Epidemiology and Management of Almond Anthracnose and Brown Rot in California

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Objectives:

1. **Epidemiology**
   a. Host-pathogen interactions: Effect of pH modulation as a pathogenicity factor for development of almond anthracnose.
   b. Develop wetness-temperature models for predicting anthracnose.
   c. Evaluate fungi associated with kernel discolorations
   d. Characterize the etiology of the newly described almond fruit russeting disorder.
      i. Evaluate powdery mildew-specific fungicides (no activity against other fungi) (e.g., quinoxyfen, V-10118) and broad-spectrum fungicides (e.g., wettable sulfur, myclobutanil, pyraclostrobin/boscalid).
      ii. From fungicide efficacy data deduce putative cause of disorder.
      iii. Greenhouse inoculation studies using infected almond fruit from the field as inoculum sources.
      iv. DNA amplification with powdery mildew-specific primers.
2. **Disease management strategies**
   a. Evaluate new fungicides and develop efficacy data based on spectrum of activity, systemic action, and persistence.
      i. Continue evaluations on brown rot, shot hole, scab, and anthracnose.
      ii. Use information on the characteristics of fungicides to develop effective rotation programs for foliar diseases
   b. Evaluate persistence and post-infection activity of selected fungicides in field/laboratory studies for management of brown rot and anthracnose.
   c. Develop baseline sensitivities of fungal pathogen populations against new fungicides and determine shifts in fungicide sensitivity.

   i. Characterize baseline sensitivities of *Monilinia, Cladosporium,* and *Colletotrichum* spp. against new fungicides including DMI and strobilurin fungicides.
   ii. Determine extent of strobilurin resistance in populations of *Cladosporium carpophilum* from several locations in California.

d. Evaluate almond genotype susceptibility to foliar diseases including brown rot that develop naturally in the almond variety orchard at UC Davis.

Interpretive Summary

Our research in 2007 on the evaluation of new fungicides against major foliar and fruit diseases of almond in California focused on the management of brown rot blossom blight, anthracnose, shot hole, and scab as well as on the etiology of a new russeting disorder of fruit. Alternaria leaf spot is discussed in a separate report. Highly effective fungicides were identified that will help to prevent the selection and build-up of resistant pathogen populations when applied in rotation or mixture programs. In a Solano Co. field trial with a high disease pressure of brown rot blossom blight, all single-fungicide, mixture, pre-mixture, or rotation programs evaluated significantly reduced the incidence of disease. The lowest incidences were found with Scala, Vangard, Enable, and the experimental Inspire, as well as with some of the pre-mixes (i.e., Pristine, Adament, Distinguish). The incidence of shot hole was most effectively controlled by strobilurin fungicides in single-fungicide, mixture, and pre-mixture programs. In a field trial in Butte Co., the incidence of brown rot and scab was low in the untreated control, but all rotation programs evaluated significantly reduced the disease. In research on the management of scab, dormant applications with liquid lime sulfur or copper-oil delayed sporulation of the pathogen on overwintering twig lesions and thus, reduced inoculum production. In a trial in Butte Co., petal fall applications with Bravo, Captan, and Maneb were very effective in reducing the disease, whereas late spring applications (early May) with selected fungicides generally were ineffective. Resistance to strobilurin fungicides was commonly found in *Cladosporium (Fusicladium) carpophilum* populations in six orchards in Northern California, emphasizing the importance of having several fungicide classes available that are active against a specific pathogen and the need to employ resistance management strategies whenever several alternatives to manage a disease are available. In studies on the etiology of a new russeting, powdery mildew-like disease, fungicide treatments indicated that a fungal organism causes the disorder. Probably, the putative pathogen is a powdery mildew fungus because powdery mildew-specific fungicides (e.g., Quintec, V-10118) also effectively reduced the incidence of this disorder. In growth chamber studies, the disorder could not be reproduced by exposing potted plants to field-infected symptomatic fruit.

Results and Discussion:

Fungicide evaluations for management of brown rot, shot hole, and gray mold in an experimental orchard. In the Solano Co. trial, blossom blight and infected spurs was significantly reduced by all treatments under high disease pressure (Table 1). Disease was reduced from 90.8 strikes per tree in the control to 6.0 to 51.6 strikes in the treatments. Among the single-fungicide programs with registered materials, Scala, Vangard, and Enable were the most effective. The experimental fungicide Inspire was similarly efficacious. All mixtures, pre-mixtures, and the rotations were highly effective. These results show that growers can effectively use fungicide pre-mixes or rotate fungicides for resistance management. The incidence of shot hole disease was high in 2007 in our Solano Co. trial with 92.5% of the fruit infected in the untreated control. The most effective treatments among the single-fungicides and pre-mixes in a three-spray program included the strobilurins Abound (2.1% disease), the experimental Evito (20.8%), and Pristine (12.3% disease), as well as the Abound-Orbit mixture (7.6% disease) (Table 1).

Table 1: Efficacy of fungicide programs for management of brown rot and shothole of Drake almonds, Solano Co. 2007.

Treatments*	Product Rate (100 gal/A)	Brown rot** Strikes per tree	LSD^	Shothole on fruit*** Incidence (%)	LSD	Severity Lesions	LSD
Control	---	90.8	a	92.5	a	6.5	a
Inspire 250EC	7 fl oz	9.0	d	32.2	fgh	1.0	defg
Orbit 3.6EC	4 fl oz	14.4	cd	74.4	b	3.4	b
Vangard 75WG	5 oz	9.2	d	89.8	a	6.0	a
Scala 500SC	12 fl oz	6.0	d	94.6	a	5.9	a
Abound 2F	12.8 fl oz	19.6	cd	2.1	j	0.0	g
Gem 500SC	3 fl oz	27.4	c	38.5	efgh	1.6	cde
Evito 480SC	6 fl oz	51.6	b	20.8	hi	0.8	efg
Rovral 4F	16 fl oz	16.4	cd	29.7	gh	1.8	cde
Enable 2F + Breakthru	6 fl oz + 0.125%	11.4	d	66.8	bc	3.0	bc
Inspire 250EC + Vangard	4 fl oz + 4 oz	6.8	d	50.4	cdef	2.2	bcd
Abound 2F + Orbit 3.6EC	3 fl oz + 4 fl oz	9.0	d	7.6	j	0.2	fg
Pristine 38WG	14.5 oz	8.8	d	12.3	ij	0.5	efg
Adament 50WG	4 oz	8.4	d	51.9	cde	2.3	bcd
Adament 50WG	6 oz	15.0	cd	64.9	bcd	2.3	bcd
Distinguish 480SC	12.8 fl oz	6.2	d	55.2	bcde	2.5	bc
Enable 2F + Breakthru	6 fl oz + 0.125%	9.8	d	44.4	defg	1.6	cdef
Enable 2F+Dithane+Breakthru	6 fl oz + 6 lb + 0.125%						

* - Treatments were applied on 2-20 (full bloom), 3-1 (petal fall), and 3-15-07 (shuck split) at a rate of 100 gal/A. The last treatment program was a rotation (Enable+Breakthru on 2-20, Enable+Dithane+Breakthru on 3-1 and 3-15-07).

** - For brown rot, the number of brown rot strikes per tree was counted on 5-24-07 for each of five single-tree replications.

***- Incidence and severity of shot hole on 5-21-07 are based on 25-30 fruit from each of five single-tree replications.

^ - Values followed by the same letter are not significantly different based on an analysis of variance and LSD mean separation ($P > 0.05$).

A limited number of these fungicides was also evaluated in laboratory experiments. Blossoms were collected in the field after a single full bloom application, inoculated with *Monilinia laxa*, and evaluated for stamen infection. Among the single-fungicide programs, Vangard was the most effective treatment with 5.5% of the stamens infected as compared to 91.8% in the control (Table 2). The strobilurins Gem and Evito were the least effective. The SBIs Orbit, Enable, and Inspire and the pre-mixtures Pristine, Adament, and Distinguish were of intermediate efficacy. For control of gray mold on field-treated flower petals that were incubated in the lab for development of natural incidence of disease, the numerically most effective fungicides were Vangard, Rovral, Pristine, as well as the Abound-Orbit mixture (Table 2).

Fungicide evaluations for management of brown rot, anthracnose, and scab in commercial orchards. In our field trial in Butte Co. in 2007 where we evaluated different rotation programs, the incidence of anthracnose was very low. The incidence of brown rot was 3.5% and for scab was 15.5% in the untreated control (Table 3). All programs were effective, reducing brown rot to 0-0.5% and scab to 0.75-2.75% incidence, respectively. A large-scale field trial in Butte Co. was designed as a split-split plot design where the main plot received or did not receive dormant applications with liquid lime sulfur (LLS). Sub-plots received selected petal fall applications, and sub-sub-plots were treated with selected late spring applications of fungicides. In this plot, timing of petal fall treatments

Table 2. Efficacy of fungicides for management of brown rot and gray mold of Drake almonds in laboratory studies 2007.

Treatments*	Product Rate (100 gal/A)	Brown rot infections** (%)	Brown rot LSD***	Gray mold** Incidence (%)	Incidence LSD	Severity % Area	Severity LSD
Control	---	91.8	a	94.4	a	2.8	a
Inspire 250EC	7 fl oz	39.7	cd	86.0	bc	1.8	bc
Orbit 3.6EC	4 fl oz	45.1	cd	83.1	bc	1.6	cd
Vangard 75WG	5 oz	5.5	d	52.0	ef	0.7	fg
Scala 500SC	12 fl oz	not done		80.9	bc	1.2	def
Gem 500SC	3 fl oz	73.6	ab	89.8	ab	2.3	ab
Evito 480SC	6 fl oz	72.0	ab	94.4	a	2.4	a
Rovral 4F	16 fl oz	not done		53.3	ef	0.8	fg
Enable 2F + Breakthru	6 fl oz + 0.125%	48.2	cd	91.3	ab	2.4	ab
Inspire 250EC + Vangard	4 fl oz + 4 oz	not done		76.8	cd	1.1	def
Abound 2F + Orbit 3.6EC	3 fl oz + 4 fl oz	not done		42.2	f	0.6	g
Pristine 38WG	14.5 oz	37.9	cd	49.5	ef	0.8	fg
Adament 50WG	4 oz	46.4	cd	not done			
Adament 50WG	6 oz	not done		75.0	cd	1.5	cde
Distinguish 480SC	12.8 fl oz	31.8	cd	66.6	de	1.0	efg

* - Treatments were applied on 2-20-07 using an air-blast sprayer at a rate of 100 gal/A.

**- For brown rot evaluation, 7 blossoms from each of 4 single-tree replications were randomly collected on 2-21-07 and inoculated with conidia of *M. laxa* (10,000 conidia/ml). The incidence of stamen infections was evaluated after 5 days of incubation at 20C. Gray mold was evaluated on petals and incubated on moist vermiculite in the laboratory.

*** - Values followed by the same letter are not significantly different based on an analysis of variance and LSD mean separation ($P > 0.05$).

was based on the previously developed inoculum-based model for forecasting scab using twig infections (see below). Scab severity, but not scab incidence, was significantly reduced after dormant applications with LLS. Two petal fall applications with Bravo-Captan, Captan-Maneb, or with Maneb alone effectively reduced the incidence and severity of scab (Table 4A), whereas late-spring applications alone with Pristine, Microthiol, or Captan had no significant effect in reducing the disease (Table 4B,C). The combination of petal fall and late spring applications generally improved the control, but there were no significant differences. A late spring application with Inspire was done at this location and this treatment was highly effective and reduced the disease to very low levels. Preliminary data obtained for this fungicide in 2006 had also indicated the high efficacy for managing scab. Thus, the fungicide Inspire will be evaluated again in 2008. In another trial in Kern Co. that was mainly established for the evaluation of fungicide programs against Alternaria leaf spot, three applications of fungicides, including Inspire, between May 8 and June 25, 2007, had no effect in reducing the incidence and severity of scab. This indicates the general ineffectiveness of treatments that are done in late spring. Thus, for management of almond scab the most effective treatment timings are petal fall applications. Our data also indicate that after dormant applications with LLS the severity of disease was reduced. This could be correlated to a reduced spore inoculum production from overwintering scab lesions on one-year old twigs. Thus, in monitoring the onset of sporulation of twig lesions we found abundant sporulation on untreated twigs in our Butte Co. trial on April 11, whereas on LLS-treated twigs only ca. 5% of the lesions sporulated at this time. On 4-26-07, ca. 22% of the lesions were found to sporulate on the LLS-treated twigs. In trials on dormant applications that were done in cooperation with a PCA, pre-bloom applications

Table 3. Efficacy of fungicide programs for management of brown rot and scab cv. Peerless almonds Butte Co. 2007.

		Application Dates			Brown Rot Incidence**		Scab Incidence**	
		2-23	3-21	4-11				
Product*	Rate	FB	PF/SS	5-wk PF	(%)	LSD***	(%)	LSD
Control	---	---	---	---	3.50	a	15.50	a
Pristine 38WG	0.92 lb	@	---	---	0.25	b	1.25	b
Ziram 75WSP	8 lb	---	@	---				
Captan 80WG	5 lb	---	---	@				
Elite 45WP + Scala 400SC	6 fl oz	@	---	---	0.25	b	1.25	b
Echo 720SC	4 pt	---	@	---				
Captan 80WG	5 lb	---	---	@				
Orbit 3.6EC + Vangard 75WG	6 fl oz	@	---	---	0.00	b	0.75	b
Echo 720SC	4 pt	---	@	---				
Captan 80WG	5 lb	---	---	@				
Vangard 75WG	5 oz	@	---	---	0.50	b	2.75	b
Captan 80WG	5 lb	---	@	---				
Manex	6 qt	---	---	@				
Scala 400SC	12.8 fl oz	@	---	---	0.00	b	1.75	b
Captan 80WG	5 lb	---	@	---				
Manex	6 qt	---	---	@				

* - Treatments were applied using an air-blast sprayer at a rate of 100 gal/A.

** - Incidence of brown rot was based on the number of infected shoots per 100 shoots evaluated, whereas incidence of scab was based on 100 fruit from each of four single-tree replications from each treatment.

*** - Values followed by the same letter are not significantly different based on an analysis of variance and LSD mean separation ($P > 0.05$).

with sulfur had no effect in delaying sporulation of twig lesions, whereas applications with copper-oil were found to be highly effective. As late as early June, the incidence of sporulating lesions was reduced by 90% as compared to untreated control trees. Thus, these dormant applications as effective inoculum reduction treatments warrant further research. Furthermore, the existing inoculum-based model to optimize application timing was confirmed as a highly effective strategy for timing scab fungicide treatments.

In vitro sensitivity o*f C. carpophilum* isolates to azoxystrobin. In vitro fungicide sensitivities were determined due to grower reports on the ineffectiveness of strobilurin fungicides, including the strobilurin-carboxamide pre-mixture Pristine. Strobilurin-resistant isolates of *C. carpophilum* were found in six orchards evaluated to date. The incidence of resistance (EC_{50} values >25 mg/L) ranged from 80 to 100% indicating that, similar to 2006, strobilurin resistance is widespread. Boscalid, the second single-site mode of action ingredient of Pristine, is generally inactive against the pathogen. Evaluation of isolates collected in 2006 from several locations had revealed a wide range of sensitivities to boscalid. Additional testing of fungal isolates collected in 2007 is ongoing for other fungicides and a baseline is being developed for difenoconazole.

Because of lack of availability of highly effective alternative fungicides, the strobilurin class of fungicides has been over-used, resulting in the widespread resistance. This stresses the need for our fungicide evaluation program to identify multiple fungicide classes that are active against a specific pathogen and the need to employ resistance management strategies whenever several alternatives to manage a disease are available. Furthermore, it emphasizes the use of currently registered multi-site materials for scab management.

Table 4. Efficacy of fungicide programs for management of scab on Carmel almond in Butte Co. 2007

A. Effect of petal fall treatments (3-25 and 4-11)

	Applic. date		No dormant lime sulfur				w/ Dormant lime sulfur			
Treatment*	3-25	4-11	Inc. (%)**	LSD***	Sev.	LSD	Inc. (%)	LSD	Sev.	LSD
Control	---	---	82.1	a	16.7	a	63.3	a	7.6	a
Bravo W'stik 64 fl oz	@	---	20.1	b	1.5	b	27.9	b	2.4	b
Captan 80WP 5.5 lb	---	@								
Maneb 8 lb	@	@	15.9	b	1.4	b	18.0	b	1.9	b
Captan 80WP 5.5 lb	@	---	18.7	b	1.3	b	19.2	b	1.7	b
Maneb 8 lb	---	@								

B) Effect of late spring applications (5-3-07) with no dormant application of liquid lime sulfur

	No petal fall applications				Bravo on 3-25 Captan on 4-11-07				Captan on 3-25 Maneb on 4-11-07			
Treatments*	Inc. (%)	LSD	Sev.	LSD	Inc. (%)	LSD	Sev.	LSD	Inc. (%)	LSD	Sev.	LSD
Control	95.8	a	21.5	a	22.9	a	1.8	a	22.9	a	1.7	a
Pristine 38WG	93.8	a	19.1	a	13.5	a	0.9	a	18.8	a	1.5	a
Microthiol	97.9	a	22.0	a	22.9	a	1.7	a	15.6	a	1.2	a
Captan 80WP	97.9	a	19.1	a	20.8	a	1.5	a	25.0	a	1.8	a

C) Effect of late spring applications (5-3-07) with a dormant application of liquid lime sulfur

	No petal fall applications				Bravo on 3-25 Captan on 4-11-07				Captan on 3-25 Maneb on 4-11-07			
Treatments*	Inc. (%)	LSD	Sev.	LSD	Inc. (%)	LSD	Sev.	LSD	Inc. (%)	LSD	Sev.	LSD
Control	88.5	a	12.7	a	35.4	a	3.1	a	11.5	a	0.8	a
Pristine 38WG	60.4	a	8.1	a	18.8	a	1.7	a	24.0	a	2.4	a
Microthiol	56.3	a	6.1	a	31.3	a	2.6	a	15.6	a	1.2	a
Captan 80WP	56.3	a	5.5	a	26.0	a	2.1	a	26.0	a	2.3	a

* - The trial was designed as a split-split plot. Treatments were applied using an air-blast sprayer at a rate of 100 gal/A. Liquid lime sulfur was applied on 1-20-07.

** - Incidence of disease on 7-18-07 was based on 25 fruit from each of four single-tree replications from each treatment. Severity was based on the number of lesions per fruit.

*** -Values followed by the same letter are not significantly different based on an ANOVA and LSD mean separation ($P > 0.05$).

Etiology of a new putative powdery mildew-like fruit russeting disease of almond. In mid- to late spring of 2005, unusual russetting of almond fruit was observed by J. Edstrom. In 2006, this disorder was more widely found throughout the central valley. In our 2006 field trials, all fungicides evaluated significantly reduced the incidence of the disorder. In 2007 at the same trial site, a low level of disease (2.3%) was found on untreated cv. Ruby control fruit. No disease was found on cv. Padre. Again, however, most of the fungicides evaluated significantly reduced the incidence of disease to 0-0.5% after two treatments between late March and late April. These results again indicate that the russeting of almond fruit is caused by a fungal organism. Furthermore, based on the activity of the powdery mildew-specific fungicides, it is likely that a type of powdery mildew fungus is involved. Previously, powdery mildew fungi reported from almond in California and other locations in the world include *Podosphaera leucotricha, P. tridactyla, and Sphaerotheca pannosa.* The almond fruit russeting infections can occur with apparently no obvious leaf infections. In growth chamber studies using potted almond plants, no symptoms were observed on fruit when plants were exposed to field-collected symptomatic fruit at different environmental conditions for up to one month. Possibly, specific environmental conditions and host maturity stage have to be present for the successful infection by the putative pathogen. Additional studies on the etiology of this disease will be conducted in the coming seasons.