California Melon Board Report, December 1, 2011

Project title – Fungicide-resistance and diversity of isolates that cause powdery mildew of melons in California

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Objectives

1) To assess fungicide resistance of isolates of powdery mildew on melons to representative fungicides from seven resistance groups.
2) To estimate the diversity of the population using the ribosomal DNA ITS sequence.
3) To establish associations between fungicide use history and fungicide resistance
4) To make recommendations regarding what fungicides may become ineffective due to mutations to fungicide resistance

Summary of Research Results:

We tested--with two independent trials to establish that our results are reproducible -- 12 isolates. Almost all (92%) are resistant to Topsin (FRAC Resistance Group 1) and 10 of 12 (83%) are moderately resistant or resistant to Quadris and Flint (FRAC ResistanceGroup 11). It is highly likely that those isolates that are resistant to Quadris and Flint are also resistant to other members of FRAC Resistance Group 11: Cabrio, Sovran and one of the components of Pristine. (However, we note that all of the isolates that we tested are apparently sensitive to Boscalid, the other fungicide in Pristine.) In addition to Pristine (which has Boscalid, which is in FRAC Resistance Group 7), all of the isolates were sensitive to Rally and Procure (both in FRAC Resistance Group 3).

Ribosomal ITS DNA sequence indicated that the rDNA ITS DNA sequence from nine distinct isolates from four counties (two isolates from Monterey Co., three isolates from Kern Co., three isolates from Yolo Co., and one isolate from Solano Co.) were all identical. All isolates were distinctly different from all of those that are currently in GenBank; our isolates have two polymorphisms with many isolates in GenBank that were identified as *Podosphaera xanthii* or one of its synonyms). Although the sample size is small, our data are consistent with their being one lineage on California melons.

In terms of recommendations, two Monterey isolates from Jim McCreight that are resistant to Topsin, Quadris and Flint apparently have not been exposed to fungicides in these groups for at least four years. Consequently, fungicide-resistance has not disappeared in the absence of selection pressure. We recommend that melon growers contact us to see if we can assay their powdery mildew for fungicide resistance (lepstein@ucdavis.edu). In the meantime,

we recommend that growers alternate between the following: sulfur if conditions are acceptable; Pristine; Procure (if label restrictions permit); and Quintec. We note that Quintec is only effective if applied preventatively or at very early stages of disease development. Although Rally did very well in our trial, we are not recommending it because it did not perform well in Tom Turini's trials, even though we tested one isolate from his plot, and it was sensitive to it.

Results

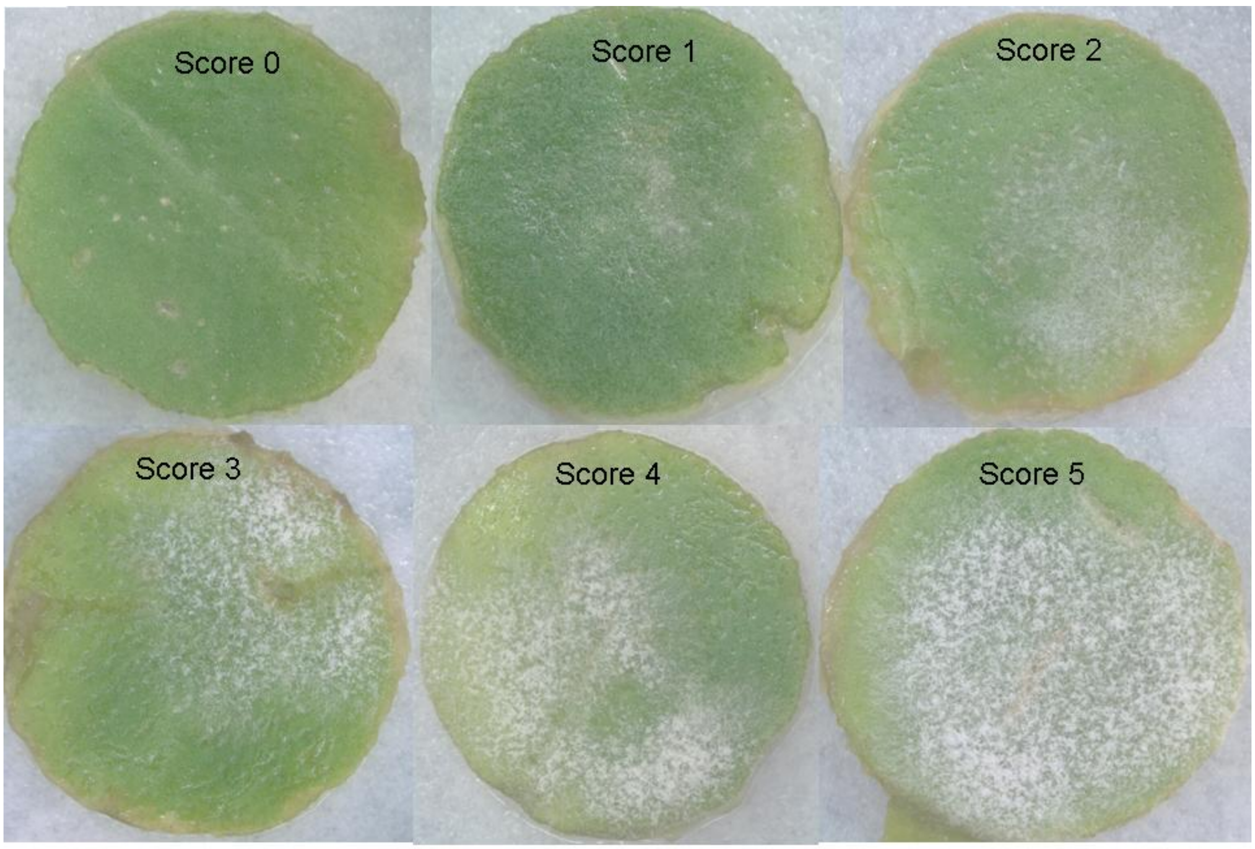
Isolates were collected with the assistance of our cooperators. Conidia of all isolates were first examined microscopically for fibrosin bodies, and were all consistent with being *Podosphaera xanthii* (synonyms, *P. fusca, Sphaerotheca fuliginea*). Another fungus, *Erysiphe cichoracearum* (=*Golovinomyces cichoracearum)* also occasionally causes powdery mildew on melons. However, both microscopy and the ribosomal ITS DNA sequence obtained for Objective 2 indicated that all isolates were *P. xan*thii.

Isolates were single colony purified in two cycles on surface-sterilized zucchini leaves to both obtain single isolates and to multiply conidia. Isolates were maintained by serial transfers on the leaves; we are continuing to try different methods of storage so that cultures can be maintained long term with far less labor. Bioassays were conducted on surface-sterilized 10 to 12 day old cotyledonary zucchini leaves. For each of two replicates in each of two independent trials, there were five leaf discs, each 0.4 inches across. To apply the fungicide, a 4.25 cm diameter Whatman 2 filter paper was soaked with 3 ml of four treatments: water for the untreated; the indicated fungicide with the lowest and the highest recommended dose; and 1/10 of the lowest 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 as shown in Fig. 1 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).

Results are shown in Table 1. As an example, Quadris and Flint were highly effective in controlling the first two isolates. Whereas the untreated leaves had an average score of 3.9 and 4.2, the leaves treated with even 1/10 of the lowest recommended concentration still had scores of all or almost all 0's (no powdery mildew visible). Consequently, these isolates are clearly sensitive to Quadris and Flint. In marked contrast, in all the other isolates (83%), Quadris and Flint were notably less effective (in "moderately resistant") or at least moderately ineffective (in "resistant" isolates). As an example, in the third isolate (Iran H Race 1, an isolate that had not been exposed to Quadris or Flint in four or more years), the untreated discs had a score of 4.2 (standard error =0.1). Regardless of the Quadris concentration, including the highest recommended dose, leaf discs had an average score of 3.0 to 3.2 (standard error=0.1 to 0.2), which we considered an ineffective control/a resistant isolate. Although Flint is in the same FRAC resistance group as Quadris, Flint may be slightly more effective than Quadris; there was a concentration-dependent effect of Flint. Nonetheless, while a grower may see some efficacy of either Quadris or Flint with this isolate, the value would be less than desired. Overall, we tested-- with two independent trials to establish that our results are reproducible -- 12 isolates. Eleven of the 12 (92%) are resistant to Topsin (FRAC Resistance Group 1) and the other isolate was only moderately sensitive to Topsin. Ten of 12 (83%) are either moderately resistant or resistant to

Quadris and Flint (FRAC ResistanceGroup 11). It is highly likely that those isolates that are resistant to Quadris and Flint are also resistant to other members of FRAC Resistance Group 11: Cabrio, Sovran and one of the components of Pristine. (However, we note that all of the isolates that we tested are apparently sensitive to Boscalid, the other fungicide in Pristine.) In addition to Pristine (which has Boscalid, which is in FRAC Resistance Group 7), all of the isolates were sensitive to Rally and Procure (both in FRAC Resistance Group 3).

Fig. 1. Microbe-free cotyledon discs (0.4 inches diameter wide) are treated with varying concentrations of the indicated fungicides and then inoculated with 500 *Podosphaera xanthii* conidia. After an eight day incubation, each disc is scored 0 to 5 to indicate increasing amounts of sporulation. The white on the cotyledon discs are masses of *P. xanthii* conidia.



Although the literature suggested that we could find variation in the ribosomal ITS DNA sequence, we found none in nine isolates from four counties (Fig. 2). Although the sequence is clearly within the *P. xanthii* clade, the isolates have two single nucleotide polymorphisms from other reported P. xanthii isolates. Although the sample size is small, our data are consistent with their being one lineage on California melons.

We did not request any funds to do Objectives 3 and 4, and they are covered in the discussion section.

Table 1. Predicted efficacy of fungicides on California isolates that cause powdery mildew of melon.

(Isolate name) Host-Source	Fungicide	Fungicide concentration, recommended dose	Score 0 (protected) to 5 (max disease)	Standard error of 4 replicates[a]	Isolate sensitivity to fungicide
Cataloupe - Sutter Co.	**Untreated**	**Untreated**	**3.9**	**0.2**	
	Quadris	1/10 the lowest	0.0	0.0	
		Lowest	**0.0**	0.0	Sensitive
		Highest	**0.0**	0.0	
	Flint	1/10 the lowest	0.0	0.0	
		Lowest	**0.0**	0.0	Sensitive
		Highest	**0.0**	0.0	
	Topsin	1/10 the lowest	4.2	0.4	
		Lowest	**4.2**	0.2	Resistant
		Highest	**3.7**	0.3	
	Rally	1/10 the lowest	3.3	0.2	
		Lowest	**0.2**	0.1	Sensitive
		Highest	**0.0**	0.0	
	Pristine	1/10 the lowest	1.7	0.1	
		Lowest	**0.0**	0.0	Sensitive
		Highest	**0.0**	0.0	
	Procure	1/10 the lowest	3.8	0.4	
		Lowest	**0.5**	0.1	Sensitive
		Highest	**0.0**	0.0	
Korean melon-Kern Co.	**Untreated**	**Untreated**	**4.2**	**0.1**	
	Quadris	1/10 the lowest	0.0	0.0	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Flint	1/10 the lowest	0.2	0.1	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Topsin	1/10 the lowest	3.9	0.3	
		Lowest	4.2	0.4	Resistant
		Highest	3.3	0.4	
	Rally	1/10 the lowest	1.3	0.7	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	1.4	0.4	

		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	3.2	0.6	
		Lowest	0.2	0.1	Sensitive
		Highest	0.0	0.0	
(Iran H Race 1) Melon-Monterey Co. (from Jim McCreight)	**Untreated**	**Untreated**	**4.2**	**0.1**	
	Quadris	1/10 the lowest	3.2	0.2	
		Lowest	**3.0**	0.1	Resistant
		Highest	**3.1**	0.2	
	Flint	1/10 the lowest	3.6	0.2	
		Lowest	**2.9**	0.2	Moderately Resistant
		Highest	**2.6**	0.3	
	Topsin	1/10 the lowest	3.4	0.4	
		Lowest	**3.9**	0.2	Resistant
		Highest	**3.4**	0.3	
	Rally	1/10 the lowest	3.3	0.4	
		Lowest	**1.4**	0.4	Sensitive
		Highest	**0.0**	0.0	
	Pristine	1/10 the lowest	2.9	0.2	
		Lowest	**1.1**	0.4	Sensitive
		Highest	**0.0**	0.0	
	Procure	1/10 the lowest	3.3	0.3	
		Lowest	**0.9**	0.6	Sensitive
		Highest	**0.0**	0.0	
Honeydew -Yolo	**Untreated**	**Untreated**	**4.1**	**0.1**	
	Quadris	1/10 the lowest	3.2	0.1	
		Lowest	2.9	0.3	Moderately Resistant
		Highest	2.8	0.1	
	Flint	1/10 the lowest	3.9	0.1	
		Lowest	3.8	0.2	Moderately Resistant
		Highest	2.7	0.3	
	Topsin	1/10 the lowest	4.6	0.2	
		Lowest	4.3	0.1	Resistant
		Highest	4.3	0.1	
	Rally	1/10 the lowest	3.1	0.2	
		Lowest	0.0	0.0	Sensitive

		Highest	0.0	0.0	
	Pristine	1/10 the lowest	2.7	0.3	
		Lowest	0.8	0.5	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	3.1	0.1	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
Casaba -Fresno Co. (Tom Turini Trial).	Untreated	Untreated	3.9	0.3	
	Quadris	1/10 the lowest	3.3	0.3	
		Lowest	3.2	0.1	Resistant
		Highest	2.8	0.4	
	Flint	1/10 the lowest	3.7	0.3	
		Lowest	3.8	0.2	Resistant
		Highest	3.1	0.2	
	Topsin	1/10 the lowest	4.3	0.1	
		Lowest	3.6	0.3	Resistant
		Highest	3.1	0.3	
	Rally	1/10 the lowest	2.8	0.1	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	3.4	0.2	
		Lowest	1.2	0.7	Sensitive
		Highest	0.2	0.1	
	Procure	1/10 the lowest	3.0	0.1	
		Lowest	0.2	0.1	Sensitive
		Highest	0.0	0.0	
Honeydew-Sutter Co.	Untreated	Untreated	4.3	0.2	
	Quadris	1/10 the lowest	3.0	0.2	
		Lowest	2.4	0.6	Moderately Resistant
		Highest	1.6	0.8	
	Flint	1/10 the lowest	3.6	0.1	
		Lowest	3.3	0.1	Resistant
		Highest	3.4	0.1	
	Topsin	1/10 the lowest	3.8	0.1	
		Lowest	3.3	0.5	Resistant
		Highest	3.3	0.3	
	Rally	1/10 the lowest	2.1	0.3	
		Lowest	0.0	0.0	Sensitive

		Highest	0.0	0.0	
	Pristine	1/10 the lowest	3.5	0.3	
		Lowest	0.6	0.4	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	2.0	0.2	
		Lowest	0.2	0.1	Sensitive
		Highest	0.0	0.0	
(92) Honeydew-Sutter Co.	Untreated	Untreated	4.1	0.1	
	Quadris	1/10 the lowest	3.4	0.6	
		Lowest	2.7	0.6	Moderately Resistant
		Highest	2.6	0.5	
	Flint	1/10 the lowest	3.2	0.4	
		Lowest	2.6	0.6	Moderately Resistant
		Highest	2.6	0.4	
	Topsin	1/10 the lowest	3.0	0.9	
		Lowest	2.7	0.9	Resistant
		Highest	2.6	0.9	
	Rally	1/10 the lowest	2.8	0.8	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	2.8	0.4	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	2.8	0.6	
		Lowest	0.1	0.1	Sensitive
		Highest	0.0	0.0	
(114) Honeydew - Yolo Co.	Untreated	Untreated	3.7	0.1	
	Quadris	1/10 the lowest	3.3	0.3	
		Lowest	3.0	0.4	Resistant
		Highest	2.8	0.2	
	Flint	1/10 the lowest	3.3	0.5	
		Lowest	2.9	0.3	Resistant
		Highest	2.6	0.3	
	Topsin	1/10 the lowest	3.7	0.3	
		Lowest	3.0	0.5	Resistant
		Highest	2.5	0.5	
	Rally	1/10 the lowest	2.3	0.4	
		Lowest	0.0	0.0	Sensitive

		Highest	0.0	0.0	
	Pristine	1/10 the lowest	2.3	0.2	
		Lowest	1.1	0.7	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	2.3	0.7	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
(Salinas GH Race SD) melon-Monterey (from Jim McCreight)	Untreated	Untreated	4.0	0.2	
	Quadris	1/10 the lowest	3.5	0.4	
		Lowest	3.2	0.2	Resistant
		Highest	3.0	0.6	
	Flint	1/10 the lowest	4.0	0.1	
		Lowest	4.1	0.2	Resistant
		Highest	2.9	0.1	
	Topsin	1/10 the lowest	1.3	0.1	
		Lowest	1.2	0.2	Moderately Sensitive
		Highest	1.3	0.1	
	Rally	1/10 the lowest	1.6	0.1	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	2.1	0.3	
		Lowest	0.1	0.1	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	2.9	0.5	
		Lowest	0.7	0.4	Sensitive
		Highest	0.0	0.0	
Watermelon-Kern Co.	Untreated	Untreated	3.1	0.4	
	Quadris	1/10 the lowest	3.8	0.5	
		Lowest	3.3	0.3	Resistant
		Highest	2.7	0.7	
	Flint	1/10 the lowest	3.7	0.3	
		Lowest	3.8	0.2	Resistant
		Highest	3.0	0.3	
	Topsin	1/10 the lowest	3.4	0.4	
		Lowest	2.7	0.7	Resistant
		Highest	2.9	0.8	
	Rally	1/10 the lowest	2.4	0.3	

		Lowest	0.2	0.1	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	2.8	0.8	
		Lowest	1.1	0.6	Sensitive
		Highest	0.0	0.0	
	Procure	1/10 the lowest	2.9	0.1	
		Lowest	0.1	0.1	Sensitive
		Highest	0.0	0.0	
Watermelon-Yolo Co.	Untreated	Untreated	4.5	0.1	
	Quadris	1/10 the lowest	4.0	0.1	
		Lowest	3.6	0.2	Resistant
		Highest	3.3	0.3	
	Flint	1/10 the lowest	4.1	0.1	
		Lowest	3.6	0.2	Resistant
		Highest	3.2	0.2	
	Topsin	1/10 the lowest	4.6	0.0	
		Lowest	4.3	0.3	Resistant
		Highest	3.9	0.1	
	Rally	1/10 the lowest	3.9	0.2	
		Lowest	1.8	0.5	Sensitive
		Highest	0.0	0.0	
	Pristine	1/10 the lowest	3.9	0.1	
		Lowest	0.1	0.1	Sensitive
		Highest	0.1	0.1	
	Procure	1/10 the lowest	3.6	0.2	
		Lowest	0.0	0.0	Sensitive
		Highest	0.0	0.0	
Watermelon - San Joaquin Co.	Untreated	Untreated	4.0	0.2	
	Quadris	1/10 the lowest	3.5	0.4	
		Lowest	2.9	0.8	Moderately Resistant
		Highest	1.9	0.8	
	Flint	1/10 the lowest	2.9	0.9	
		Lowest	2.2	0.8	Moderately Resistant
		Highest	2.0	0.2	
	Topsin	1/10 the lowest	3.9	0.2	
		Lowest	3.7	0.3	Resistant
		Highest	3.4	0.5	
	Rally	1/10 the lowest	1.7	1.0	

	Lowest	0.0	0.0	Sensitive
	Highest	0.0	0.0	
Pristine	1/10 the lowest	2.3	0.8	
	Lowest	0.3	0.2	Sensitive
	Highest	0.0	0.0	
Procure	1/10 the lowest	2.1	0.9	
	Lowest	0.0	0.0	Sensitive
	Highest	0.0	0.0	

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

Fig. 2. The ITS ribosomal DNA sequence of nine isolates of powdery mildew from melons in California in 2011.

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GTAGGTGACCTGCGGAGGATCATTACTGAGCGCGAGGCC
CCGCAGCGCGCACGCGCTGCGGCGGTTGACCCTCCACCCGTGTGAACTCT
TATCTGTTGCTTTGGCGGGCCGGGCTCGACCTGCCGGCTCCGGCTGGCGA
GTGCCCGTCAGAGAAGCCCCAACTCGTGCTGTGAGTGTTGTCTGAGGAAA
TGTGGAATTAGTAAAACTTTCAACAACGGATCTCTTGGCTCTGGCATCGA
TGAAGAACGCAGCGAAATGCGATAAGTAATGTGAATTGCAGAATTTAGTG
AATCATCGAATCTTTGAACGCACATTGCGCCCCCCGGCATTCCGAGGGGC
ATGCCTGTTCGAGCGTCAGAACACCCCTCAAGCCTAGCTTGGTCTTGGGG
CTCGCCGGCTCGGCGGCCCCTAAACGCAGTGGCGGTGCTGGTGTGCTCTC
CGCGTAGTCATGTATCTCGCGACAGAGTGGCGACGGCACCCGCCAGAACC
CCAGTCTTTGGATGACCTCGGATCAGGTAGGGATACCCGCTGAACTTAAG
CATATCAAT
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Discussion

Fungicide resistance to *P. xanthii* has been reported both in the U.S. and internationally multiple times (Table 2; 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. 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. This table does not address three issues that should be noted. 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). (Here's an explanation of fitness costs…After fungicide resistance appears in a population, when the fungicide is present, those cells with the resistance will be selected for and will reproduce to a greater extent than the susceptible population. For alternation to suppress the development of field-level resistance, in the absence of the fungicide, the fungicide-sensitive population must reproduce to a greater extent than the fungicide-resistant population. If the fungicide-sensitive population does out-reproduce the fungicide-resistant population in the absence of the fungicide, there is a "fitness cost" to fungicide resistance, and the extent that fungicide-resistance isolates declines depends upon the cost. If there isn't a fitness cost, the resistant population will remain at the proportion that it was the last time that the fungicide of interest was applied). The fact that our two Monterey Co. isolates from Jim McCreight have not been exposed to any of these fungicides for four or more years suggests that there might not be a fitness cost of fungicide resistance.Thus, it is critical to determine whether or not there is a fitness cost of the current fungicide resistance in California melons. 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 "quinone outside inhibitor." 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 and Quadris Top contain two fungicides, each from a different group. Consequently 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 the costs of fungicide resistance that melon growers face.

Table 2. Fungicides, used for control of powdery mildew on melons in California, based on their fungicide resistance group, mode of action, and FRAC's risk of fungicide resistance[a].

Fungicide Resistance Group[a]	Mode of action	Fungicides in the group[b]	Risk for development of resistance	Observed resistance to the most relevant powdery mildew fung[c]
11	Quinone outside inhibitor (QoI)	Azoxystrobin (Quadris & Quadris Top[d]) Trifloxystrobin (Flint) Pyraclostrobin (Cabrio) Kresoxim-methyl (Sovran) Pyraclostrobin (Pristine[d])	High	*P. xanthii* on cucumber (Heaney *et al.* 2000 ; Ishii *et al.* 2001; Fernandez-Ortuno *et al.* 2006 & 2008a) and cucurbits (McGrath & Shishkoff 2003a, b)
1	B-tubulin assembly in mitosis	Thiophanate-methyl (Topsin)	High	*P. xanthii* on cucurbits (Schroeder & Providenti 1971; Naegler *et al.* 1977)
7	Succinate dehydrogenase inhibitor (SDHI)	Boscalid (Pristine[d])	Medium to high	*P. xanthii* on melon (FRAC 2007, McGrath 2008, Miazzi & McGrath 2008; Miyamoto et al. 2010)
3	Demeth-ylation inhibitor of sterol biosyn-thesis	Triflumizole (Procure) Myclobutanil (Rally) Difenoconazole (Quadris Top[d])	Medium	*P. xanthii* on cucumber (Schepers 1983, 1984 & 1985) & cucurbits (López-Ruiz et al. 2010)

13	Unknown but involves signal trans-duction	Quinoxyfen (Quintec)	Medium	Various on wheat, barley and grapevine (Genet & Jaworska 2009; Hollomon *et al.* 1997)
M2[e]	Multi-site contact activity	Micronized sulfur (Microthiol, Thiolux) Sulfur dust	Low	No
M5[e]	Multi-site	Various, e.g. Chlorothalonil	Low	No

[a]Groups and risk assigned by the Fungicide Resistance Action Committee (FRAC) http://www.frac.info/. This table is limited to those groups of fungicides that are registered and used in California to control powdery mildew on melons. **Fungicide resistance in *P. xanthii* also has arisen in at least four other fungicide groups** (see list in McGrath 2001).
[b]When one fungicide in a group is resistant, there is a greater probability that other fungicides in the group also will be resistant; however, there may be exceptions.
[c]*P., Podosphaera*. The major causal agent of powdery mildew on melons in California has been called various names: *Podosphaera xanthii*, *P. fusca*, *Sphaerotheca fuliginea,* and *S. fuligenea*. They are all called *P. xanthii* in this table but are called by a synonym in the cited papers.
[d]Pristine and Quadris Top each contain two fungicides, each with different modes of action.
[e] M, Multi-site fungicides are not subject to the "alternating" rule.

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