GRAPE (*Vitis vinifera* 'Chardonnay')
Powdery Mildew; *Erysiphe necator*

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Efficacy of tank mixing biological fungicides with sulfur for management of grape powdery mildew, 2023.

Tank mixes of biological fungicides and micronized sulfur were used for grape powdery mildew (GPM) management of Chardonnay vines at the Botany and Plant Pathology Field Laboratory in Corvallis, Oregon. The treatments focused on evaluating whether tank mixes of each of three different biological fungicides and a low (below labeled) rate of Microthiol Disperss (MD) micronized sulfur would provide better control than using the low rate of MD alone (Table 1).

Treatments (Table 1) were arranged in a randomized complete block design. A 50 gallon Pak-blast air blast sprayer (Rears Mfg., Coburg, OR) with TeeJet ceramic D3 discs and DC25 core nozzles was used to apply the treatments and operated using a Kubota M5N-111 tractor. The blocks used consisted of 'Chardonnay' planted in 1998 on V. *rupestris x V. riparia* 101-14 rootstock with 7x8 ft spacing. A single buffer rootstock vine was trained between each set of treatment vines and a buffer row of rootstock vines separated each varietal row, which helped minimize plot-plot interference. Vines were trained to a Guyot (vertical shoot position) system and pruned by 27 Mar. Shoot thinning by hand occurred from 9 May to 25 May and sucker removal by hand was continuous throughout the season. Shoots were cut above the top wire on 15 Jun and maintained at this height throughout the growing season. Fungicide treatments were applied every 7-10 days. Each treatment was replicated on 4 sets of 5 vines.

Table 1. Biological fungicide treatments applied to Chardonnay vines in 2023.

Treatment^{xy}
Non-treated control
2 lb MD/A Control
30 fl oz/100gal Aviv + 2 lb MD/A
4.5 oz/100gal Lifegard + 2 lb MD/A
3 lb/A Theia + 2 lb MD/A

^{x}Treatments applied at 80psi at approx. 430 PTO rpm and 3mph.
^{y} MD = Microthiol Disperss.

Spring weather conditions were normal to dry in April and first week of May but then became very dry with little rainfall for the remainder of the season. Symptoms of powdery mildew were first found on 22 May as a few individual colonies on scattered vines. Flag shoots were not observed in this block. Bloom took place from approximately 4 Jun to 14 Jul with most caps detaching from 6 to 10 Jun.

Leaf and cluster data were taken on the middle three vines of each experimental plot by randomly examining either 25 clusters or leaves on both the east and west side of the row for a total of 50 units examined per plot. The incidence of powdery mildew on leaves was recorded weekly from 12 Jun through 10 Aug. The severity of powdery mildew on clusters was taken on 10 Aug. Leaf incidence data was analyzed by calculating the area under disease progress curve (AUDPC) which was calculated by multiplying the mean incidence from two observation dates by the number of days between observations ($\Sigma[Y_{i+1} + Y_i)/2][X_{i+1}-X_i]$ where Y_i is incidence of mildew at i*th* observation and X_i is the day of the i*th* observations) and adding together the values. AUDPCs were calculated using the agricolae package and modeled with a linear model. Cluster severity percentages were modeled using a generalized linear mixed model with block fitted as a random effect. Cluster severity treatment contrasts were conducted using the emmeans package and model fit was checked with the DHARMa package. Uncertainty was estimated using asymptotic 95% confidence intervals. All data was analyzed in R version 4.0.3.

AUDPC values were significantly higher in the non-treated plots than all fungicide treated plots. Among fungicide treatments, the plots treated with a mixture of Theia + 2 lb MD/A resulted in the lowest observed AUDPC value that was significantly lower than the Lifegard + 2 lb MD/A treatment and the 2 lb/A MD alone control. However, the Theia tank mix was not significantly different from the Aviv + 2 lb MD/A treatment (Table 2). The lowest level of cluster severity was also observed in the Theia + 2 lb MD/A treated plots, with all other fungicide treatments resulting in approximately 30% more cluster severity on average, representing a significant difference. The non-

Table 2. Area under disease progress curve (AUDPC, leaf disease) and percent infected berries from the Chardonnay biological fungicide and sulfur tank mix trial at the Botany and Plant Pathology field lab in 2022.

Treatment[y]	AUDPC[w]	Percent Infected Berries[w]
Non-treated control	2605 (2389-2822) A	93.2 (86.3-96.7) A
2 lb MD/A Control	1205 (988-1422) B	72.4 (54.8-85.1) B
30 fl oz/100gal Aviv + 2 lb MD/A	910 (693-1126) BC	62.6 (43.6-78.4) B
4.5 oz/100gal Lifegard + 2 lb MD/A	1059 (843-1276) B	65.5 (46.7-80.4) B
3lb/A Theia + 2 lb MD/A	556 (339-772) C	34.4 (19.5-53.2) C

[y]All treatments were applied at 80psi at approx. 430rpm PTO. MD = Microthiol Disperss
[z]Estimates are followed by asymptotic 95% confidence intervals in parentheses. Treatments followed by different letters are significantly different than each other, marginal means contrast ($p<0.05$) with p values adjusted using Tukey method.

treated control plots resulted in 93.2% cluster severity, which was significantly higher than all fungicide treated plots (Table 2).

Spray volume applied for fungicide treatments was relatively consistent and fluctuated around 60 GPA for the entire growing season (Figure 1). The amount of lifeguard applied over the course of the season ranged from a minimum of 2.6 oz/A to a maximum of 2.8 oz/A which are both within the label recommended rate range of 1 oz/A to 4.5 oz/A (Figure 2A). The amount of Aviv applied over the course of the season ranged from a low of 17.4 fl oz/A to 19.2 fl oz/A, which was within the label recommended range of 15 fl oz/A to 25 fl oz/A. The amount of Theia applied over the course of the season ranged from 3.2 lb/A to 3.9 lb/A, which was all within the label rate range of 1.5 lb to– 5 lb/A for control of GPM (Figure 2A). For all fungicide treated vines the amount of MD applied in the tank mixes was fairly consistent, ranging from 2.2 lb/A to 2.7 lb/A (Figure 2B) which are all below labeled rate.

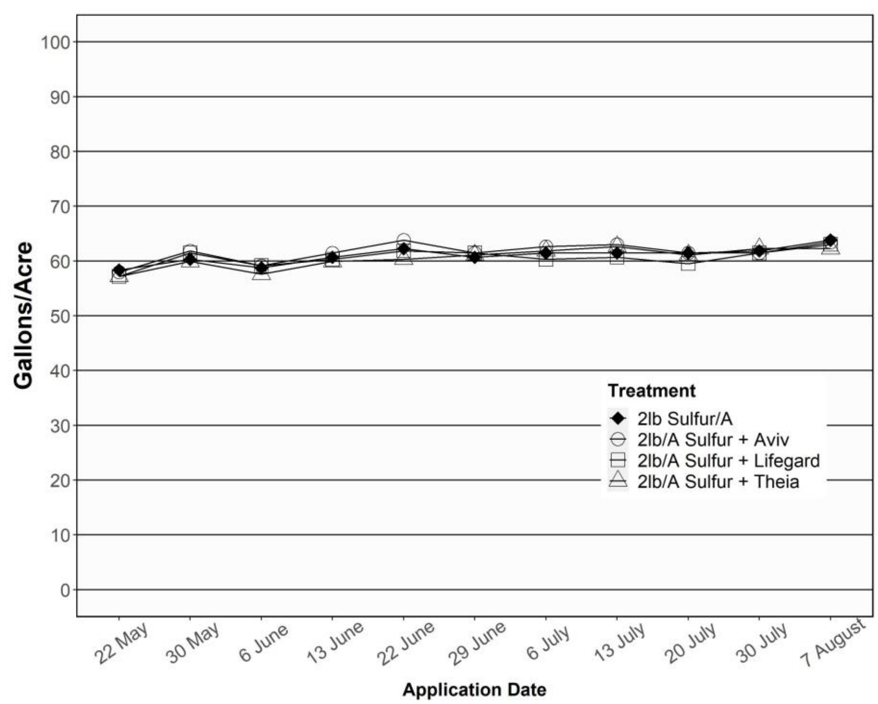

Figure 1. Spray volumes applied to vines in the Chardonnay tank mix trial.

Over the last two growing seasons the Theia tank mix has been consistently more effective at managing GPM than Lifegard or Aviv tank mixes. This was across two growing seasons with differing disease pressure; the 2022 growing season had high GPM pressure, while the 2023 growing season had average disease pressure. Biological fungicides, like all fungicides, are most effective when applied preventatively, and have lower residual efficacy than conventional fungicides. This translates to biological fungicides having a lower propensity to control active infections than conventional fungicides. Since the Theia tank mix was able to manage GPM infections on leaves and clusters for the duration of the season better than the 2 lb of MD alone points to the Theia having both efficacy at preventing and managing infections. We suspect it would do very well under typical low disease pressure found in most commercial vineyards.

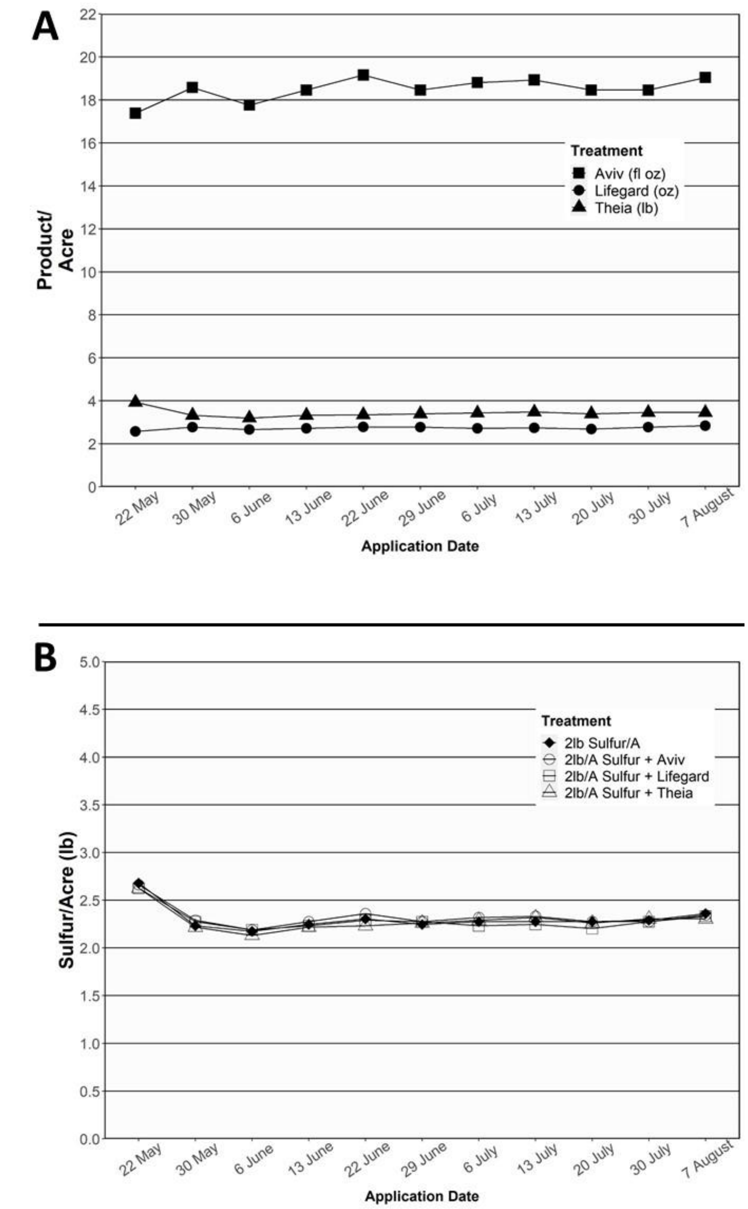

Figure 2. The amount of biological fungicide (A) and Microthiol Disperss (B) applied Chardonnay vines during each application.

All biological fungicides in this experiment were tank mixed with MD and applied in that mix for every application during the season. Biological fungicides each have their own mode of action profile with Theia and Aviv having similar profiles. This includes production of anti-microbial compounds, competition for space on the plant, and activation of plant defenses through the systemic acquired resistance (SAR) response. Lifegard works solely by activating a plant's SAR response. Lifegard may have been less effective at augmenting disease control throughout the season because over time infections became established on plants which Lifegard had no activity against, whereas Theia and Aviv could have had some activity in preventing new and controlling already established infections. On leaves, Aviv did result in lower leaf incidence counts than in Lifegard treated plots for the first half of the season, however, leaf incidence increased to a similar level to Lifegard treated plots during the second half of the season (data not shown). For the entire season Theia had consistently lower leaf incidence levels than the Aviv or Lifegard tank mixes.

The formulation of a biopesticide can be a determinant of its efficacy. The three biopesticides used in this study all have different formulations with different proportions of active ingredient. Lifegard, Theia, and Aviv formulations are wettable granule, dry flowable, and suspension concentrate that each contain contains 40%, 100%, and 0.08% of active ingredient in their formulations, respectively. Aviv and Theia, the two most effective products in this study are very different formulations and have a huge difference in the amount of active ingredient in the product formulation. Vines treated with Theia had lower leaf incidence levels at each evaluation point of the season and also had significantly lower GPM on the clusters. It is stated on the Aviv label that the formulated product contains some natural chemistry, but that most of the activity is with spores of the active ingredient bacterium that colonize leaf tissue and subsequently protect the plant. While the Aviv formulation is easy to handle and apply, perhaps part of the reason it was less efficacious than Theia was because Theia may have more anti-microbial compounds already present in the formulated product, whereas Aviv may be reliant on the active ingredient bacterium becoming established on the plant surface prior to producing the majority of these compounds.

Future trials could investigate the usage of adjuvants in combination with biological fungicide tank mixes to determine any synergistic benefit. Additionally, plating of tank mixes to investigate bacterial viability could determine any detrimental impact of the tank mix or application method.