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I. Abstract

Powdery mildew of cucurbits, caused by the pathogen *Podosphaera xanthii* or other Erysiphaceae, is an important foliar disease in California. Disease is often managed by application of synthetic fungicides. We tested 11 fungicide treatment regimes to assess control of powdery mildew on pumpkin in a field trial in northern California. Foliage was sprayed weekly or biweekly; two biocontrol treatments were also soil-drenched prior to foliar applications. Disease attained high levels of incidence (nearly 100% of leaves infected) and severity (from 0.97 to 2.2 colonies per cm^2) on the upper surface of leaves in unsprayed/undrenched, unsprayed/water drenched and water-sprayed controls. Biological and organic treatments, including Actinovate (*Streptomyces lydicus* WYEC108) and Phyton 016-B (copper sulfate pentahydrate), did not effectively control the disease. Treatment with Rally alternated with Quintec (myclobutanil/quinoxyfen), LEM17 (penthiopyrad), LEM17 + other synthetics, or Inspire Super (difenoconazole + cyprodinil) however, lowered disease incidence on the upper surface of leaves and gave up to several fold reductions in colony density relative to plants sprayed with water.

II. Introduction

Powdery mildew of cucurbits is caused by several species of the Erysiphaceae, including *Podosphaera xanthii* (= *Sphaerotheca fulginea*) (McGrath and Thomas 1996). Disease effects on the host include reductions in fruit yield (Bost et al. 1991) and premature tissue loss in leaves (McGrath and Thomas 1996). Favorable environmental conditions, including temperatures between 20 and 27°C, can lead to rapid proliferation of the pathogen (McGrath and Thomas 1996).

Powdery mildew management practices for cucurbit crops include disease resistant cultivars and application of fungicides (McGrath and Thomas 1996). No-tillage practices may also lead to a modest reduction in disease (Everts 2002). Typical synthetic fungicides used for control of cucurbit powdery mildew include chlorothalonil, trifloxystrobin, azoxystrobin, myclobutanil and trimefon (McGrath and Shishkoff 2000, Shishkoff and McGrath 2002, McGrath and Shishkoff 2003, Pscheidt and Ocamb 2008). Other products such as oils, potassium bicarbonate, microbial antagonists, and even milk can be effective at reducing disease impacts (McGrath and Shishkoff 1999, 2000, Ferrandino and Smith 2007). In California, successful management of the disease has been attained with 14-17 day applications of triflumizole and triflumizole combined or rotated with quinoxyfen (Janousek et al. 2008). Slight reductions in disease were achieved with weekly applications of the biofungicides *Streptomyces lydicus* WYEC108 and *Bacillus subtilis* GB03 (Janousek et al. 2008).

We conducted a field trial at the UC Davis plant pathology experimental farm (Solano Co., CA) during fall 2008 to assess biological and chemical fungicide effects on disease in a mildew-susceptible variety of pumpkins (*Cucurbita pepo* cv. Small Sugar). Modest temperatures (average daily temperatures ranged from 9.8 to 28.9°C; CIMIS Davis weather station data from wwwcimis.water.ca.gov) and generally dry conditions (only one period of significant rainfall occurred from 30 October to 3 November; CIMIS data) were conducive to powdery mildew development. Foliar treatments started just after plants began producing runners, about 6 weeks following planting. Two treatments of EA-7402 were also seed coated with dried product and then soil drenched at the seedling and rosette stages prior to foliar fungicide applications. Following six weeks of foliar application of biological and chemical fungicides, disease incidence and severity (colony density) was assessed on the upper and lower surface of pumpkin leaves in all treatments.

III. Materials and Methods

A. Layout of the trial

Experimental design	Complete randomized block design with 6 replicates.		
Application method	Hand gun sprayers mounted on 25-50 gallon tank sprayers.		
Plot length	14 feet	Bed spacing	16 feet
No. plants/plot	Approximately 7 - 8	Plot area	112 ft^2 (14 ft by 8 ft)
Plant spacing	ca 1.5 ft, but variable	Area/6 plots	672 ft^2 (=0.0154 acres)
Application period	8 September – 17 September 2008 (soil drenches) 6 October 2008 – 13 November 2008 (foliar spraying)		
Volume water applied	150 gallons/acre (=2.3 gallons per treatment)		

B. Experimental treatments

Trt no.	Flag	Product	Interval (d)	FP/Acre	FP/Treatment	Notes
1	O+K	Unsprayed, undrenched control	none	none	none	
2	W	Unsprayed control, water drenched	none	none	none	With 2 soil drenches (water only).
3	P+K	Water control	7	none	none	No water drenches; but water sprayed.
4	Br	Actinovate AG + ThermX-70	7	6 oz 4 fl oz/100 gal	2.6 g 2.7 ml	
5	B+K	Actinovate AG + Whey	7	6 oz 6 lbs	2.6 g 41.9 g	
6	R	EA-7408 + Silwet L-77	7	1.5 oz 3 fl oz	0.65 g 1.4 ml	With 2 soil drenches.
7	K	EA-7408 + Silwet L-77	7	3.0 oz 3 fl oz	1.3 g 1.4 ml	With 2 soil drenches.
8	R+K	Phyton-016-B	7	25 fl oz	11.4 ml	
9	G	LEM17 SC	14	16.8 fl oz	7.7 ml	
10	P	LEM17 SC	14	24.0 fl oz	10.9 ml	
11	O	LEM17 SC alt Quintec 2.08 SC	14	16.8 fl oz 4.0 fl oz	7.7 ml 1.8 ml	
12	B	Rally alt LEM17 SC	14	5.0 oz 16.8 fl oz	2.2 g 7.7 ml	
13	Pu	Rally alt Quintec	14	5.0 oz 4.0 fl oz	2.2 g 1.8 ml	
14	Y	Inspire Super	14	20 fl oz	9.1 ml	

Notes: FP = formulated product; alt = alternated with.

C. Trial map

Block 1	Block 2	Block 3	Block 4	Bock 5	Block 6
R+K	W	W	P+K	W	O+K
P	Y	R	P	G	R+K
Pu	K	Br	B+K	R+K	P
B	O+K	B+K	R+K	P	G
K	G	K	W	Br	K
R	O	R+K	Br	R	B+K
O+K	R+K	P+K	Y	B	Br
W	B+K	G	Pu	K	W
Y	R	P	K	Pu	P+K
P+K	P	O	O	P+K	O
Br	P+K	B	O+K	B+K	Y
O	Pu	Pu	R	O	Pu
B+K	B	O+K	G	Y	R
G	Br	Y	B	O+K	B

D. Experimental chronology

Date	Event
26 August 2008	Seeds planted in 6 rows. Treatments 4 and 5 were pretreated with a dry coating of EA-7408 prior to planting. All other seeds were not fungicide treated.
24 September	Plots thinned to about 7 plants per plot.
18-21 November	Trial evaluated for disease.
Rows were furrow irrigated approximately every two weeks.	

E. Fungicide applications

A	M 8 September 2008	The rhizosphere of seedlings in treatments 5 and 6 were drenched with EA-7408. Treatment 2 plants were each drenched with 50 ml water.	Rhizosphere drench: 3 oz/10 gallons	Seedling stage.
B	W 17 September 2008	The rhizosphere of plants in treatments 5 and 6 were drenched with EA-7408. Treatment 2 plants were each drenched with 50 ml water.	Rhizosphere drench: 3 oz/10 gallons	Small plants of several leaves.
C	M 6 October 2008	Sprayed treatments 3-14.	150 gallons/acre	Numerous plants with runners; a very few in flower.
D	Tu 14 October 2008	Sprayed treatments 3-8.	150 gallons/acre	Plants running and in flower. Some disease observed in area on 13 Oct.
E	W 22 October 2008	Sprayed treatments 3-14.	150 gallons/acre	Plants in flower; small fruits present.
F	W 29 October 2008	Sprayed treatments 3-8.	150 gallons/acre	Plants in flower; small fruits present.
G	F 7 November 2008	Sprayed treatments 3-14.	150 gallons/acre	Fruits present; some leaves scenescing for some time now.
H	Th 13 November 2008	Sprayed treatments 3-8.	150 gallons/acre	Fruits present; Some leaves scenescing. Mildew extensive on some leaves.

F. Disease evaluation and statistical analysis

Disease evaluation	Incidence and severity were determined on both the upper and lower surface of leaves from 18-21 November. About 30 randomly-collected leaves per plot were rated for disease incidence (the proportion of leaves with at least some disease present); disease severity was assessed on 10 leaves per plot by estimating colony density (number of colonies per cm^2) within the center of the terminal lobe of the leaf. When discreet colonies were too difficult to count, percent coverage of mildew on the leaf surface was estimated; this was then changed into a density by using the following conversions: 19.5 colonies cm^{-1} for upper surfaces and 9.0 colonies cm^{-1} for lower surfaces (based on average colony size of 5.1 and 11.1 mm^2 on upper and lower surfaces of untreated leaves).
Statistical analysis	Incidence and severity data are presented as means ± 90% confidence intervals (Rao 1998). To further illustrate differences between treated plants and the unsprayed/un-innoculated control, effect sizes were calculated for each treatment using Hedges response ratio (Hedges et al. 1999): $L_i = \ln(\text{mean}_{trt}/\text{mean}_{control})$. 90% confidence intervals on each L_i were computed following procedures in Hedges et al. (1999).

IV. Results and discussion

Powdery mildew was first observed on, or just a few days prior to, 13 October, about one week following the initiation of foliar fungicide applications. Disease progression was rapid. On October 30, a preliminary census of disease incidence in the field was conducted by observing the upper leaf surface of 20-25 leaves in each plot. Disease incidence in most plots in the experiment exceeded zero at this time, and at least half of the plots in the best treatments (Rally alt Quintec and all LEM17 treatments) showed at least some level of disease.

Full assessment of disease was conducted from 18 to 21 November. At this time, differences in disease levels among treatments were readily apparent visually (Figure 1). Within more diseased plots, mildew colonies were distributed randomly, with some leaves hosting many colonies, and others showing minimal disease. Disease incidence was high across the trial, indicating a tendency for leaves to often host at least one mildew colony (Figure 2). Incidence approached 100% on both the upper and lower surface of leaves in all control treatments, in all biological treatments (Actinovate, EA-7408), and in Phyton 016-B-treated plots. Incidence on the upper surface of leaves was substantially reduced (below 50%) for all synthetic fungicide treatments. There was a trend towards higher incidence on the lower surface of synthetically-treated leaves, but the magnitude of difference between upper and lower colony incidence was dependent on treatment. Incidence in Inspire Super-treated plots was twice as high on the lower surface (86% vs. 43%).

Mean disease severity was high on the upper surface of leaves in unsprayed and undrenched, unsprayed but drenched, and water-treated control treatments (1-2 colonies cm^{-2}; Figure 3). Average disease severity may have been even higher on the upper surface of EA-7402 treated leaves, but very high leaf-to-leaf variability in colony density was also evident. Disease severity was lowest with synthetic fungicide treatments. In treatments showing the highest overall levels of disease severity, severity tended to be higher on the upper surface of leaves rather than on the lower surface of leaves. However, this pattern may reflect an artifact of how densities were estimated for the most severely-infected leaves (lower leaf surfaces hosted larger colonies and thus smaller densities at 100% coverage).

Effect size statistics suggested that only synthetic fungicides significantly reduced powdery mildew severity relative to untreated plants (Figure 4). Disease severity was not reduced by Phyton 016-B or by any of the biological treatments. Maximum disease reduction on the upper surface of leaves was achieved with Rally alternated with Quintec.

Our overall results are consistent with synthetic and biofungicide effects on cucurbit mildew in similar experiments conducted at the same site in California (Janousek et al. 2008). Despite weekly application of microbial antagonists, these products were unable to control the spread of powdery mildew colonies. Microbial antagonists are more likely to show better performance if used in combination with synthetic materials (McGrath and Shishkoff 1999). Quintec, Rally, and LEM17 appear to consistently give substantial reductions in powdery mildew (Janousek et al. 2006, 2008).

Figure 1. (A) Field and microscopic view (inset) of powdery mildew colonies on unsprayed and undrenched leaves. Bar = 50µm. (B) Field view of leaves in a plot treated with Rally alternated with Quintec.

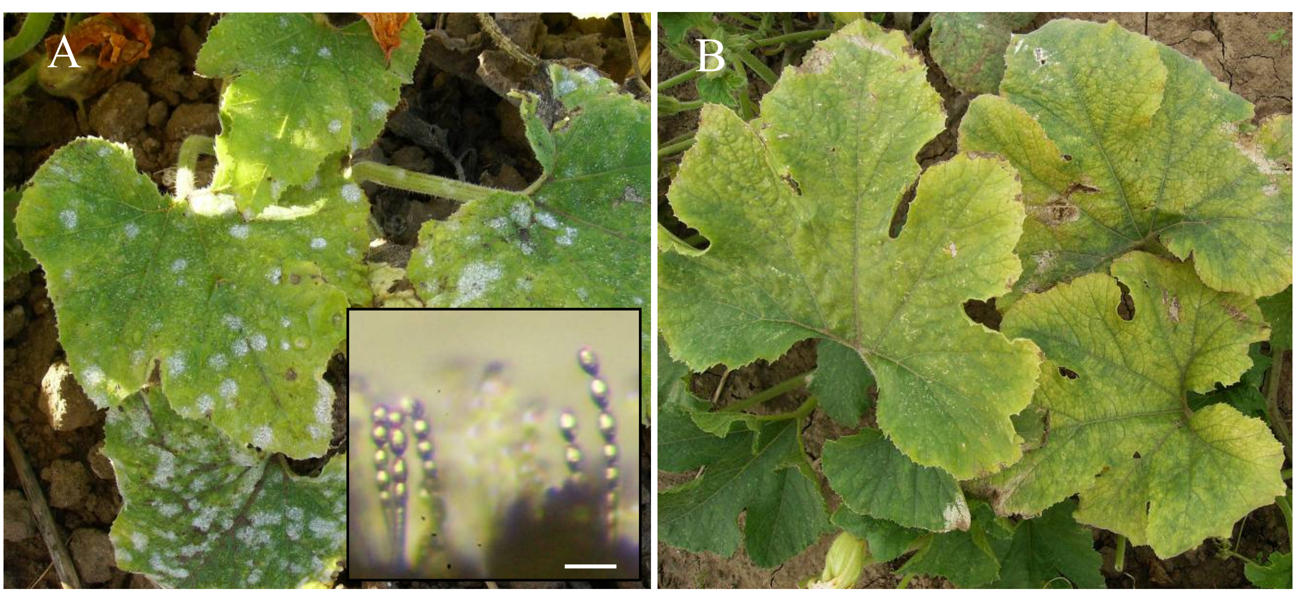


Figure 2. Disease incidence on the upper and lower surface of leaves at the time of disease evaluation (6 weeks following the initiation of spraying). Data in means ±90% confidence intervals.

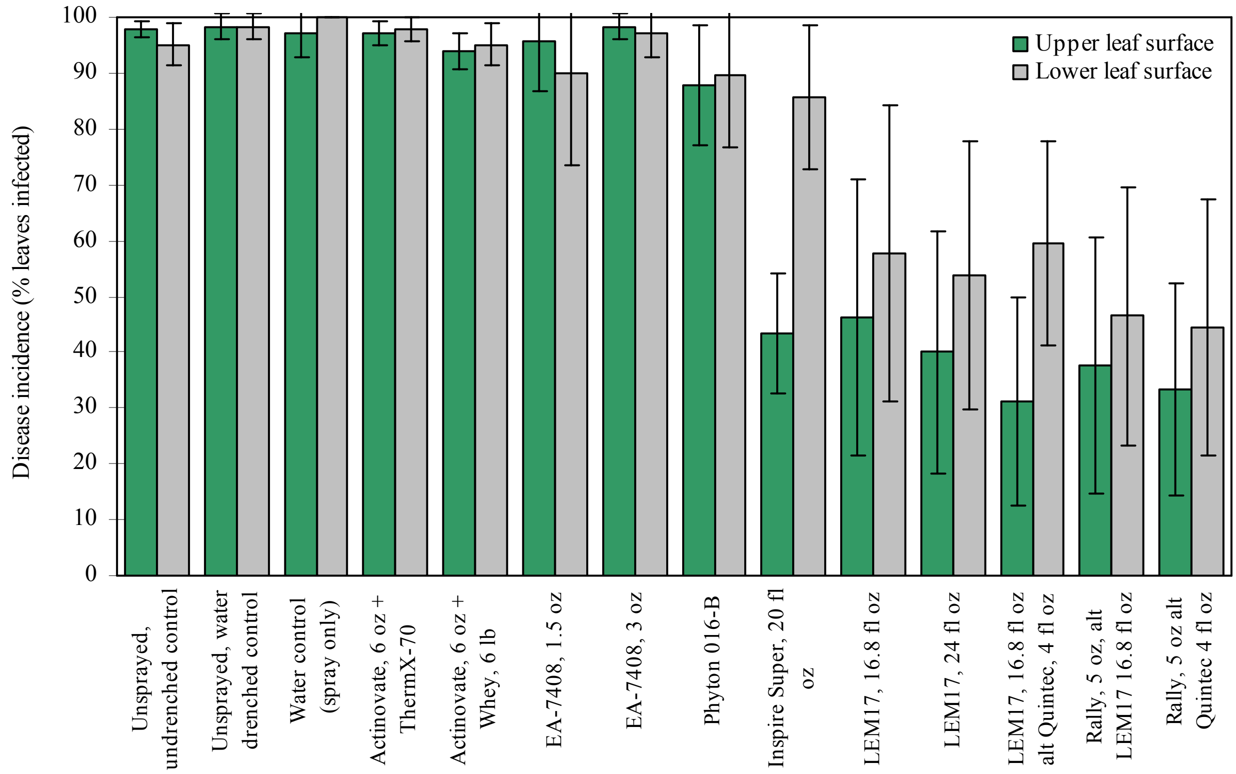


Figure 3. Disease severity (number of colonies per cm^2) on the upper and lower surface of leaves at the time of disease evaluation (6 weeks following the initiation of spraying). Data in means ± 90% confidence intervals.

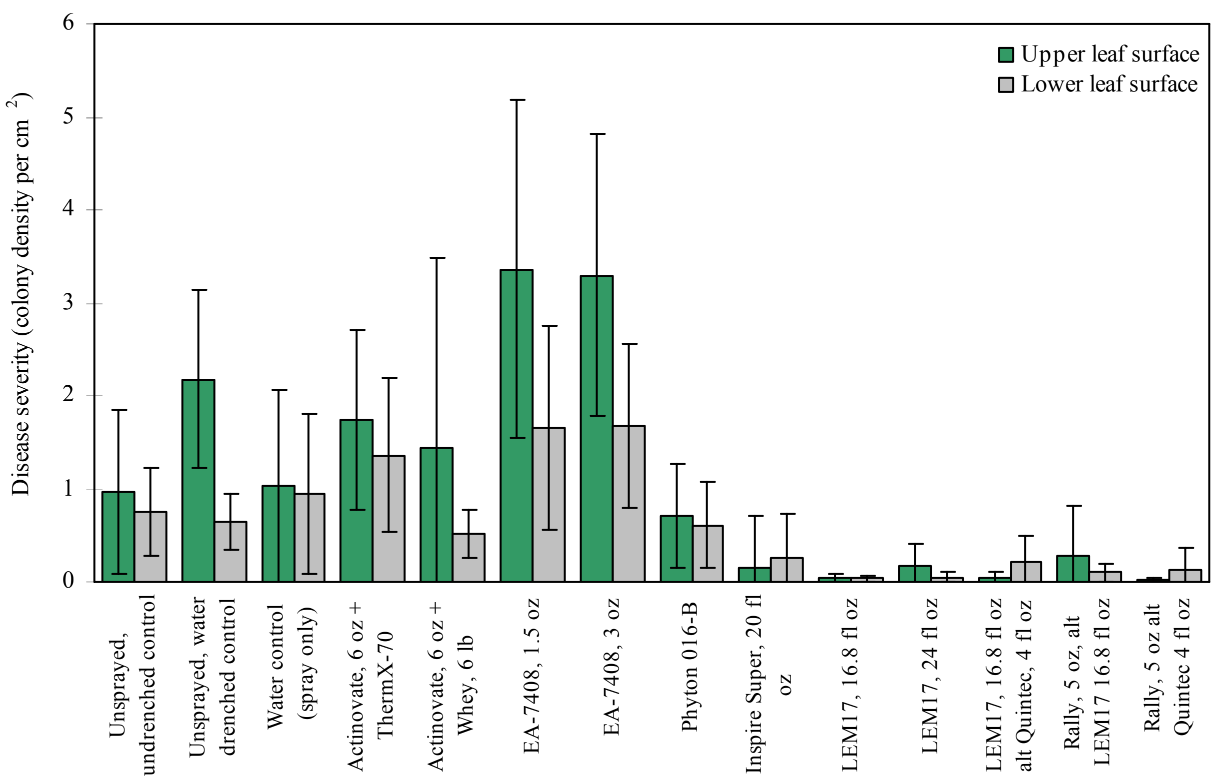
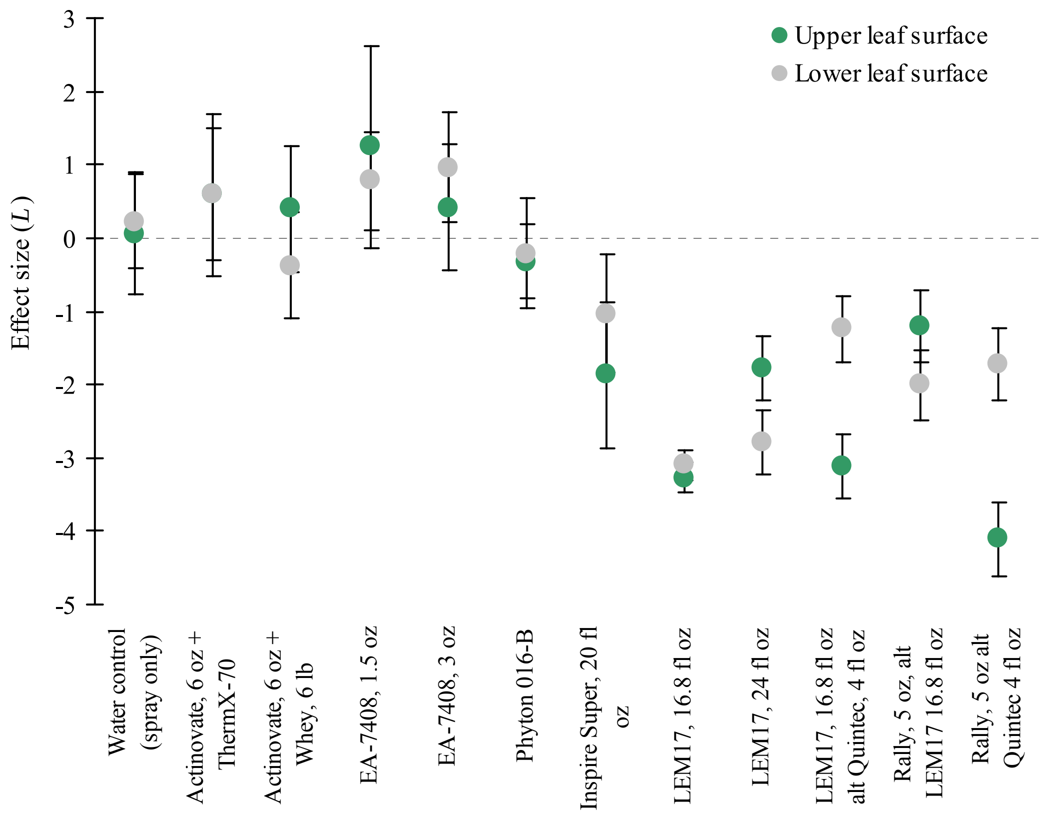


Figure 4. Treatment effect sizes relative to the unsprayed control for severity data. Effect sizes, L_i, calculated as $\ln(m_{fungicide}/m_{unsprayed\ control})$. Negative effect sizes indicate a reduction in powdery mildew severity relative to untreated leaves. Error bars show 90% confidence intervals.



V. Acknowledgements

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VI. References

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VII. Appendix: materials

Chemical products and adjuvants

Product	Active ingredient and concentration	Manufacturer
Inspire Super (A16001)	cyprodinil (24%) + difenoconazole (8.4%)	Syngenta Crop Protection, Inc.
LEM17 20SC	penthiopyrad (20%)	DuPont
Phyton-016-B	copper sulfate pentahydrate (21.4%)	Phyton Corporation
Quintec 2.08SC	quinoxyfen (22.58%)	Dow AgroSciences LLC
Rally	myclobutanil (40%)	Dow AgroSciences LLC
Silwet L-77	polyalkyleneoxide modified heptamethyltrisiloxane & allylooxypolyethylene glycol methyl ether (100%)	Helena Chemical Company
ThermX-70	saponin from *Yucca shidigera* (20%)	American Extracts

Biological products

Product	Organism and concentration	Manufacturer
Actinovate AG	*Streptomyces lydicus* WYEC108 (1 x 10^7 cfu/g; 0.0371%)	Natural Industries, Inc.
EA-7408	Biological preparation	Biopreparaty spol. s.r.o.
VersaPRO whey		Davisco Foods International, Inc.

Data sources: (1) NPIRS database at http://ppis.ceris.purdue.edu. (2) Product MSDS, (3) UC Cooperative Extension reports (2007 cucurbit PM, 2008 apple scab, and 2008 grape PM) available at http://plantpathology.ucdavis.edu/ext.