Epidemiology and Management of Almond Brown Rot, Scab, and Other Foliar Diseases in California

Project No.: **08-PATH4-Adaskaveg**

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Objectives

I. Disease management strategies
   A. Evaluate new fungicides and develop efficacy data based on spectrum of activity, systemic action, and persistence.
      a. Continue evaluations on brown rot, jacket rot, shot hole, and scab.
      b. Evaluate fungicide additives such as BioForge for their increase in efficacy as compared to the use of fungicides alone.
      c. Evaluate persistence and post-infection activity of selected fungicides in field/laboratory studies for management of foliar diseases.
      d. For scab management, evaluate the effect of dormant applications (liquid lime sulfur, copper-oil) on sporulation of infected twig lesions, as well as the fungicides dodine and difenoconazole for in-season use.
      e. Use information on the characteristics of fungicides to develop effective rotation programs for disease management of almond.
   B. Develop baseline sensitivities of fungal pathogen populations against new fungicides and determine shifts in fungicide sensitivity.
      a. Characterize baseline sensitivities of *Monilinia, Cladosporium,* and other fungal species against SBI and other fungicides
      b. Determine extent of strobilurin resistance in populations of *C. carpophilum* and anilinopyrimidine (AP) (e.g., cyprodinil – Vangard) resistance in *Monilinia* spp. in CA.
   C. Evaluate almond genotype susceptibility to foliar diseases including brown rot

and other diseases that develop naturally in the almond variety orchard at UC Davis under simulated rainfall as part of an ongoing collaboration with T. Gradziel.

II. Epidemiology

B. Characterize the etiology of the newly described almond fruit russeting disorder.

a. Apply 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) in affected orchards.
b. From fungicide efficacy data deduce putative cause of disorder (fungal, specific fungi, non-fungal).
c. Greenhouse inoculation studies using infected almond fruit from the field as inoculum sources.
d. DNA amplification of infected almond tissues with powdery mildew-specific primers.

Interpretive Summary:

Our research in 2008 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. The incidence of springtime diseases was low in most locations due to the dry spring weather and data could not be obtained from all trials. Still, highly effective single-fungicides (Inspire, Quash, USF2015) and pre-mixtures (A13703, A13909, Inspire Super, Distinguish, USF2016, USF2017, etc.) were identified that will be excellent materials providing broad spectrum of activity and help in preventing the selection and build-up of resistant pathogen populations when applied in rotation or mixture programs. Bravo was identified as an excellent scab treatment. Resistance to date has not been reported in populations of *Monilinia laxa* (brown rot), *Botrytis cinerea* (gray mold), or *Wilsonomyces carpophilus* (shot hole), but is common in *Cladosporium carpophilum* (scab) against the QoI fungicides. Additionally, we evaluated the natural incidence of brown rot in our variety block and showed a range of susceptibility among early, mid- and late blooming varieties. Integration of host resistance, cultural practices, and effective fungicides wit unique modes of action will provide sustainable approaches to foliar disease control of almonds.

Materials and Methods:

<u>Fungicide evaluations for management of brown rot, shot hole, and gray mold in an experimental orchard</u>

Field trials were conducted at UC Davis on cv. Drake. Treatments were done as single-fungicide, mixture, or pre-mixture programs as shown in **Table 1**. Treatments were applied using an air-blast sprayer at a rate of 100 gal/A. For brown rot evaluation, the number of brown rot strikes per tree was counted for each of five single-tree replications. Incidence and severity of shot hole were based on 25-30 fruit from each of five single-tree replications from each treatment. In additional studies, field-treated blossoms were taken to the laboratory, placed on moist vermiculite, and inoculated with conidia of *M. fructicola* (10,000 conidia/ml). The incidence of stamen infections was determined after 5 days of incubation at 20C. Treated flower petals were also collected and incubated on moist vermiculite for 5 days at 20C for the development of natural incidence of gray mold. Data were evaluated using an analysis of variance and LSD mean separation ($P > 0.05$).

Fungicide evaluations for management of brown rot, anthracnose, and scab in commercial orchards

In a field trial in Butte Co. on cv. Peerless, treatments were done as rotation programs as shown in **Table 3**. Treatments were applied using an air-blast sprayer at a rate of 100 gal/A at full bloom, petal fall/shuck split, and 5-wk after petal fall. Incidence of disease based on 100 blossoms or fruit from each of four single-tree replications from each treatment. Data were evaluated using an analysis of variance and LSD mean separation ($P > 0.05$).

Specifically for scab management, a second a large-scale field trial was conducted in Butte Co. using a split-split plot design. The main plots consisted of rows treated or not treated with liquid lime sulfur (16 gal/A), oil (4 gal/100 gal/A), copper (Kocide 2000 6 lb/A), or copper-oil (Kocide 2000-4% oil or NuCop 6 lb-4% oil) in January of 2008. Sub-plots were established that were not treated or treated in late March or early April (petal fall applications) with Captan, Ziram, Echo, Orbit, or Syllit. The effect of liquid lime sulfur on sporulation of scab lesions was evaluated in two-week intervals starting in March. The incidence (percent diseased fruit) and severity (number of lesions/fruit) of scab was evaluated on 24 fruit for each of the single-tree replications. Data were evaluated using an analysis of variance and LSD mean separation ($P > 0.05$).

In vitro sensitivity of *Cladosporium carpophilum* or *Monilinia laxa* isolates to selected fungicides

Isolates were collected from seven orchards in Butte and Kern Co. Using the spiral gradient dilution method, the inhibition of conidial germination on azoxystrobin-amended agar media was evaluated after ca. 20 h of incubation. Boscalid, difenoconazole, and cyprodinil were evaluated in mycelial growth assays. A baseline sensitivity range study was initiated for difenoconazole using selected populations of *C. carpophilum*.

Etiology of a new putative powdery mildew-like fruit russeting disease of almond

Based on previous studies using powdery mildew specific-fungicides, we were able to indirectly assess that the putative disease of almonds causing fruit russeting is probably caused by a powdery mildew fungus. Attempts to isolate fungi from infected tissue using standard microbiological media were unsuccessful. Thus, to determine if the pathogen could be cultured on almond plants, infected fruit collected from commercial orchards were placed adjacent to potted almond plants grown in a humidity chamber or scrapings from the affected fruit were sprayed onto almond leaves. Potted almond plants were held in a growth chamber for 4 weeks to determine if a biotrophic pathogen could be propagated directly on the plant.

Field evaluation of almond cultivar susceptibility

Almond cultivars grown in the UC Davis almond variety plot was irrigated from early spring to early summer using a high-angle sprinkler system to create favorable conditions for the occurrence of diseases. Trees were evaluated for brown rot and other diseases that occur naturally in this orchard including anthracnose, rust, shot hole, and scab. The goal is to have a standardized field study for comparing disease susceptibility among many almond cultivars to foliar diseases, unlike what can be done in commercial orchards where only a limited number of cultivars is grown. All 32 varieties are on the same rootstock and in the same soil type. All data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures of SAS.

Results and Discussion:

Field trials on disease management

In a Solano Co. trial we emphasized the evaluation of new pre-mixtures, a comparison between new and registered SBI fungicides, and on the efficacy of a natural product. All pre-mixtures, including the newly registered Distinguish were very effective against brown rot (**Table 1**). Disease was reduced from 81.8 strikes per tree in the control to 6-15 strikes in the treatments. For gray mold control, Adament, Distinguish, and two numbered compounds (USF2016A and USF2017A) had the lowest disease levels (4.7-9.9% incidence as compared to the control with 83.5%). Among the SBI fungicides tested, Orbit performed best against brown rot (8.6 strikes per tree) and the numbered compound USF2015 was the most effective against gray mold (5.8% incidence). A rotation of the soon to be registered SBI Quash, Pristine, and Ziram provided very good control against both diseases. These results indicate that growers can use fungicide pre-mixes and rotate fungicides for effective disease control and resistance management. In an additional trial to evaluate the effect of a single full bloom fungicide treatment on yield of almond cv. Carmel (8 yrs old), Pristine and Vangard were compared in a commercial orchard. Average kernel weight per tree was 17.8 and 17.7 Kg/tree for Vangard and Pristine, respectively. Thus, in this high production orchard, no significant differences on yield were observed between these fungicides and any growth regulator effect induced by these fungicides was not observed.

Table 1. Efficacy of fungicide programs for management of brown rot and gray mold of Drake almonds at the UC – Davis experimental orchard 2008.

				Applications			Brown rot**		Gray mold***	
			Product Rate	2-27	3-3	3-19	Strikes		Incidence	
No.	Program	Treatments*	(100 gal/A)	FB	PF	SS	per tree	LSD^	(%)	LSD
1	---	Control	---	---	---	---	81.8	a	83.5	a
2	Single fungicides	Quash 50WG	2.5 oz	@	@	@	15.2	cd	19.6	bcdefg
3		Orbit 3.6EC	6 fl oz	@	@	@	8.6	d	28.5	bc
4		Indar 2F +BT	6 fl oz	@	@	@	52.8	b	25.3	bc
5		USF2015A SC	5 fl oz	@	@	@	15.6	cd	5.8	hi
6		MOI 106	1.0%	@	@	@	39.8	bc	32.4	b
7	Pre-mixtures	A15909	25 fl oz	@	@	@	11.6	d	16.4	cdefgh
8		A13703	14 fl oz	@	@	@	12.4	d	20.3	bcdef
9		A8122	7 fl oz	@	@	@	9.8	d	23.3	bcd
10		Inspire Super SC	10 fl oz	@	@	@	15.0	cd	12.2	defghi
11		Inspire Super SC	14 fl oz	@	@	@	10.0	d	11.3	defghi
12		Adament 50WG	6 oz	@	@	@	12.6	d	5.4	i
13		Adament 50WG	8 oz	@	@	@	10.8	d	4.7	i
14		Distinguish 480SC	12.8 fl oz	@	@	@	11.8	d	8.5	ghi
15		Distinguish 480SC	18 fl oz	@	@	@	10.0	d	9.9	efghi
16		USF2016A	5 fl oz	@	@	@	8.0	d	7.0	hi
17		USF2017A	6 fl oz	@	@	@	6.0	d	8.7	fghi
18	Rotation	Quash 50WG	2.5 oz	@	---	---	12.2	d	20.8	bcde
		Pristine 38WG	14.5 oz	---	@	---				
		Ziram 76DF	8 lb	---	---	@				

* - Treatments were applied using an air-blast sprayer at a rate of 100 gal/A.
** - For brown rot evaluation, the number of brown rot strikes per tree was counted on 5-27-08.
***- Gray mold was evaluated on flower petals that were collected on 3-5-08 and incubated in the laboratory. Incidence of gray mold was based on ca. 50 petals for each treatment replication.
^ - Values followed by the same letter are not significantly different based on an analysis of variance and LSD mean separation ($P > 0.05$).

All fungicides from this field trial also exhibited very high pre- and post-infection activities (i.e., inoculation 48 h before or after treatment) in laboratory studies, reducing the incidence of stamen infections by $\geq$79% from the untreated control. The three natural products evaluated were more effective as post-infection treatments than as pre-infection treatments, but were still less effective as compared to the fungicides (**Table 2**). MOI 104 at 1% reduced the incidence of infection from 94.1% in the control to 24.1%. At effective rates, MOI 106 and MOI 107 caused phytotoxicity on the petals. The lack of good pre-infection activity of these three natural compounds indicates that they are not very persistent.

Timing of after-petal-fall treatments for scab control was based on the previously developed inoculum-based model for forecasting scab using twig infections. Incidence of scab on fruit in two Butte Co. trials was between 15.5 and 26.3% and all treatments evaluated significantly reduced the incidence of disease (**Table 3**). In a large-scale trial with a split-plot design (dormant treatments, petal fall treatments), the incidence was less than 1% and no data were obtained.

Still, valuable information was obtained on the efficacy of dormant treatments. These treatments can be an effective strategy to inhibit or delay the sporulation of scab lesions on previous year's growth that produce new inoculum in the spring. Sporulation was first observed on lesions occurring on shoots from previous year's late summer/fall growth, as opposed to lesions on spring growth. Sporadic sporulation on older growth in this orchard was not observed before May. This observation indicates that the promotion of vigorous tree growth in late summer/fall before dormancy can lead to the production of highly susceptible host tissue and thus, should be avoided. By the end of March, ca. 80% of the lesions on fall growth of untreated trees produced spores, whereas after treatments with copper-oil less than 10% of the lesions sporulated. In a comparison between different dormant treatments that was done in mid-April, the incidence of sporulation was 76% in the control, 64.4% after oil treatments, 42% after copper treatments, 33.3% after treatment with liquid lime sulfur, and 2-16% after treatment with copper-oil mixtures. Thus, dormant applications can be highly effective inoculum reduction treatments. They should be included into any scab management program, also because a reduced amount of inoculum will reduce the risk for selection for fungicide resistance.

Table 2. Evaluation of the pre- and post-infection activity of natural products for control of brown rot blossom blight of cv. Drake almond in laboratory studies 2008

			Post-infection activity*		Pre-infection activity**	
		Product Rate	Inc. stamen infections		Inc. stamen infections	
No.	Treatments	(100 gal/A)	%	LSD***	%	LSD***
1	Control	---	94.1	a	74.3	a
2	MOI 104	0.01%	70.5	b	88.0	ab
3	MOI 104	0.10%	75.7	b	94.7	a
4	MOI 104	1%	24.1	c	74.0	b
5	MOI 106	0.5%	95.4	a	84.0	ab
6	MOI 106****	1%	61.4	b	80.7	ab
7	MOI 107****	0.5%	31.4	c	81.6	ab
8	Vangard 75WG	5 oz	1.1	d	16.3	c

Blossoms were collected at popcorn stage and opened in the laboratory.

* - For evaluation of the post-infection activity, blossoms were inoculated with conidia of *M. laxa* (10,000 conidia/ml) and treated after 48 h using a hand sprayer.

**- For evaluation of the pre-infection activity, blossoms were first treated and inoculated with *M. laxa* after 48 h.

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

**** - Phototoxicity was observed on blossom petals.

Table 3. Efficacy of fungicide programs for management of scab of cv. Peerless almonds, Butte Co. 2008

No.	Program	Treatment*	Product Rate (/A)	Application Dates 2/28 20-50% bloom	3/4 FB	3/25 2-wk-after PF	Scab Incidence** (%)	LSD***
1	---	Control	---	---	---	---	26.3	a
2	Single	Polyoxin-D 11.2WDG	16 oz	@	@	@	1	b
3		Orbit 3.6EC	6 fl oz	@	@	@	1.5	b
4		Indar 2F	6 fl oz	@	@	@	0.5	b
5	Premixtures	Pristine 38WG	14.5 oz	@	@	@	2	b
6		Distinguish 480SC	18 fl oz	@	@	@	1	b
7		Inspire Super SC	20 fl oz	@	@	@	1.5	b
8		Adament 50WG	8 oz	@	@	@	3	b
9	Rotations	Orbit 3.6EC	6 fl oz	@			1.5	b
		Inspire Super SC	20 fl oz		@			
		A15909A-AO SC	25 fl oz			@		
10		Elite 45WP	6 oz	@			2	b
		Distinguish 480SC	18 fl oz		@			
		Adament 50WG	8 oz			@		
11		Indar 2F	6 fl oz	@			3.5	b
		Pristine 38WG	14.5 oz		@			
		Indar 2F/Dithane F45	6 fl oz/192 fl oz			@		
12		T-Methyl 70W	24 oz	@			2.5	b
		Iprodione 4L	16 fl oz		@			
		Captan 80WDG	80 oz			@		
13		Vangard 75WG	5 oz	@			1.5	b
		Syllit FL	32 fl oz		@	@		

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

** - 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 least significant difference (LSD) mean separation ($P > 0.05$).

Sensitivity of pathogens to selected fungicides

Isolates of *M. laxa* were collected from three locations where brown rot was unsatisfactorily controlled after Vangard treatments. The in vitro sensitivity of 18 isolates were within the baseline range for this fungicide (e.g., 0.04 - 0.15 mg/L). Thus, the lack of fungicide efficacy was not due to resistance, but due to improper timing or inadequate application methods. This stresses proper application strategies to provide complete full-bloom or canopy coverage.

There were no other reports on fungicide efficacy in 2008, as disease pressure was low. Because of this low pressure at most locations, the spread of resistance in *Cladosporium carpophilum* (scab pathogen) against QoI fungicides possibly was slowed down and the development of new resistances was not favored. Still, we will continue to evaluate and develop new classes of fungicides to have several classes available for each disease that will facilitate the implementation of resistance management strategies.

Etiology of a new putative powdery mildew-like fruit russeting disease of almond

The disease did not develop on leaves of potted almond plants. It appears restricted to almond fruit. Thus, additional studies will be done on fruit in test orchards with early season disease samples.

Susceptibility of almond varieties against brown rot blossom blight

The natural host resistance was evaluated in the UC Davis variety plot. There was a wide range of susceptibilities among early-, mid-, and late-blooming accessions and data were mostly consistent with previous observations (**Table 4**). These ongoing studies on natural host resistance will help growers to select cultivars and breeders to design new selections.

Table 4. Susceptibility of almond varieties against brown rot blossom blight – UC – Davis 2008.

A. Early-blooming varieties

No.	Variety	No. strikes*	LSD**
1	Aldrich	8.0	b
2	1-87	10.7	b
3	Sonora	16.3	b
4	13-1	24.3	b
5	Peerless	26.8	b
6	NePlus Ultra	40.5	b
7	Rosetta	121.3	a

B. Mid-blooming varieties

No.	Variety	No. strikes	LSD
1	Nonpareil	5.5	c
2	Johlyn	10.0	c
3	Sauret No. 1	13.5	c
4	F10D, 3+4-25	15.3	c
5	Jenette	17.5	c
6	Price	21.0	c
7	Alamo	27.3	c
8	Chips	34.8	bc
9	F7, 1-1	68.0	b
10	Wood Colony	123.3	a

C. Late-blooming varieties

No.	Variety	No. strikes	LSD
1	2-19E	1.3	g
2	Ferragnes F7,4-7	1.5	g
3	Ruby	1.8	g
4	Livingston	5.5	fg
5	Mission	7.0	fg
6	Plateau	12.3	efg
7	Monterey	14.3	defg
8	Carmel	17.3	defg
9	Padre	26.0	cdef
10	Merced	30.5	cde
11	LeGrand	34.5	bcd
12	Fritz	44.3	abc
13	Butte	53.8	ab
14	25-75	60.5	a

* - For evaluation, the number of brown rot strikes per tree was counted in June 2008.

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