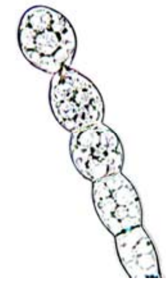
Powdery mildew control on pumpkin with organic and synthetic fungicides: 2009 field trial



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Abstract

Several species of powdery mildews are obligate biotrophs of crops in the Cucurbitaceae. These pathogens rapidly colonize green tissues via asexual reproduction and can negatively affect host physiology. We conducted a field experiment to evaluate the efficacy of organic and synthetic fungicides (registered and experimental products) for control of powdery mildew in pumpkin cv. Sorcerer. Following six weeks of fungicide applications, disease incidence (percentage of infected leaves within a plot) and disease severity (colony density on the leaf surface) was generally lowest in plants treated with synthetic materials (quinoxyfen, penthiopyrad, triflumizole, and mixed programs of triflumizole/quinoxyfen, myclobutanil/quinoxyfen/ trifloxystrobin, and myclobutanil/penthiopyrad/ trifloxystrobin). 'Soft-chemistry' materials such as paraffinic oil, tea tree oil, hydrogen peroxide, and the biocontrol agent, *Strepyomyces lydicus* WYEC108, were less effective at managing disease when used alone. However, tea tree oil and *S. lydicus* substantially reduced disease incidence and severity when used in a program with quinoxyfen, suggesting that good disease management can be maintained while significantly reducing use of synthetic fungicides.

Introduction

Powdery mildew is an important disease in commercially-valuable members of the cucumber family. At least two species of the Erysiphales – *Podosphaera fusca* (synonyms: *P. xanthii*, *Sphaerotheca fulginea* and *S. fusca*) and *Golovinomyces cichoracearum* – can infect cucurbit tissues (McGrath and Thomas 1996, Pérez-García et al. 2009). Over-wintering chasmothecia produce ascospores that then develop into whitish colonies on leaves, leaf petioles, and stems (McGrath and Thomas 1996, Glawe 2008). Wind or insect vectors disperse asexually-produced conidia and spread the disease (Blancard et al. 1994). Favorable conditions for disease epidemics include temperatures between 20-27°C and lower-intensity light (McGrath and Thomas 1996). Disease outbreaks in the Central Valley of California tend to occur during autumn months, but coastal areas may be continuously threatened (Davey et al. 2008). Infections have the potential to reduce the yield and quality of fruit and can lead to early plant senesce (Blancard et al. 1994, McGrath and Thomas 1996).

Disease management in cucurbits usually involves foliar applications of synthetic fungicides and/or use of disease resistant cultivars (McGrath and Thomas 1996). Fungicides such as azoxystrobin, myclobutanil, quinoxyfen, trifloxystrobin, triflumizole, and micronized sulfur can be used to treat plants (Davis et al. 2008). Sulfur has the advantage of little or no risk of selecting for resistant mildew strains (Blancard et al. 1994). Previous work in our lab has shown that quinoxyfen, triflumizole, and penthiopyrad are highly effective at managing powdery mildew in disease susceptible varieties (Janousek et al. 2007, 2009).

We conducted a field trial at the UC Davis plant pathology experimental farm in Solano County, California to evaluate the effectiveness of 'soft-chemistry' and synthetic fungicides in managing powdery mildew on pumpkins (*Cucurbita pepo*) using the susceptible cultivar Sorcerer. We applied fungicides every 7 to 14 days for a six week period beginning when plants began to develop horizontal runners. Following the application period, we assessed disease incidence and powdery mildew colony density on the upper and lower surfaces of leaves in each treatment.

Materials and Methods

The field trial consisted of 8 rows of Sorcerer pumpkins planted on 15 July 2009 in Yolo silty clay loam (NRCS 2009) on 4.9m (16ft) centers (to allow ATV and sprayer access). 4.3m-long (14ft) plots were arranged in a completely randomized design (n = 6 per treatment; Figure 1). On 24 August, emergent plants were thinned to about 7 plants per plot. The field was furrow irrigated on 16 July, 31 July, 12 August, 27 August, 11 September, 28 September and 2 October. Insect populations were not actively managed.

20 fungicide programs were tested with an unsprayed control and water-only control (Table 1). Fungicides were applied using hand gun sprayers connected to 25 gallon stainless steel tanks that provided constant agitation for the products. Spraying was conducted each Tuesday morning from 25 August to 29 September. OxiDate treatments were made weekly (6 total applications), but all other treatments were applied every other week (3 total applications). Applications on 25 August and 1 September were made in 150 gallons/acre of water; subsequent applications were made in 225 gallons/acre. Spray coverage was generally best on the upper surfaces of leaves. Per acre use rates of fungicides were scaled to the total area of 6 plots (0.0154 acres), based on a predetermined plot size of 4.3m by 2.4m; plants, however, did not grow to fill the entire plot area by the end of the experiment.

Disease evaluation was conducted from 2-7 October 2009. At least 20 leaves were haphazardly collected from each plot and brought to the lab for disease assessment. 20 leaves were rated for disease incidence (the percentage of leaves with at least one mildew colony). Disease severity was also assessed on the first 12 leaves inspected for incidence. Severity was estimated as colony density (mean number of colonies per cm^2) on the central lobe of the leaf. In some cases colony coverage was extensive, making counts of individual colonies difficult or impossible. For such leaves, first an estimate of percentage colony coverage was made which was later converted to colony density using the following estimates derived from measuring mean colony size on moderately-infected leaves: 9.1 colonies cm^{-2} for upper leaf surfaces and 2.0 colonies cm^{-2} for lower leaf surfaces.

Incidence and severity were determined on both the upper and lower surface of leaves. Differences among treatments were evaluated with Fisher's LSD *a posteriori* test (at $\alpha = 0.10$) using SAS® 9.1 software.

Figure 1. Layout of plots in the experimental area. * = unused plot (plant density too low).

O	Pu	G	P+B	Br	O	P+B	R
W+K	G+Pu	P	Y	R	W	K	B+K
P+Br	O	P+B	W	*	P+O	Y+B	B
Pu	P+B	Teal+Clear	W+R	Pu	Y+G	B+K	G+Pu
K	W+R	Br	P	W+K	W+G	G	W+G
G	Y+G	Y+B	R	W+R	K	W	*
W	Silver	P+Br	W	B	P+B	Y	K
W+K	W+G	B	G	B+K	P+Br	Pu	Y+G
P+ Br	P	G+Pu	Pu	Pu	G+Pu	*	R
Y+B	P+O	W+R	G	P+Br	P+B	*	Teal+Clear
Br	W+K	R	Br	W+K	Y+B	P	Silver
Silver	Br	W+K	Silver	W	Br	W+G	Y
G+Pu	*	W+R	B+K	O	*	O	P+O
Y	Silver	*	P+O	P	B+K	W+G	Teal+Clear
Y+G	Y+B	P	Teal+Clear	*	B	G+Pu	K
*	Y	B	P+O	Y	Teal+Clear	P+Br	B+K
W+G	B	Silver	W+R	*	Y+B	K	R
O	P+O	Teal+Clear	Y+G	*	*	G	Y+G

Table 1. Experimental fungicide treatments. "alt" = alternated with; "FP" = formulated product

Treatment	Flag color	Application interval (days)	Application rate (per acre)	FP/application
Unsprayed control	W	none	none	none
Water control	Y	14	water only	water only
Rally then Quintec then Flint	K	14	5 oz 4 fl oz 2 oz	2.2 g 1.8 ml 0.87 g
LEM17	B	14	16 fl oz	7.3 ml
LEM17 alt Quintec	O	14	16 fl oz 4 fl oz	7.3 ml 1.8 ml
Rally then LEM17 then Flint	P	14	5 oz 16 fl oz 2 oz	2.2 g 7.3 ml 0.87 g
JMS Stylet-oil	Silver	14	2% (v/v)	174 ml (at 150 gal/acre) 265 ml (at 225 gal/acre)
OM2	R	14	2% (v/v)	174 ml (at 150 gal/acre) 265 ml (at 225 gal/acre)
Nutrol + HiWett (adjuvant) + Kumulus then Kumulus (2 applications)	Br	14	7 lb + 2 fl oz + 1.5 lb 1.5 lb	49 g 0.9 ml 10.5 g 10.5 g
Nutrol + HiWett alt Flint	G	14	10 lb + 2 fl oz alt 2 oz	70 g 0.9 ml 0.87 g
HiPeak fertilizer + HiWett + Kumulus	Pu	14	7 lb + 2 fl oz + 1.5 lb	49 g 0.9 ml 10.5 g
HiPeak fertilizer + HiWett alt Flint	Teal + Clear	14	10 lb + 2 fl oz alt 2 oz	70 g 0.9 ml 0.87 g
Procure	W+K	14	6 fl oz	2.7 ml
Procure	W+R	14	8 fl oz	3.6 ml
Procure alt Quintec	Y+B	14	8 fl oz alt 4 fl oz	3.6 ml 1.8 ml
Procure alt Flint	Y+G	14	8 fl oz alt 2 oz	3.6 ml 0.87 g
Quintec	G+Pu	14	4 fl oz	1.8 ml
Timorex Gold	P+B	14	0.5% (v/v)	43.5 ml (at 150 gal/acre) 66 ml (at 225 gal/acre)
Timorex Gold alt Quintec	P+Br	14	0.5% (v/v) alt 4 fl oz	43.5 ml 1.8 ml
Actinovate + Silwet L-77 (adjuvant)	P+O	14	6 oz + 0.03% (v/v)	2.6 g + 2.6 ml (at 150 gal/acre) 4.0 ml (at 225 gal/acre)
Actinovate + Silwet L-77 alt Quintec	W+G	14	6 oz + 0.03% (v/v) alt 4 fl oz	2.6 g + 2.6 ml (at 150 gal/acre) alt 1.8 ml
OxiDate + NuFilm P (adjuvant)	B+K	7	1% (v/v) + 6 fl oz	87 ml (at 150 gal/acre) 132 ml (at 225 gal/acre) + 2.7 ml

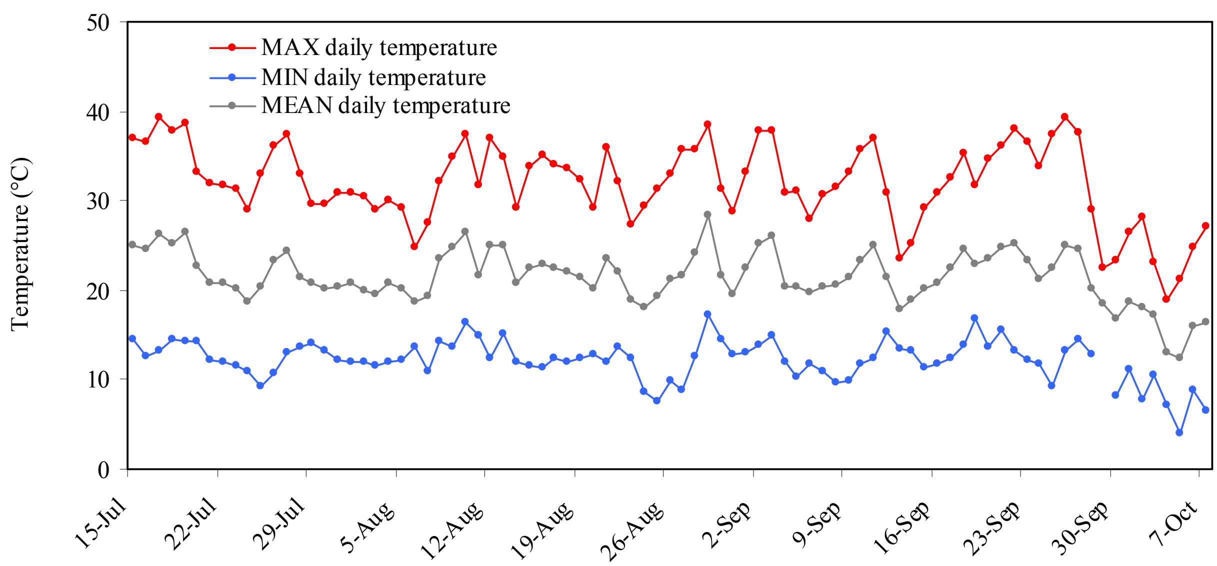
Results and Discussion

Average daily temperatures in Davis, California from July through early October were conducive to rapid spread of the disease (Figure 2). Colonies were first detected in the field on about 24 August. Later, samples of the pathogen were collected for taxonomic identification based on morphological attributes. Based on the shape of maturing conidia on the conidiophore and the position of the conidial germination tube (after incubation for 24-48 hr in water), samples appeared to belong to *Podosphaera* (McGrath and Thomas 1996, Braun et al. 2002; Figure 3). *G. cichoracearum*, another causal agent, appears to be rare in California (Davis et al. 2008).

Disease developed rapidly during the course of the experiment. At the time of evaluation, disease incidence on the upper surfaces of leaves was 78.3 ± 6.9% in the water control and 80.0 ± 6.3% on untreated plants (Table 2). Colony density averaged 0.48 and 0.31 colonies cm^{-2} on the upper surface in these treatments respectively. Plants treated with quinoxyfen (Quintec), penthiopyrad (LEM17), and triflumizole (Procure) generally showed substantially lower disease incidence and colony densities on upper leaf surfaces than control treatments. Quintec applications at 4 fl oz acre^{-1} gave the best results with 0% upper surface incidence and no observable colonies in the central lobe of leaves.

The high efficacy of quinoxyfen for control of cucurbit powdery mildew is in agreement with other studies (McGrath 2003, Matheron and Porchas 2004, McGrath and Davey 2007a, Gilardi et al. 2008). Our trial suggested good management of the disease with triflumizole, however some degree of DMI resistance may be a problem in other growing regions (McGrath et al. 1996, McGrath and Davey 2007). Moderate to excellent control of mildew with penthiopyrad has also been achieved in other field research (Hausbeck and Cortright 2005, McGrath and Davey 2007a). Many synthetic materials also gave a marked reduction in disease incidence and severity on lower leaf surfaces despite generally poor spray coverage on these surfaces. For example, three applications of quinoxyfen at 4 fl oz/acre reduced disease incidence on lower leaf surfaces to only 5%.

Figure 2. Daily high, low and average temperatures for Davis, California (from http://wwwcimis.water.ca.gov/) during the experimental period. No measurable precipitation fell during this time.



Soft-chemistry products generally had only a small effect on disease incidence and severity when used alone throughout the experimental period. Hydrogen peroxide at 1% (v/v) and paraffinic oil at 2% (v/v) with and without adjuvant were somewhat effective at reducing colony density on upper leaf surfaces, but still gave colony densities several orders of magnitude larger than the best synthetic materials. Powdery mildew control with *Streptomyces lydicus* (Actinovate) and tea tree oil (Timorex Gold) was generally poor when these products were used alone. In fact, three successive applications of *S. lydicus* led to more than twice the upper leaf surface colony density than observed in both controls. *S. lydicus* also failed to adequately control disease in a similar trial in Solano County in 2008 (Janousek et al. 2009). These results contrast with McGrath and Davey (2007b) who found a greater than 50% reduction in upper leaf surface mildew severity (AUDPC) on pumpkin with application of *S. lydicus* at 6 oz/acre. However, these authors also found that the biological was outperformed by fungicide programs utilizing synthetic fungicides and sulfur.

In our trial, disease management by *Streptomyces* was substantially improved when used in rotation with quinoxyfen (a single application). Tea tree oil was also effective when used in a similar rotation. These results suggest that alternation of soft chemistry materials with highly effective synthetic materials can maintain good disease control with reduced synthetic use; such a strategy may also assist with resistance management (McGrath and Shishkoff 2003).

Figure 3. Powdery mildew in the trial. (A) Infected leaf from a water control plot (photograph taken, 9 October) (B) Conidiophore isolated from the trial (C) 48 hr-old germinating conidium; bar = 25 µm.

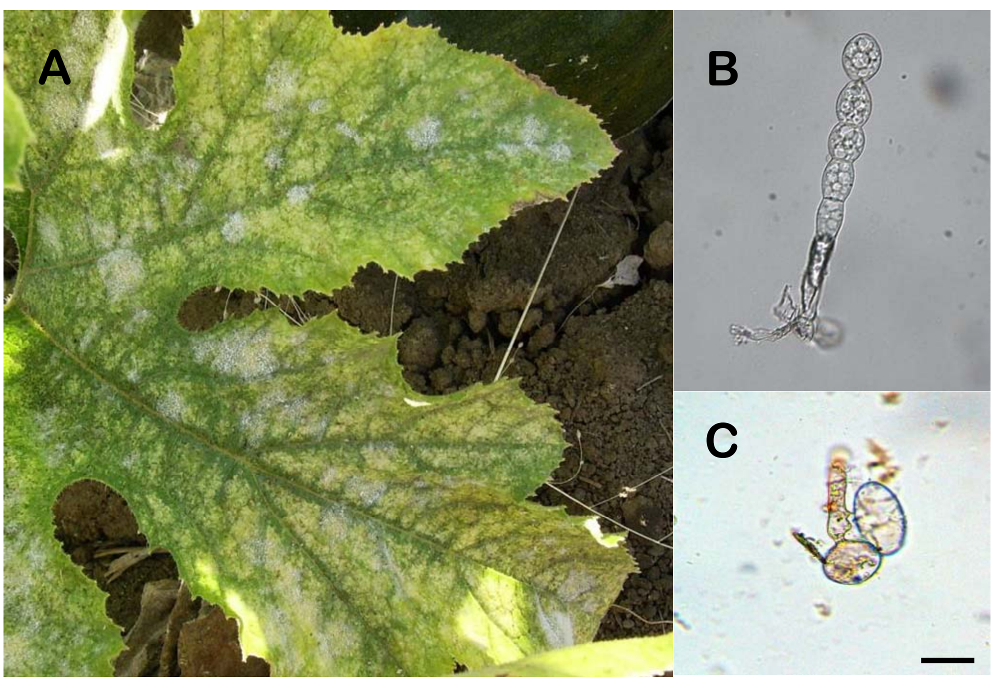


Table 2. Treatment effects on disease incidence (percentage of leaves infected in a plot) and leaf colony density (colonies cm^{-2}) on the upper surfaces of leaves. Treatments sharing the same letter within a column are not significantly different according to Fisher's LSD test at $\alpha = 0.10$ and n = 6.

	Upper leaf surface			
Treatment	**Incidence (%)**		**Colony density (cm^{-2})**	
Quintec, 4 fl oz	0.0 ± 0.0	f	0.000 ± 0.000	d
LEM17, 16 fl oz	0.8 ± 0.8	f	0.000 ± 0.000	d
Procure, 8 fl oz alt Quintec, 4 fl oz	5.0 ± 2.2	ef	0.000 ± 0.000	d
Rally, 5 oz then Quintec, 4 fl oz then Flint, 2 oz	7.5 ± 2.8	ef	0.001 ± 0.001	d
LEM17, 16 fl oz alt Quintec, 4 fl oz	10.8 ± 4.9	ef	0.043 ± 0.042	d
Timorex Gold, 0.5% (v/v) alt Quintec, 4 fl oz	11.7 ± 4.8	ef	0.004 ± 0.002	d
Rally, 5 oz then LEM17, 16 fl oz then Flint, 2 oz	12.5 ± 5.3	ef	0.005 ± 0.003	d
Procure, 8 fl oz alt Flint, 2 oz	14.2 ± 4.0	ef	0.028 ± 0.025	d
Actinovate, 6 oz + Silwet L-77 alt Quintec, 4 fl oz	21.7 ± 8.5	de	0.010 ± 0.005	d
Procure, 8 fl oz	21.7 ± 4.2	de	0.007 ± 0.003	d
HiPeak, 7 lb + HiWett + Kumulus, 1.5 lb	35.8 ± 12.9	d	0.048 ± 0.028	d
Procure, 6 fl oz	35.8 ± 10.8	d	0.029 ± 0.011	d
Nutrol, 7 lb + Kumulus, 1.5 lb + HiWett then Kumulus, 1.5 lb (2X)	62.5 ± 10.1	c	0.316 ± 0.184	bc
OxiDate, 1% (v/v) + NuFilmP	63.3 ± 12.5	bc	0.122 ± 0.066	cd
Timorex Gold, 0.5% (v/v)	64.2 ± 6.4	bc	0.182 ± 0.117	cd
Nutrol, 10 lb + HiWett alt Flint, 2 oz	64.2 ± 4.4	bc	0.058 ± 0.028	d
OM2, 2% (v/v)	65.8 ± 10.8	bc	0.105 ± 0.034	cd
JMS Stylet-oil, 2% (v/v)	66.7 ± 9.7	abc	0.192 ± 0.068	cd
Water control	78.3 ± 6.9	abc	0.476 ± 0.223	b
HiPeak, 10 lb + HiWett alt Flint, 2 oz	79.2 ± 6.0	abc	0.159 ± 0.079	cd
Unsprayed control	80.0 ± 6.3	ab	0.310 ± 0.097	bc
Actinovate, 6 oz	83.3 ± 2.1	a	0.972 ± 0.258	a

Table 3. Treatment effects on disease incidence and leaf colony density on lower leaf surfaces. Treatments with the same letter within a column are not significantly different according to Fisher's LSD test at α = 0.10 and n = 6.

	Lower leaf surface			
Treatment	**Incidence (%)**		**Colony density (cm^{-2})**	
Quintec, 4 fl oz	5.0 ± 1.3	i	0.001 ± 0.001	c
Procure, 8 fl oz alt Quintec, 4 fl oz	10.8 ± 4.7	i	0.000 ± 0.000	c
Rally, 5 oz then Quintec, 4 fl oz then Flint, 2 oz	17.5 ± 5.3	hi	0.001 ± 0.001	c
LEM17, 16 fl oz alt Quintec, 4 fl oz	17.5 ± 7.9	hi	0.024 ± 0.020	c
Actinovate, 6 oz + Silwet L-77 alt Quintec, 4 fl oz	28.3 ± 11.0	gh	0.028 ± 0.024	c
LEM17, 16 fl oz	35.0 ± 9.1	fg	0.012 ± 0.004	c
Timorex Gold, 0.5% (v/v) alt Quintec, 4 fl oz	35.0 ± 9.2	fg	0.011 ± 0.006	c
Procure, 8 fl oz alt Flint, 2 oz	38.3 ± 10.1	fg	0.018 ± 0.008	c
Rally, 5 oz then LEM17, 16 fl oz then Flint, 2 oz	48.3 ± 7.9	ef	0.020 ± 0.008	c
Procure, 8 fl oz	56.7 ± 8.1	ed	0.035 ± 0.010	bc
HiPeak, 7 lb + HiWett + Kumulus, 1.5 lb	70.8 ± 4.5	cd	0.170 ± 0.101	bc
Timorex Gold, 0.5%	73.3 ± 4.0	bc	0.099 ± 0.044	bc
Procure, 6 fl oz	74.2 ± 8.1	bc	0.174 ± 0.067	bc
Nutrol, 7 lb + Kumulus, 1.5 lb + HiWett then Kumulus, 1.5 lb (2X)	80.8 ± 5.5	abc	0.208 ± 0.106	bc
Unsprayed control	81.7 ± 7.1	abc	0.178 ± 0.044	bc
Nutrol, 10 lb + HiWett alt Flint, 2 oz	82.5 ± 4.2	abc	0.174 ± 0.093	bc
HiPeak, 10 lb + HiWett alt Flint, 2 oz	82.5 ± 6.9	abc	0.787 ± 0.645	a
OxiDate, 1% (v/v) + NuFilmP	85.0 ± 8.0	abc	0.227 ± 0.095	bc
Actinovate, 6 oz	88.3 ± 2.8	ab	0.376 ± 0.076	b
JMS Stylet-oil, 2% (v/v)	90.0 ± 2.2	a	0.343 ± 0.067	bc
Water control	90.0 ± 2.9	a	0.265 ± 0.081	bc
OM2, 2% (v/v)	90.8 ± 3.5	a	0.339 ± 0.059	bc

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Appendix: materials

Product	Active ingredient and concentration	Manufacturer
Actinovate	*Streptomyces lydicus* WYEC108	Natural Industries, Inc.
HiWett	polysiloxane polyether copolymer, polyoxyethylene-polyoxypropylene copolymer & alcohol ethoxylate (100%)	First Choice
Flint	trifloxystrobin (50%)	Bayer Cropscience LP
HiPeak (fertilizer)	potassium dihydrogenorthophosphate + dipotassium hydrogenorthophosphate	Rotem Amvert Negal, Ltd.
JMS Stylet-oil	paraffinic oil (97.1%)	JMS Flower Farms, Inc.
Kumulus DF	sulfur (80%)	BASF
LEM17 SC	penthiopyrad (20%)	DuPont
Nutrol (fertilizer)	phosphate (50%), potash (30%)	Rotem BKG
OM2	paraffinic oil + OE 444(an oil-based adjuvant)	JMS Flower Farms, Inc. and DuGussa/Goldschmidt
OxiDate	hydrogen peroxide (27%)	BioSafe Systems
Procure 480SC	triflumizole (42.14%)	Chemtura Corporation
Quintec 2.08SC	quinoxyfen (22.58%)	Dow AgroSciences LLC
Rally	myclobutanil (40%)	Dow AgroSciences LLC
Silwet L-77 (adjuvant)	polyalkyleneoxide modified heptamethyltrisiloxane + allyooxypolyethylene glycol methyl ether (100%)	Helena Chemical Company
Timorex Gold	tea tree oil derived from *Melaleuca alterniflora* (23.8%)	Biomor, Israel Ltd.

Appendix sources: (1) NPIRS on-line database at http://ppis.ceris.purdue.edu, (2) Janousek et al. (2009) at http://escholarship.org/uc/item/12t1z046 and Janousek et al. (2009) at http://escholarship.org/uc/item/8fz3p4vc, (3) Product-specific MSDS and/or labels, and (4) Pscheidt, JW and CM Ocamb (eds). (2006) *2006 Pacific Northwest Plant Disease Management Handbook.* Oregon State University, 607 pp.