
Epidemiology and Management of Phytophthora Root and Crown Rot of Almond in California

Project No.: PATH15-Adaskaveg/Browne

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A. Summary

Highly efficacious, non-phytotoxic, alternative fungicides with different modes of action that can be applied as soil chemigation treatments are being developed for managing *Phytophthora* root and crown rot of almond. Alternatives to mefenoxam and phosphites are needed because soil fumigations are being greatly restricted, and resistance has been reported to both fungicides in *Phytophthora* species on other tree crops. High in vitro activities of the new fungicides oxathiapiprolin (Orondis), mandipropamid (Revus), fluopicolide (Presidio), and ethaboxam (Intego), all with different modes of action (different FRAC codes), against 11 *Phytophthora* species from tree fruit crops in California were demonstrated by us previously. Oxathiapiprolin had the highest activity with EC₅₀ values for mycelial growth inhibition of <0.001 mg/liter. In field studies at UC Davis (initiated in 2016) where almond trees on Hansen or Nemaguard rootstocks were inoculated, *P. cactorum* was found to be more virulent than *P. cambivora*, *P. citrophthora*, or *P. niederhauseri*. In our final evaluation of the first efficacy trial in Sept 2019 (two years after the last of two applications), Orondis at three different rates was the most effective treatment with no or very little tree death or gumming of the lower trunk observed. Revus and Presidio/Intego only numerically reduced the incidence of disease. In the second trial, trees treated with high or intermediate rates of Orondis or with Revus showed no disease. Presidio and Presidio/Intego were also very effective. This indicates that under high disease pressure, some fungicides will need to be applied at least twice annually. They all should be applied in rotations or mixtures once registered. Studies with Orondis in commercial orchards are ongoing, and Revus is being evaluated on potted trees before orchard planting (i.e., its current labeled use for some tree crops). Respective registrants are supporting almond registration. Orondis should be commercially available in 2021-22.

B. Objectives

I. In vitro toxicity of new fungicides against *Phytophthora* species from almond.

a) **Baseline sensitivities.** We previously demonstrated the high in vitro toxicity of oxathiapiprolin, mandipropamid, fluopicolide, and ethaboxam. Oxathiapiprolin was the most active against several life stages of *Phytophthora* spp. We are currently collecting more isolates for these studies. Baselines will be used as references in future resistance monitoring.

b) **Resistance potential.** Studies with outliers of isolates that tolerate higher concentrations of some new fungicides are ongoing to determine the resistance potential.

II. Evaluate oxathiapiprolin, mandipropamid, fluopicolide, and ethaboxam for the management of root of almond in field studies.

a) **Orchards.** Two almond orchards on Hansen or Nemaguard rootstocks were established at UC Davis. Trees were inoculated with *P. cactorum*, *P. citrophthora*, *P. cambivora*, and/or *P. niederhauseri*. One trial is completed, the other one is ongoing. Commercial field studies with research authorizations have been initiated.

b) **Treatment efficacy.** In our studies at UC Davis, Orondis was the most effective in preventing Phytophthora crown rot in both trials, but Revus, Presidio, and Presidio/Intego were also very effective in the second trial. All fungicides will be continued to be evaluated in the second trial at UC Davis. Respective registrants are supporting registration on almond.

Field inoculation studies, orchard observations, and grower reports indicated that Phytophthora crown rot is more seriously affecting tree health than root rot; trees often collapse rather suddenly. In our studies, *P. cactorum* was more virulent than the other species used for inoculation. However, in commercial orchards, a newly identified taxon related to *P. cinnamomi* was also found to be highly virulent.

c) **Trunk inoculations of treated trees to determine differences in internal movement of fungicides from soil applications.** Inoculation methods for potted plants are currently being developed in greenhouse studies.

C. Annual Results and Discussion

I. **Evaluate the in vitro toxicity of new fungicides against selected Phytophthora species occurring on almond.** Our previous evaluation of 80 isolates of different species including *P. niederhauseri*, *P. syringae*, *P. citricola*/*P. citricola* complex, and *P. cactorum* indicated that all were most sensitive to oxathiapiprolin with EC₅₀ values for mycelial growth inhibition of <0.001 mg/liter. A rather narrow range of EC₅₀ values (0.001 to 0.01 mg/liter) among all isolates was also found for mandipropamid, whereas for ethaboxam and fluopicolide generally higher rates were needed. We are currently collecting additional isolates of *Phytophthora* from almond, and these will be evaluated in the future. The importance of baselines is that they will be used as references in future resistance monitoring because all isolates were collected before commercial use of the fungicides being tested.

II. **Evaluate oxathiapiprolin, mandipropamid, fluopicolide, and ethaboxam in field studies for the management of Phytophthora root rot of almond and compare to mefenoxam and potassium phosphite.** In our final evaluation of the first trial at UC Davis in Sept 2019 (two years after the last of two applications), data were combined for Hansen and Nemaguard rootstocks. Among untreated trees, 30% showed gumming on the lower trunk that often led to tree death. Based on isolations, the disease was determined to be caused by *P. cactorum*, one of the four species that were used for inoculation. Orondis was the most effective treatment with no or very little tree death or gumming of the lower trunk observed when using three different rates (Fig. 1). Revus and Presidio/Intego only numerically reduced the incidence of disease, and Presidio or Intego by themselves as well as Prophyt and Ridomil Gold were no longer effective. We concluded that Orondis has a

long residual life possibly by penetrating into the plant tissues, and that the other fungicides will have to be applied more frequently to obtain high efficacy.

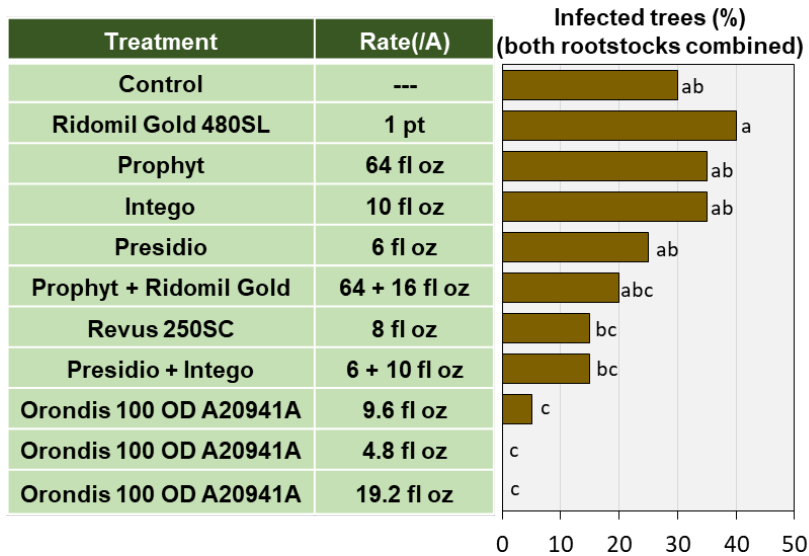


Fig. 1. Efficacy of new and registered fungicides for managing *Phytophthora* crown rot of almond at UC Davis – Plot 1.

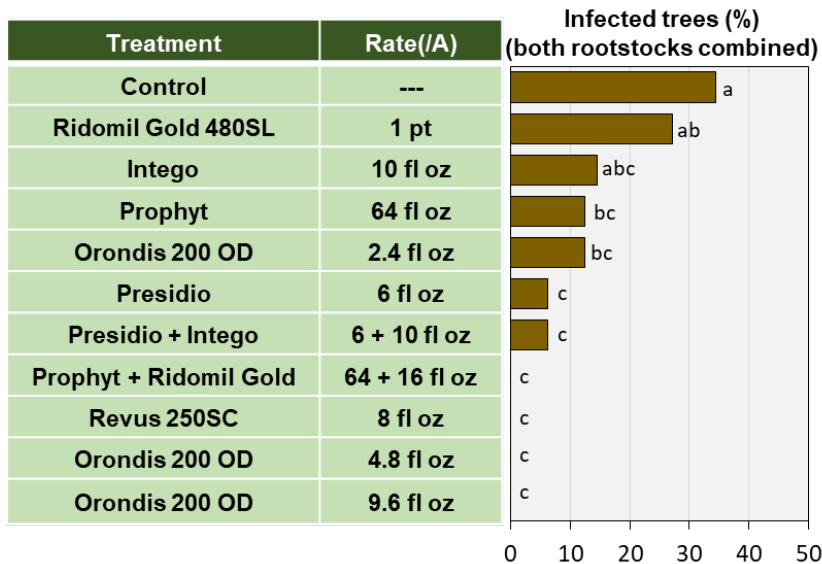


Fig. 2. Efficacy of new and registered fungicides for managing *Phytophthora* crown rot of almond at UC Davis – Plot 2.

In the second trial that was established in late 2017 and treated after planting and inoculation, again in late 2018, and in spring 2018, trees treated with high or intermediate rates of Orondis or with Revus showed no disease, but Presidio, and Presidio/Intego were also very effective (Fig. 2). Treatments with low rates of Orondis, or with Intego or Prophyt were intermediate in efficacy. None of the treatments caused phytotoxicity. The disease again was found to be caused by *P. cactorum*. Studies in commercial orchards are ongoing. These experiments show that highly effective new fungicides were identified. Orondis should be commercially available to the almond industry in 2021-22. The label that we requested for Revus will be for a nursery treatment for potted almond plants similar to its registration for potted citrus plants. We are also in discussions with Valent for registering Presidio and Intego on almonds.

In commercial orchards, a newly identified taxon related to *P. cinnamomi* was detected to cause crown rot in recent years, sometimes at high incidence and severity. Thus, this taxon was found to be highly virulent, possibly similar to *P. cactorum*. Greenhouse inoculation studies are currently being conducted to compare the virulence of the most common species of *Phytophthora* occurring on almond. Studies are also ongoing to determine the exact taxonomic status of the new taxon. Our field observations indicated that disease caused by this taxon was most severe in the warmer months of the year. In vitro temperature studies supported this finding: growth rates of three isolates were highest at 30°C, and growth was still very high at 35°C (Fig. 3).

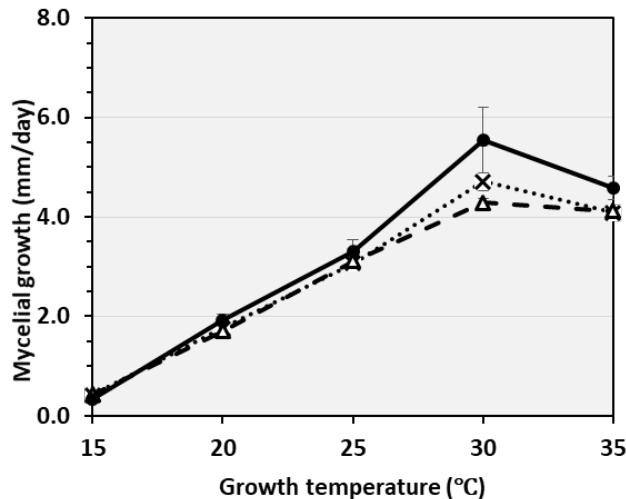


Fig. 3. Temperature-growth relationships of three *Phytophthora cinnamomi*-like isolates obtained from almond trunk cankers.

D. Outreach Activities

1. Dr. Adaskaveg participated at several grower/PCA meetings at different locations in California over the year and gave presentations on almond diseases including *Phytophthora* root and crown rot and their management. At each meeting, there were approximately 40-50 participants.
 - a. January 2019, Managing Diseases of Almond in California; Bayer Tree, Nut, and Vine Meeting; Organizer: Bayer CropScience; Universal Studios, Universal City, CA 91608
 - b. January 2019, Almond Diseases: Key Economic Pests, ID, Biology, and Treatments in Almonds; 2019 Independent PCA Symposium; Organizer: Bayer CropScience; Monterey Plaza Hotel and Spa, Monterey, CA 93940
 - c. January 2019, Review of Almond and Citrus Diseases of Economic Significance; Independent PCA Meeting; Organizer: Syngenta Crop Protection; Paso Robles, CA.
 - d. January 2019, Almond Disease Management, Colusa Winter Almond Meeting; Organizer: UCCE; Granzella's Banquet Hall, Williams, CA
 - e. Feb 5, 2019, Bloom and Foliar Diseases; Annual Almond Production Meeting; Organizer: UCCE; Norton Hall, Woodland, CA
 - f. Nov 8, 2019, Foliage, Blossom and Nut Diseases; Almond Short Course, Organizer UCCE; Visalia Convention Center, Visalia, CA

E. Materials and Methods:

- a. **Baseline sensitivities.** In vitro sensitivities were determined using the spiral gradient dilution (SGD) method as described previously (Forster et al., *Phytopathology* 94:163-70. 2004).
- b. **Evaluate oxathiapiprolin, mandipropamid, fluopicolide, and ethaboxam in field studies for the management of *Phytophthora* root of almond and compare to mefenoxam and potassium phosphite.** Two orchards with cv. Nonpareil on Hansen or Nemaguard rootstocks were established at UC Davis in 2016 and 2017, respectively. Plots were laid out as randomized complete-block designs with 4 trees for each rootstock and 10 replications for each treatment in the first plot, or with 2 trees for each rootstock and 5 replications for each treatment in the second plot. Inoculum was grown in plastic jars on an oat-vermiculite-V8 juice substrate. Trees were inoculated at the root zone with *P. cactorum*, *P. citrophthora*, and *P. cambivora* in the first plot and *P. cactorum*, *P. citrophthora*, and *P. niederhauseri* in the second plot. In the first plot, treatments were applied around each tree trunk in July 2016 (after planting) and July 2017. In the second plot, they were applied Dec 2017 (after planting), Nov 2018, and May 2019. Trees were evaluated periodically for disease. A tree was considered infected by *Phytophthora* sp. if profuse amber-colored gumming was present at the lower parts of the trunk. The presence of the pathogen was confirmed by culturing from infected plant tissues. Trees were also evaluated for any phytotoxicity. Disease incidence was based on the number of diseased trees of the total number of trees for each treatment in each replication. Data were analyzed using analysis of variance and multiple mean separation methods of SAS ver. 9.4.

F. Publications that emerged from this work

1. This information will be prepared in a manuscript for publication as we provide enough efficacy data to allow registration of the effective fungicides in the state of California.
2. Our outreach is the form of posters at the Annual Almond Board Conference and in UCANR and other extension meetings (listed above).