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Project title – Fungicide-resistance and an induced resistance strategy to assist in maintenance of fungicide efficacy for control of powdery mildew of melons in California

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Objectives

1) To continue to assess fungicide resistance to *P. xanthii* isolates from melons in California, including to additional fungicides including Quadris Top, and any newly registered fungicides or fungicide blends
2) To further develop a fungicide-resistance testing protocol so that growers can have their isolates tested cost-effectively.
3) To determine if soil applications of potassium silicate are a promising strategy for inducing resistance to powdery mildew on melons

Summary of Research Results:

Podosphaera xanthii (synonyms, *P. fusca*, *Sphaerotheca fuliginea*) is the major causal agent of powdery mildew on melons in California. 2013 appeared to be a light powdery mildew year; we had difficulty obtaining isolates and there was no powdery mildew in the field trial designed to address Objective 3. In 2013, we tested the efficacy of eight recently collected isolates of *Podosphaera xanthii* from honeydew to a range of concentrations of ten fungicides. Seven of the isolates were from one area in Yolo Co. where the grower was treating solely with sulfur; this allowed us to examine variability of fungicide resistance in a relatively small area in which there was no selection pressure to maintain resistance to any of the active ingredients in our screen. As in 2012, all isolates were highly sensitive to Quintec (FRAC resistance group 13) in our lab assay. Also similar to 2011 and 2012, 88% or more of the isolates were resistant to Topsin (FRAC resistance group 1). Over the 2011 to 2013 period, some of the isolates were resistant to at least one of the four strobilurins tested (FRAC resistance group 11) and/or the two DMIs (FRAC resistance group 3). Some resistance was also detected within the SDHI (FRAC resistance group 7). There was evidence of some cross-resistance within the strobilurins, i.e., isolates that were resistant to one strobilurin were often resistant to multiple strobilurins, but most isolates were not resistant to all of the strobilurins. In 2012, all isolates had some fungicide-resistance to fungicides with different modes of action. Our data are consistent with the hypothesis that isolates that cause powdery mildew on melon have variable fungicide-resistance, and that management for maintenance of fungicide-efficacy would be most effective on a regional basis and will remain a challenge for the melon industry. We recommend that growers include wettable sulfur in their fungicide program if the cultivar/weather conditions permit its use.

Results

Isolates were collected with the assistance of our cooperators. Conidia of all isolates were first examined microscopically for fibrosin bodies, and were all consistent with being *P. xanthii* (synonyms, *P. fusca, Sphaerotheca fuliginea*). We have not observed *Erysiphe cichoracearum* (=*Golovinomyces cichoracearum)*, which occasionally causes powdery mildew on melons.

Isolates were single colony purified in two cycles on surface-sterilized zucchini leaves to both obtain single isolates and to multiply conidia. All isolates have been stored on silica gel at -70 °C, essentially as described by Pérez-Garcia et al. (2006); recovery has been checked periodically and survival is good. Bioassays were conducted essentially as described by López-Ruiz et al. (2010) except that the density of spore suspensions is carefully controlled. Each isolate was screened on surface-sterilized, 10 to 12 day old cotyledonary zucchini leaves. For each of two replicates in each of either one or two independent trials, there were five leaf discs, each 0.4 inches across. To apply the fungicide, a 5.5 cm diameter Whatman 1 filter paper was soaked with 3 ml of four treatments: water for the untreated; the indicated fungicide with the the highest and lowest recommended dose; and a lower than recommended dose, as an indication of residual activity. The leaf discs were then placed upside down on the treatment for 24 hours at 68 °F. Then leaf discs were transferred to sterilized filter paper and placed on a sucrose (0.02M)-mannitol (0.1M)-0.8% agar medium with tetracycline.(Bardin et al. 2007). After 8 days at approximately 68 °F, leaf discs were scored as follows: 0, no mildew seen; 1, visible mildew, but on less than 5% of the leaf surface; 2, sporulation but only on 1/20 to ¼ of the leaf surface; 3, sporulation on more than ¼ but less than ½ of the leaf surface; 4, sporulation on more than ½, but less than ¾ of the leaf surface; and 5. at least ¾ of the leaf disc sporulating (Ishii et al. 2001). Pictures of each of the scores are shown in our 2011 report.

Table 1. Summary of results on fungicide resistance of *Podosphaera xanthii* from melons in California in 2011, 2012 and 2013.

Mode of action	FRAC group	Fungicide	2011, n=12	2012, n=10	2013, n=8
			Resistant isolates, %[a]		
QoI	11	Quadris[b]	83	90	12
QoI & DMI	11 & 3	Quadris Top[b]	Not tested	Not tested	0
QoI	11	Flint[c]	83	90	100
QoI & SDHI	11 & 7	Luna Sensation[c]	Not tested	Not tested	88
QoI	11	Cabrio[d]	Not tested	80	38
QoI	11	Sovran	Not tested	40	100
QoI & SDHI	11 & 7	Pristine[d]	0	10	38
B-tubulin	1	Topsin	100	90	88
DMI	3	Procure	0	30	0
DMI	3	Rally	0	0	88
(Signal Transduction)	13	Quintec	Not tested	0	0

[a] Leaf discs were scored on a scale of 0 (no visible sporulation) to 5 (sporulation on more than ¾ of the leaf disc). The average of untreated discs was 3.6 or higher. In Table 2, each isolate-fungicide combination was rated as either highly resistant (no control), resistant (possible control), or moderately-resistant (some control) or on an analogous scale of fungicide-sensitivity. Consequently, there was some control in some of the isolates grouped as resistant in this table.
[b] Azoxystrobin is the sole ingredient in Quadris, and one of the two fungicides in Quadris Top.
[c] Trifloxystrobin, the active ingredient in Flint, is also one of the two fungicides in Luna Sensation.
[d] Pristine includes the active ingredient in Cabrio, in addition to the SDHI boscalid.

A summary of our results in comparison to the two previous years is shown in Table 1. A more detailed summary of results from 2013 is shown in Table 2. In 2013, all isolates except for one Fresno Co. isolate were from Yolo Co. The Fresno Co. isolate (SD-FS-1) appeared to be highly sensitive to two relatively new active ingredients: the SDHI fluopyram (one of the ingredients in Luna Sensation) and the DMI difenoconazole (one of the ingredients in Quadris Top). It was also highly sensitive to the strobilurin Cabrio, the two DMI's Procure and Rally, and Quintec. However, this isolate is moderately resistant to the strobilurins in Flint, Quadris, Sovran and presumably the strobilurin in Pristine. The isolate is presumably also at least moderately resistant to the SDHI boscalid (a component in Pristine), and is resistant to the tubulin inhibitor Topsin. This multi-drug pattern of moderate resistance may suggest that the isolate has at least one mutation that results the continuous activity of a transporter that is involved in exporting fungicides from the pathogen.

Unexpectedly, last year, the Fresno Co. isolate from 2012 developed chasmothecia, the sexual structures, on zucchini leaves in the laboratory; in addition to mutation, sexual recombination could provide a mechanism for generating novel fungicide-resistance in the fungus. This year, we wanted to know how much diversity we would detect in fungicide resistance from seven Yolo Co. isolates. All seven isolates were notably different from the Fresno Co. isolate: all Yolo Co. isolates were sensitive or highly sensitive to Quadris, and resistant or highly resistant to Flint, Luna Sensation and Rally. However, there were sufficient differences within the seven Yolo Co. isolates that they presumably represent at least three different strains, based on differential responses to Cabrio (from highly sensitive to resistant), Pristine (from highly sensitive to moderately resistant) and Topsin (from highly sensitive to resistant). The high diversity within a limited geographic area complicated our efforts to reduce the labor costs for testing, as indicated in Objective 2.

In response to fungicide resistance, fungicide manufacturers have been selling mixtures of fungicides. This year we tested three fungicide mixtures, each with a strobilurin: Quadris Top, Luna Sensation and Pristine. The majority of isolates were resistant to at least one of the fungicides in the mixture.

Discussion

Podosphaera xanthii (synonyms, *P. fusca*, *Sphaerotheca fuliginea*) is the major causal agent of powdery mildew on melons in California. The fungus has a relatively wide host range; in addition to infecting many plants in the cucurbit family, *P. xanthii* infects multiple species in the Solanaceae. Fungicides are critical for sustained disease control of *P. xanthii* on melons. However, our data show widespread resistance to QoIs (strobilurins, FRAC resistance Group 11) and Topsin (FRAC group I); we note that QoIs might still have some, albeit diminished, efficacy against the resistant isolates. That is, genetic changes to fungicide resistance can confer either quantitative or qualitative differences (McGrath 2001). In addition, in keeping with last year's data, some isolates have resistance to DMI fungicides (FRAC resistance group 3). We have only tested SDHI fungicides (FRAC resistance group 7) in fungicide mixtures; nonetheless, the data also are consistent with some resistance to FRAC resistance group 7.

California is not unique in having fungicide-resistant *P. xanthii*. *P. xanthii* previously has been reported both in the U.S. and internationally multiple times (Ortuno *et al.* 2006 & 2008a; FRAC 2007; Heaney *et al.* 2000; Ishii *et al.* 2001; López-Ruiz et al. 2010; McGrath 2008; McGrath & Shishkoff 2003a&b; Miazzi & McGrath 2008; Naegler *et al.* 1977; Schepers 1983, 1984 & 1985; Schroeder & Providenti 1971). Clearly sustained fungicide efficacy will require careful management of fungicide use, and preferably on a regional level. Currently, the main UCCE recommendation for controlling or at least delaying fungicide resistance is to alternate fungicides with different modes of action. That is, if fungicides in either groups 1, 3, 7, 11, or 13

are used, they should be followed by a fungicide in a different group. However, there are several potential complications. One, whether or not alternation actually delays the development of field-level fungicide resistance depends upon there being a "fitness cost" of fungicide resistance (van den Bosch F & Gilligan 2008); sometimes there is, but often there is not. For example, in powdery mildew on wheat, the researchers could not detect any fitness cost of strobilurin resistance (Chin et al. 2001). It is unknown whether there is a fitness cost for any of the fungicide resistances in any California melon isolates. However, two Monterey Co. isolates from Jim McCreight that we examined in 2011 apparently had not been exposed for four or more years to any of the fungicides to which they were resistant, suggesting that there might not be a fitness cost of their fungicide resistance. Perhaps similarly, our seven Yolo Co. isolates had not been exposed to any of the fungicides that we tested for this year, but were still resistant to multiple fungicides. Secondly, the recommendation for alternation of fungicides with different modes of action is based on the fact that resistance to fungicides in each group can be caused by a spontaneous mutation in a single site, e.g., resistance in group 11 is caused by a mutation in the "**q**uinone **o**utside *i*nhibitor" (QoI). However, just as there are multi-drug resistant bacterial pathogens of humans, there are plant pathogenic fungi that can have spontaneous mutations in various "transporters" (typically ABC and MFS) that confer multi-fungicide resistance (e.g., deWard et al. 2006, Kretschmer et al. 2009). Basically, the transporters are "pumps" in the membranes that expel fungicides and other toxins from the fungus. Typically, in fungi with multi-fungicide resistance, the mutations are in the regulatory portion of the genes (the promoters), and the mutant transporters are "constitutively" active, i.e., they expel fungicides (and other toxins) all the time. The best strategy for avoiding development of multi-drug resistance is unclear. Regardless, alternation of fungicides in different groups does not reduce risk from this kind of resistance, because this resistance spans multiple (although not all) groups (Kretschmer et al. 2009). Thirdly, the fungicides Pristine, Quadris Top, and Luna Sensation contain two fungicides, each from a different group. Growers should be aware that fungicide manufacturers are increasingly introducing mixes with two fungicides. Although the fungicide manufacturers have argued that mixes will decrease the likelihood of fungicide resistance (FRAC, 2010), this is debatable point, and it is at least unclear to what extent the mixes are a sales strategy in which the lack of efficacy of a product is obscured by an efficacious product. Regardless, if one is following the alternation strategy, Pristine for example should not be followed by any fungicide in either groups 7 or 11. To summarize, the current UCCE recommendations to alternate fungicides in different groups addresses one kind of risk of fungicide resistance but not necessarily all kinds of fungicide resistance in California melons.

Matherhon and Porchas (2013) have suggested adding relatively ineffective 'soft' materials into fungicide rotations as a strategy to decrease the risk of fungicide resistance. However, they present no data that this recommendation actually reduces the incidence and/or severity of fungicide-resistance. It is particularly unclear whether this strategy will be effective in common situations in which the pathogen can blow into a field from a neighboring property, and/or when growers lease land and consequently do not get long-term benefits from their own fungicide management.

Data from the Department of Pesticide Regulation's Pesticide Use Reports are several years behind (and can have errors); Table 3 has data from 2010 and 2011. The data suggest that many growers are using fungicides to control powdery mildew that are relatively ineffective; Rally appeared to be the most frequently used treatment in 2011, but resistance was widespread at least in Yolo Co. in 2013. In terms of area treated, the active ingredients in Cabrio, Procure, Quadris, Flint, and Topsin were the fourth through eighth most commonly used fungicides for powdery mildew on melon in California in 2011. We have identified strains with varying degrees of resistance to each of these fungicides.

Table 2. Predicted efficacy of fungicides on California isolates collected in 2013 that cause powdery mildew of melon.

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Fresno Co., SD-FS-1	Untreated	Untreated	4.1	0.3	
	Flint	Highest	1.8	0	Moderately resistant
		Lowest	1.8	0	
		1/10 the highest	2.4	0.6	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Quadris	Highest	1.5	0.1	Moderately resistant
		Lowest	1.8	0.2	
		1/2 the highest	2.9	0.3	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	1.4	0.2	Moderately resistant
		Lowest	2.5	0.3	
		1/10 the highest	3.4	0.2	
	Cabrio	Highest	0	0	Highly Sensitive
		Lowest	0	0	
		1/10 the lowest	1.7	0.2	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.6	0.4	Moderately resistant
		Lowest	2.4	0.0	
		1/10 the highest	3.3	0.1	
	Procure	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.8	0.4	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	3.0	0.2	
	Topsin	Highest	2.3	0.3	Resistant
		Lowest	3.1	0.3	
		1/2 the lowest	3.4	0.2	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, Isolate name	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-69	Untreated	Untreated	3.6	0.2	
	Flint	Highest	2.5	0.3	Resistant
		Lowest	3.1	0.1	
		1/10 the highest	3.1	0.1	
	Quadris	Highest	1.9	0.1	Resisant
		Lowest	2.2	0.2	
		1/2 the highest	3.1	0.1	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	2.1	0.1	Resistant
		Lowest	2.2	0.0	
		1/10 the highest	2.8	0.2	
	Cabrio	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	0.4	0.4	
	Procure	Highest	0.0	0.0	Sensitive
		Lowest	0.3	0.1	
		1/10 the lowest	3.3	0.1	
	Rally	Highest	0.0	0.0	Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	1.3	0.3	
	Topsin	Highest	2.0	0.0	Resistant
		Lowest	2.7	0.1	
		1/2 the lowest	3.3	0.5	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.4	0.2	Moderately resistant
		Lowest	1.5	0.7	
		1/10 the highest	3.1	0.1	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error[a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-117	Untreated	Untreated	4.2	0.2	
	Flint	Highest	2.7	0.3	Resistant
		Lowest	3.2	0.2	
		1/10 the highest	3.5	0.1	
	Quadris	Highest	2.4	0.2	Resistant
		Lowest	2.3	0.1	
		1/2 the highest	2.9	0.1	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	0.0	0.0	Moderately resistant
		Lowest	2.6	0.2	
		1/10 the highest	3.0	0.2	
	Cabrio	Highest	0.0	0.0	Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	0.4	0.4	
	Procure	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.8	0.0	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	3.3	0.5	
	Topsin	Highest	2.7	0.5	Resistant
		Lowest	3.4	0.0	
		1/2 the lowest	3.2	0.0	
	Pristine (Pyraclostrobin + Boscalid)	Highest	1.8	0.0	Resistant
		Lowest	2.2	0.0	
		1/10 the highest	2.9	0.1	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-77	Untreated	Untreated	4.4	0.0	
	Flint	Highest	3.7	0.1	Resistant
		Lowest	3.6	0.4	
		1/10 the highest	4.0	0.0	
	Quadris	Highest	2.9	0.3	Resistant
		Lowest	3.6	0.0	
		1/2 the highest	3.7	0.3	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Sensitive
		Lowest	0.4	0.4	
		1/10 the highest	1.2	0.8	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	1.6	0.2	Resistant
		Lowest	2.9	0.3	
		1/10 the highest	3.8	0.0	
	Cabrio	Highest	1.2	0.6	Moderately Resistant
		Lowest	2.4	0.6	
		1/10 the lowest	2.9	0.1	
	Procure	Highest	0.3	0.3	Moderately sensistive
		Lowest	1.2	0.2	
		1/10 the lowest	3.7	0.1	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	1.9	0.3	
	Topsin	Highest	3.8	0.2	Highly Resistant
		Lowest	4.1	0.1	
		1/2 the lowest	4.1	0.1	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.1	0.1	
		1/10 the highest	2.8	0.0	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-NT	Untreated	Untreated	4.8	0.0	
	Flint	Highest	2.7	0.1	Resistant
		Lowest	3.3	0.1	
		1/10 the highest	3.7	0.5	
	Quadris	Highest	2.8	0.2	Resistant
		Lowest	3.2	0.2	
		1/2 the highest	3.7	0.1	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.4	0.4	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	3.3	0.1	Resistant
		Lowest	3.5	0.1	
		1/10 the highest	3.3	0.3	
	Cabrio	Highest	0.4	0.4	Moderately Resistant
		Lowest	1.5	0.3	
		1/10 the lowest	2.4	0.4	
	Procure	Highest	0.0	0.0	Moderately Resistant
		Lowest	2.3	0.3	
		1/10 the lowest	3.2	0.0	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.1	0.3	
	Topsin	Highest	3.4	0.2	Highly Resistant
		Lowest	3.5	0.1	
		1/2 the lowest	3.7	0.1	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.1	0.1	Moderately Sensitive
		Lowest	0.9	0.3	
		1/10 the highest	3.4	0.2	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-116	Untreated	Untreated	4.7	0.1	
	Flint	Highest	3.4	0.2	Resistant
		Lowest	3.5	0.1	
		1/10 the highest	4.1	0.3	
	Quadris	Highest	3.0	0.2	Resistant
		Lowest	3.5	0.3	
		1/2 the highest	3.5	0.3	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	1.0	0.4	Moderately Resistant
		Lowest	2.7	0.2	
		1/10 the highest	3.1	0.5	
	Cabrio	Highest	1.5	0.3	Resistant
		Lowest	2.0	0.6	
		1/10 the lowest	2.9	0.1	
	Procure	Highest	0.4	0.0	Moderately Resistant
		Lowest	2.5	0.1	
		1/10 the lowest	3.4	0.2	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.4	0.2	
	Topsin	Highest	3.4	0.4	Highly Resistant
		Lowest	4.1	0.1	
		1/2 the lowest	4.4	0.0	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.6	0.4	Moderately Resistant
		Lowest	2.1	0.1	
		1/10 the highest	2.7	0.3	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-103	Untreated	Untreated	4.7	0.1	
	Flint	Highest	1.7	0.1	Resistant
		Lowest	2.4	0.2	
		1/10 the highest	3.3	0.3	
	Quadris	Highest	3.0	0.0	Highly Resistant
		Lowest	3.6	0.2	
		1/2 the highest	3.8	0.2	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	2.4	0.2	Highly Resistant
		Lowest	4.0	0.4	
		1/10 the highest	4.6	0.2	
	Cabrio	Highest	0.3	0.3	Moderately Sensitive
		Lowest	0.9	0.1	
		1/10 the lowest	2.1	0.3	
	Procure	Highest	0.0	0.0	Sensitive
		Lowest	0.3	0.3	
		1/10 the lowest	2.5	0.1	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.1	0.7	
	Topsin	Highest	3.7	0.1	Highly Resistant
		Lowest	3.8	0.0	
		1/2 the lowest	4.0	0.2	
	Pristine (Pyraclostrobin + Boscalid)	Highest	1.8	0.2	Resistant
		Lowest	3.1	0.1	
		1/10 the highest	3.5	0.1	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

Host, Source, (Isolate name)	Fungicide	Fungicide concentration: highest and lowest recommended dose and a below the minimum recommended as an estimate of residual concentration	Score 0 (protected) to 5 (max disease)	Standard error [a]	Isolate sensitivity to fungicide
Honeydew, Yolo Co., HM-YO-M2	Untreated	Untreated	4.4	0.4	
	Flint	Highest	1.9	0.1	Resistant
		Lowest	2.7	0.1	
		1/10 the highest	3.5	0.1	
	Quadris	Highest	3.4	0.2	Highly Resistant
		Lowest	3.4	0.2	
		1/2 the highest	3.7	0.1	
	Quadris Top (Quadris + Difenoconazole)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Luna Sensation (Flint+ Fluopyram)	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	
	Sovran	Highest	3.1	0.1	Resistant
		Lowest	3.0	0.4	
		1/10 the highest	3.5	0.1	
	Cabrio	Highest	0.1	0.1	Sensitive
		Lowest	0.1	0.1	
		1/10 the lowest	1.9	0.5	
	Procure	Highest	0.0	0.0	Moderately Sensitive
		Lowest	1.4	0.4	
		1/10 the lowest	3.8	0.0	
	Rally	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the lowest	2.5	0.7	
	Topsin	Highest	1.9	1.1	Resistant
		Lowest	2.9	0.3	
		1/2 the lowest	3.9	0.5	
	Pristine (Pyraclostrobin + Boscalid)	Highest	0.7	0.3	Moderately Resistant
		Lowest	2.5	0.3	
		1/10 the highest	3.4	0.4	
	Quintec	Highest	0.0	0.0	Highly Sensitive
		Lowest	0.0	0.0	
		1/10 the highest	0.0	0.0	

[a]The scores are the means of two independent replicates each with five determinations per replicate.

Table 3. Department of Pesticide Regulations' (DPR) 2010 and 2011 Pesticide Use Reports (PUR) of fungicides on melons (not including watermelon) that were probably used for powdery mildew control[a].

Fungicide active ingredient	Fungicides	Was fungicide resistance detected in 2011-2013? [b]	DPR PUR data on melons		
			2011		2010
			Lbs.	Acres treated[c]	
Myclobutanil	**Rally**	**Yes**	**685**	**5.314**	**4,606**
Quinoxyfen	Quintec	No	340	3,950	916
Sulfur	(Many)	Not tested, but highly unlikely	29,282	3,632	2,856
Pyraclostrobin	**Cabrio**	**Yes**	**459**	**2,707**	**2,100**
Triflumizole	*Procure*	*Some*	*443*	*2,243*	*2,122*
Azoxystrobin	Quadris, one component in Quadris Top	Yes	176	1,366	**2,253**
Trifloxystrobin	Flint	Yes	47	755	530
Thiophanate-methyl	Topsin	Yes	239	681	31
Chlorothalonil	Bravo, Chloronil, (others)	Not tested, but unlikely	698	420	1,032
Boscalid	Endura, one component in Pristine	Probably (only tested Pristine)	29	152	26
Kresoxim-methyl	Sovran	Yes	8	55	621
Difenoconazole	One component in Quadris Top	No	4	41	Not used

[a]Fungicides that were applied onto melons in 2011 onto more than 2,000 acres and in which fungicide-resistance seems common based on our data are bolded. Fungicides that were applied in 2011 onto more than 2,000 acres and in which fungicide-resistance was not common but detected are in italics.

[b] Based on our data, summarized in Table 1.

[c] An acre that is treated twice is counted as two treated acres.

To conclude, we have identified a high incidence of fungicide-resistance in the two FRAC risk groups (11 and 1), and what appears to be emerging resistance in FRAC groups 7 and 3. Unfortunately, our current laboratory assay for fungicide-resistance does not at least completely predict fungicide performance in the field; Quintec has performed best in our laboratory assay, but is only effective in the field if applied preventatively or at very early stages of disease development. At this point, if the weather and cultivar permit, we recommend inclusion of wettable sulfur in a rotation of fungicides for powdery mildew control.

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