Biology and Management of Almond Brown Rot, Jacket Rot, Shot Hole, Rust, and Hull Rot

Project No.: **PATH4-Adaskaveg**

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A. Summary

In 2019, we evaluated new treatments against major foliar and fruit diseases of almond in California in the field and laboratory. Among new treatments, we tested Cevya (FRAC Code - FC 3), Fervent (FC 3/7), pyraziflumid (FC 7), and Sercadis (FC 7). Numbered products included UC-2 (FC 3/?), F4406-3 (FC 7/?), EXP-AF (FC 7/?), EXP-AD(FC 7/?), EXP-19A, V-10424 (FC 3), and V-10484 (FC 7). Among biologicals, we tested Dart, Cr-7, Serenade ASO, Cinetis, and Ecoswing. These were compared to registered single-active-ingredient and pre-mixture compounds belonging to the DMIs (FC 3), SDHIs (FC 7), anilinopyrimidines (FC 9), and QoIs (FC 11).

Incidence of brown rot, shot hole, and Botrytis gray mold was often high in the spring of 2019. For brown rot management on cvs. Drake and Wood Colony, all conventional fungicides were highly effective, reducing the disease to 5.5 strikes/tree or less as compared to 35.8 and 19.8 strikes/tree in the untreated controls of each cultivar, respectively. On cv. Wood Colony, the biologicals Dart, Ecoswing, and Cr-7 were also very effective. For shot hole on cv. Drake, most fungicides performed extremely well, whereas Rhyme and Luna Sensation were somewhat less effective.

In a second-year survey of orchards in Butte, Colusa, Sutter, San Joaquin, and Stanislaus Co., *R. stolonifer* was found to be the predominant cause of hull rot; whereas *A. niger* was much less common. Studies on the management of hull rot were conducted in orchards with *Rhizopus stolonifer* as the main pathogen. Fungicides containing FC 3, 7, 11, or 19, as well as the nutritional optimizer Cinetis and the alkalizing foliar fertilizer dipotassium-phosphate (di-KPO4) reduced the incidence of hull rot over the last three years. Di-KPO_4 was applied to possibly neutralize fumaric acid that is produced by hull rot pathogens and is responsible in part for dieback symptoms of branches. The desiccant $AlSO_4$ was least effective. Phytotoxicity was not observed in any treatment. Quadris Top or Serenade ASO applied to the soil significantly reduced hull rot in one trial but not the other. In our studies, 60 to 75% control was consistently obtained with a two-application foliar program regardless of cultivar. Hull rot management should always include cultural methods including proper nitrogen fertilization and irrigation practices. A two-spray program is suggested for hull rot at pre-hull split in early/mid-June (targeting *Monilinia* sp. pathogens) and at early hull split (targeting the *Rhizopus* pathogen). Management strategies for hull rot caused by *Aspergillus* sp. need to be developed.

In evaluation of natural host resistance to diseases in our variety block, data were obtained for brown rot blossom blight, shot hole, and rust for 23 varieties or genotypes in 2019. Over sevral years of evaluations, some new cultivars such as Capitola, Folsom, Sterling, Supareil, Jenette, and several numbered genotypes showed consistent low susceptibility to brown rot , similar to Nonpareil. For shot hole on fruit, Capitola, Supareil, Sterling, UCD 8-160 and 2-19e Total (Kester) showed reduced susceptibility.

B. Objectives

1. **Evaluate new conventional and organic compounds for their spectrum of activity, systemic action, and persistence against brown rot, jacket rot, shot hole, and hull rot.** Field trials for evaluation of new brown rot, shot hole, and gray mold treatments were done on several cultivars at UC Davis and KARE (Adaskaveg, Thompson, Förster, Cary).

   Evaluate **pre- and post-infection activity** of selected fungicides in laboratory studies for management of brown rot (Adaskaveg, Thompson, Förster).

2. In field trials on **hull rot** management pre-mixtures or tank mixtures of FRAC 3+7, 3+9, 7+11, 3+11, and 3+19 were evaluated along with experimentals that include conventional fungicides, foliar fertilizers, and biorational materials (Adaskaveg, Wade, Förster).

3. **Establish baseline sensitivities** of fungal pathogens against new fungicides and determine potential shifts in fungicide sensitivity where disease was not satisfactorily managed after fungicide treatment (Adaskaveg, Förster).

4. **Evaluate almond genotype susceptibility to foliar diseases that develop naturally in an almond variety trial at UC Davis** (Adaskaveg, Thompson, and Förster)**.**

Table 1. Main Goal(s), key objectives, timelines, and milestones.

Objective(s)	Date to be accomplished	Milestones and deliverables associated to the objective
1A. Field efficacy studies	2020-2022	Identify effective conventional (new FRACs) and biological treatments (2020 and 2021)
1B. Pre- and post-infection activity in lab studies	2020-2022 (new treatments evaluated every year)	Identify treatments that can be applied after infection periods
2. Cultural practices for hull rot	2020-2021	When should nitrogen application be stopped before hull split
3. In vitro sensitivities	2020-2021	Determine baselines and potential shifts in sensitivity
4. Almond genotype susceptibility to diseases	2020-2022	Identify new cultivars and genotypes with reduced susceptibility to disease

C. Annual Results and Discussion

1. **New treatments against brown rot, jacket rot, and shot hole.**
   Five field trials were conducted, and disease developed in three, three, and one orchard for these diseases, respectively. Results are presented for representative studies. On cv. Drake at UC Davis, brown rot developed at high severity on untreated control trees (35.8 strikes/tree), and all conventional fungicide treatments applied, including a rotation of Vangard, Quadris Top, Bravo, and Inspire significantly reduced the disease to 5.5 strikes/tree or less (**Fig. 1A**). Similarly on cv. Wood Colony with 19.8 strikes/control tree, all fungicides were highly effective (**Fig. 1B**). New highly effective materials include pyraziflumid, Cevya, Fervent, UC-2, EXP-AD, EXP-AF, and F4406-3. Additionally, in the

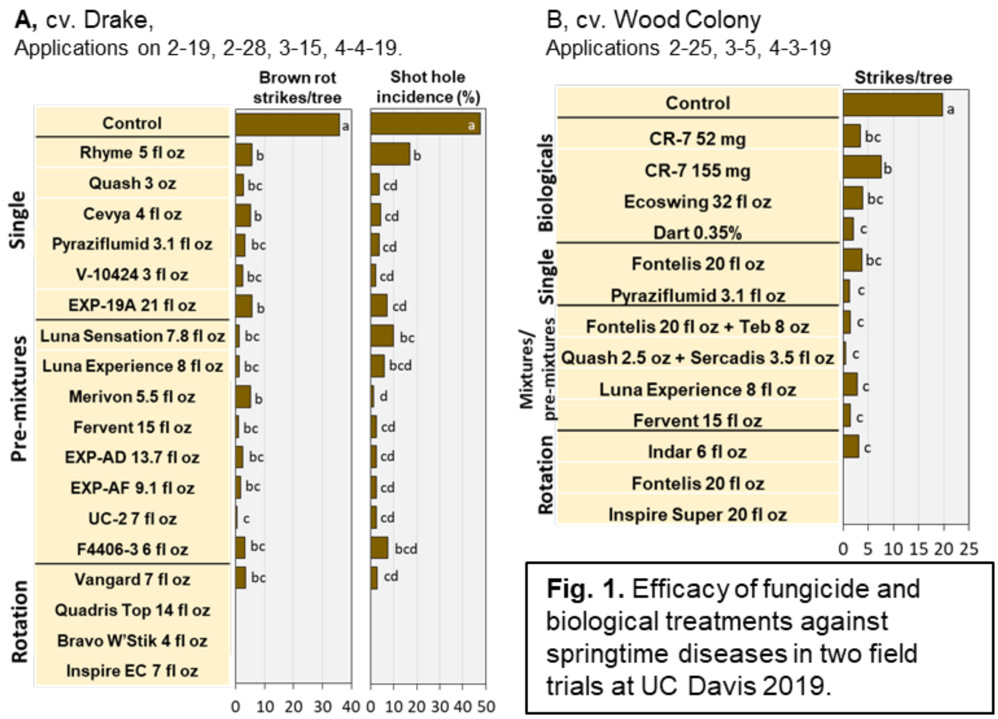

Fig. 1. Efficacy of fungicide and biological treatments against springtime diseases in two field trials at UC Davis 2019.

Table 1. Evaluation of the pre- and post-infection activity of biologicals and fungicides for control of brown rot blossom blossom blight of cvs. Drake and Wood Colony in laboratory studies 2019.

			Post-infection activity				Pre-infection activity			
			cv. Drake		cv. Wood Colony		cv. Drake		cv. Wood Colony	
		Product Rate	Incid. stamen infection		Incid. stamen infection		Incid. stamen infection		Incid. stamen infection	
No.	Fungicide	(100 gal/A)	%	LSD	(%	LSD	%	LSD	(%	LSD
1	Control	---	90.7	a	100.0	a	99.3	a	92.1	a
2	Dart XF 17001	0.25%	82.1	a	100.0	a	98.2	a	84.1	a
3	Cr-7	155/75 mg/L	84.3	a	93.6	b	74.1	b	91.5	a
4	Ecoswing	32 fl oz	95.9	a	94.9	ab	96.9	a	82.6	a
5	Quash	3 oz	5.1	bc	1.0	ef	6.3	cde	2.8	bc
6	Cevya	4 fl oz	3.8	bc	24.8	c	6.3	cde	5.5	bc
7	Fontelis	20 fl oz	13.5	b	11.9	cd	8.9	cd	9.0	b
8	Pyraziflumid	3.1 fl oz	1.1	c	0.0	f	4.8	cde	0.0	c
9	V-10424	3 fl oz	0.0	c	0.0	f	0.0	f	0.0	c
10	EXP-19A	21 fl oz	3.0	bc	2.7	ef	13.8	c	1.1	bc
11	Quash + Sercadis	2.5 + 3.5 fl oz	2.1	bc	0.0	f	0.0	f	0.6	c
12	Quash + V-10484	2.5 + 3.75 oz	2.0	c	0.0	f	0.0	f	0.0	c
13	EXP-AD	13.7 fl oz	2.9	bc	2.8	ef	3.1	def	0.0	c
14	EXP-AF	9.1 fl oz	3.0	c	0.0	f	0.0	f	0.3	c
15	F4406-3	6 fl oz	1.6	c	8.3	de	0.6	ef	1.3	c

* - Popcorn-stage blossoms were collected on 2-20-19 (Drake) and 2-27-19 (Wood Colony) and allowed to open in the laboratory. For evaluation of the post-infection activity, blossoms were inoculated with conidia of *M. laxa* (20,000 conidia/ml) and treated after 20 h of incubation at 22C. For evaluation of the pre-infection activity, blossoms were first treated, air-dried, and then inoculated. The incidence of stamen infections was evaluated after 5 days of incubation at 20C.

second trial, three new biologicals (the biocontrol CR-7, the plant extract Ecoswing, and the capric/caprylic acid mixture Dart) were similarly effective as the fungicides (**Fig. 1B**).

The pre- and post-infection activity of treatments was evaluated in the laboratory. All fungicides were very effective using both inoculation-treatment timings (**Table 1**), indicating that they still can be effectively used some time after an infection period. The biologicals, however, showed little efficacy in these studies that were conducted under conditions with high inoculum, favorable temperatures, and high relative humitity. They were still effective in the field where conditions are less favorable for infection and disease development. Perhaps the bioassay needs to be modified to allow for growth of the biocontrol before inoculation with the pathogen.

The efficacy of new treatments against jacket rot was evaluated in a petal assay where field-treated flowers were incubated in the laboratory for natural development of gray mold (*data not shown*). Effective treatments included FRAC 7 (e.g., pyraziflumid) and 9 (e.g., Vangard) compounds, mixtures and pre-mixtures of FRAC 3+7 (e.g. Luna Experience), 3+9, 3+11, 7+11, 3+19 (e.g., Teb + Ph-D), as well as the experimentals EXP-AF and UC-2. *Botrytis cinerea*, the cause of jacket rot/gray mold is more difficult to manage than many other pathogens of almond, and many fungicides do not have high activity against this pathogen.

The efficacy against shot hole was evaluated on cv. Drake at UC Davis where the disease developed at an incidence of 47.7% on fruit of untreated control trees. All conventional fungicides used significantly reduced the disease (**Fig. 1A**). Treatments with high efficacy included the FRAC 3 Quash and Cevya, the FRAC 7 pyraziflumid, the FRAC 3/7 Luna Experience and Fervent, the FRAC 7/11 Merivon, a rotation of Vangard, Quadris Top, Bravo, and Inspire, as well as the experimentals V-10424, EXP-19A, EXP-AD, EXP-AF, and UC-2.

Treatment*	Rate (/A)	7-3	7-10	7-10	7-30
Control	---	---	---	---	---
Utilize	12 fl oz	@	---	@	---
Cinetis	24 fl oz	@	---	@	---
Rotation: Cinetis	24 fl oz	---	@	---	---
Rotation: Cinetis + Ph-D*	24 fl oz + 6.2 oz	---	---	@	---
DiKPO4	48 oz	@	---	@	---
DiKPO4 + Cinetis	48 oz+24 fl oz	---	@	---	---
Al-sulfate hydrate + DiKPO4	125 + 48 oz	---	---	@	@
Aproach*	8 fl oz	---	---	@	@
Quash + Ph-D*	8 fl oz + 8 oz	---	---	@	@
Aproach + Bumper*	8 + 8 fl oz	---	---	@	@
V-449 + Intuity*	3.5 + 2 fl oz	---	---	@	@
Luna Sensation*	7.8 fl oz	---	---	@	@
Luna Experience*	8 fl oz	---	---	@	@
Quadris Top*	14 fl oz	---	---	@	@
Merivon*	6.5 fl oz	---	---	@	@
EXP-AD*	14 fl oz	---	---	@	@
EXP-AF*	7 fl oz	---	---	@	@

* Applied with DynAmic

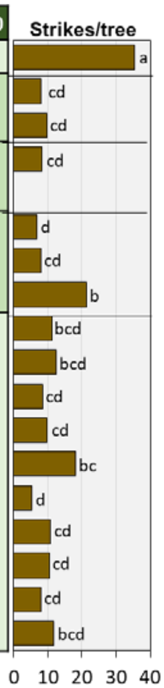

Fig. 2. Efficacy of fungicides, foliar fertilizers, and nutritional optimizers on the management of hull rot of Nonpareil almond in Colusa Co. 2019.

2. **Hull rot management.**
In three field trials on cv. Nonpareil, foliar and soil treatments were evaluated. Among foliar fungicides, 2 applications of pre-mixtures or tank mixtures of FRAC 3+7 (e.g., Luna Experience), 7+11 (e.g., Merivon), 3+11 (e.g., Quadris Top, Aproach+Bumper), and 3+19 (e.g., Quash +Ph-D). Experimentals EXP-AD, EXP-AF resulted in good disease control (**Fig. 2**). Reductions in hull rot obtained in 2019 field studies are typical compared with what we have seen in our previous studies. With any treatment evaluated over the years, reductions range from 60 to 75%, but we were never able to obtain very low or zero levels. This is probably because hull split in an orchard that provides susceptible senescent tissue and entry

wasy of pathogen propagules into the fruit occurs over a prolonged time, and it is difficult to provide continuous protection of these tissues by fungicide or fertilizer applications.

As in previous years, dipotassium phosphate ($DiKPO_4$) as well as Cinetis and Utilize (two formulations of a kelp extract containing ammonium nitrogen and phosphate) were similarly effective as the fungicides. A mixture of $DiKPO_4$ and Cinetis and a rotation of cinetis with Cinetis/Ph-D also resulted in a similar reduction in disease. Earlier timings were used for these treatments to allow time for the plant to adjust its metabolism to become moe resistant to infection. The alkaline fertilizer $DiKPO_4$ possibly acts by neutralizing fumaric acid that is released by *R. stolonifer* into host tissues and causes dieback. The mode of action of Cinetis and Utilize is currently unknown.

In two other trials, foliar applications were combined with soil applications of either Quadris Top or Serenade ASO. The soil applications significantly, but only slightly reduced the amount of hull rot in one of the studies (**Fig. 3**) but not in the other trial (not shown). All foliar applications using fungicides, foliar fertilizers, or a biocontrol (i.e., Serenade ASO) were significantly more effective than the soil applications by themselves, and the soil applications did not increase the efficacy of foliar applications. Thus, the use of soil applications to inactivate soil-borne inoculum of the hull rot pathogens may not be economically warranted under low disease pressure. Instead, in addition to foliar treatments, an emphasis should be placed on water management (i.e., deficit irrigation), restricted nitrogen fertilization (applied by early May or after harvest for Nonpareil), and dust reduction programs.

Foliar applications

Treatment	Rate (/A)	7-3	7-15	7-30
Control	---	---	---	---
Quash + Ph-D	3 + 6.2 oz	---	@	@
$Al_2(SO_4)_3 \times H_2O$ + $DiKPO_4$*	125+48 oz	---	@	@
$DiKPO_4$	48 oz	@	@	---
Serenade ASO*	96 fl oz	---	@	@
Cinetis*	24 fl oz	@	@	---
$DiKPO_4$*	48 oz	@	---	---
Cinetis + $DiKPO_4$*	24 fl oz+48 oz	---	@	---
				Mean

*Applied with DynAmic (8 fl oz/A).

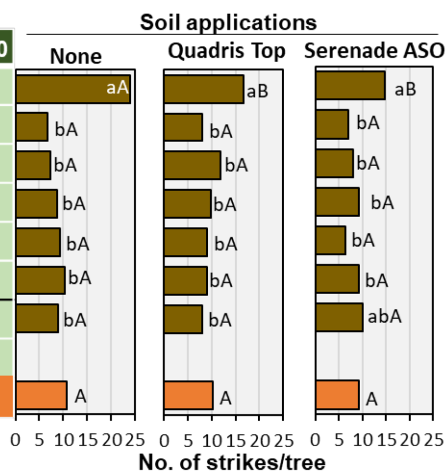

Fig. 3. Efficacy of foliar applications with fungicides, foliar fertilizers, or nutritional optimizers and soil applications with Quadris Top or Serenade ASO on the management of hull rot of Nonpareil almond in Colusa Co. 2019. Soil treatments were applied on 6-21 and 7-15-19 and were watered in. LSD comparisons by row in upper case, those by column in lower case letters.

4. Almond genotype susceptibility to foliar diseases in an almond variety trial at UC Davis.

Natural host susceptibility of new genotypes in the UCD variety block was compared to standard and newly introduced cultivars. This is part of a long-term strategy to manage almond diseases by introducing more resistant germplasm into new cultivars, and to help farm advisors and PCAs to advise growers in selecting less susceptible cultivars for new plantings. In our evalutions over several years, some genotypes/cultivars consistently had less disease than other. Thus, for brown rot blossom blight, cvs. Capitola, Folsom, Sterling, Supareil, Jenette, and several numbered genotypes showed low susceptibility, similar to Nonpareil from

2017 to 2019 (**Fig. 4A**). For shot hole on fruit, fewer lesions were observed in the three years on Capitola, Supareil, Sterling, UCD 8-160 and 2-19e Total (i.e., Kester) (**Fig. 4B**). Data for leaf rust were available for 2019 and 2015. Cultivars and genotypes with low disease in both years included Jenette, Capitola, Winters, and Y117-91-03.

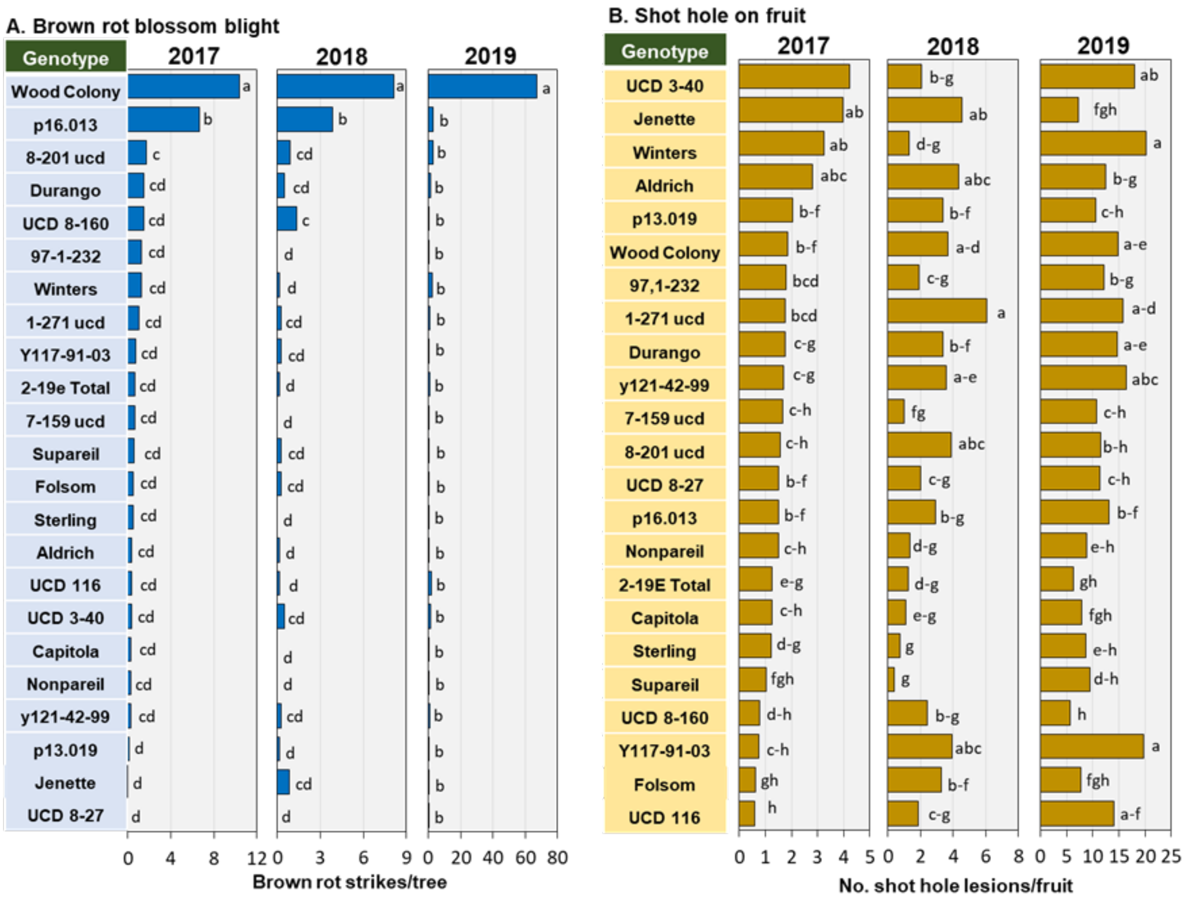

Fig. 4. Natural host susceptibility of cultivars and new genotypes in the UCD variety block to brown rot blossom blight and shot hole on fruit 2017-19.

D. Outreach Activities

Dr. Adaskaveg participated at several grower/PCA meetings at different locations in California over the year and gave presentations on almond diseases including scab and Alternaria leaf spot and their management. At each meeting, there were approximately 50-100 participants.

1. January 2019. Managing Diseases of Almond in California; Bayer Tree, Nut, and Vine Meeting; Organizer: Bayer CropScience; Universal Studios, Universal City, CA 91608
2. January 2019. Almond Diseases: Key Economic Pests, ID, Biology, and Treatments in Almonds; 2019 Independent PCA Symposium; Organizer: Bayer CropScience; Monterey Plaza Hotel and Spa, Monterey, CA 93940
3. January 2019. Almond Disease Management, Colusa Winter Almond Meeting; Organizer: UCCE; Granzella's Banquet Hall, Williams, CA

4. Feb 5, 2019. Bloom and Foliar Diseases; Annual Almond Production Meeting; Organizer: UCCE; Norton Hall, Woodland, CA
5. Nov 8, 2019, Foliage, Blossom and Nut Diseases; Almond Short Course, Organizer UCCE; Visalia Convention Center, Visalia, CA

E. Materials and Methods:

Fungicide evaluations for management of brown rot, gray mold, and shot hole in experimental orchards. Field trials were conducted at UC Davis on cvs. Drake, Wood Colony, and Sonora, and at the Kearney Agricultural Research and Extension (KARE) Center on cv. Sonora (not shown). Treatments were done as single-fungicide, mixture, pre-mixture, or rotation programs using an airblast sprayer at 100 gal/A (see **Fig. 1**). Three or four applications were done at UC Davis from pink bud to petal fall and a single application at KARE. For brown rot evaluation, the number of strikes per tree was counted for each of four or six single-tree replications. Selected fungicides were also evaluated in laboratory studies on detached blossoms of cvs. Drake and Wood Colony that were inoculated with conidia of *M. laxa* (20,000 conidia/ml) either 20 h before or after treatment. The incidence of stamen infections was determined after 5 days of incubation at 20C. Gray mold was evaluated on cvs. Drake, Wood Colony, and Sonora. For this, flower petals were collected after the full bloom field spray and incubated on moist vermiculite for 5-6 days at 20C for the development of natural incidence of the disease.

Fungicide evaluations for management of hull rot. Field trials were conducted in cv. Nonpareil orchards in Colusa Co. and at KARE where hull rot was mostly caused by *R. stolonifer*. Different timings were used for fungicide and alkaline foliar fertilizer/biological treatments (see **Figs. 2,3**). Fungicides were applied between early- and mid-hull split. In two trials, Serenade ASO or Quadris Top were additionally applied before foliar treatments to the soil under trees with a weed sprayer to reduce soil inoculum. Hull rot was evaluated by counting the number of shoot infections for a specific time period for each tree or by evaluating 300 fruit per tree.

Evaluation of natural host susceptibility against diseases. Naturally occurring disease was evaluated in an orchard block at UC Davis (established spring 2014) with 23 new or standard almond varieties and genotypes that were planted in a randomized block design. Brown rot (number of strikes/tree) and shot hole (average number of lesions/fruit for 25 fruit from each tree) were evaluated in the spring and leaf rust (based on a rating scale from 0 to 10) was evaluated in late summer of 2019.

Statistical analysis of data. All data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures (P > 0.05) of SAS version 9.4. Percent data was arcsin transformed whereas $\log_{10}$ transformation was used for count data.

F. Publications that emerged from this work

1. Adaskaveg, J. E. , et al. 2017. UC IPM Pest Management Guidelines: Almond Diseases. UC ANR Publication 3431. https://www2.ipm.ucanr.edu/agriculture/almond/.
2. Adaskaveg, J. E., Gubler, D., and Michailides, T. 2017. Fungicides, bactericides, and biologicals for deciduous tree fruit, nut, strawberry, and vine crops. http://ipm.ucanr.edu/PDF/PMG/fungicideefficacytiming.pdf. (update for 2020 in progress)
3. Efficacy of fungicides against hull rot of almond. Manuscript in preparation.