Control of powdery mildew on pumpkin leaves by experimental and registered fungicides: 2007 trials

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I. Introduction

Powdery mildew, caused by the pathogens *Podosphaera xanthii, Golovinomyces orontii* and *G. cucurbitacearum*, is an important global disease of cucurbit crops, with many pumpkin, squash, cucumber, and melon varieties being particularly susceptible to infection (Jahn et al. 2002). The disease negatively impacts fruit yield (Bost et al. 1991) and is traditionally controlled mainly by the application of fungicides (McGrath et al. 1996). However, pathogen resistance to chemical fungicides, particularly benomyl and trimefon (a DMI), has been documented in the field (McGrath et al. 1996), suggesting that new materials or novel cultural practices may need to be eventually integrated into current control regimes.

We conducted two adjacent trials at the University of California, Davis Plant Pathology Farm (Solano Co., CA) to test the efficacy of different fungicide products against foliar occurrence of powdery mildew on pumpkin cultivars of *Cucurbita pepo*, a highly morphologically variable species of Cucurbitaceae (Robison and Decker-Walters 1997, Paris 2001). In trial I, we evaluated different concentrations of the unregistered materials Topguard (active ingredient = flutriafol), LEM17 (penthiopyrad), and SilverDYNE (colloidal silver). Trial I also included the registered fungicides Pristine (boscalid + pyraclostrobin), Procure (triflumizole) and 2 combinations of Procure and Quintec (a rotation and tank mixture). In Trial II we tested the efficacy of microbial-based biofungicides and organic products. Treatments consisted of unsprayed and water only controls, two concentrations of Actinovate (*Streptomyces lydicus*), two concentrations of Sporan (plant-derived aromatic oils) and Companion (*Bacillus subtilis*) applied with and without Quintec. Following a 6 week test period, we determined disease incidence and severity on upper and lower leaf surfaces in both trials.

II. Materials and Methods

A. Layout of Trials

Experimental design	Randomized complete block design with 6 replicates (Trial 1). Randomized complete block design with 9 replicates (Trial 2).		
Application method	Tank sprayers.		
Plot length	14 feet	Row spacing	16 feet
No. plants/plot	≤ 8	Plot area	112 ft^2 (14 ft by 8 ft)
Plant spacing	variable	Area/6 plots (Trial 1) Area/9 plots (Trial 2)	672 ft^2 (= 0.0155 acres) 1008 ft^2 (= 0.0232 acres)
Applications began	September 2007	Applications ended	October 2007

Trial 1	Volume water/acre	Volume water/treatment	Volume water/treatment (including additional 10%)
	150 gallons	2.3 gallons	2.6 gallons

Trial 2	Volume water/acre	Volume water/treatment	Volume water/treatment (including additional 10%)
	100 gallons	2.3 gallons	2.6 gallons

B. Experimental chronology

Date	Activity
13 August 2007	Seeds planted.
16 August	Crop first irrigated.
31 October	Spraying completed.
1-7 November	Disease evaluated in trial I.
2-6 November	Disease evaluated in trial II.

C. Experimental treatments

Trial I

Host: *Cucurbita pepo*, Merlin variety

Product	Flag	Interval (d)	FP/Acre	FP/Treatment*
Unsprayed control	Pu+Br	none	none	none
Topguard	K	14-17	10.0 fl oz	5.1 ml
Topguard	Br+Br	14-17	14.0 fl oz	7.0 ml
Procure + Silwet L-77	Pu	14-17	8.0 fl oz + 0.03%	4.1 ml + 2.9 ml (150 gal)
Procure + Quintec + Silwet L-77	R	14-17	4.0 fl oz + 4.0 fl oz + 0.03%	2.0 ml + 2.0 ml + 2.9 ml (150 gal)
Quintec alt Procure + Silwet L-77	G+K	14-17	6.0 fl oz alt 8.0 fl oz + 0.03%	3.1 ml alt 4.1 ml + 2.9 ml (150 gal)
Pristine	Br	12	15.0 oz	7.3 g
LEM 17 20EC	K+W	12	2.0 oz ai	4.8 ml
LEM 17 20EC	G	12	3.5 oz ai	8.5 ml
LEM 17 20EC	K+K	12	5.0 oz ai	12.1 ml
LEM 17 20SC	W	12	2.0 oz ai	4.8 ml
LEM 17 20SC	K+K+G	12	3.5 oz ai	8.5 ml
LEM 17 20SC	B	12	5.0 oz ai	12.1 ml
SilverDYNE	R+K	7	0.1%	9.6 ml

Notes: * These quantities include an extra 10% of product to account for unsprayed residual liquid left in tanks. FP = formulated product; alt = alternated with.

Trial II

Host: *Cucurbita pepo*, Wee-Be-Little variety

Product	Flag	Interval (d)	FP/Acre	FP/Treatment*
Unsprayed control	B	none	none	
Water control	Y	7	-	Water only: 2.6 gallons
Sporan + Silwet L-77	R+R	14	4 pt 0.03 %	48.4 ml + 2.9 ml (100gal)
Sporan + Silwet L-77	P+B	14	6 pt 0.03 %	72.5 ml + 2.9 ml (100gal)
Actinovate	Y+R	7	3 oz	2.2 g
Actinovate	Y+Y	7	6 oz	4.4 g
Companion	Y+B	7	3 qt	72.5 ml
Companion + Quintec	W	7	3 qt + 3 fl oz	72.5 ml + 2.3 ml
Quintec	R	7	3 fl oz	2.3 ml

Notes: * These quantities include an extra 10% of product to account for unsprayed residual liquid left in tanks. FP = formulated product; alt = alternated with.

The treatments described in this report were conducted for experimental purposes only and crops treated in a similar manner may not be suitable for commercial or other use.

D. Fungicide applications

Trial I

Dates of application

Treatment	Sep 28	Oct 3	Oct 10	Oct 15	Oct 17	Oct 22	Oct 24	Oct 29	Oct 31	Nov 1–7
SilverDYNE, 0.1%	X	X	X		X		X		X	DISEASE EVALUATION
Topguard, 10 fl oz	X			X				X		
Topguard, 14 fl oz	X			X				X		
Pristine, 15 oz	X		X			X				
Procure, 8 fl oz	X			X				X		
Procure + Quintec	X			X				X		
Quintec, 6 fl oz alt	X							X		
Procure, 8 fl oz				X						
LEM17 SC, 2 oz ai	X		X			X				
LEM17 SC, 3.5 oz ai	X		X			X				
LEM17 SC, 5 oz ai	X		X			X				
LEM17 EC, 2 oz ai	X		X			X				
LEM17 EC, 3.5 oz ai	X		X			X				
LEM17 EC, 5 oz ai	X		X			X				
	Some plants flowering		Plants in flower; fruits develpoing							

Trial II

Dates of application

Treatment	September 26	October 3	October 10	October 17	October 24	October 31	November 1–6
Water control	X	X	X	X	X	X	DISEASE EVALUATION
Sporan, 4 pt	X		X		X		
Sporan, 6 pt	X		X		X		
Actinovate, 3 oz/acre	X	X	X	X	X	X	
Actinovate, 6 oz/acre	X	X	X	X	X	X	
Companion, 3 qt/acre	X	X	X	X	X	X	
Companion + Quintec	X	X	X	X	X	X	
Quintec, 3 fl oz	X	X	X	X	X	X	
	Plants not yet in flower	Some plants in flower	Plants in flower; some with fruit				

E. Trial maps

Trial I

Block					
Block 1	Pu+Br	K	Br+Br	Pu	R
	-	G+K	Br	K+W	G
	K+K	W	K+K+G	B	R+K
Block 2	-	K+K+G	B	R	K
	G	Br+Br	Pu+Br	R+K	Pu
	Br	G+K	K+K	K+W	W
Block 3	W	G	B	K+W	Pu
	K+K+G	Br+Br	Pu+Br	R	G+K
	K	-	K+K	Br	R+K
Block 4	Pu+Br	G+K	Pu	-	K+W
	R	Br	R+K	B	K+K
	W	G	K+K+G	K	Br+Br
Block 5	R+K	K+K+G	K	R	-
	K+W	G	B	G+K	Br
	W	Br+Br	K+K	Pu	Pu+Br
Block 6	-	K+W	B	Br	Br+Br
	Pu	K	R	K+K+G	W
	Pu+Br	K+K	G	R+K	G+K

Trial II

						Block
B	Y	Y+R	Y+Y	Y+B	W+B	Block 1
P	O+B	R	W	R+R	P+B	
Y	R+R	O+B	Y+R	B	Y+Y	Block 2
P	W	Y+B	P+B	W+B	R	
Y+B	Y+R	P+B	O+B	P	W	Block 3
R+R	B	W+B	Y+Y	R	Y	
Y+R	R+R	Y	Y+B	O+B	Y+Y	Block 4
W+B	P+B	R	P	W	B	
B	Y+R	R+R	W	P	P+B	Block 5
Y+B	O+B	R	Y	W+B	Y+Y	
Y+Y	O+B	W+B	Y	R	Y+R	Block 6
B	P+B	P	R+R	Y+B	W	
P+B	Y+R	P	Y+Y	O+B	W	Block 7
R	B	W+B	Y+B	R+R	Y	
R+R	Y+B	R	P+B	O+B	B	Block 8
P	W+B	Y+Y	W	Y	Y+R	
R	B	P	Y+Y	W	Y	Block 9
P+B	Y+B	R+R	W+B	Y+R	O+B	

F. Disease evaluation and statistical analysis

Field evaluation of disease	Approximately 15-30 (usually about 30) haphazardly-collected leaves were rated for disease incidence in each plot (incidence is defined as the proportion of leaves with at least one mildew colony present). Disease severity was also assessed on about 10 leaves per plot and estimated as colony density (mean number of colonies per cm^2) by placing small paper quadrats on the leaf, centered over the upper lobe. Incidence and severity estimates were collected on both upper and lower leaf surfaces.
Statistical evaluation	Raw data is presented as means with 90% confidence intervals. Additionally, treatment effect sizes (ES) were determined for each fungicide relative to the unsprayed control in for severity data in each trial. ES were calculated using Hedges Response Ratio, $L = \ln(m_{trt}/m_{control})$ where m_{trt} and $m_{control}$ are treated and control population means (Hedges et al. 1999). Larger negative values of L correspond with greater reductions in disease severity by a given treatment. (In most ES calculations, mean to standard error ratios were less than three for the smaller member of a pair of means, suggesting that L may have a small bias [Hedges et al. 1999]).

III. Results and discussion

Following 6 weeks of fungicide application, powdery mildew colonies were ubiquitous in both trials. Disease development, however, seemed to be faster in Merlin plants than in the Wee-Be-Little variety, appearing soon after the initiation of fungicide treatments. In both pumpkin varieties, powdery mildew colonies were present on both the upper and lower surface of leaves (Figure 1).

Trial I. Disease incidence across the trial was high, with 90% of leaves in untreated plots showing at least some colony presence (Figure 2). The upper surface of leaves in several fungicide treatments showed at least 50% disease incidence, but infection dropped to 10-20% in the best treatments (Procure, Procure + Quintec and LEM17 EC). In many treatments, disease incidence was higher on the lower leaf surface, although substantial overlap in confidence intervals suggests these differences were not statistically significant. The generally good performance of Procure and Quintec treatments (and somewhat more modest performance of Topguard applications) agrees well with results obtained during fall 2006 with similar fungicide treatments (Janousek et al. 2006).

Disease severity (measured as the density of colonies on the leaf surface) was also high in untreated plants (Figure 3). Upper leaf surface disease severity was greatly reduced in all fungicide treatments except SilverDYNE applied at 0.1%. Leaves treated with Procure + Quintec showed disease had zero colony density (the ~10% frequency of disease incidence observed in this treatment occurred because colonies appeared outside of the upper lobe of the leaf where severity was measured, or on the additional leaves that were not evaluated for severity).

Effect size data on disease severity also suggested that all treatments (except SilverDYNE) showed significantly less disease than control plots (Figure 4). Importantly, the ES data better elucidate differences among fungicide treatments, suggesting that for the upper leaf surface, most LEM17 treatments and both Procure treatments resulted in the lowest density of pathogen colonies.

Trial II. Disease incidence in the Wee-Be-Little pumpkins approached 80% on the upper leaf surfaces of unsprayed plants and exceeded 50% on the upper leaf surface of most treatments (Figure 5). Like the Merlin variety, disease incidence generally appeared to be greater on the lower surfaces of leaves. Quintec applied alone or with the biofungicide Companion, greatly reduced disease incidence and markedly outperformed other biofungicides and organic products.

Severity data suggested that all biofungicide and oil treatments reduced colony density relative to the control at least by a factor of three (Figure 6). Nevertheless, leaf-to-leaf variation in severity was high, resulting in large confidence intervals. Quintec and Companion + Quintec treated plants showed the greatest reduction in disease severity. However, ES data also suggested that for upper leaf surfaces, reduction of disease severity was significantly different from zero for both Sporan treatments, Companion, and Actinovate applied at 3 oz/acre (Figure 7). Companion (*Bacillus subtilis*) appeared to be the best organic product.

Overall, ES estimates were much larger for most synthetic fungicides in trials I and II relative to the organic products in trial II suggesting that synthetic products generally outperform organic materials. Companion gave the best control of the organic materials tested and it disease reduction approximately matched that of Topguard (compare Figures 4 and 7).

Figure 1. Powdery mildew colonies on leaves of Merlin (left) and Wee-Be-Little (right) varieties.

Figure 2. Powdery mildew incidence on upper and lower leaf surfaces in trial I treatments (means ± 90% confidence intervals).

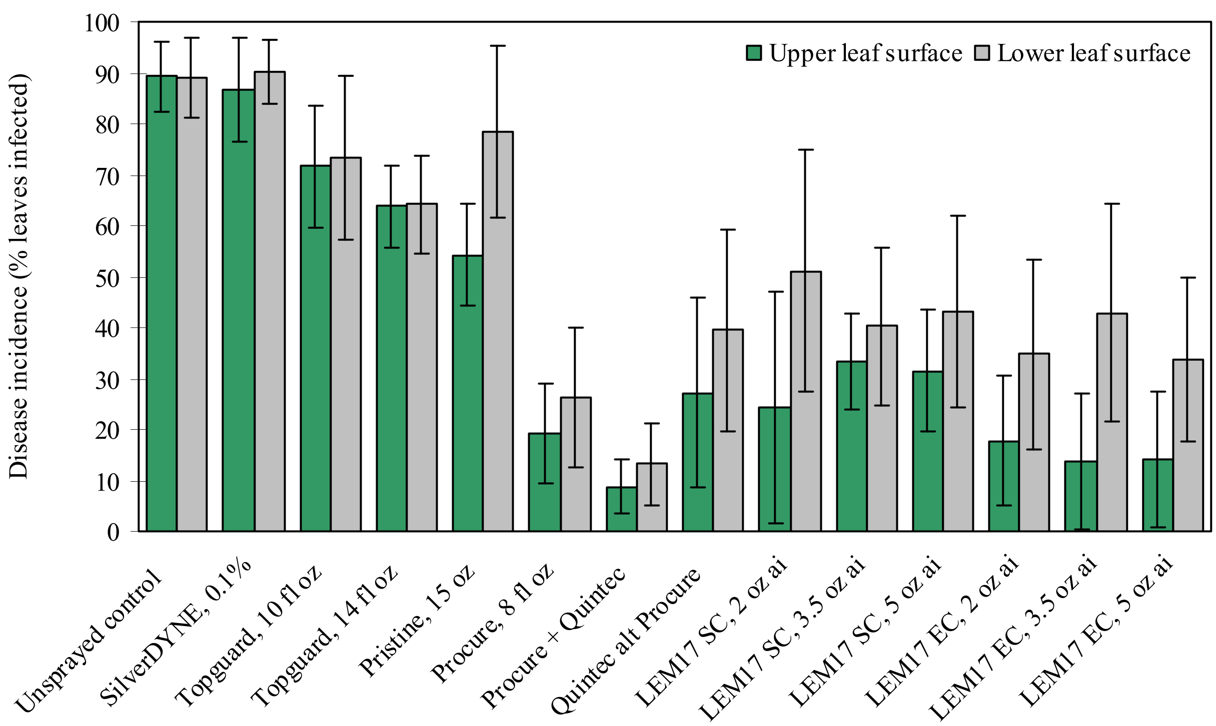


Figure 3. Disease severity (colony density per cm^2) on upper and lower leaf surfaces in trial I treatments (means ± 90% confidence intervals).

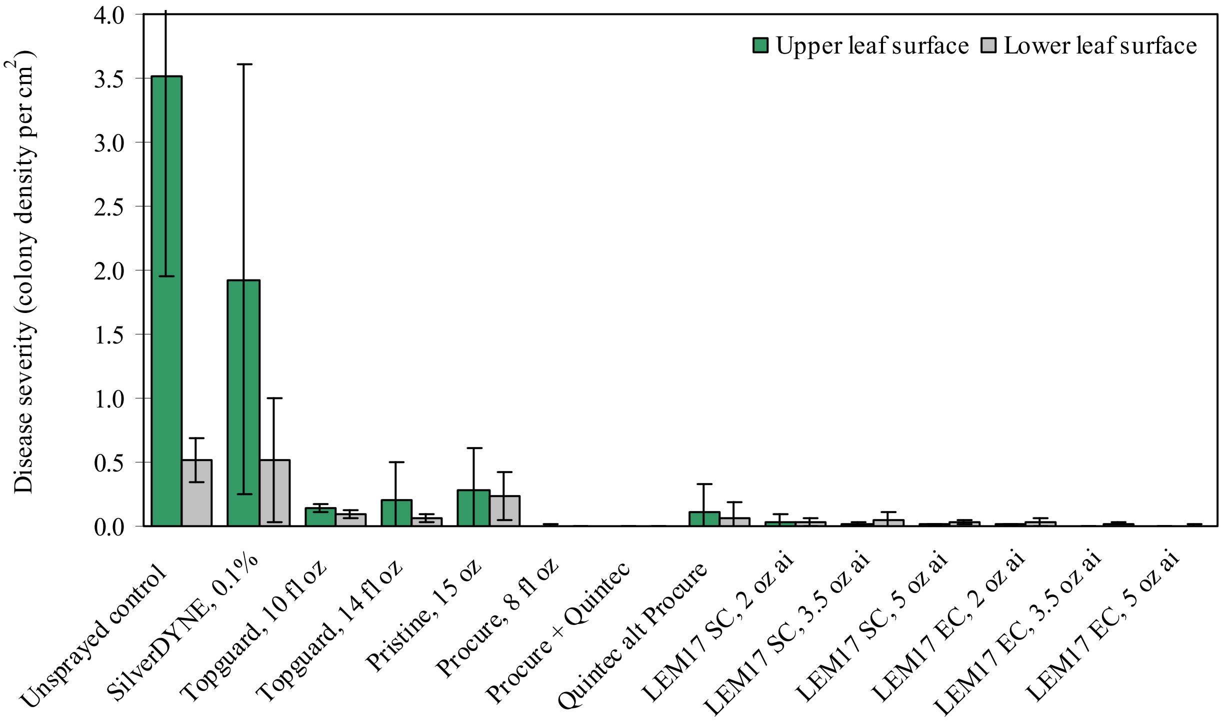


Figure 4. Effect size estimates (*L*) for trial I treatments on upper and lower leaf surfaces (± 90% confidence intervals). Increasingly negative ES estimates show greater reductions in powdery mildew severity compared with untreated leaves. No estimate of *L* was possible for the disease severity on the upper and lower leaf surfaces of the Procure + Quintec treatment because severity was 0.

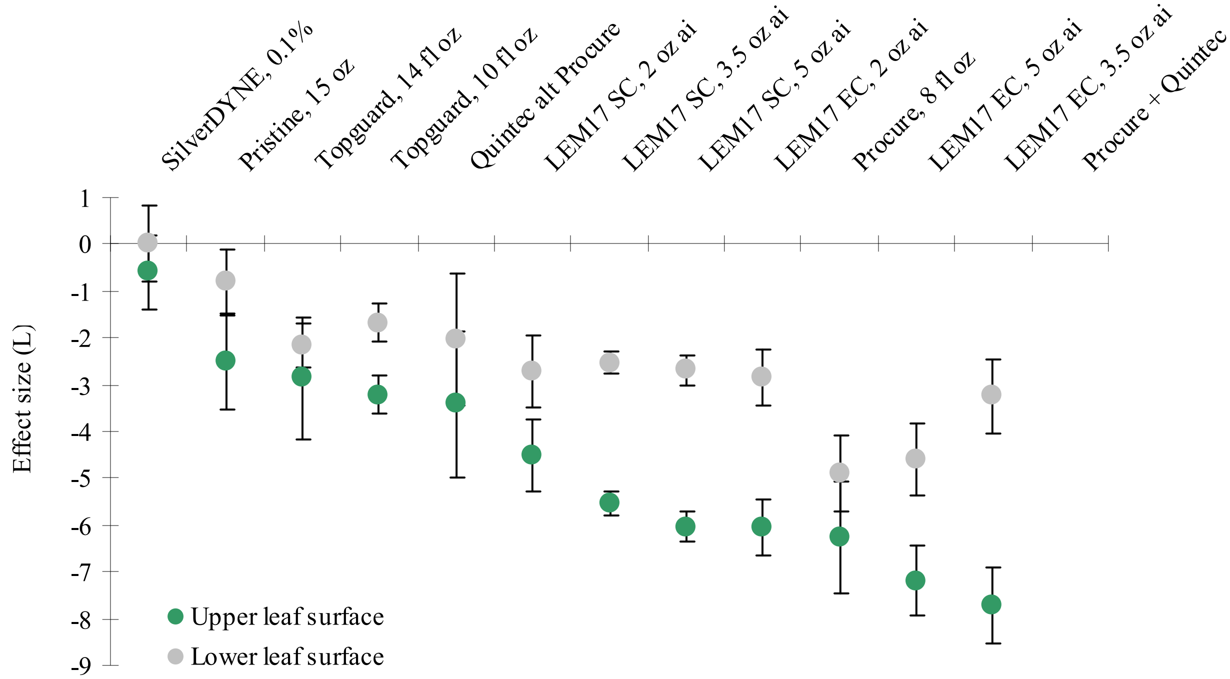


Figure 5. Powdery mildew incidence on upper and lower leaf surfaces in trial II treatments (means ± 90% confidence intervals).

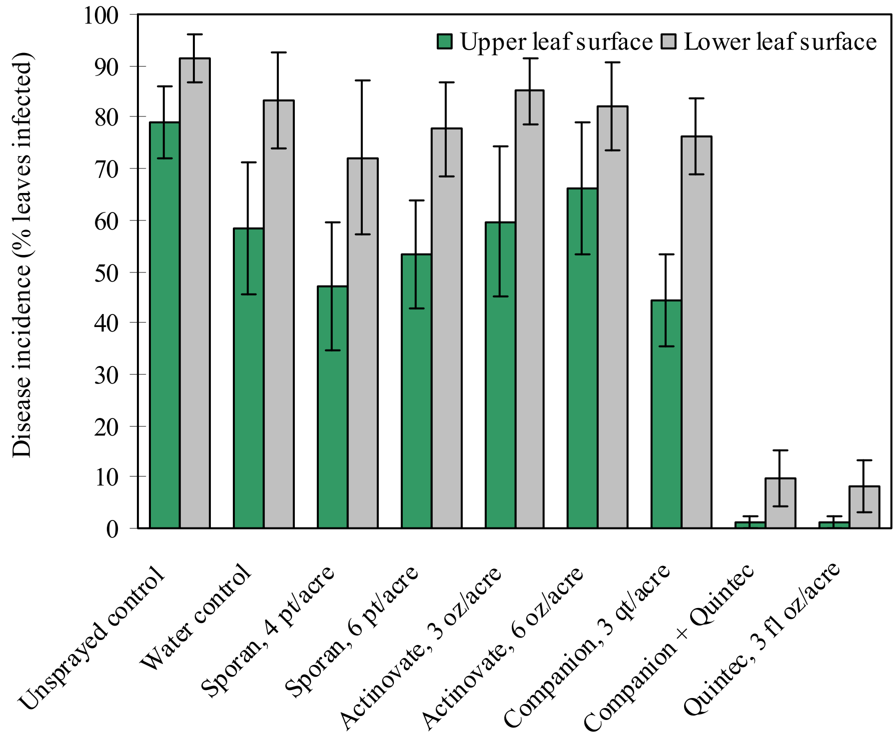


Figure 6. Powdery mildew severity (colony density per cm^2 of leaf surface) on upper and lower leaf surfaces in trial II treatments (means ± 90% confidence intervals).

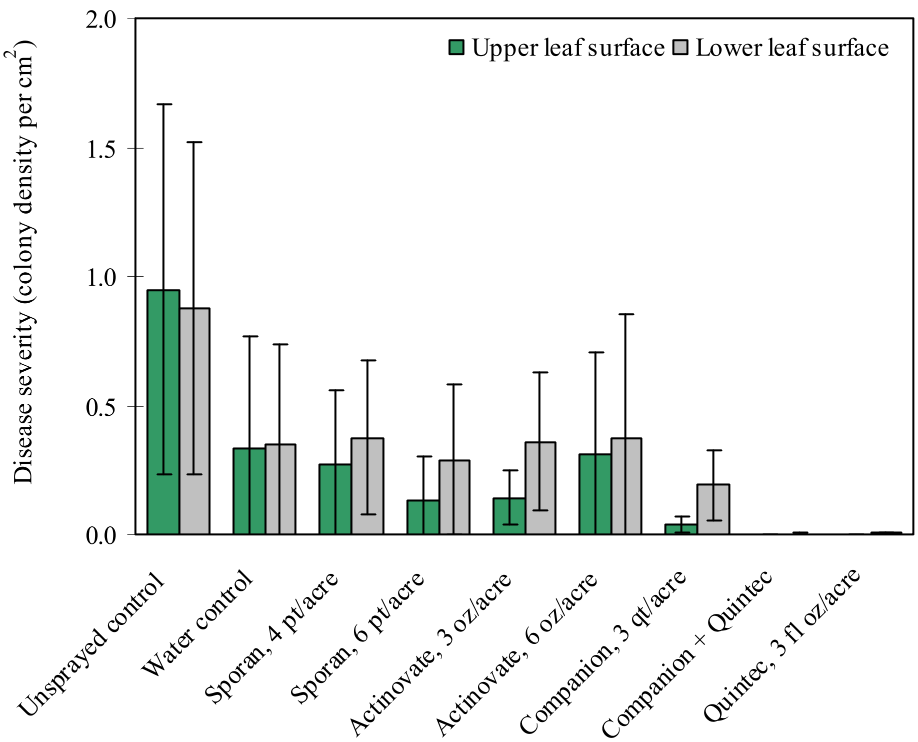
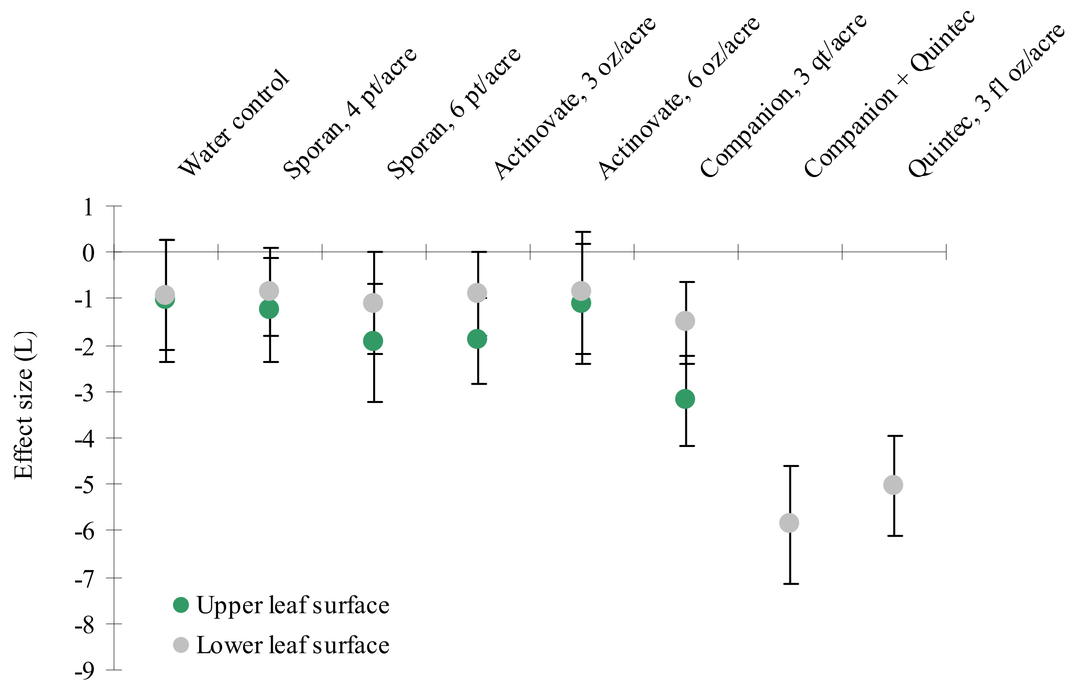


Figure 7. Effect size estimates (*L*) for trial II treatments (magnitude of treatment reduction of powdery mildew severity) on upper and lower leaf surfaces (± 90% confidence intervals). No estimate of *L* was possible for the disease severity on the lower leaf surface of Quintec and Quintec + Companion treatments because severity was 0.



IV. Acknowledgements

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V. References

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VI. Appendix: materials

Chemical products

Product	Active ingredient and concentration
LEM17 20EC	penthiopyrad (20%)
LEM17 20SC	penthiopyrad (20%)
Pristine 38WDG	boscalid (25.2%) + pyraclostrobin (12.8%)
Procure 480SC	triflumizole (480 g/L)
Quintec 2.08SC	quinoxyfen (300 g/L)
SilverDYNE	colloidal silver (0.39%)
Silwet L-77	trisilicone ethoxylate (>97%)
Sporan	clove oil (10%) + rosemary oil (18%) + thyme oil (10%)
Topguard SC	flutriafol (125 g/L)

Biological products

Product	Organism and concentration
Actinovate	*Streptomyces lydicus* (1 x 10^7 cfu/g)
Companion	*Bacillus subtilis* GB03 (2.7 x 10^7 cfu/ml)

Appendix references: 1. Pscheidt, J.W. and C. M. Ocamb (editors). 2006. *2006 Pacific Northwest Plant Disease Management Handbook.* Oregon State University. 607 pp. 2. www.agraquest.com 3. www.growthproducts.com