SRSFC Project 2024 R-11: Efficacy studies of surfactant adjuvants and air induction sprayer nozzles combined with elemental sulfur for management of powdery mildew of grape

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Abstract. To test their ability to increase disease suppression when combined with sulfur, three non-ionic organosilicone surfactants (Cohere, Hi-Wett, and Silwet L-77) were tank-mixed in a standard sulfur spray regimen in northern Georgia (U.S.) on a block of 'Chardonnay' vines in 2024. This trial was conducted using CO_2 backpack sprayers. A second, different trial was conducted in a 'Merlot' block at the same site. In an effort to determine whether an air induction nozzle would provide better efficacy than a cone nozzle, sulfur, with and without surfactants, was applied with air induction and cone nozzles arrayed on each side of an airblast sprayer manifold. Surfactants applied alone reduced grapevine powdery mildew (GPM) severity on both fruit and leaves. When surfactants were tank-mixed with sulfur, surfactants improved disease control over sulfur alone. However, results were variable, with Hi-Wett and Silwet L-77 providing the most consistent improvement in sulfur efficacy against GPM on leaves and fruit. Synergistic interactions were generally not observed, though Silwet L-77 did show a synergistic interaction with sulfur for disease control on fruit. Applying sulfur through an air induction nozzle provided less disease control than that provided by a traditional cone nozzle. Though difficult to explain, surfactants provided more consistent improvement in disease control when using the cone nozzle as well. Overall, we found that sulfur efficacy for control of GPM was improved by combination with non-ionic organosilicone surfactants, while an air induction nozzle did not improve GPM disease control over a cone nozzle.

Objective. Determine the efficacy of surfactant adjuvants and air induction nozzles in tank mixes when combined with sulfur sprays

Justification and Description. The wine grape industry in Georgia is limited by the intense disease pressure caused by a number of pathogens observed in our warm and wet climate. One such disease is grapevine powdery mildew (GPM) caused by the pathogen *Erysiphe necator* (Fig. 1). Grape growers spend thousands of dollars each year for the control of this pathogen, as well as others. The economic viability of growing grapes in Georgia hinges on the cost, effectiveness, and availability of fungicides. One impending threat to the economic sustainability of the grape industry is the loss of widely used chemical modes of action such as demethylation inhibitors (DMI; FRAC 3) and quinone outside inhibitors (QoI; FRAC 11), due to selection for fungicide resistance among several pathogens, to include *E. necator*. Growers use these chemical classes because of their efficacy and broad-spectrum activity, but these chemicals are also highly prone to resistance development. DMI and QoI-resistant powdery mildew populations have been detected in Georgia, and resistance will only worsen with their continued use.

The stability of the grape industry in Georgia and elsewhere depends on our ability to adapt to an ever-changing fungicide landscape. One option centers on better incorporation of fungicides that do not develop resistance. Elemental sulfur has been used for over a hundred years to control powdery mildew, and resistance has never been reported in *E. necator* populations. However, there are several disadvantages to sulfur which prevent growers from utilizing it to its full potential. This research focused on exploring methods for increasing the efficacy of sulfur formulations for the control of powdery mildew on grape, namely surfactants and air-induction (AI) nozzles.

Materials and Methods. In the first trial, three non-ionic organosilicone surfactants (Hi-Wett, Cohere, and Silwet L-77) were selected to examine their effect on powdery mildew control when combined with Microthiol Disperss (sulfur). Products were tested at the Georgia Mountain Research Center on a block of 'Chardonnay' grapevines.

Figure 1. Powdery mildew of grape on leaves and fruit.

Treatments included: (1) an untreated control [no material applied], (2) Microthiol Disperss, (3) Hi-Wett, (4) Cohere, (5) Silwet L-77, (6) Microthiol Disperss + Hi-Wett, (7) Microthiol Disperss + Cohere, and (8) Microthiol Disperss + Silwet L-77. All treatments were applied at the maximum legal rate using CO_2 backpack sprayers equipped with one TT11002 (TeeJet Technologies, Wheaton, IL) nozzle. Treatments were applied until runoff and rates were calculated to correspond to a 50 gallon per acre spray volume. Treatments were applied during pre-bloom, bloom, post-bloom, bunch closure, and then during 14-day intervals until data collection ceased. Cultural practices mimicked those of commercial vineyards and additional pest management products were applied with an air blast sprayer, also in a 50 gallon per acre spray volume. All other relevant foliage and bunch diseases were controlled through multiple maintenance applications. Means were compared using a Fisher's protected LSD test ($\alpha = 0.05$).

In a second trial, two sets of air blast sprayer nozzles were examined for differences in their abilities to control powdery mildew when applying Microthiol Disperss (sulfur) and two surfactant products, Cohere and Hi-Wett. A standard air blast sprayer was equipped with eight TX-VK6 hollow cone spray tip nozzles (TeeJet Technologies, Wheaton, IL) on one side and eight AITXA80VK air induction spray tip nozzles (TeeJet Technologies, Wheaton, IL) on the other side. Treatments were applied by making one pass on each side of each treatment vine corresponding to the side of the tractor with the correct spray tip for the treatment. Products were tested at the Georgia Mountain Research Center on a block of 'Merlot' vines. Treatments included: (1) an untreated control [no material applied], (2) Microthiol Disperss [with cone nozzle], (3) Microthiol Disperss + Hi-Wett [with cone nozzle], (4) Microthiol Disperss + Cohere [with cone nozzle], (5) Microthiol Disperss [with air induction nozzle], (6) Microthiol Disperss + Hi-Wett [with air induction nozzle], and (7) Microthiol Disperss + Cohere [with air induction nozzle]. The tractor was calibrated to 1700 RPM and 150 PSI at a constant speed of 2 mph. Similar to the CO_2 sprayer trials, treatments were applied at the maximum legal rates calculated to correspond with a 50 gallons per acre spray volume. Treatments were applied during pre-bloom, bloom, post-bloom, bunch closure, and then during 14-day intervals until data collection ceased. Cultural practices mimicked those of commercial vineyards and additional pest management products were applied with an air blast sprayer at a rate of 50 gallons per acre. All other relevant foliage and bunch diseases were controlled through multiple maintenance applications. Means were compared using a Fisher's protected LSD test ($\alpha = 0.05$).

Results and Discussion. Surfactant adjuvants have been found to enhance coverage when tank mixed in chemical applications. In our trials, we found that the addition of non-ionic organosilicone surfactants generally had an overall positive effect on disease management outcomes, though the effect seemed to vary in magnitude from product to product (Table 1). To reiterate, the combination of Microthiol Disperss and a surfactant generally provided a statistically significant advantage over Microthiol Disperss alone. This improvement is most likely due to the greater coverage area resulting from the altered water properties provided by the surfactant. However, the significant control effect of surfactants alone compared to the untreated control suggests that surfactant activity against powdery mildew may extend beyond just enhanced sulfur coverage. Organo-silicone surfactants have been shown to increase absorption into plant stomata, and given the effect of surfactants on water properties and their well-known anti-microbial properties, it is likely that surfactants have some direct activity against fungal mycelium or spores of *E. necator*. Among products tested, Hi-Wett and Silwet L-77 provided the most consistent disease control, while Cohere performed inconsistently. This difference in performance raises questions as to the chemical mechanisms behind the surfactant formulations – questions beyond the scope of this study. The lack of consistency between products is consistent with previous findings.

Air induction nozzles are designed to combine the canopy-penetrating effect of larger spray droplets with the coverage-enhancing effect of smaller spray droplets. This technology has potentially useful implications in vineyard settings, as canopy penetration is essential for complete leaf and cluster coverage. Additionally, the incorporation of surfactants with this technology has the potential to synergistically enhance spray characteristics. However, we found that the efficacy performance of the AI nozzle was overall inferior to that of standard cone nozzle (Table 2), but had we used a systemic material, as opposed to sulfur, results may have been different. In theory, the penetration advantage of AI nozzles would be a net benefit for spray characteristics, thus outperforming the less advanced cone nozzles. However, treatments sprayed with cone nozzles had consistently lower disease levels on both leaves and fruit compared to those sprayed with AI nozzles. This result is not entirely unexpected, as reduced fungicide efficacy is consistent with some previous studies, although reports are variable. Similar reductions in efficacy have been reported for various diseases on apples, especially in years with high disease pressure. Studies finding comparable efficacies between these nozzle types mainly examined herbicidal applications, where AI nozzles are favored for their anti-drift capabilities. The efficacy-enhancing effect of the surfactants found in the 'Chardonnay' trial was also observed in the 'Merlot' trial, albeit only when the treatments were applied with a cone nozzle. Both Hi-Wett and Cohere, when combined with Microthiol Disperss, provided statistically significant advantages for powdery mildew control, with Cohere having slightly less effect than Hi-Wett (Table 2). This consistency between trials, despite differences in application methods, provides insight into the effectiveness of organosilicone surfactants when combined with sulfur. However, this consistency was notably absent in treatments sprayed with an AI nozzle. Though Hi-Wett appeared to provide some effect on leaves, control outcomes on fruit worsened with a surfactant. This could suggest an interference with the physics behind the spray technology. Applications to water-sensitive cards indicated a very different spray pattern when using the AI nozzles, with larger spots on cards separated by longer distances from spot to spot. The coverage was much more uniform when using cone nozzles. Again, if we had used a systemic fungicide, the results may have been different, but when using a contact material such as sulfur, uniform coverage is critical. Whatever the cause, in this trial the finer spray of the cone nozzle was able to outperform the coarse spray with the AI nozzle.

Impact. As fungicide restrictions become increasingly more stringent and fungicide resistance more widespread, it will become substantively more important to maximize the use of low-toxicity compounds that will not cause resistance in fungal populations. Vineyards are especially prone to resistance development in fungi, and large pesticide inputs and resulting environmental concerns currently threaten the industry. Sulfur applications for powdery mildew control provide one of the greatest single pesticide inputs in vineyard operations, making even small increases in efficacy valuable. In this study, we provide sufficient evidence for the utility of organosilicone non-ionic surfactant use for improving the efficacy of sulfur sprays within vineyard systems. Organosilicone surfactants, though varying in effect from product to product, can definitely increase the effectiveness of sulfur sprays targeted for grapevine powdery mildew. However, air induction nozzles were found to lack the efficacy of standard cone nozzles for this purpose. While cone nozzles responded positively with an incorporated surfactant, air induction nozzles did not. Perhaps the utility of AI nozzles lies in their drift-reduction capabilities for herbicidal sprays and not in their penetration enhancement for vineyard settings. The findings of this study provide relevant information of value to grape producers throughout the Southeast, as powdery mildew is one of the primary diseases of concern on *Vitis vinifera* grapes, and any information that can be utilized to enhance control of this disease will be valuable.

Table 1. Efficacy of sulfur and non-ionic organosilicone surfactants, alone and when tank-mixed, on grapevine powdery mildew management as measured by disease severity.

	Powdery mildew fruit severity[b]							Powdery mildew leaf severity[c]				
Treatment[a]	14 Jun	21 Jul	28 Jul	5 Jul	12 Jul	19 July	AUDPC[d]	28 Jun	5 Jul	12 Jul	19 Jul	AUDPC[d]
Untreated	94.5 a[ef]	94.5 a	98.2 a[f]	98.4 a	94.3 a	97.9 a	3371.2 a	22.8 a	52.1 a	55.6 a	55.8 a	1030.3 a
Hi-Wett	74.2 b	79.6 b	84.5 b	88.2 b	92.8 a	95.6 ab	2999.5 b	11.4 b	28.5 b	32.4 b	40.0 b	607.6 b
Cohere	55.3 b	73.9 b	83.3 b	83.2 bc	87.8 a	91.4 bc	2807.8 b	17.8 a	47.3 a	48.9 a	61.4 a	951.5 a
Silwet L-77	66.2 b	70.8 b	82.9 b	81.4 c	85.9 a	89.0 c	2787.9 b	7.3 b	18.4 c	27.7 b	37.2 b	478.9 b
LSD (P≤0.05)	5.4	12.1	1.5	6.2	9.2	5.6	277.13	5.5	8.7	12.3	13.8	179.9
Microthiol	16.6 a	29.3 ab	43.0 a	51.2 a	53.1 a	65.7 a	1525.7 a	6.2 ab	9.4 a	13.5 a	13.2 ab	229.6 a
Microthiol + Hi-Wett	15.3 a	29.8 ab	44.7 a	41.7 a	46.6 a	57.2 a	1394.4 a	4.7 ab	7.6 ab	8.5 b	8.8 b	160.7 b
Microthiol + Cohere	11.9 ab	33.0 a	41.8 a	51.7 a	54.8 a	66.8 a	1546.4 a	6.5 a	10.9 a	12.0 ab	14.9 a	235.8 a
Microthiol + Silwet L-77	7.6 b	16.3 b	22.8 b	27.2 b	31.0 b	31.9 b	820.2 b	3.7 b	4.1 b	7.6 b	8.6 b	126.4 b
LSD (P≤0.05)	7.5	14.8	15.6	13.5	9.1	11.9	334.3	2.7	4.2	5.0	4.8	60.5

[a] Treatment dates: 26 April (pre bloom), 13 May (bloom), 28 May (post bloom), 10 Jun (first cover), 25 Jun (second cover), 9 Jul (third cover)

[b] Percent fruit area covered by powdery mildew calculated from five clusters per plant.

[c] Percent leaf area covered by powdery mildew calculated from 25 leaves per plant.

[d] Area under the disease progress curve.

[e] Means followed by the same letter are not significantly different when using Fisher's protected LSD ($P \leq 0.05$).

[f] An arcsin transformation was used for analysis for this date for the surfactant-only treatments. Backtransformed means are shown.

Table 2. Effect of sulfur on powdery mildew control with different nozzles and added surfactants.

Treatment[a]		Powdery mildew fruit severity[bc]							Powdery mildew leaf severity[bc]				
		14 Jun	21 Jun	28 Jun	5 Jul	12 Jul	19 Jul	AUDPC[d]	28 Jun	5 Jul	12 Jun	19 Jul	AUDPC[d]
	Untreated	34.9	50.6	54.2	62.6	72.1	76.6	2067.3	5.9	18.8	16.7	24.4	355.1
Cone Nozzle	Microthiol	11.4 a	25.5 a	34.1 a	49.3 a	54.7 a	65.3 a	1413.3 a	2.4[f]	5.9[f]	4.9 a[e]	6.8[f]	109.7[f]
	Microthiol + Hi-Wett	11.0 a	18.2 a	22.8 b	32.9 b	44.3 ab	52.4 b	1046.6 b	1.8	3.6	3.1 b	3.8	66.9
	Microthiol + Cohere	9.5 a	19.8 a	18.7 b	32.6 b	40.3 b	56.1 b	1010.9 b	1.8	4.1	5.0 a	4.2	85.7
	LSD (P≤0.05)	3.8	7.3	10.1	12.3	10.7	4.3	236.6	-	-	0.15	-	-
Air Induction Nozzle	Microthiol	14.8 a	30.8 a	32.6 a	42.7 a	52.7 a	61.7 a	1379.1 a	5.7 a	10.7 a	7.8 a	11.6 a	190.3 a
	Microthiol + Hi-Wett	19.0 a	28.0 a	33.4 a	45.0 a	49.4 a	67.6 a	1394.7 a	4.5 a	7.7 a	3.6 b	7.7 a	121.2 b
	Microthiol + Cohere	21.3 a	37.3 a	40.1 a	49.2 a	56.1 a	72.1 a	1605.9 a	5.4 a	10.6 a	8.1 a	10.9 a	187.8 a
	LSD (P≤0.05)	8.9	15.6	14.5	8.5	19.2	13.6	417.4	2.9	4.2	3.1	4.3	63.6

[a] Treatment dates: 26 April (pre bloom), 13 May (bloom), 28 May (post bloom), 10 Jun (first cover), 25 Jun (second cover), 9 Jul (third cover)

[b] Powdery mildew severity (% area of leaves covered by powdery mildew) was calculated from 25 leaves and 5 clusters per treated plant

[c] Means followed by the same letter are not significantly different when comparing each pair using fishers protected LSD ($P \leq 0.05$).

[d] Area under the disease progress curve

[e] An arcsin transformation was used for analysis for this date for the surfactant-only treatments. Backtransformed means are shown.

[f] Statistics not shown due to high variability and insignificant ANOVA F-test. Data shown for reference only