HortScience 60(3):446–454. 2025. https://doi.org/10.21273/HORTSCI18302-24

# Managing Phytophthora Root and Crown Rot on English Lavender in the Greenhouse with Fungicides

**Daniel M. Dlugos**
*Department of Plant and Environmental Sciences, Clemson University, Clemson, SC 29634, USA*

**William C. Bridges**
*School of Mathematical and Statistical Sciences, Clemson, University, Clemson, SC 29634, USA*

**Steven N. Jeffers**
*Department of Plant and Environmental Sciences, Clemson University, Clemson, SC 29634, USA*

*Keywords.* disease management, fungicides, greenhouse, *Lavandula angustifolia*, Mefenoxam, phosphate, *Phytophthora nicotianae*

***Abstract.*** **Phytophthora root and crown rot (PRCR) of lavender is an emerging disease that has become one of the most significant threats to the lavender industry worldwide. Primarily caused by *Phytophthora nicotianae*, the disease impacts multiple species of lavender, and the primary causal agent is spread largely through the nursery industry. This study examined 12 fungicides that target diseases caused by species of *Phytophthora* and other oomycetes for efficacy against PRCR using artificially inoculated English lavender (*Lavandula angustifolia*) plants in a research greenhouse. Some fungicide treatments significantly reduced disease symptoms while maintaining plant size, but there was considerable variation in efficacy among the fungicide products. The products with the best performance were phosphonates, and a product containing the relatively new active ingredient oxathiapiprolin. An industry standard, mefenoxam, which is the active ingredient in Subdue Maxx, was also effective, but to a lesser degree. The results indicate a strong potential to manage PRCR on lavender with commercially available fungicides, particularly phosphonate products.**

Reports of *Phytophthora nicotianae* attacking nursery-grown English lavender plants (*Lavandula angustifolia*) were first published in 1991 in Maryland (Putnam 1991). Since that time, it has been found that the disease, now known as Phytophthora root and crown rot (PRCR), is caused by numerous species of *Phytophthora* and impacts several species of lavender (Cho and Shin 2004; Dlugos et al. 2024; Farr and Rossman 2021; Jung et al. 2016). The most common and widely occurring species that causes this disease in the United States is *P. nicotianae* (Dlugos et al. 2024; Dlugos and Jeffers 2021).

Lavender is in the genus *Lavandula* and the family Lamiaceae/Labiatae; this family includes more than 6900 species of herbs, shrubs, and trees (US Department of Agriculture, Natural Resources Conservation Service 2021; Zomlefler 1994). Lavender is native to regions with Mediterranean climates, including portions of Europe, Africa, Asia, and the Middle East (Upson 2002). There are 32 species and additional hybrids in the genus (Upson 2002), with English lavender being one of the most common (McCoy and Davis 2021), hardy (Adam and Rittenhouse 2018), and economically important species (Singh et al. 2007). The economic impact of lavender production in the United States has not been reported, but it is quickly becoming popular for ornamental plantings and farms that focus on cut and dried flowers, the production of essential oil, and agritourism (Adam and Rittenhouse 2018).

Lavender is typically planted as rooted cuttings or young plants, which are produced in greenhouses and nurseries, by means of vegetative propagation (Adam and Rittenhouse 2018; Naghibi et al. 2005). However, a concern is that nurseries, and the ornamental plant trade in general, have a history of moving plant pathogens, in part, because a single nursery can cover one to many hectares and contain hundreds of species of plants from various locations (Jones and Baker 2007; Jung et al. 2016; Parke and Grünwald 2012). This can lead to nurseries being sources of inoculum for *Phytophthora* species, including *P. nicotianae* (Bienapfl and Balci 2014; Schwingle et al. 2007). After introduction to other nurseries, landscapes, or fields, *Phytophthora* species can become established and persist in soils and container mixes (Jeffers et al. 2010), and these pathogens can be disseminated locally (e.g., within a field of lavender) by moving contaminated plant material and soil or by splashing and flowing water that can move motile zoospores (Erwin and Ribeiro 1996).

*P. nicotianae* is one of the most studied species of *Phytophthora* (Kamoun et al. 2015). It was first described in 1896 as a cause of disease on tobacco, and it is now known to be pathogenic to plants in 255 genera and 90 families, with a cosmopolitan distribution (Cline et al. 2008; Erwin and Ribeiro 1996; Farr and Rossman 2021). In addition to causing problems on English lavender in the United States, it also affects lavender plants in Spain (Álvarez et al. 2007), Italy (Davino et al. 2002; Faedda et al. 2013), Bulgaria (Nakova 2011), and Greece (Erwin and Ribeiro 1996). Symptoms of infection include grey discoloration and wilting of the foliage, discoloration and rotting of the roots, vascular discoloration, and plant mortality (Putnam 1991).

Managing plant diseases, including those caused by *Phytophthora* species, can be summarized as a four-part plan of pathogen exclusion, avoidance of conducive environmental conditions, pathogen eradication, and plant protection (Agrios 2005; Jarvis 1992; Ludowici et al. 2013; Schumann and D'Arcy 2009). For established pathogens, management often relies, in part, on plant protection, and the most common strategy for diseases caused by fungi and oomycetes, such as species of *Phytophthora*, is the application of chemical fungicides (Agrios 2005; Erwin and Ribeiro 1996; Jarvis 1992). Some fungicides can prevent infection and symptom development and limit pathogen colonization of host tissue, thereby masking pathogen presence and detection (Scott et al. 2013; Shishkoff 2014). The fungicide active ingredients metalaxyl and mefenoxam, commonly used against oomycetes, are actually fungistatic; they are not fungicidal (Brasier and Jung 2006; Linderman and Davis 2008; Olson et al. 2013). They inhibit pathogen activity without killing the oomycete pathogens and can result in pathogens being spread in infected but asymptomatic plants and infested soil (Brasier 2005). For this reason, nursery use of oomycete-specific fungicides without proper sanitation leads to the spread of *Phytophthora*

Received for publication 7 Nov 2024. Accepted for publication 6 Jan 2025.
Published online 26 Feb 2025.
Current address for D.M.D.: The Holden Arboretum, 9500 Sperry Road, Kirtland, OH 44094, USA
This material is based on work supported by the 2018 Herb Society of America Research Grant, a Clemson University College of Agriculture, Forestry, and Life Sciences Wade Stackhouse Graduate Fellowship, the US Department of Agriculture Agricultural Research Service Floriculture and Nursery Research Initiative (under agreement numbers 58-8062-5-037, 58-8062-8-015, and 58-2072-0-058), and the National Institute of Food and Agriculture/US Department of Agriculture (under project numbers SC-1700534 and SC-1700591). Technical Contribution No. 7398 of the Clemson University Experiment Station.
We thank Angela Sterling for extensive laboratory and greenhouse support throughout the duration of the project, and Garner Powell, Dick Baker, and Maxwell Sturdivant for their assistance in the greenhouse.
D.M.D. is the corresponding author. E-mail: ddlugos@holdenfg.org.

species within and from nurseries (Drenth and Guest 2013).

The objective of this study was to examine the efficacy of currently registered and commercially available fungicide products for managing Phytophthora root and crown rot on lavender plants in a greenhouse. Information from this study can be used to identify fungicides that should be tested in lavender fields where PRCR has become a serious problem (Dlugos and Jeffers 2021; Dlugos et al. 2024). Products that specifically target diseases caused by species of *Phytophthora* and that had labels for application to ornamental plants or herbs were selected. Efficacy was evaluated by assessing foliage symptom severity, area under disease progress curves (AUDPCs), and fresh plant masses.

## Materials and Methods

*Greenhouse and plants.* Two trials of each of two independent experiments were conducted during Summer 2018 (Expt. 1) and Summer 2019 (Expt. 2) in a research greenhouse in the Biosystems Research Complex at Clemson University, Clemson, SC, USA. Trial durations varied from 38 to 42 d (Table 1). In Expt. 1, there were 4 weeks between initiation of trials 1 and 2, and there was 1 week between the initiation of the two trials in Expt. 2 (Table 1). During the four trials of these two experiments, environmental conditions in the greenhouse, which were controlled and measured by a central computerized system (Argus Controls; Conviron, Winnipeg, MB, Canada), were relatively uniform based on measurements taken every 15 min. The mean greenhouse temperature during each trial ranged from 23.2 to 24.4 °C, with a 9 to 13 °C difference between the minimum and maximum temperatures in the four trials (Table 1). The mean relative humidity during each trial ranged from 69.2% to 77.9% for each trial; the difference between the minimum and maximum in the four trials ranged from 40% to 56% (Table 1). A 16-h photoperiod was maintained throughout all four trials, with artificial lighting that turned on when outside light energy was less than 350 W/m$^2$.

English lavender plants (*Lavandula angustifolia* 'Hidcote') were used in both experiments. All plants came from the same wholesale nursery (Creek Hill Nursery, Leola, PA, USA). Plants were received as plugs in 72-cell trays, and each cell measured 3.8 × 3.8 × 5.7 cm. A subsample of the plugs (approximately 30% to 50%) for each trial was tested to determine the presence of *Phytophthora* species by a nondestructive baiting bioassay to confirm that plugs were not contaminated with these pathogens before use. Individual plugs were transplanted into 1.3-L pots (15 cm top diameter, 11 cm bottom diameter, 11.5 cm tall). Each pot contained 1 L of a soilless peat and bark-based container mix (Fafard 3B; Sun Gro Horticulture, Agawam, MA, USA). Plants were placed on a bench in the greenhouse, watered overhead by hand as needed, and fertilized weekly with a fertilizer solution delivering 100 ppm of nitrogen (N) (PowerPak 20–20–20 N–P–K Soluble Fertilizer with Minor Elements; Southern Agricultural Insecticides, Inc., Hendersonville, NC, USA).

*Fungicides and treatments.* In this article, we refer to fungicides by product trade names for clarity and to avoid confusion because the same active ingredient is used in several fungicides. All necessary information about the fungicides used in this study (including active ingredient, source, label, application rates, etc.) is reported in Table 2. A total of 11 commercially available fungicides and one experimental formulation of a commercially available fungicide were evaluated in the two experiments; nine fungicides were evaluated in Expt. 1 and five fungicides were evaluated in Expt. 2 (Table 2). Two fungicides were used in both experiments and served as standards. The 11 commercially available fungicides are registered for use on ornamental plants or herbs and labeled to manage diseases caused by species of *Phytophthora* and other oomycetes. These fungicides represented a diverse array of the active ingredients available for managing oomycete diseases, including nine different chemical groups recognized by the Fungicide Resistance Action Committee (https://www.frac.info/home) (Table 2). In addition to the fungicides, two nontreated control treatments were used in each trial—an inoculated control and a noninoculated control; therefore, there were 11 and seven treatments in Expt. 1 and Expt. 2, respectively. Six replicate plants were assigned to each treatment in each trial based on size and vigor so that each treatment had a similar assortment of plants; then, plants in all treatments were arranged in a completely randomized design on the greenhouse bench. All products except for Reliant Trifecta, an experimental granular formulation of potassium salts of phosphorous acid, were applied at label rates by making a single soil drench application to individual pots. For each of the 11 commercially available products, 3 L of fungicide suspension was prepared, and 400 mL of suspension was poured around each plant, which was enough to soak the root zone and container mix in each pot with a slight amount (approximately 10–20 mL) of runoff from the bottom of a pot. Plants were not watered for at least 24 h after fungicide application. Reliant Trifecta was applied dry to the soil surface at a rate recommended by the manufacturer (1 g per pot) (Table 2); then, it was watered into the container mix by gently pouring 400 mL of water over the surface in each pot.

*Isolates and inoculation.* All plants except for those in the noninoculated control were inoculated 4 d after treatments were applied. Three isolates of *P. nicotianae* were used as inoculum: PPC.15-0718, PPC.16-0718, and SC.4284. These were isolated from diseased lavender plants from South Carolina, Pennsylvania, and Virginia, respectively, that had been submitted for diagnosis to the Clemson Plant and Pest Diagnostic Clinic or the S. N. Jeffers Laboratory at Clemson University. All isolates were recovered from roots of *L. angustifolia* 'Hidcote' plants with typical symptoms of PRCR and are now stored in a permanent collection maintained by S. N. Jeffers at Clemson University. Because some isolates of *P. nicotianae* are known to be resistant to the fungicide mefenoxam, these three isolates were tested in vitro and found to be sensitive to mefenoxam using a standard method whereby mycelium growth by isolates was compared on nonamended and mefenoxam-amended media in 48-well culture plates (Olson et al. 2013). Inoculum was prepared by independently growing each isolate on sterile vermiculite moistened with 10% V8 juice broth (2:1 v:v) in glass bottles (Jeffers 2015b; Roiger and Jeffers 1991). Bottles were placed in the dark at 25 °C for 2 weeks so each isolate could thoroughly colonize the vermiculate in a bottle. After 10 to 12 d of incubation, a small aliquot (1–2 mL) of vermiculite from each bottle was spread on a plate of 10% clarified V8 juice agar (Jeffers 2015b) to ensure purity and uniform colonization. Equal amounts of colonized vermiculite from each of the three isolates were combined and thoroughly mixed to prepare a composite batch of inoculum.

Each plant was inoculated by spreading approximately 10 mL of composite inoculum

Table 1. Dates, durations, and environmental conditions of four trials conducted in a greenhouse to evaluate the efficacy of fungicides for managing *Phytophthora nicotianae* on English lavender plants.

| | | Trial dates[i] | | | Temp (°C)[ii] | | | | Relative humidity (%)[ii] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Expt. | Trial | Start | End | Trial duration (days) | Mean | *SD* | Min | Max | Mean | *SD* | Min | Max |
| 1 | 1 | 19 Jul 2018 | 30 Aug 2018 | 42 | 24.4 | 2.2 | 19.2 | 32.1 | 77.6 | 8.2 | 38.6 | 91.3 |
| | 2 | 17 Aug 2018 | 25 Sep 2018 | 39 | 24.3 | 1.9 | 19.2 | 28.3 | 77.9 | 7.4 | 51.0 | 90.7 |
| 2 | 1 | 13 May 2019 | 20 Jun 2019 | 38 | 23.2 | 2.1 | 14.9 | 28.3 | 69.2 | 12.0 | 35.1 | 91.3 |
| | 2 | 20 May 2019 | 28 Jun 2019 | 39 | 23.5 | 2.0 | 18.3 | 28.3 | 71.9 | 11.4 | 35.1 | 91.3 |

[i] Start dates are when plants were treated with fungicides; end dates are when plants were harvested for data collection.
[ii] Temperature and relative humidity during each trial are summarized as the mean, standard deviation (*SD*), minimum (Min), and maximum (Max) values based on data collected every 15 min.

Table 2. Twelve fungicides that target diseases caused by *Phytophthora* species and other oomycetes were evaluated for efficacy at managing *Phytophthora nicotianae* on English lavender plants in a greenhouse.

| Expt.[i] | Fungicide | Active ingredient | Company | Label rate (per 100 gal)[ii] | Use rate (per L)[ii] | FRAC Code[c] | FRAC group name[iii] |
|---|---|---|---|---|---|---|---|
| 1 | Adorn | Fluopicolide | Valent USA Corporation | 4 fl oz | 0.31 mL | 43 | Benzamides |
| 2 | Aliette | Aluminum tris (O-ethyl phosphonate) | Bayer Environmental Science | 12.8 oz | 1.0 g | P07 | Phosphonates |
| 1 | Areca | Aluminum tris (O-ethyl phosphonate) | OHP, Inc. | 12.8 oz | 1.0 g | P07 | Phosphonates |
| 2 | Banol | Propamocarb hydrochloride | Bayer Environmental Science | 25 fl oz | 1.95 mL | 28 | Carbamates |
| 1 | Micora | Mandipropamid | Syngenta Crop Protection, LLC | 8 fl oz | 0.62 mL | 40 | Carboxylic acid amides |
| 2 | Orvego | Ametoctradin + dimethomorph | BASF Corporation | 14 fl oz | 1.09 mL | 45 + 40 | Quinone outside inhibitors, stigmatellin binding type + Carboxylic acid amides |
| 1, 2 | Reliant | Potassium salts of phosphorous acid | Quest Products | 12.8 fl oz | 1.0 mL | P07 | Phosphonates |
| 1 | Reliant Trifecta | Potassium salts of phosphorous acid | Quest Products | —[iv] | 1.0 g/pot[iv] | P07 | Phosphonates |
| 1 | Segovis | Oxathiapiprolin | Syngenta Crop Protection, LLC | 3.2 fl oz | 0.25 mL | 49 | Oxysterol binding protein homologue inhibitors |
| 1 | Segway O | Cyazofamid | OHP, Inc. | 6 fl oz | 0.47 mL | 21 | Quinone inside inhibitors |
| 1, 2 | Subdue Maxx | Mefenoxam | Syngenta Crop Protection, LLC | 2 fl oz | 0.16 mL | 4 | Phenylamides |
| 1 | Terrazole | Etridiazole | OHP, Inc. | 7 fl oz | 0.55 mL | 14 | Heteroaromatics |

[i] Fungicides were evaluated during two independent experiments (Expts. 1 and 2); two trials of each experiment were conducted.
[ii] Rates are those recommended for soil drench applications, except for Reliant Trifecta.
[iii] FRAC = Fungicide Resistance Action Committee.
[iv] Experimental granular formulation applied to the surface of the container mix in each pot.

on the surface of each pot; then, the inoculum was mixed by hand into the upper 1 cm of the container mix. A 1-cm layer of fresh container mix was added to each pot to cover the inoculum, and all pots were gently watered to incorporate the inoculum and prevent desiccation. Plants in the noninoculated control treatment did not receive inoculum; however, additional container mix was added to each pot, and these pots were also gently watered. After inoculation, each pot was placed in a plastic saucer (diameter, 14 cm; depth, 3.5 cm), and plants were watered from the bottom by adding water to the plastic saucers for the remainder of the experiment to keep the container mix in each pot at or near field capacity throughout the trial, which promoted disease development and minimized splashing of treated container mix and pathogen propagules among pots.

*Data collection and analysis.* Each trial was run for a period of approximately 5.5 to 6 weeks postinoculation (Table 1). Plants were evaluated weekly and at the end of each trial to determine foliage symptom severity based on the percentage of foliage showing symptoms of grey discoloration, wilting, or necrosis and assigned the following scores: 0, 0% of foliage symptomatic, no symptoms; 1, 1% to 10%; 2, 11% to 50%; 3, 51% to 90%; 4, 91% to 99%; and 5, 100% of foliage symptomatic, mortality. The differences in range sizes for the symptom severity scores are based on a modification of the Horsfall-Barratt disease scale, which was developed to promote accuracy and consistency in visual assessments (Horsfall and Cowling 1978; Madden et al. 2007). Before statistical analyses, symptom severity scores were converted to the midpoint of each range, for example, a symptom severity score of 1 (1% to 10%) was converted to 5.5% and a score of 2 (11% to 50%) was converted to 30.5%, so that reported disease data were based on percentages of foliage showing symptoms. At the end of each trial, plants were harvested independently and separated into aboveground (shoot) and below-ground (root) material. Roots were washed free of container mix and debris and blotted dry, and fresh root and shoot masses were weighed. The AUDPC was calculated based on weekly and final foliage evaluations using the method reported by Shaner and Finney (1977). The AUDPC is a relative measure of the amount of disease over time. To estimate the effect of fungicides on infection, roots from two representative plants from each treatment in each trial were used for isolation after roots were weighed. Five root bundles from each plant were embedded in PARPH-V8 selective medium (Jeffers 2015a) to isolate the pathogen. Root bundles were composed of 5 to 10 segments (approximately 1 to 2 cm in length) of fibrous feeder roots. Isolation plates were held at 25 °C in the dark for 7 d and examined regularly for typical hyphae of *P. nicotianae*.

The data initially were examined using a one-way analysis of variance (ANOVA) along with Levene's and Shapiro-Wilk's tests for variance and normality assumptions (JMP Pro, Cary, NC, USA). Results of analyses using data transformations and nonparametric tests were consistent with those of standard analyses; therefore, standard parametric analyses were used for all analyses. Trials of each of the two experiments were analyzed together with blocking by trial as a factor. Because there were significant ($P < 0.05$) treatment × trial interactions and changes in the rank order of treatment means between trials, the trials in Expt. 1 were analyzed separately. However, in Expt. 2, treatment × trial interactions were not significant, and the rank order of treatment means was consistent between trials; therefore, these two trials were combined and analyzed together. Based on the nature of the response variables, we determined that a one-way ANOVA with a generalized linear model (SAS, Cary, NC, USA) would be the most appropriate analysis for the data and would provide the most accurate and meaningful results. When the effect of treatments was significant ($P < 0.05$) in an analysis, means were separated by individual pairwise comparisons.

## Results

In this study, two experiments were conducted to evaluate 12 fungicides that target diseases caused by *Phytophthora* species for managing PRCR on lavender (Table 2). All products could not be evaluated at one time because of limitations to the number of plants available and greenhouse bench space. Therefore, nine fungicides were evaluated in Expt. 1, including three phosphonate products, and three additional products plus two products from Expt. 1 were evaluated in Expt. 2 (Table 2). The two products used in both experiments, Reliant and Subdue Maxx, served as standards to demonstrate consistency between experiments. Reliant was the most effective fungicide in both experiments; however, Subdue Maxx was more effective at managing PRCR in Expt. 2 than in Expt. 1 (Figs. 1 and 2); however, this did not prevent the results in the two experiments from being compared and interpreted together.

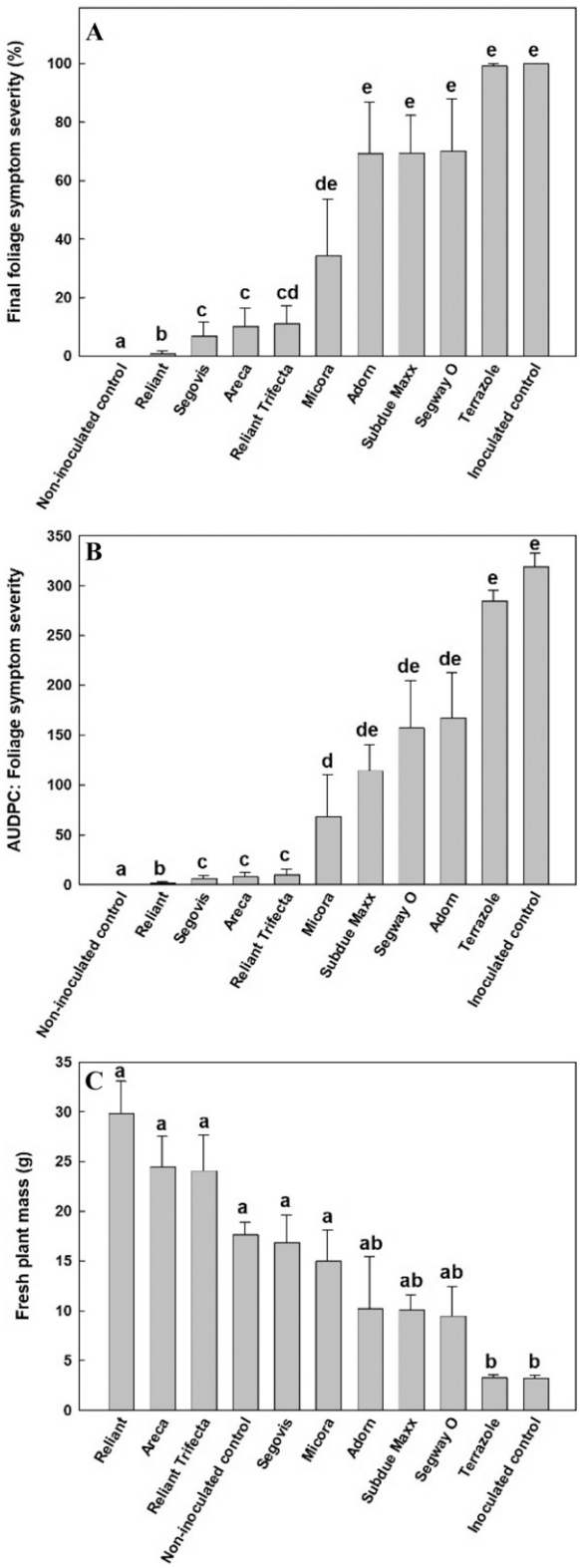


Fig. 1. Expt. 1, trial 1. Three disease parameters were used to evaluate the efficacy of nine fungicides to protect 'Hidcote' English lavender plants that were inoculated with *Phytophthora nicotianae* and grown for 42 d in a greenhouse. (**A**) Percentage of the foliage showing symptoms of discoloration, wilting, or necrosis at the end of the trial. (**B**) Foliage symptoms were assessed weekly and on the last day of the trial, and the area under the disease progress curve (AUDPC) was calculated. (**C**) At the end of the trial, fresh mass of each plant was measured. Values in all graphs are means of six replicate plants; error bars are standard errors. In each graph, means with the same letter are not significantly different ($P \geq 0.05$) based on a one-way analysis of variance followed by *t*-tests between all pairs of means.

Three disease parameters were used to evaluate efficacy: final foliage symptom severity, AUDPC based on the weekly progress of foliage symptom development, and fresh plant mass at the end of each trial. Although root and shoot masses were weighed separately, these weights were combined for analysis because this provided the best separation of treatments. However, fresh plant mass did not prove to be the most accurate measure of treatment efficacy, perhaps because lavender plants produce relatively short, narrow leaves; therefore, the difference in mass between healthy and diseased leaves was not great.

*Experiment 1.* In Expt. 1, environmental conditions in the greenhouse were very conducive to disease development over the course of both trials because plants in the noninoculated control treatments had 100% of the foliage showing symptoms at the ends of the two trials (Figs. 1A and 2A). Foliage symptoms were not observed on plants in the noninoculated control treatment in trial 1, and noninoculated plants in trial 2 had only 6% of the foliage showing symptoms at the end of the trial.

The two trials of this experiment were analyzed separately because statistical tests determined the trials should not be combined. The significant treatment × trial interaction and changing rank order between trials may have been attributable to the difference in age between the plants in trial 1 and trial 2. Plants for both trials came from a single shipment of lavender plants, but the trials were started 4 weeks apart (Table 1); therefore, plants in trial 1 were much younger and likely more susceptible than the plants in trial 2. Data of fresh plant mass indicated that plants in trial 1 were considerably smaller than those in trial 2 (Figs. 1C and 2C), and AUDPC data suggested that disease severity was greater on the younger plants in trial 1 than on the older plants in trial 2 (Figs. 1B and 2B). These differences in plant age and possibly susceptibility provide additional justification for analyzing these two trials independently. It is interesting that plants treated with the three phosphonate fungicides (Reliant, Reliant Trifecta, and Areca) had numerically greater fresh plant masses than those of plants that were not inoculated in both trials; however, these greater masses were not significant (Figs. 1C and 2C).

In trial 1, there were significant differences among the 11 treatments in all three disease parameters evaluated based on *F* statistics in one-way ANOVAs (Table 3). Treatment means for the three disease parameters in trial 1 were compared and separated in the graphs in Fig. 1. Based on final foliage symptom severity and AUDPC, the phosphonate product Reliant provided the best level of disease management by allowing very little development of foliage symptoms. Three other fungicides—Segovis, Areca, and Reliant Trifecta—also provided effective disease management, but at a level significantly less than that of Reliant. Two of these products, Areca and Reliant Trifecta, also are phosphonates. Four of the fungicides—Terrazole, Adorn, Segway O, and Subdue Maxx—provided no significant level of disease management based on final foliage symptom severity and AUDPC because these means were similar to the means for the inoculated, nontreated control plants. Micora did provide a moderate level of disease management based on the development of foliage symptoms over time.

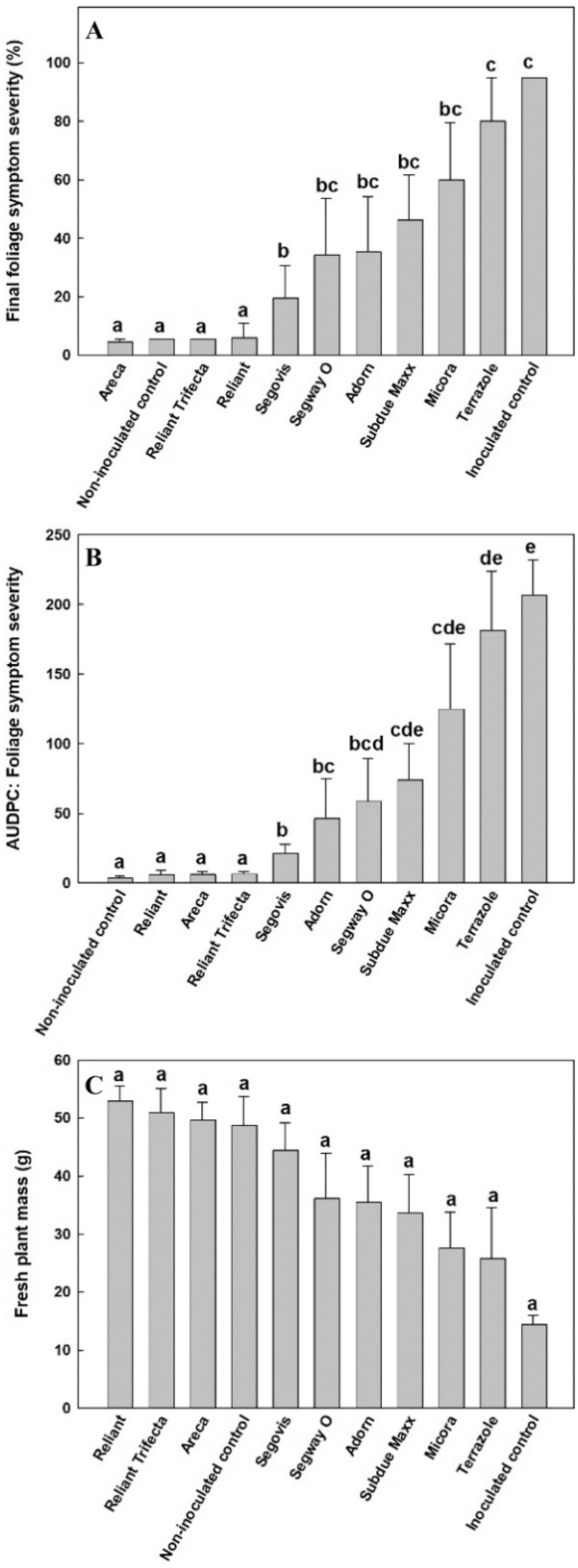


Fig. 2. Expt. 1, trial 2. Three disease parameters were used to evaluate the efficacy of nine fungicides to protect 'Hidcote' English lavender plants that were inoculated with *Phytophthora nicotianae* and grown for 39 d in a greenhouse. (**A**) Percentage of the foliage showing symptoms of discoloration, wilting, or necrosis at the end of the trial. (**B**) Foliage symptoms were assessed weekly and on the last day of the trial, and the area under the disease progress curve (AUDPC) was calculated. (**C**) At the end of the trial, fresh mass of each plant was measured. Values in all graphs are means of six replicate plants; error bars are standard errors. In each graph, means with the same letter are not significantly different ($P \geq 0.05$) based on a one-way analysis of variance followed by *t*-tests between all pairs of means.

Several treatments had plants that died during this trial. Mortality was first observed during week 4 on plants treated with Terrazole and Segway O and on plants that were inoculated and not treated. By week 5, mortality rates were 100% for plants in the inoculated control treatment and 83%, 33%, and 17% for plants treated with Terrazole, Segway O, and Adorn, respectively. When roots from representative plants were tested by isolation on PARPH-V8 medium, *P. nicotianae* was not detected on plants in the noninoculated control treatment or on plants treated with Segovis and Terrazole, but *P. nicotianae* was detected in the roots of plants that were treated with the other seven fungicides or not treated but inoculated.

In trial 2 of this experiment, the overall results were similar to those in trial 1, but the rank order of the treatments was different. In this trial, there were significant differences among the 11 treatments in two of the three disease parameters, final foliage symptom severity and AUDPC, based on *F* statistics in one-way ANOVAs (Table 3). There was no significant difference ($P = 0.5252$) in fresh plant mass among treatments (Table 3). Treatment means for the three disease parameters in this trial were compared and separated in the graphs in Fig. 2. In this trial, the three phosphonate fungicides—Areca, Reliant, and Reliant Trifecta—provided the best level of disease management, with foliage symptom severity and AUDPC values being statistically similar to those of the noninoculated control treatment. Based on final foliage symptom severity, Segovis also provided a significant level of disease management, but five fungicides—Terrazole, Micora, Subdue Maxx, Adorn, and Segway O—were not effective at managing PRCR because the treatment means for these fungicides were not significantly different from that for the inoculated control. However, when AUDPCs of these six fungicides were evaluated, Segovis, Adorn, and Segway O significantly reduced disease progress compared with that on inoculated control plants. In this trial, mortality was observed in only one treatment, presumably because the plants were older and less susceptible than those in trial 1. In week 5, 17% of the plants treated with Micora were dead. When two representative plants from each treatment were tested for the pathogen by isolation, *P. nicotianae* was detected in roots from all treatments except Segovis and the noninoculated control.

*Experiment 2.* As in Expt. 1, greenhouse conditions were very conducive for disease development. Trials in this experiment were combined for analysis because of the consistent results between the two trials. On inoculated control plants, 97% of the foliage showed symptoms by the end of the trials; however, only 6% of the foliage on noninoculated plants showed symptoms (Fig. 3A). There were significant differences among the seven treatments in all three disease parameters based on *F* statistics in one-way ANOVAs (Table 3). Treatment means for the three disease parameters in this experiment were compared and separated in the graphs in Fig. 3. Based on the final foliage symptom severity and AUDPC, three fungicides were most effective at managing PRCR on lavender plants—the two phosphonate products, Reliant and Aliette, and Subdue Maxx. The other two fungicides, Orvego and Banol,

Table 3. Results from one-way analyses of variance (ANOVA) of data for the efficacy of 12 fungicides to manage *Phytophthora nicotianae* on English lavender (*Lavandula angustifolia* 'Hidcote') plants in two experiments conducted in a greenhouse[i].

| | | Expt. 1[iv] | | Expt. 2[v] |
|---|---|---|---|---|
| Disease parameter[ii] | ANOVA statistic[iii] | Trial 1 | Trial 2 | Trials 1 + 2 |
| Final foliage symptom severity | *F* | 14.08 | 8.27 | 10.50 |
| | *P* > *F* | <0.0001 | <0.0001 | <0.0001 |
| | *df* | 10, 55 | 10, 55 | 6, 77 |
| AUDPC: Foliage symptom severity | *F* | 21.89 | 13.63 | 10.08 |
| | *P* > *F* | <0.0001 | <0.0001 | <0.0001 |
| | *df* | 10, 55 | 10, 55 | 6, 77 |
| Fresh plant mass | *F* | 3.39 | 0.92 | 3.18 |
| | *P* > *F* | 0.0017 | 0.5252 | 0.0077 |
| | *df* | 10, 55 | 10, 55 | 6, 77 |

[i] Two trials of each of two experiments were conducted, and a different set of fungicides was used in each experiment. Nine fungicides were used in Expt. 1, and five fungicides were used in Expt. 2. There were six replicate plants used for each treatment in each trial.

[ii] Three disease parameters were used to evaluate treatment efficacy: final foliage symptom severity was assessed as the percentage of the foliage on each plant with disease symptoms at the end of a trial; foliage symptoms were assessed weekly for 5 weeks, and then the area under the disease progress curve (AUDPC) was calculated; and the fresh mass of each plant was measured at the end of a trial.

[iii] Summary statistics for treatments when each disease parameter was analyzed by the one-way ANOVA. *F* = the calculated *F* ratio for each disease parameter; *P* > *F* = the probability of a greater *F* ratio occurring; *df* = degrees of freedom, numerator and denominator.

[iv] There were significant ($P < 0.05$) trial × treatment interactions in Expt. 1, and treatment rank order varied in the two trials; therefore, data in these trials were analyzed separately.

[v] There were no significant ($P > 0.05$) trial × treatment interactions in Expt. 2, and treatment rank order was consistent between trials; therefore, data in these trials were combined and analyzed together.

were not effective at managing this disease because means for these two treatments were not significantly different from those for the inoculated control. When fresh plant mass was weighed, Aliette, Reliant, and Subdue Maxx also produced the largest plants, and their masses were similar to the mass of the plants in the noninoculated control treatment. Masses of plants treated with Banol and Orvego weighed the least, and these masses were not significantly different from the mass of plants that were inoculated and not treated. However, the mass of plants treated with Subdue Maxx also was not significantly different from the mass of inoculated plants.

Some mortality also was observed on plants in this experiment. Dead plants were first observed during week 4; at week 5, 42% of inoculated control plants had died, 25% of Orvego-treated plants had died, and 8% of Banol-treated plants had died. Mortality was not observed on plants in any of the other treatments. When two representative plants from each treatment were tested for *P. nicotianae* by isolation, the pathogen was detected in roots from at least one plant in all treatments except the noninoculated control.

## Discussion

Throughout the four trials of both experiments, registered fungicide products were shown to have a significant impact on the development of PRCR on English lavender plants in the greenhouse, with some products consistently performing better than others. Some products were successful at both limiting disease development and maintaining fresh plant mass, with a trend toward increasing fresh mass over that of the noninoculated, nontreated control plants. One product, Terrazole, which is one of the oldest registered products for managing Phytophthora diseases, performed poorly in all trials and consistently had little effect on PRCR development on lavender plants in the greenhouse. In addition, mortality of plants treated with this product was more common than it was on plants treated with any other product. Only the inoculated control plants had more mortality during these experiments. The observed mortality on Terrazole-treated lavender plants suggested the potential for phytotoxicity on lavender that warrants further investigation. There was no evidence of phytotoxicity with any of the other 10 fungicide products used in this study.

By far, the best performing products in this study were what are collectively referred to as phosphonates—Aliette, Areca, Reliant, and Reliant Trifecta (Table 2) (Landschoot and Cook 2023). Reliant Trifecta is an experimental granular formulation of Reliant that was developed to give growers another application option. It can be sprinkled on the soil surface and watered into the soil instead of being applied as a soil drench. Phosphonate products consistently limited disease development and kept symptom severity to a minimum while also showing a trend toward increasing fresh plant mass compared with plants in the noninoculated control treatment. Phosphonates are known to be absorbed and translocated in plant tissues, persisting for weeks or even months (Guest and Grant 1991; McDonald et al. 2001; Ouimette and Coffey 1989; Rohrbach and Schenck 1985; Smillie et al. 1989). The products are systemic, with transport in both the xylem and phloem (Guest and Grant 1991; Ouimette and Coffey 1989, 1990), and are reported to work against oomycetes by multiple modes of action (Guest and Grant 1991; Smillie et al. 1989). It has also been debated whether physiological responses occur in plants to stimulate host defenses (Guest and Grant 1991; Parween and Jan 2019; Rouhier et al. 1993; Smillie et al. 1989). Regardless of the mechanisms involved, the success of phosphonates is not the same in all pathosystems (Guest and Grant 1991).

Although not statistically significant, plants treated with phosphonate products in each trial had fresh plant masses that were numerically greater than or equivalent to the fresh mass of control plants that were not inoculated or treated. For example, in trial 1 of Expt. 1, plants treated with Reliant had a mass (29.9 g) that was 1.7-times greater than the mass (17.6 g) of the noninoculated control plants. In addition, the phosphonate-treated plants appeared visually more robust. While phosphonates are often labeled as fertilizers, this use is controversial. Phosphonates were tested as early as the 1930s, but they were not suitable as fertilizers because only delayed enhanced growth was observed (Guest and Grant 1991; Landschoot and Cook 2023). Research has determined that phosphonates are not a suitable source of phosphorous for plants, and any increase in leaf tissue nutrient content was caused by increased concentrations in what were smaller tissues because of less growth (Ratjen and Gerendás 2009). Positive benefits are still documented, however. In citrus production, foliar applications of potassium phosphite appear to increase fruit yield per tree (Lovatt 1999). Phosphonates have also been reported to increase turf quality without explanation (Landschoot and Cook 2023). However, the reverse has also been demonstrated; Aliette was found to have a negative impact on root and shoot growth in onion (Sukarno et al. 1993).

Subdue Maxx, with the active ingredient mefenoxam, has long been one of the most popular compounds for managing diseases caused by oomycetes, including species of *Phytophthora* (Agrios 2005; Herman et al. 2019; Olson et al. 2013). In this study, the efficacy of Subdue Maxx was inconsistent and varied considerably between the two experiments. In Expt. 1, it did not effectively manage PRCR; however, in Expt. 2, its efficacy was similar to that of the two phosphonate products. This is important information to know for PRCR on lavender because it is known that the effectiveness of fungicides in some host–pathogen relationships does not equally translate to all (Linderman and Davis 2008). Although inoculations were made only 4 d posttreatment, that should not have impacted the active ingredient efficacy. Mefenoxam products are known to be taken up by the roots and are capable of working relatively quickly—for example, a soil drench with Ridomil (a similar product containing the active ingredient mefenoxam) provided protection of tomato plants in 1-L pots within 1 h (Cohen et al. 1979). It also protected the tomato plants when applied 2 d after inoculation (Cohen et al. 1979). It is also unlikely that the duration of the trial had a

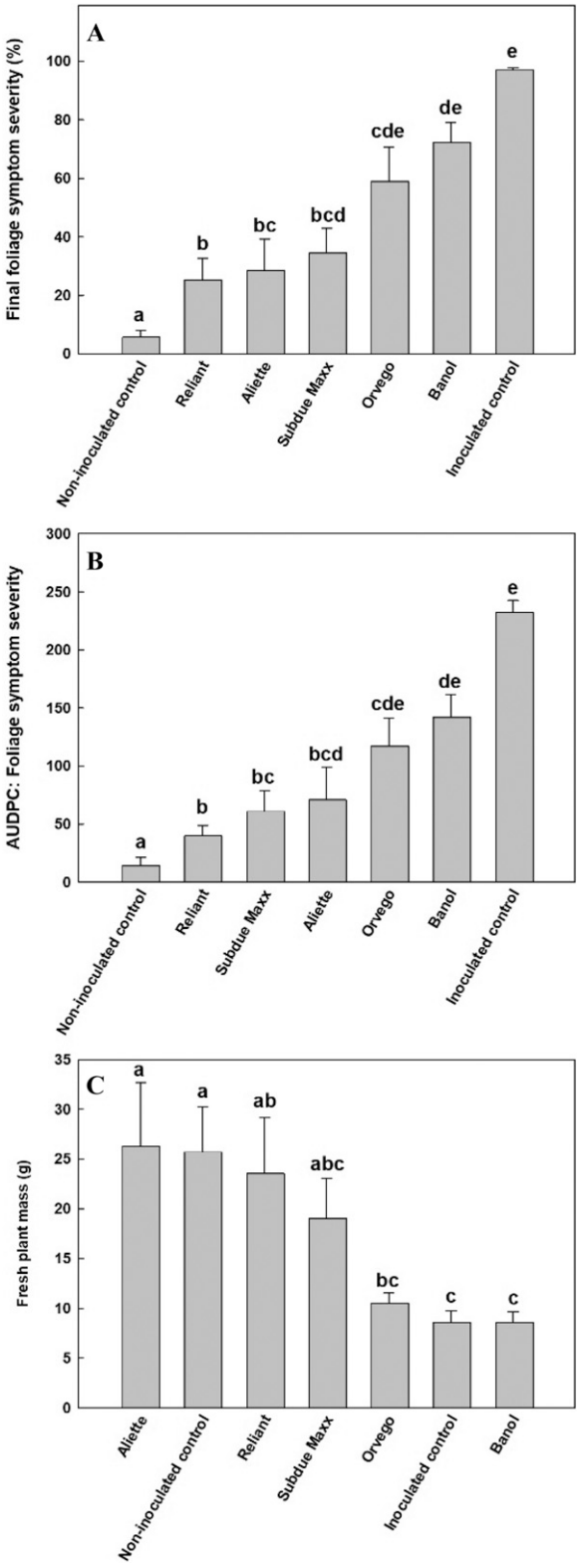


Fig. 3. Expt. 2, trials 1 and 2 combined. Three disease parameters were used to evaluate the efficacy of five fungicides to protect 'Hidcote' English lavender plants that were inoculated with *Phytophthora nicotianae* and grown for 38 d (trial 1) and 39 d (trial 2) in a greenhouse. (**A**) Percentage of the foliage showing symptoms of discoloration, wilting, or necrosis at the end of the trial. (**B**) Foliage symptoms were assessed weekly and on the last day of each trial, and the area under the disease progress curve (AUDPC) was calculated. (**C**) At the ends of the trials, fresh mass of each plant was measured. Values in all graphs are means of 12 replicate plants, with six in each trial; error bars are standard errors. In each graph, means with the same letter are not significantly different ($P \geq 0.05$) based on a one-way analysis of variance followed by *t*-tests between all pairs of means.

negative impact on mefenoxam efficacy because mefenoxam is extremely long-lasting, with the effectiveness of Subdue Maxx lasting up to 6 weeks (Linderman and Davis 2008). Additionally, the current label recommends application intervals of at least 1 to 2 months.

Segovis was repeatedly one of the most effective products in both trials of Expt. 1. This relatively new product with the active ingredient oxathiapiprolin, which has a unique mode of action, has been very successful at managing other Phytophthora diseases, including black shank on tobacco caused by *P. nicotianae* (Ji et al. 2014) and late blight on tomato caused by *P. infestans* (Cohen et al. 2018). This product also prevented isolation of *P. nicotianae* from lavender roots on representative plants in one trial. Isolates of *Phytophthora* species that developed insensitivity to mefenoxam were shown to be sensitive to oxathiapiprolin because the two fungicides have different modes of action, and there was no evidence of cross-resistance between these two fungicides (Bittner and Mila 2016; Cohen et al. 2018). However, Bittner and Mila (2016) suggested resistance to oxathiapiprolin could be possible with the overuse of this active ingredient in fungicides.

Unfortunately, the other five fungicides evaluated in this study—Adorn, Banol, Micora, Orvego, and Segway O (each with a different active ingredient)—were not effective at managing PRCR on lavender plants in the greenhouse even though these products are labeled to manage diseases on ornamental crops caused by *Phytophthora* species. Some may be more effective when applied as foliar sprays to manage leaf and stem diseases, or they may need to be applied more frequently. The three isolates of *P. nicotianae* used in this study were tested for sensitivity to mefenoxam, but they were not tested for sensitivity to the active ingredients in these five fungicides. Therefore, fungicide insensitivity could be one reason for the lack of efficacy.

In conclusion, we identified commercially available fungicides that were effective at managing PRCR on English lavender plants (*L. angustifolia* 'Hidcote') in the greenhouse. Phosphonate products with two different active ingredients (aluminum tris [O-ethyl phosphonate] also known as fosetyl-Al and potassium salts of phosphorous acid) were very effective, and Segovis, with the active ingredient oxathiapiprolin, was also effective. Subdue Maxx, with mefenoxam as the active ingredient, was effective in one experiment, but not in the other one. In the field, PRCR is much more of a problem than it is in the greenhouse (Dlugos and Jeffers 2021; Dlugos et al. 2024); therefore, based on the results in this greenhouse study, phosphonate products and products with oxathiapiprolin and mefenoxam as the active ingredients should be evaluated for efficacy on lavender plants growing in the field.

## References Cited


Adam KL, Rittenhouse T. 2018. Lavender production, markets, and agritourism. Appropriate technology transfer for rural areas (ATTRA) and the National Center for Appropriate Technology (NCAT). https://attra.ncat.org.

Agrios GN. 2005. Plant pathology (5th ed). Elsevier Academic Press, Burlington, MA, USA.

Álvarez LA, Pérez-Sierra A, Armengol J, García-Jiménez J. 2007. Characterization of *Phytophthora nicotianae* isolates causing collar and root rot of lavender and rosemary in Spain. J Plant Pathol. 89:261–264. https://www.jstor.org/stable/41998386.

Bienapfl JC, Balci Y. 2014. Movement of *Phytophthora* spp. in Maryland's nursery trade. Plant Dis. 98(1):134–144. https://doi.org/10.1094/PDIS-06-13-0662-RE.

Bittner RJ, Mila AL. 2016. Effects of oxathiapiprolin on *Phytophthora nicotianae*, the causal agent of black shank of tobacco. Crop Prot. 81:57–64. https://doi.org/10.1016/j.cropro.2015.12.004.

Brasier CM. 2005. Preventing invasive pathogens: Deficiencies in the system. The Plantsman. 4:57–57.

Brasier C, Jung T. 2006. Recent developments in Phytophthora diseases of trees and natural ecosystems in Europe, p 5–16. In: Brasier C, Jung T, Oßwald W (eds). Progress in research on Phytophthora diseases of forest trees: Proceedings of the Third International IUFRO Working Party S07. 02.09. Forest Research, Farnham, Surrey, UK.

Cline ET, Farr DF, Rossman AY. 2008. A synopsis of *Phytophthora* with accurate scientific names, host range, and geographic distribution. Plant Health Prog. 10.1094/PHP-2008-0318-01-RS.

Cho WD, Shin HD. 2004. List of plant diseases in Korea (4th ed). Korean Society of Plant Pathology. Korea Institute of Science and Technology Information, Daejeon, South Korea.

Cohen Y, Reuveni M, Eyal H. 1979. The systemic antifungal activity of Ridomil against *Phytophthora infestans* on tomato plants. Phytopathology. 69(6):645–649. https://doi.org/10.1094/Phyto-69-645.

Cohen Y, Rubin AE, Galperin M. 2018. Oxathiapiprolin-based fungicides provide enhanced control of tomato late blight induced by mefenoxam-insensitive *Phytophthora infestans*. PLoS One. 13(9):e0204523. https://doi.org/10.1371/journal.pone.0204523.

Davino S, Cacciola SO, Pennisi AM, Nicosia MGLD. 2002. *Phytophthora palmivora* a new pathogen of lavender in Italy. Plant Dis. 86(5):561. https://doi.org/10.1094/PDIS.2002.86.5.561C.

Dlugos DM, Bridges WC, Jeffers SN. 2024. Phytophthora root and crown rot of lavender: New host-pathogen relationships involving six species of *Phytophthora* and three species of *Lavandula*. Plant Dis. 108(3):769–777. https://doi.org/10.1094/PDIS-03-23-0477-RE.

Dlugos DM, Jeffers SN. 2021. Identification of *Phytophthora* species causing Phytophthora root and crown rot on lavender in the United States (abstr). Phytopathology. 111:104.S2.

Drenth A, Guest D. 2013. *Phytophthora palmivora* in tropical tree crops, p 187–196. In: Lamour K (ed). *Phytophthora a* global perspective. CAB International, Boston, MA, USA.

Erwin DC, Ribeiro OK. 1996. Phytophthora diseases worldwide. The American Phytopathological Society, St. Paul, MN, USA.

Faedda R, Cacciola SO, Pane A, Szigethy A, Bakonyi J, Veld WAMI, Martini P, Schena L, di San Lio GM. 2013. *Phytophthora ×pelgrandis* causes root and collar rot of *Lavandula stoechas* in Italy. Plant Dis. 97(8):1091–1096. https://doi.org/10.1094/PDIS-11-12-1035-RE.

Farr DF, Rossman AY. 2021. Fungal databases. U.S. National Fungus Collections, ARS, USDA. https://nt.ars-grin.gov/fungaldatabases/. [accessed 20 Jun 2021].

Guest D, Grant B. 1991. The complex action of phosphonates as antifungal agents. Biol Rev. 66(2):159–187. https://doi.org/10.1111/j.1469-185X.1991.tb01139.x.

Herman DC, McKenzie D, Cohen Y, Gisi U. 2019. Phenylamides: Market trends and resistance evolution for important Oomycete pathogens more than 35 years after the first product introduction (FRAC Code 4), p 69–84. In: Stevenson KL, McGrath MT, Wyenandt CA (eds). Fungicide resistance in North America (2nd ed). The American Phytopathological Society, St. Paul, MN, USA.

Horsfall JG, Cowling EB. 1978. Pathometry: The measurement of plant diseases, p 119–136. In: Horsfall JG, Cowling EB (eds). Plant disease: An advanced treatise. Vol. II: How disease develops in populations. Academic Press, New York, NY, USA.

Jarvis WR. 1992. Managing diseases in greenhouse crops. The American Phytopathological Society, St. Paul, MN, USA.

Jeffers SN. 2015a. Protocol 07-04.1: PARP(H)-V8A. In: Ivors K (ed). Laboratory protocols for *Phytophthora* species. American Phytopathological Society, St. Paul, MN, USA. http://dx.doi.org/10.1094/9780890544969.07.04.1.pdf.

Jeffers SN. 2015b. Protocol 07-11.1: V8 agar (V8A) or broth. In: Ivors K (ed). Laboratory protocols for *Phytophthora* species. American Phytopathological Society. St. Paul, MN, USA. http://dx.doi.org/10.1094/9780890544969.07.11.1.pdf.

Jeffers SN, Hwang J, Wamishe YA, Oak SW. 2010. Detection of *Phytophthora ramorum* at retail nurseries in the southeastern United States, p 69–71. In: Frankel S, Kliejunas JT, Palmieri KM (eds). Proceedings of the sudden oak death fourth science symposium. Gen. Tech. Rep. PSW-GTR-229. US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, USA.

Ji P, Csinos AS, Hickman LL, Hargett U. 2014. Efficacy and application methods of oxathiapiprolin for management of black shank on tobacco. Plant Dis. 98(11):1551–1554. https://doi.org/10.1094/PDIS-02-14-0172-RE.

Jones DR, Baker RHA. 2007. Introductions of non-native plant pathogens into Great Britain, 1970-2004. Plant Pathol. 56:891–910. https://doi.org/10.1111/j.1365-3059.2007.01619.x.

Jung T, Orlikowski L, Henricot B, Abad-Campos P, Aday AG, Aguín Casal O, Bakonyi J, Cacciola SO, Cech T, Chavarriaga D, Corcobado T, Cravador A, Decourcelle T, Denton G, Diamandis S, Doğmuş-Lehtijärvi HT, Franceschini A, Ginetti B, Green S, Glavendekić M, Hantula J, Hartmann G, Herrero M, Ivic D, Horta Jung M, Lilja A, Keca N, Kramarets V, Lyubenova A, Machado H, Magnano di San Lio G, Mansilla Vázquez PJ, Marçais B, Matsiakh I, Milenkovic I, Moricca S, Nagy ZÁ, Nechwatal J, Olsson C, Oszako T, Pane A, Paplomatas EJ, Pintos Varela C, Prospero S, Rial Martínez C, Rigling D, Robin C, Rytkönen A, Sánchez ME, Sanz Ros AV, Scanu B, Schlenzig A, Schumacher J, Slavov S, Solla A, Sousa E, Stenlid J, Talgø V, Tomic Z, Tsopelas P, Vannini A, Vettraino AM, Wenneker M, Woodward S, Peréz-Sierra A. 2016. Widespread Phytophthora infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of Phytophthora diseases. For Pathol. 46(2):134–163. https://doi.org/10.1111/efp.12239.

Kamoun S, Furzer O, Jones JDG, Judelson HS, Ali GS, Dalio RJD, Roy SG, Schena L, Zambounis A, Panabieres F, Cahill D, Ruocco M, Figueiredo A, Chen XR, Hulvey J, Stam R, Lamour K, Gijzen M, Tyler BM, Grünwald NJ, Mukhtar MS, Tomé DFA, Tör M, Van Den Ackerveken G, McDowell J, Daayf F, Fry WE, Lindqvist-Kreuze H, Meijer HJG, Petre B, Ristaino J, Yoshida K, Birch PRJ, Govers F. 2015. The top 10 oomycete pathogens in molecular plant pathology. Mol Plant Pathol. 16(4):413–434. https://doi.org/10.1111/j.1364-3703.2012.2011.00783.x.

Landschoot P, Cook J. 2023. Understanding the phosphonate products. Penn State Extension: Pennsylvania State University, University Park, PA, USA. https://extension.psu.edu/understanding-the-phosphonate-products.

Linderman RG, Davis EA. 2008. Evaluation of chemical agents for the control of *Phytophthora ramorum* and other species of *Phytophthora* on nursery crops. Plant Health Prog. 9(1). https://doi.org/10.1094/PHP-2008-0211-01-RS.

Lovatt CJ. 1999. Timing citrus and avocado foliar nutrient applications to increase fruit set and size. HortTechnology. 9(4):607–612. https://doi.org/10.21273/HORTTECH.9.4.607.

Ludowici VA, Zhang W, Blackman LM, Hardham AR. 2013. *Phytophthora nicotianae*, p 113–123. In: Lamour K (ed). *Phytophthora* a global perspective. CAB International, Boston, MA, USA.

Madden LV, Hughes G, van den Bosch F. 2007. Chapter 2: Measuring plant diseases, p 11–31. In: Madden LV, Hughes G, Van Den Bosch F (eds). The study of plant disease epidemics. The American Phgytopathological Society, St. Paul, MN, USA.

McCoy JA, Davis JM. 2021. Lavender: History, taxonomy, and production. NC State Extension: New Crops and Organics. NC State University, Raleigh, NC, USA. https://newcropsorganics.ces.ncsu.edu/herb/lavender-history-taxonomy-and-production/. [accessed 27 Oct 2024].

McDonald AE, Grant BR, Plaxton WC. 2001. Phosphite (phosphorous acid): Its relevance in the environment and agriculture and influence on plant phosphate starvation response. J Plant Nutr. 24(10):1505–1519. https://doi.org/10.1081/PLN-100106017.

Naghibi F, Mosaddegh M, Motamed SM, Ghorbani A. 2005. Labiatae family in folk medicine in Iran: From ethnobotany to pharmacology. Iran J Pharm Res. 2:63–79.

Nakova M. 2011. Phytosanitary monitoring of lavender diseases. AgriSci. III(5):5–10. https://doi.org/10.22620/agrisci.2011.05.001.

Olson HA, Jeffers SN, Ivors KL, Steddom KC, Williams-Woodward JL, Mmbaga MT, Benson DM, Hong CX. 2013. Diversity and mefenoxam sensitivity of *Phytophthora* spp. associated with the ornamental horticultural industry in the southeastern United States. Plant Dis. 97(1):86–92. https://doi.org/10.1094/PDIS-04-12-0348-RE.

Ouimette DG, Coffey MD. 1989. Phosphonate levels in avocado (*Persea americana*) seedlings and soil following treatment with fosetyl-Al or potassium phosphonate. Plant Dis. 73(3):212–215. https://doi.org/10.1094/PD-73-0212.

Ouimette DG, Coffey MD. 1990. Symplastic entry and phloem translocation of phosphonate. Pesticide Biochemistry and Physiology. 38(1):18–25. https://doi.org/10.1016/0048-3575(90)90143-P.

Parween T, Jan S. 2019. Ecophysiology of pesticides: Interface between pesticide chemistry and plant physiology. Academic Press, Cambridge, MA, USA.

Parke JL, Grünwald NJ. 2012. A systems approach for management of pests and pathogens of nursery crops. Plant Dis. 96(9):1236–1244. https://doi.org/10.1094/PDIS-11-11-0986-FE.

Putnam M. 1991. Root rot of lavender caused by *Phytophthora nicotianae*. Plant Pathol. 40(3): 480–482. https://doi.org/10.1111/j.1365-3059.1991.tb02408.x.

Ratjen AM, Gerendás J. 2009. A critical assessment of the suitability of phosphite as a source of phosphorous. Z Pflanzenernähr Bodenk. 172(6):821–828. https://doi.org/10.1002/jpln.200800287.

Roiger DJ, Jeffers SN. 1991. Evaluation of *Trichoderma* spp. for biological control of Phytophthora crown and root rot of apple seedlings. Phytopathology. 81(8):910–917. https://doi.org/10.1094/Phyto-81-910.

Rohrbach KG, Schenck S. 1985. Control of pineapple heart rot, caused by *Phytophthora parasitica* and *P. cinnamomi*, with metalaxyl, fosetyl Al, and phosphorous acid. Plant Dis. 69:320–323. https://www.apsnet.org/publications/plantdisease/backissues/Documents/1985Articles/PlantDisease69n04_320.pdf.

Rouhier P, Bruneteau M, Pivot V, Bompeix G, Michel G. 1993. Effect of phosphonate on the composition of the mycelial wall of *Phytophthora capsici*. Phytochemistry. 32(6):1407–1410. https://doi.org/10.1016/0031-9422(93)85147-J.

Schumann GL, D'Arcy CJ. 2009. Essential plant pathology (2nd ed). The American Phytopathological Society, St. Paul, MN, USA.

Schwingle BW, Smith JA, Blanchette RA. 2007. *Phytophthora* species associated with diseased woody ornamentals in Minnesota nurseries. Plant Dis. 91(1):97–102. https://doi.org/10.1094/PD-91-0097.

Scott P, Burgess T, Hardy G. 2013. Globalization and Phytophthora, p 226–232. In: Lamour K (ed). *Phytophthora* a global perspective. CAB International, Boston, MA, USA.

Shaner G, Finney RE. 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology. 77(8):1051–1056. https://doi.org/10.1094/Phyto-67-1051.

Shishkoff N. 2014. Growth-inhibiting fungicides affect detection of *Phytophthora ramorum* from infected foliage and roots. Plant Health Prog. 15(1):36–40. https://doi.org/10.1094/PHP-RS-12-0124.

Singh S, Singh VK, Babu GD, Kaul VK, Ahuja PS. 2007. Economics of lavender (*Lavandula officinalis* L.) in Himachal Pradesh. J Non-Timber Forest Prod. 14(2):97–100. https://doi.org/10.54207/bsmps2000-2007-J0VIG8.

Smillie R, Grant BR, Guest D. 1989. The mode of action of phosphite: Evidence for both direct and indirect modes of action on three *Phytophthora* spp. in plants. Phytopathology. 79(9):921–926. https://doi.org/10.1094/Phyto-79-921.

Sukarno N, Smith SE, Scott ES. 1993. The effect of fungicides on vesicular-arbuscular mycorrhizal symbiosis. I. The effects on vesicular-arbuscular mycorrhizal fungi and plant growth. New Phytol. 125(1):139–147. https://doi.org/10.1111/j.1469-8137.1993.tb03872.x.

Upson T. 2002. The taxonomy of the genus *Lavandula* L., p 2–34. In: Lis-Balchin M (ed). Lavender: The genus Lavandula. Taylor & Francis, New York, NY, USA.

US Department of Agriculture, Natural Resources Conservation Service. 2021. The plants database (http://plants.usda.gov, 08/16/2021). National Plant Data Team, Greensboro, NC, USA.

Zomlefler WB. 1994. Guide to Flowering Plant Families. University of North Carolina Press, Chapel Hill, NC, USA.