Efficacy of Organic Fungicides for Control of Powdery Mildew, Downy Mildew, and Plectosporium in Pumpkins

Trevor Simmons

Major Project/Report submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Agricultural and Life Sciences

In

Plant Sciences and Pest Management

Anton Baudoin, Department of Plant Pathology, Physiology, and Weed Science, Chair

David Langston, Tidewater Agricultural Research and Extension Center

Gregory Welbaum, Department of Horticulture

May 2, 2017

Blacksburg, VA

Keywords: organic pumpkins, organic cucurbits, organic fungicides, powdery mildew, plectosporium

Contents

Abstract:

Increased agritourism in the state of Virginia has led to an increase in the pumpkin planting acreage for pick-your-own operations across the commonwealth. Virginia pumpkin producers face yield losses from numerous sources, including several fungal diseases. The objective of this research was to compare the efficacy of certified organic fungicides against a conventional fungicide program for the control of powdery mildew, downy mildew, and plectosporium. Cultivar Warty Goblin pumpkins were grown in Rockville, Virginia during the 2016 crop season. Five different treatments (water, Kaligreen, Nordox 75, Regalia, and Bravo +Quintec/Proline) were assessed for their control of powdery mildew, downy mildew, and plectosporium. Disease observations and treatments were made weekly from August 12 – September 15. Disease ratings for powdery mildew showed that conventional fungicides provided the greatest control, with organic products Kaligreen and Nordox (the latter applied at an above-label rate) providing next-best control, statistically equivalent in some analyses. Regalia did not provide significantly better disease control than untreated water controls. Plectosporium disease severity was reduced the most in plots receiving conventional fungicides, with Nordox being almost as effective. Kaligreen provided no control of plectosporium. Regalia provided modest control, which in some analyses was significantly better than the untreated control. Downy mildew pressure was extremely limited, and no significant differences in disease incidence were seen among the treatments. In conclusion, several of the tested organic materials proved to be statistically as effective as the conventional fungicides in controlling both powdery mildew and plectosporium, although conventional fungicides provided numerically superior control for all diseases.

Introduction:

Commercial production of cucurbits, including pumpkins, relies heavily on use of chemical inputs, including synthetic fungicides. These fungicides are used to prevent and control the spread of pathogens that decrease plant vigor and reduce yield. As more is learned about the potential negative consequences of these chemicals in the environment, producers are looking to find less harmful treatment options in response to growing consumer pressure. The fungal diseases powdery mildew, downy mildew, and plectosporium all may limit production of cucurbits in the United States and around the world. Historically, much of the academic research for control of these organisms has focused on synthetic chemistries, with less attention given to biological or naturally derived products. The focus of this investigation was to compare disease control efficacy of several organically approved treatment options with that of a conventional fungicide program.

Powdery Mildew

Powdery mildews impact several important vegetable species, with cucurbits being some of the most severely affected. Cucurbit powdery mildew can be caused by two major causal organisms. The species now thought to be most common in the mid-Atlantic United States is *Podosphaera xanthii* (synonym: *Sphaerotheca fuliginea* or *S. fusca);* a second species (or, according to some, several species), *Erysiphe cichoracearum, Golovinomyces cichoracearum, G. orontii, or E. orontii* (Perez-Garcia et al. 2009) is present in other regions but is rarely found in the eastern USA (McGrath 2011; Shishkoff, personal communication). Powdery mildew in cucurbits is a fungal disease marked by white powdery lesions that appear on the upper and lower leaf surfaces, petioles, and stems of the plant family Cucurbitaceae. The typical white lesions seen in powdery mildew are mostly due to reproductive conidia produced by the infecting fungus (Glawe 2008).

Powdery mildews are obligate parasites that require host tissue to evolve through their life cycle. Unfortunately for researchers, this characteristic makes research difficult as studies cannot be conducted in artificial media. Further difficulties in powdery mildew research result from existence of both sexual (teleomorph) and asexual (anamorph) reproductive methods (Glawe 2008).

Infection by powdery mildew occurs as the result of ascospores or conidia landing on a suitable host. These structures then germinate to form a germ tube that expands to form a hypha, with structures called haustoria, that penetrate into the host cells. The penetration into host cell tissue is enabled by turgor pressure and enzymatic activity (Glawe 2008). Infection may be the result of either local or long range spore dispersal.

On a commercial level, powdery mildew is often controlled and/or prevented with multiple applications of synthetic fungicides and/or plant breeding techniques that produce resistant cultivars. Most extension services recommend a program rotating fungicide classes with a 7-10-day spray schedule once disease detection has occurred (McGrath 2011), (Mid-Atlantic Commercial Vegetable Production Guide 2016). Unfortunately, several instances of fungicide resistance have been documented in cucurbit powdery mildew, including resistance to the strobilurin fungicides (Ishii et al. 2001).

Further issues with control of powdery mildew result from favored infection location of abaxial leaf surfaces vs adaxial leaf surfaces (McGrath 2001). Hyphal growth on the abaxial leaf surfaces is harder to control as non-systemic fungicides may have less applied coverage on underside of leaf surfaces. Higher application rates and blower-style sprayers are often recommended for complete plant coverage. Due to the fact that most of the plant infection by powdery mildew occurs on the exterior of leaf surfaces, contact fungicides provide excellent control of powdery mildew provided good coverage is achieved. Numerous biological/organic contact controls exist, making control of powdery mildew in pumpkins potentially possible without the use of synthetic fungicides (Keinath & Dubose 2012)

Resistance to synthetic fungicides and increasing demand for limited pesticide residues on food crops/organic production have caused an increased interest in organically approved fungicides. (Reuveni et al 1996).

Plectosporium

Plectosporium blight is a relatively new disease of the cucurbit family, caused by the organism *Plectosporium tabacinum* (formerly also known as *Microdochium tabacinum* and *Fusarium tabacinum*). Damage to numerous cucurbit species by this organism have been observed in Europe and Asia, however the strain found in the United States mostly impacts gourds, pumpkins, summer squash, and zucchini (Boucher 2012). Plectosporium blight was first found in the United States in 1988 in Tennessee and has spread rapidly throughout the eastern United States (Boucher 2012). Plectosporium blight was first documented in Virginia in 1994 when it appeared in zucchini and pumpkin fields (Hansen 2009).

Plectosporium blight infects the fruit, leaves, and stems of the pumpkin plant with small, diamond-shaped white lesions. These lesions may first appear on petioles or leaf veins. The lesions may enlarge and severe infestation may cause complete defoliation and/or turn the pumpkin vines/stems completely white. White lesions may also appear on fruit, with the fruit stem possibly turning completely white. (Hansen 2009). Lesions on the fruit and handle specifically in pumpkins can render fruit unmarketable and also allow for secondary infection by fruit rots that result in further crop losses and reduced shelf life. Yield losses can be as high as 100% in years that favor disease development (Boucher 2012).

As Plectosporium is a relatively new threat to cucurbits, very little is known about its reproductive cycle. What is known is that Plectosporium produces two-celled spores that appear cylindrical to ellipsoidal in shape and are slightly curved (Babadoost 2012). Published literature has conflicting opinions on favorable weather conditions for this fungus. Certain sources say that disease is favored under cool, wet weather (Boucher 2012), where others claim that Plectosporium is favored under warm, wet weather (University of Massachusetts Extension 2013). The Plectosporium fungus can persist on crop residue for several years and may also be dispersed long distances through aerial spores (Boucher 2012). Disease may also spread through rain splash (University of Massachusetts Extension 2013).

Numerous extension services recommend the use of crop rotation and chemical fungicides for controlling Plectosporium (University of Massachusetts Extension 2013), (Babadoost 2012), (Hansen 2009). The practice of no-till planting into a cover crop has also been shown to decrease the incidence of Plectosporium blight and decrease need for fungicide applications (Everts 2002)

Downy Mildew

Downy mildew of cucurbits is caused by the organism *Pseudoperonospora cubensis* (Berkeley & Curtis) Rostovtsev. This organism causes downy mildew in cucumber, pumpkin, watermelon, and squash (Savory et al. 2011). The organism was discovered in 1868 in Cuba and described by researchers Berkeley and Curtis. Downy mildew is one of the major economic pests of cucurbits around the world (Lebeda & Cohen 2011). *P. cubensis* is an obligate parasite and cannot survive without host plant material except as oospores (Lebeda & Cohen 2011). Downy mildew utilizes both asexual and sexual reproduction for disease proliferation. Although both types of reproduction exist, sexual reproduction is extremely rare and not seen as a major source of infection in the United States (Lebeda & Cohen 2011). Asexual spores, or sporangia, are the main source of infection. Sporangia are distributed by wind or water splash (Lebeda & Cohen 2011). In the presence of free water, sporangia release zoospores that possess locomotive appendages, called flagella, that are used to move towards stomatal openings in leaf tissue. Once a stomatal opening is found, a zoospore forms a germ tube that is able to penetrate into new host tissue. After initial infection, the pathogen develops inside of the plant tissue (Colucci & Holmes 2010).

Although the same causal organism infects different members of the cucurbit family, symptoms can vary based on the environment and crop species. In pumpkins, downy mildew forms yellow lesions on leaves that may eventually turn brown (Egel, 2008). The leaf lesions result in loss of photosynthetic ability of the plant, with a corresponding loss in yield. Unlike powdery mildew, no downy mildew-resistant cultivars of pumpkins are commercially available. Agronomic practices that limit the amount of free water on leaf tissue, such as irrigating in the morning, may help slow or prevent the progression of downy mildew. If inoculum is present and conditions are ideal for infection, the lack of resistant cultivars makes chemical control the primary control method for growers.

Downy mildew favors warm, humid weather making the southeast United States an ideal environment. Each year, downy mildew migrates northward from more southern regions like Florida and Georgia all the way to the New England and Great Lake States. Downy mildew is not able to survive outside of a host and requires the continuous production areas of the southeast and greenhouse cultivation to produce inoculum that migrates northward as seasonal temperatures warm (Colucci & Holmes 2010).

A forecasting model managed by several land grant universities is available at http://cdm.ipmpipe.org/. The tool tracks reported cucurbit downy mildew infections so that growers can make preventative fungicide applications and increase scouting efforts when inoculum is most likely to be present. Although this tracker is a valuable tool, downy mildew spores are very easily dispersed in the air and can travel great distances between infection sites, with documented spread of greater than 800 km between infected fields (Ojiambo & Holmes 2011). For that reason, extension recommendations generally suggest frequent scouting and preventative fungicide applications. After disease is observed, suggested spray programs rotate fungicide chemistries on a 7-day or shorter schedule (Wyenandt 2016); (Mid Atlantic commercial vegetable production guide 2016).

Known Efficacy of Tested Materials

Plectosporium:

Compared to downy mildew and powdery mildew, Plectosporium has been the subject of limited research investigating organic control methods. The limited data availability is understandable given the more-recent discovery of the disease compared to powdery and downy mildew. None of the organic agents tested (Kaligreen, Nordox, Regalia) claim any efficacy against Plectosporium on their labels. Bravo (chlorothalonil) has shown partial control of Plectosporium in previous trials and is recommended by several university extension programs as part of a fungicide program (Miller, Mera, & Baysal-Gurel, 2012), (Mid Atlantic commercial vegetable production guide 2016). Quintec and Proline conventional fungicides used in this experiment are not labeled for control of Plectosporium. One study has limited data showing effectiveness in reducing Plectosporium incidence with a combined spray of Quintec and Pristine, neither of which are labeled for Plectosporium (Egel, & Hoke, 2010).

Powdery Mildew

All tested materials in this experiment are labeled for control of powdery mildew. Kaligreen and Regalia have proven effectiveness in controlling powdery mildew in cucurbits (Everts & Newark, 2013), (McGrath & Shishkoff, 1999), (Reuveni, Agapov, & Reuveni, 1995). The literature provided several examples supporting the efficacy of Kaligreen. No field trial data could be found for Nordox control of powdery mildew in cucurbits; however, other OMRI-listed copper-based products have shown efficacy (Marine et al. 2016). The conventional fungicides Bravo, Quintec, and Proline are all labeled for powdery mildew and extensive data are available showing their efficacy and they are recommended by several university extension programs.

Downy Mildew:

Tested materials Regalia and Nordox are both labeled for control of downy mildew in cucurbits. No data were found to support Regalia s having any efficacy in reducing downy pressure. No field trial data could be found for Nordox control of downy mildew in cucurbits, however, other OMRI-listed copper-based products have shown efficacy (Everts & Newark, 2013). Copper containing compounds are effective treatments for several fungal foliar diseases and have been used to treat them for a long time. The conventional fungicide Bravo is recommended as part of a spray program for control of downy mildew by several university extension programs (Mid Atlantic commercial vegetable production guide 2016). Quintec and Proline are not labeled for downy mildew control in cucurbits.

Materials and Methods

The field experiment was conducted during the 2016 growing season at Lloyd Family Farms in Rockville, Virginia. The soil at the experimental site was a Cecil Fine Sandy Loam. To prepare the experimental field, herbicide and fertilizer were applied according to Virginia Cooperative Extension recommendations. Additional hand removal of weeds was performed weekly as needed. Five rows of cultivar Warty Goblin were planted with intra-row spacing of 4 feet and inter-row spacing of 9 feet on July 1st, 2016.

To ensure 100% stand, plots were planted at a higher-than-normal population density. Final plot density was higher than desired due to researcher time constraints regarding thinning. Every 4' within each row there were 2 pumpkin plants, instead of 1 as is the commercially recommended practice. Although different from commercial recommendations, this method of over-seeding to ensure 100% stand is common practice for the farm on which research was performed.

A randomized block design was used to assign 4 replicates of the 5 treatments within the experimental field. Chemical applications were made using a backpack sprayer with a handheld 4-nozzle spray boom configuration with Teejet 8002VS tips spaced at 18". All chemicals were applied using a carrier rate of 20 gallons of water per acre (GPA) at 35 PSI. Spray volume accuracy was ensured by a pressure gauge on the boom and spray volume catch test. Disease observations and treatments were made weekly from

August 5 – September 15.

Visual disease ratings were made weekly from August 5th to September 15th. Disease ratings represent percent of plant foliage/stems showing symptoms of disease; this includes the undersides of leaves, stems and appearance of lesions on fruit. Disease ratings were made for the 4 centrally located pumpkin plants in the research plots, to offset potential impacts from over-spray in adjacent plots. Disease ratings were made based on % of plant tissues showing lesions. The crop was scouted weekly to monitor for disease pressure. Chemical applications were made according to Table 1.

JMP 13 was used for statistical analysis. Individual disease ratings showed distinct relationships between means and standard deviations, and no single transformation performed best with respect to homogenizing variances. Areas under the disease progress curve (AUDPC) were calculated for the last 3 weeks; disease ratings for each plot were summed over the three weeks, and equality of variance was tested. Three analyses approaches were compared. One used JMP's Fit Y by X platform for a one-way ANOVA of log-transformed AUDPC values, followed by means separation using Tukey's HSD at α=0.05. The second approach also used the Fit Y by X platform, and fitted a generalized linear model using a Poisson distribution. The data were somewhat over-dispersed, and the overdispersion factor was used to adjust the test statistics. Individual contrasts were compared using the Holm-Bonferroni correction to adjust the overall error rate. The third approach used JMP's Fit Model platform, and fitted a mixed model, analyzing the individual ratings of weeks 4 through 6 as repeated measures, and considering Treatment, Block, and Week as fixed and Week*Block as random variables.

Table 1. (Application Dates including Products and Rates)

Date	**Water** (control)	**Kaligreen** (Potassium Bicarbonate) Arysta LifeScience North America LLC	****Nordox 75WG** (83.9% Cuprous Oxide) Monterey AgResources	**Regalia** (5% Extract of *Reynoutria sachalinensis*) Marrone Bio Innovations	**Conventional Fungicides** **Bravo Weather Stik** (chlorothalonil 54%) Syngenta **Proline** (prothioconazole, 41%) Bayer Crop Science **Quintec** (quinoxyfen 22.58%) Dow AgroSciences **Presidio** (fluopicolide 39.5%) Valent
8/5/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 4 oz/acre Quintec
8/12/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 4 oz/acre Quintec
*8/19/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 5.7 oz/acre Proline
8/26/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 4 oz/acre Quintec
9/2/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 5.7 oz/acre Proline
9/9/2016	20 GPA carrier volume only	2.5 lbs/acre	1.5 lbs/acre	32 oz/acre	32 oz/acre Bravo, 4 oz/acre Quintec

*Presidio applied to all treatments (including water control) at rate of 4 oz/acre on 8/19/2016 to control downy mildew. Downy mildew was controlled to maintain research focus on powdery mildew. Subsequent treatments of Presidio to control downy mildew were not made as the disease did not progress further.

**Nordox 75WG was mistakenly applied at a higher than labeled rate (1.5 lb/A rather than 1.25 lb/A) due to a misunderstanding about the formulation involved.

Results and Discussion:

Weekly means of disease severity for weeks 4 through 6 are shown in Table 2, along with the results of the three different statistical analyses.

Downy Mildew:

Downy mildew pressure was extremely limited due to dry weather and judging from lack of disease development elsewhere on the farm. Presidio was applied to all treatments, including water control, on 8/19/2016 (week 2) to control downy mildew, in order to maintain research focus on powdery mildew/plectosporium which appeared to have greater potential for disease development. No significant differences in downy mildew severity were seen between different research plots. Subsequent treatments of Presidio to control downy mildew were not made as the disease did not progress further.

Table 2: Mean Disease Severity (% plant tissue showing disease symptoms)						Mean separation *		
Disease	Treatment	Week 4	Week 5	Week 6	AUDPC	1	2	3
Powdery Mildew	Water**	8	11	14	33	a	a	a
	Kaligreen, 2.5 lbs/acre	2	3	6	11	ab	b	b
	Regalia, 32 oz/acre	4	8	14	25	ab	a	a
	Nordox 75, 1.5 lbs/acre	0	3	4	8	b	b	b
	Conventional ***	0	0	0	0	c	c	b
Downy Mildew	Water**	2	6	6				
	Kaligreen, 2.5 lbs/acre	1	4	4				
	Regalia, 32 oz/acre	0	3	4				
	Nordox 75, 1.5 lbs/acre	0	1	1				
	Conventional ***	0	1	1				
Plectosporium	Water**	21	33	54	108	a	a	a
	Kaligreen, 2.5 lbs/acre	26	36	45	108	a	a	a
	Regalia, 32 oz/acre	16	24	29	69	a	b	b
	Nordox 75, 1.5 lbs/acre	9	9	11	28	b	c	c
	Conventional ***	6	6	6	19	b	c	d

* Analysis method and mean separation: 1: AUDPC (log-transformed); 2: AUDPC GLM with Holm-Bonferroni correction; 3: Repeated measures, mixed model. Means in same column with similar letters are not significantly different using significance level of $\alpha=0.05$ (Tukey's HSD Method)

**all treatments applied using 20 gallons water/acre

*** Bravo 32 oz/A + Quintec 4 oz/A (Week 1, 2, 4, 6), Bravo 32 oz/A + Proline 5.7 oz/A (week 3, 5)

Powdery Mildew:

Plants treated with the conventional fungicide treatments (Bravo + Quintec rotated with Bravo + Proline) showed the most effective powdery mildew control. Regalia provided no significant control. Plots treated with the organic treatments Nordox and Kaligreen plots showed significantly less disease than water control but were less effective than conventional fungicides in two of the three analyses. No statistically observable differences in disease development were seen between plants treated with water and Regalia.

Plectosporium:

Plants treated with conventional fungicide treatments had the least amount of disease. Disease development in plots treated with Nordox showed no statistical difference from those treated with conventional fungicides in two of the three analyses, and were better than Regalia in all analyses.

Regalia provided slight disease control, significantly different from water in two of the three analyses. Kaligreen provided no disease control.

For both powdery mildew and Plectosporium, the conventional fungicide rotation offered the greatest protection from disease, but several organic products often provided a significant level of control that sometimes (Nordox against Plectosporium) was statistically equivalent. These data are valuable as it shows effective control of both diseases can be accomplished with pesticides that may be less harmful to human and environmental health.

Abnormal chlorosis and necrosis were noticed in the plots treated with Nordox. This may have been due to over-application; the maximum rate for Nordox 75 is 1.25 lb/A, but 1.5 lb/A was applied. The symptoms resembled those of copper toxicity in cucurbits: marginal chlorosis and subsequent foliar necrosis. Chemical analysis of leaf tissue was not performed to confirm increased copper concentrations within leaf tissue, but based on field observations it is believed that Nordox caused partial damage to all plants receiving treatment. The observed damage can be seen in Table 3, and Appendix Figures 2 and 3.

Costs of different materials are compared in Table 4. The cost of the organic materials is similar to the conventional products used. The cost of the Nordox treatment at the maximum label rate (1.25 lb/A) would have been $63.75 for the season instead of $76.50, but its efficacy at that rate might have been somewhat lower. The total cost of the conventional treatment per acre is higher due to the use of 2 products tank mixed per application in the conventional trial plots vs only 1 product per application in the other plots.

Table 3. Nordox Damage (% leaf area showing chlorosis or chemical injury)**

	Nordox plot 1	Nordox plot 2	Nordox plot 3	Nordox plot 4
2-Sep*	20	20	40	25
9-Sep	20	25	20	25
15-Sep	20	25	30	25

*Nordox damage was not rated on August 12, August 19, August 26

**Nordox 75WG was mistakenly applied at a higher than labeled rate (1.5 lb/A rather than 1.25 lb/A) due to a misunderstanding about the formulation involved.

Project Limitations and Future Recommendations

Improvements to this research could be made in several areas. Increased plot size could provide more statistical robustness, while also limiting the possibility of spray drift. Chemical analysis of plant tissues to determine copper toxicity from Nordox would be beneficial to the future use of this product in cucurbits, while also exploring the efficacy of lower application rates. Future plot design might incorporate larger plot areas that include room for designated walkways/paths to avoid plant destruction as fungicide applications are made and disease observations are made. Additional efficacy may be gained by combining multiple organic products similarly to the standard practice of "tank-mixing" multiple conventional fungicides.

Table 4. Cost comparison of treatments

Product	Unit	Cost per unit *	rate applied	Cost per acre	Season Cost (acre)**
Bravo Weather Stik	gallon	$ 47.00	32 oz/acre	$ 11.75	
Proline	gallon	$ 587.00	5.7 oz/acre	$ 26.14	
Quintec	ounce	$ 3.25	4 oz/acre	$ 13.00	
Conventional Total					174.78***
Regalia	gallon	$ 65.00	32 oz/acre	$ 16.25	97.50
Nordox	lb	$ 8.50	1.5 lbs/acre	$ 12.75	76.50
Kaligreen	lb	$ 10.87	2.5 lbs/acre	$ 27.18	70.50

*Prices are MSRP provided by manufacturers/distributors.
**Cost of 6 applications/acre
***Conventional spray program consisting of 6 applications of Bravo, 2 applications of Proline, 4 applications of Quintec

Conclusion:

Fungicide efficacy in controlling powdery mildew and plectosporium blight was observed in 2016. Several organic fungicides showed statistically similar ability to control both diseases for several weeks during this study, although not all organic controls provided statistically significant protection. Farmers looking to utilize organic products or production methods to produce pumpkins in Virginia should find that several of the tested materials may be suitable in their fungicide programs. The costs of the organic materials should be comparable to the costs associated with conventional fungicides.

References

Babadoost, M. 2012. "Plectosporium Blight of Cucurbits". *University of Illinois Extension* RPD No. 946. University of Illinois. http://extension.cropsciences.illinois.edu/fruitveg/pdfs/946_cmplt.pdf

Boucher, T. J. 2012. "Plectosporium Blight and New Spray Recommendations for 2005." *University of Connecticut Cooperative Extension System.* University of Connecticut. http://ipm.uconn.edu/documents/raw2/Plectosporium%20Blight%20and%20New%20Spray%20Recom mendations%20for%202005/Plectosporium%20Blight.php

Colucci, S.J. and G.J. Holmes. 2010. Downy Mildew of Cucurbits. *The Plant Health Instructor.* DOI: 10.1094/PHI-I-2010-0825-01.
http://www.apsnet.org/edcenter/intropp/lessons/fungi/Oomycetes/Pages/Cucurbits.aspx

Egel, D. 2008. “Downy Mildew of Pumpkin”. *Purdue University Extension* BP-140-W. Purdue University.
https://www.extension.purdue.edu/extmedia/BP/BP-140-W.pdf

Egel, D. S., and S. Hoke. 2011. "Evaluation of Fungicides for the Control of Powdery Mildew and Plectosporium Blight on Pumpkin, 2010." *Plant Disease Management Reports* 5:V023 Online publication. doi: 10.1094/PDMR05.

Everts, K. L. 2002. "Reduced Fungicide Applications and Host Resistance for Managing Three Diseases in Pumpkin Grown on a No-Till Cover Crop." *Plant Disease* 86: 1134-1141.

Everts, K. L., and M. J. Newark. 2014. "Evaluation of Fungicides for Management of Mildew Diseases in Organic Squash and Pumpkin, 2013." *Plant Disease Management Reports* 8:V211.
https://www.plantmanagementnetwork.org/pub/trial/pdmr/volume8/abstracts/v211.asp

Hansen, M. A. 2009. “Plectosporium Blight of Cucurbits.” *Virginia Cooperative Extension Publication* 450-709. Virginia Tech.
https://vtechworks.lib.vt.edu/bitstream/handle/10919/55180/450-709.pdf

Glawe, D. A. 2008. "The Powdery Mildews: A Review of the World's Most Familiar (Yet Poorly Known) Plant Pathogens." *Annual Review of Phytopathology* 46: 27-51.
http://annualreviews.org/doi/abs/10.1146/annurev.phyto.46.081407.104740

Ishii, H., B. A. Fraaije, T. Sugiyama, K. Noguchi, K. Nishimura, T. Takeda, T. Amano, and D. W. Hollomon. "Occurrence and Molecular Characterization of Strobilurin Resistance in Cucumber Powdery Mildew and Downy Mildew” *Phytopathology* 91.12 (2001): 1166-1171.
https://www.ncbi.nlm.nih.gov/pubmed/18943331

Jasinski, J. R., S. A. Miller, M. L. Lewis Ivey, L. H. Rhodes, R. M. Riedel, and R. J. Precheur, 2011. "Efficacy of Conventional and Bio-rational Fungicides on Cucurbit Powdery Mildew on Pumpkin in OH, 2010." *Plant Disease Management Reports* 5.V170.
https://www.plantmanagementnetwork.org/pub/trial/pdmr/volume5/abstracts/v170.asp

Keinath, A. P., and V. B. Dubose. 2012. "Controlling Powdery Mildew on Cucurbit Rootstock Seedlings in the Greenhouse with Fungicides and Biofungicides." *Crop Protection* 42: 338-344.
http://www.vegetablegrafting.org/wp/wp-content/uploads/2013/12/1-s2.0-S0261219412001871-main-keinath.pdf

Lebeda, A., and Y. Cohen 2011. "Cucurbit Downy Mildew (Pseudoperonospora Cubensis)-biology, Ecology, Epidemiology, Host-pathogen Interaction and Control." *European Journal of Plant*

Pathology 129: 157-192.
https://www.researchgate.net/publication/226432381_Cucurbit_downy_mildew_Pseudoperonospora_cubensis-biology_ecology_epidemiology_host-pathogen_interaction_and_control

Marine, S. C., M. J. Newark, R. C. Korir, and K. L. Everts. 2016. "Evaluation of Rotational Biopesticide Programs for Disease Management in Organic Cucurbit Production." *Plant Disease* 100.11: 2226-2233. http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS-02-16-0252-RE

McGrath, M. T. 2001. "Fungicide Resistance in Cucurbit Powdery Mildew: Experiences and Challenges." *Plant Disease* 85.3: 236-45.
http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS.2001.85.3.236

McGrath, M. T. 2011. "Powdery Mildew of Cucurbits." *Powdery Mildew of Cucurbits Fact Sheet*. Cornell University.
http://vegetablemdonline.ppath.cornell.edu/factsheets/Cucurbits_PM.htm

McGrath, M. T., and N. Shishkoff. 1999. "Evaluation of Biocompatible Products for Managing Cucurbit Powdery Mildew." *Crop Protection* 18.7: 471-478. http://agris.fao.org/agris-search/search.do?recordID=US201302944143

Miller, S. A., J. R. Mera, and F. Baysal-Gurel. 2013. "Evaluation of Fungicides for the Control of Plectosporium Blight and Powdery Mildew of Pumpkin, 2012." *Plant Disease Management Reports* 7.V091).
https://www.plantmanagementnetwork.org/pub/trial/pdmr/volume7/abstracts/v091.asp

Ojiambo, P. S., and G. J. Holmes. 2011. "Spatiotemporal Spread of Cucurbit Downy Mildew in the Eastern United States." *Phytopathology* 101.4: 451-461.
https://www.ncbi.nlm.nih.gov/pubmed/21117875

Perez-Garcia, A., D. Romero, D. Fernandez-Ortuno, F. Lopez-Ruiz, A. de Vicente, and J. A. Tores. 2009. “The Powdery Mildew Fungus *Podosphaera fusca* (synonym *Podosphaera xanthii*), a Constant Threat to Cucurbits.” *Molecular Plant Pathology*, 10: 153–160. doi:10.1111/j.1364-3703.2008.00527.x

Reuveni, M., V. Agapov, and R. Reuveni. 1996. "Controlling Powdery Mildew Caused by Sphaerotheca Fuliginea in Cucumber by Foliar Sprays of Phosphate and Potassium Salts." *Crop Protection* 15.1: 49-53. https://www.researchgate.net/publication/248416002_Controlling_powdery_mildew_by_Sphaerotheca_fuliginea_in_cucumber_by_foliar_spray_of_phosphate_and_potassium_salts

Reuveni, M., V. Agapov, and R. Reuveni. 1995. "Suppression of Cucumber Powdery Mildew (Sphaerotheca Fuliginea) by Foliar Sprays of Phosphate and Potassium Salts." *Plant Pathology* 44.1: 31-39.
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-3059.1995.tb02713.x/full

Savory, E. A., L. Granke, L., L. M. Quesada-Ocampo, M. Varbanova, M. K. Hausbeck, and B. Day. 2011.

"The Cucurbit Downy Mildew Pathogen Pseudoperonospora Cubensis." *Molecular Plant Pathology* 12.3: 217-226.
http://onlinelibrary.wiley.com/doi/10.1111/j.1364-3703.2010.00670.x/abstract

University of Massachusetts Extension. 2013. "Cucurbits, Plectosporium". *University of Massachusetts Extension.* University of Massachusetts.
https://ag.umass.edu/vegetable/fact-sheets/cucurbits-plectosporium

Wyenandt, A. (editor). 2016. Pumpkins and Winter Squash. Pages F142-F154 in: *2016 Mid-Atlantic Commercial Vegetable Production Guide.* Virginia Cooperative Extension.
https://pubs.ext.vt.edu/456/456-420/456-420.html

Appendix:

Appendix Figure 1: Plot layout using randomized block design.

Row 5	Row 4	Row 3	Row 2	Row 1
Rep I	Rep I	Rep I	Rep I	Rep I
Rep II	Rep II	Rep II	Rep II	Rep II
Rep III	Rep III	Rep III	Rep III	Rep III
Rep IV	Rep IV	Rep IV	Rep IV	Rep IV

Treatment 1	Water Control
Treatment 2	Kaligreen
Treatment 3	Nordox
Treatment 4	Regalia
Treatment 5	Conventional Fungicides

Each cell above represents 1 "plot". Each "plot" contained 4 sets of 2 plants, with 4 feet spacing between each set of 2 plants. Each "plot" contained 8 plants. Each "row" consisted of 32 plants

Figure 2: Suspected copper toxicity from Nordox applications. Notice marginal chlorosis (8-26-2016)

Figure 3: Suspected copper toxicity from Nordox applications. Rust colored deposits are residues from chemical applications (8-26-2016)

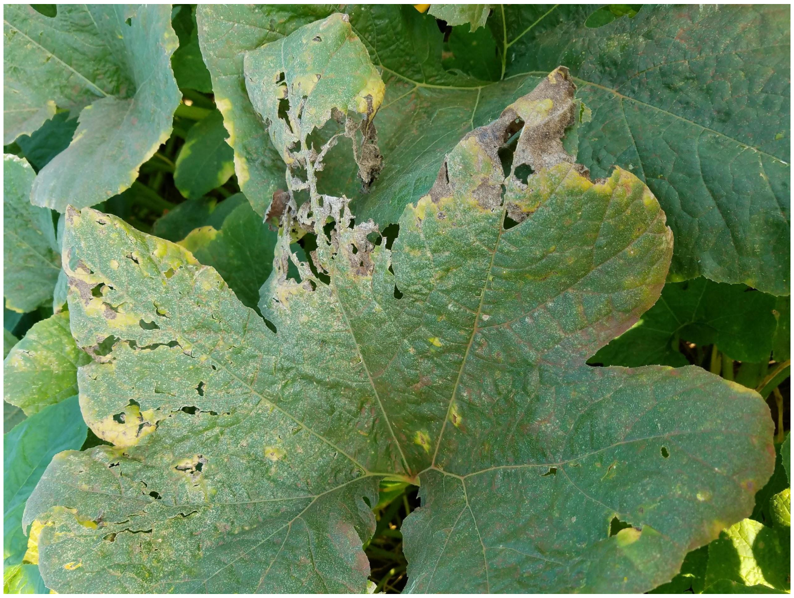

Figure 4: Plectosporium lesions on pumpkin vine (9-2-2016)

Figure 5: Research plots before major disease pressure (8-19-2016)

Figure 6: Near-complete death of vine due to Plectosporium (9-9-2016)

Figure 7: Seed variety and lot used in research