapiprolin/chlorothalonil is recommended for use because chlorothalonil is a multisite contact fungicide with proven efficacy in our study. This is an effective way to manage fungicide resistance (Hobbelen et al. 2011).

Other single-site active ingredients provided better control of CDM than the untreated control in all years. Fluazinam (FRAC group 29) is effective against CDM and is registered for use against other oomycete pathogens, including *Phytophthora infestans*. However, this fungicide is not widely used by Michigan growers owing to its high cost. Ethaboxam is in FRAC group 22 and was effective against CDM in 2015 and 2016, similar to previous studies conducted in the United States (Adams et al. 2012; Adams and Quesada-Ocampo 2014; Gugino and Grove 2015; Hausbeck et al. 2015; Miller et al. 2011; Miller and Mera 2013) and Canada (Trueman 2014). In 2017, ethaboxam was significantly less effective than the best-performing fungicides but performed similarly to mancozeb/zoxamide; ethaboxam and zoxamide are in the same FRAC group. Ethaboxam was registered late in 2017, and crops treated with it should be closely monitored for pathogen resistance. Tank mixing with chlorothalonil or mancozeb, as well as alternating with effective CDM fungicides, will reduce the risk of pathogen resistance to maintain this effective fungicide. Zoxamide is available as a premixture with chlorothalonil (Zing!, Gowan Company, Yuma, AZ) or mancozeb (Gavel, Gowan Company). Although only the mancozeb/zoxamide premix was tested in this study, the zoxamide/chlorothalonil premix also provides protection from CDM (Hausbeck et al. 2016). Both premixes provide good options for resistance management (Hobbelen et al. 2011). Cyazofamid, ametocradin/dimethomorph, and mancozeb/zoxamide consistently provided good control of CDM and were among the most efficacious products in all three years. This is consistent with other studies across the United States on cucurbits (Adams and Quesada-Ocampo 2014; Gugino and Grove 2015; Keinath 2016). Ametocradin is the only active ingredient in FRAC group 45 that is registered for CDM, available as a premix with dimethomorph. Cyazofamid is the only FRAC group 21 fungicide registered and has shown consistent efficacy.

Isolates of *P. cubensis* have been reported to exhibit a reduced sensitivity to cymoxanil, propamocarb, mandipropamid, fluopicolide, and dimethomorph (Keinath 2016). In this study,

mandipropamid, propamocarb, copper octanoate, dimethomorph, and fluxapyroxad/pyraclostrobin were similar to the control each year of this study. Cymoxanil was not different from the untreated control in 2016 and 2017, and fluopicolide and famoxadone/cymoxanil were not effective in 2017. Commercial fungicides that only contain the following FRAC groups are not recommended for Michigan growers to manage CDM: benzamides (FRAC group 43), carbamates (FRAC group 28), quinone outside inhibitors (FRAC group 11), cyanoacetamide-oximes (FRAC group 27), and carboxylic-acid amides (FRAC group 40). Local fungicide testing should continue annually based on the dynamic fungicide market for Michigan pickling cucumber growers.

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Literature Cited

- Adams, M., Ojiambo, P. S., and Thornton, A. C. 2012. Evaluation of fungicides for control of downy mildew on cucumber, Clinton, 2011. Plant Dis. Manag. Rep. 6:V123.
- Adams, M., and Quesada-Ocampo, L. M. 2014. Evaluation of fungicides for control of downy mildew on cucumber, Clinton, 2013. Plant Dis. Manag. Rep. 8:V241.
- Céspedes-Sánchez, M. C., Naegele, R. P., Kousik, C. S., and Hausbeck, M. K. 2015. Field response of cucurbit hosts to *Pseudoperonospora cubensis* in Michigan. Plant Dis. 99:676-682.
- Cohen, Y. 2015. The novel oomycide oxathiapiprolin inhibits all stages in the asexual life cycle of *Pseudoperonospora cubensis* - causal agent of cucurbit downy mildew. PLoS One 10:e0140015.
- Fry, W. E. 1978. Quantification of general resistance of potato cultivars and fungicide effects for integrated control of potato late blight. Phytopathology 68:1650-1655.
- Fungicide Resistance Action Committee (FRAC). 2013. Pathogen Risk List. http://www.frac.info/docs/default-source/publications/pathogen-risk/pathogen-risk-list.pdf?sfvrsn=669d419a_8
- Fungicide Resistance Action Committee (FRAC). 2018. FRAC Code List 2018: Fungicides sorted by mode of action (including FRAC Code numbering). <http://www.phi-base.org/images/fracCodeList.pdf>
- Gisi, U., and Sierotzki, H. 2015. Oomycete fungicides: Phenylamides, quinone outside inhibitors, and carboxylic acid amides. Pages 145-174 in: Fungicide Resistance in Plant Pathogens. H. Ishii and D. W. Hollomon, eds. Springer, Tokyo, Japan.
- Goldenhar, K. E., and Hausbeck, M. K. 2016. Evaluation of fungicides for control of downy mildew of cucumber when applied after pathogen establishment, 2016. Plant Dis. Manag. Rep. 11:V080.
- Granke, L. L., Morrice, J. J., and Hausbeck, M. K. 2014. Relationships between airborne *Pseudoperonospora cubensis* sporangia, environmental conditions, and cucumber downy mildew severity. Plant Dis. 98:674-681.
- Gugino, B. K., and Grove, T. L. 2015. Evaluation of select biofungicides and fungicide programs for the management of downy mildew of cucumber, 2014. Plant Dis. Manag. Rep. 9:V014.
- Hausbeck, M. 2018. Managing cucumber diseases in 2019. Pages 2-5 in: Pickling Cucumber Session Summaries, Great Lakes Fruit, Vegetable and Farm Market Expo, Grand Rapids, MI, 4 Dec. <https://glexpo.com/wp-content/uploads/2018/12/Pickling-Cucumber.pdf>
- Hausbeck, M. K., Brisco-McCann, E. I., Goldenhar, K. E., and Cook, A. J. 2016. Evaluation of fungicide programs for control of downy mildew of cucumber, 2016. Plant Dis. Manag. Rep. 11:V063.
- Hausbeck, M. K., Cook, A. J., Naegele, R. P., and Linderman, S. D. 2015. Evaluation of an experimental and registered fungicides for control of downy mildew of cucumber, 2014. Plant Dis. Manag. Rep. 9:V093.
- Hausbeck, M. K. and Cortright, B. 2012a. Evaluation of fungicides for control of downy mildew on pickling cucumber, 2011. Plant Dis. Manag. Rep. 6:V134.
- Hausbeck, M. K. and Cortright, B. 2012b. Evaluation of fungicides and application methods for control of downy mildew of cucumber, 2010. Plant Dis. Manag. Rep. 6:V136.
- Hausbeck, M. K., and Linderman, S. D. 2014. Evaluation of fungicides for control of downy mildew of cucumber, 2013. Plant Dis. Manag. Rep. 8:V304.
- Hobbelen, P. H. F., Paveley, N. D., and Van den Bosch, F. 2011. Delaying selection for fungicide insensitivity by mixing fungicides at a low and high

- risk of resistance development: A modeling analysis. *Phytopathology* 101: 1224-1233.
- Holmes, G., Wehner, T., and Thorton, A. 2006. The history and re-emergence of cucurbit downy mildew. *Phytopathology* 99:S171.
- Holmes, G. J., Ojiambo, P. S., Hausbeck, M. K., Quesada-Ocampo, L., and Keinath, A. P. 2015. Resurgence of cucurbit downy mildew in the United States: A watershed event for research and extension. *Plant Dis.* 99: 428-441.
- Horsfall, J. G., and Barratt, R. W. 1945. An improved grading system for measuring plant diseases. *Phytopathology* 8:655.
- Keinath, A. P. 2016. Utility of a cucumber plant bioassay to assess fungicide efficacy against *Pseudoperonospora cubensis*. *Plant Dis.* 100:490-499.
- Madden, L. V., Hughes, G., and van den Bosch, F. 2007. *The Study of Plant Disease Epidemics*. American Phytopathological Society, St. Paul, MN.
- Miller, S., and Mera, J. R. 2013. Evaluation of fungicides for the control of downy mildew of cucumber, 2012. *Plant Dis. Manag. Rep.* 7:V096.
- Miller, S., Mera, J. R., and Baysal-Gurel, F. 2011. Evaluation of fungicides for the control of downy mildew of cucumber 2010. *Plant Dis. Manag. Rep.* 5:V006.
- Ojiambo, P. S., Paul, P. A., and Holmes, G. J. 2010. A quantitative review of fungicide efficacy for managing downy mildew in cucurbits. *Phytopathology* 100:1066-1076.
- Raid, R. 2013. Evaluation of fungicides for control of downy mildew on cucumbers, Spring 2013. *Plant Dis. Manag. Rep.* 7:V142.
- Savory, E. A., Granke, L. L., Quesada-Ocampo, L. M., Varbanova, M., Hausbeck, M. K., and Day, B. 2011. The cucurbit downy mildew pathogen *Pseudoperonospora cubensis*. *Mol. Plant Pathol.* 12:217-226.
- Trueman, C. 2014. Evaluation of fungicides for management of downy mildew in cucumbers 2013. *Plant Dis. Manag. Rep.* 8:V181.
- United States Department of Agriculture. 2019. *Vegetables Annual Summary*. <https://usda.library.cornell.edu/concern/publications/02870v86p?locale=en>.
- Wyenandt, C. A. 2013. Evaluation of fungicides for the management of downy mildew in cucurbit 2012. *Plant Dis. Manag. Rep.* 7:V137.