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

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Project Leader: **J. E. Adaskaveg, Dept. of Microbiology and Plant Pathology, University of California, Riverside, CA 92521, (951) 827-7577, jim.adaskaveg@ucr.edu**

Project Cooperators and Personnel:

H. Förster and D. F. Thompson, Dept. of Microbiology and Plant Pathology, University of California, Riverside, CA 92521

A. Summary

During this funding cycle, we set up laboratory and field trials each year to evaluate new fungicides, biocontrols, and biopesticides against major foliar and fruit diseases of almond in California. We included the newly registered Cevya (FRAC Code - FC 3) and Fervent (FC 3/7), as well as the experimentals pyraziflumid and fluindapyr (FC 7), Miravis Prime (FC 7/12), and Miravis Top (-Duo) (FC 3/7). Numbered products with FCs partially or not disclosed included UC-2 (FC 3/?), F4406-3, EXP-19A, V-10424, and GWN-10570. We tested new biologicals (e.g., CR-7, Double Nickel, Serifel), and natural products (e.g., Dart, GWN-10474, EcoSwing), and naturally derived systemic acquired resistance (SAR) compounds (e.g., LifeGard). These were compared to conventional registered single active ingredient and pre-mixture compounds. Under California conditions, the availability and use of fungicides with different modes of action in rotation or mixture programs will prevent the selection and build-up of resistant pathogen populations. Furthermore, the use of pre-mixtures and tank mixtures expands the spectrum of activity allowing management of several diseases with a single treatment.

Natural incidence of brown rot, shot hole, and Botrytis gray mold was generally low in the untreated controls in each spring season due to low rainfall and low temperatures during bloom. Still, treatments were effectively evaluated on highly susceptible cultivars. For brown rot, gray mold, and shot hole management on cvs. Drake, Wood Colony, and Sonora, all conventional fungicides were highly effective, generally reducing the incidence by 85% to 96% compared to the untreated controls of each cultivar (20% to 35% disease incidence) over several years. Penthiopyrad, pyraziflumid, isofetamid, fluindapyr, and pydiflumetofen are new FC 7 fungicides along with metrifluconazole (FC 3) that performed extremely well. Pre-mixtures and tank mixtures of FC 7 fungicides with other FCs (FC 3, 11, 12) were outstanding against brown rot, gray mold, and shot hole.

Some of the biologicals and natural products showed very good and, in some cases, high efficacy. Under low to moderate brown rot blossom blight pressure, CR-7, EcoSwing, Dart, and GWN 10474 performed similar to conventional fungicides. These materials, however, showed moderate to low efficacy against gray mold and low efficacy against shothole.

In evaluation of natural host resistance to diseases in our genotype (variety) block, brown rot blossom blight susceptibility varied over a wide range but was consistent for most genotypes over the last several years. Wood Colony along with p16.013, 8-201, Durango, and UCD 8-160 were the most susceptible, whereas Nonpareil, Capitola, Folsom, Sterling, Supareil, Jeanette, and the numbered genotypes y121-42-99, p13.019, and UCD 8-27 were the least susceptible. Overall, all the varieties were more susceptible to shot hole and rust. Cultivars/genotypes less susceptible to these two latter diseases were Capitola, Supareil, Sterling, 2-19e Total (Kester), UCD 8-160, and UCD 7-159.

For hull rot, we will continue to evaluate orchards for the presence of *R. stolonifer, Monilinia* spp*.,* and *Aspergillus niger*. As in previous years, hull rot was predominantly caused by *R. stolonifer* in Butte, Colusa, Sutter, San Joaquin, and Stanislaus Co. *M. fructicola* was found mostly in Stanislaus Co., whereas *A. niger* was much less commonly present in these central to northern regions of the state. In 2020, *R. stolonifer* was also the major cause of hull rot in Kern Co.

Studies on the management of hull rot were done in orchards where *R. stolonifer* is the main pathogen. Fungicides containing FC 3, 11, 19, (and premixtures with FC 7) or undisclosed experimentals, as well as Cinetis and the alkalizing foliar fertilizer dipotassium-phosphate (di-KPO_4) continued to perform well reducing the disease between 60-75% in orchards where minimal irrigation was done, where nitrogen applications were minimized or stopped in June and July, and fungicides were applied at the beginning of hull split. The role of nutrients like Di-KPO_4 and Cinetis (Utilize) is to possibly neutralize fumaric acid that is produced by hull rot pathogens and is responsible in part for dieback of branches. Additionally, they are to balance the overuse of nitrogen with the two other macronutrients potassium and phosphate. Phytotoxicity was not observed in any treatments over the years.

Hull rot management should always include cultural methods including proper nitrogen fertilization and irrigation practices. For Nonpareil and other susceptible cultivars (e.g., Monterey), a two-spray program is suggested rot at pre-hull split in early/mid-June (targeting *Monilinia* pathogens) and at early hull split (targeting *Rhizopus* and possibly the *Aspergillus* pathogens). Soil applied treatments to reduce inoculum and stimulate SAR effects were not as effective as foliar treatments for managing hull rot.

In baseline sensitivity studies, isolates of *M. laxa* were highly sensitive to the new SDHIs pyraziflumid, pydiflumetofen, and isofetamid. Other new SDHIs (e.g., GWN-10570, fluindapyr), as well as the new mode of action EXP-19A are still pending evaluation. A much wider range in sensitivities was determined for *B. cinerea*, and sensitivity characteristics of isolates were similar for pydiflumetofen and pyraziflumid. This indicates that cross resistance is present among SDHI sub-groups and that SDHI fungicides should always be rotated with different FRAC codes.

B. Objectives

1) Evaluate new conventional and organic compounds for their spectrum of activity, systemic action, and persistence in managing brown rot, jacket rot, shot hole, gray mold, rust, and hull rot.
    - Pre- and post-infection - brown rot – **Significant findings:** *All conventional fungicides evaluated show pre-and post-infection activity in laboratory assays.*
    - Natural incidence – all diseases listed **Significant findings:** *Field tests demonstrated high activity of new FC 3 and 7 fungicides used alone, in premixtures, or in tank mixtures for managing brown rot, gray mold, and shot hole of almond. New organics were also identified with EcoSwing, Serifel, Dart, CR-7 and GWN-10474 showing high efficacy under low disease pressure against brown rot but were less effective against other diseases.*
    - Cultural and nutritional strategies for hull rot management – **Significant findings:** *Fungicides (FC 3, 11, 19) and alkaline fertilizers integrated with cultural practices to minimize nitrogen fertilization in June and July and reduce irrigations provide high efficacy in managing hull rot.*
2) Establish baseline sensitivities of fungal pathogens against new fungicides and determine shifts in fungicide sensitivity. **Significant findings:** *Isolates of M. laxa and M. fructicola*

were mostly highly sensitive but there were outliers that were less sensitive to the new SDHIs. The new DMI mefentrifluconazole showed consistent high toxicity. These baselines are used to monitor population sensitivities after field usage.

3) Evaluate almond genotype susceptibility to foliar diseases that develop naturally in an variety trial at UC Davis. **Significant findings:** *Among 23 genotypes, brown rot blossom blight susceptibility varied over a wide range but was mostly consistent over the last four years. Overall, all the varieties were more susceptible to shot hole and rust but several showed reduced susceptibility to all three diseases.*

C. Results and Discussion

Objective 1 - Evaluate new conventional and organic compounds for their spectrum of activity, systemic action, and persistence in managing brown rot, jacket rot, shot hole, gray mold, rust, and hull rot.

Efficacy of several new conventional, biological, and natural products for managing brown rot, gray mold (jacket rot), and shot hole diseases was evaluated in field and lab studies. In field trials, the newly registered Cevya (FRAC Code - FC 3), the experimentals pyraziflumid and fluindapyr (FC 7), as well as the recently registered Fervent (FC 3/7), Miravis Prime (FC 7/12), and Miravis Top (-Duo) (FC 3/7) were highly effective against the three diseases. Numbered products with FCs partially or not disclosed included UC-2 (FC 3/?), F4406-3 (FC 3/7), EXP-19A, V-10424, and GWN-10570 (FC 7) were also highly effective in 2018-2020 (shown in Table 1) evaluations.

Table 1. Efficacy of fungicide treatments for management of brown rot, gray mold, and shot hole of cv. Drake almonds at UC Davis.

					Applications				Brown rot**		Gray mold***		Shot hole on fruit****	
					2-18 Pink bud	2-23 Full bloom	3-4 Petal fall	3-26 3wk after Petal fall						
No.	Program	Treatment*	Rate/A	Additive					Strikes/ tree	LSD^	Severity	LSD	Inc. (%)	LSD
1	---	Control	---	---	---	---	---	---	28.7	a	2.7	ab	64.8	a
2	Single	Cevya	5 fl oz	NIS 6 fl oz	@	@	@	@	1.5	bc	1.0	f	2.0	b
3		Fontelis	20 fl oz	---	@	@	@	@	1.2	c	2.1	de	0.1	b
4		GWN 10570	10 fl oz	---	@	@	@	@	1.0	c	2.9	ab	2.0	b
5	Mixtures	Merivon + Serifel	5.5 fl oz + 8 oz	NIS 6 fl oz	@	@	@	@	2.8	bc	2.6	bc	0.0	b
6		Quash + 505 (Ph-D)	3 + 6.2 oz	NIS 6 fl oz	@	@	@	@	3.5	bc	0.4	g	0.0	b
7		Quash liquid + Ph-D	3 fl oz + 6.2 oz	NIS 6 fl oz	@	@	@	@	4.0	bc	0.5	g	0.0	b
8		Fontelis + Teb 45DF	20 fl oz + 8 oz	---	@	@	@	@	2.0	bc	1.8	e	0.0	b
9	Pre-mixtures	Luna Sensation	7.8 fl oz	NIS 6 fl oz	@	@	@	@	1.3	bc	3.0	a	2.0	b
10		Luna Experience	8 fl oz	NIS 6 fl oz	@	@	@	@	1.2	c	2.3	cd	0.0	b
11		Fervent	15 fl oz	NIS 6 fl oz	@	@	@	@	3.7	bc	0.5	g	2.0	b
12		UC-2	7 fl oz	NIS 6 fl oz	@	@	@	@	0.8	c	1.0	f	2.0	b
13		Miravis Top	13.7 fl oz	---	@	@	@	@	4.7	b	1.8	e	0.0	b
14		Miravis Prime	9.1 fl oz	---	@	@	@	@	1.8	bc	1.2	f	1.0	b
15	Rotations	Quash 50WG	3 oz	NIS 6 fl oz	@	@	---	---	3.5	bc	1.0	f	4.0	b
		Ziram	6 lbs	---	---	---	@	@						
16		Indar 2F	6 fl oz	---	@	---	---	---	2.8	bc			6.0	b
		Fontelis	20 fl oz	---	---	@	---	---						
		Inspire Super	20 fl oz	---	---	---	@	@						

* - Treatments were applied using an air-blast sprayer at a rate of 100 gal/A. NIS = DyneAmic.
**- For brown rot evaluation in late April, the number of strikes per tree was counted for each of four single-tree replications. Gray mold was evaluated on flower petals that were collected after the FB application and incubated on moist vermiculite in the laboratory. Severity was evaluated using a rating scale: 0=0, 1=<25%, 2=26-50%, 3= 51-75%, 4=76-100% petal area diseased. For shot hole evaluations, 20-30 fruit were collected from each single-tree replication and evaluated using a rating scale of 0=0, 1=1-3, 2=4-6, 3=7-10, and 4=>10 lesions/fruit.

These findings are significant for the industry because they emphasize that new conventional fungicides are highly effective in tank or pre-mixtures or when used in rotation with older products against multiple fungal pathogens. Many of the fungicides (those in FCs 7, 9, 11, 12) are reduced risk and are safer for the environment. Programs evaluated also demonstrated how integrated single- and multi-site mode of action fungicide can be developed that are safe for pollinators. For example, ziram was not used during bloom and only during petal fall periods in a rotation program with efficacy statistically the same as the tank and pre-mixtures evaluated (Table 1). Non-ionic surfactants were added to some of the treatments and, in most cases, no significant improvement was shown. This emphasizes that for managing bloom and early-season diseases, adjuvants are not necessarily needed to obtain high performance. These results are in-line with the almond industry's goals of obtaining broad spectrum disease control with no impact on pollinators when using new, reduced risk fungicides by themselves and not in tank mixtures with non-fungicide products (i.e., insecticides, foliar fertilizers, etc.).

Some of the biologicals and natural products showed very good and, in some cases, high efficacy against brown rot. Under low to moderate brown rot blossom blight pressure (19.8% incidence in the untreated control), CR-7, EcoSwing, Dart, and others such as GWN 10474 (not shown) performed similar to conventional fungicides (Table 2).

Table 2. Efficacy of biologicals, natural products, and fungicide treatments for management of brown rot blossom blight of Wood Colony almond at UC Davis.

					Applications			Brown rot strikes/tree**	
No.	Program	Treatment*	Rate/A	Adjuvant	2-25 PB	3-5 FB	4-3 PF	No.	LSD^
1	---	Control	---	---	---	---	---	19.8	a
2	Biologicals	CR-7	52 mg	---	@	@	@	3.5	bc
3		CR-7	155 mg	---	@	@	@	7.7	b
4		Ecoswing	32 fl oz	---	@	@	@	3.8	bc
5		Dart XF 17001	0.35%	---	@	@	@	2.0	c
6	Single	Fontelis	20 fl oz	---	@	@	@	3.7	bc
7		Pyraziflumid	3.1 fl oz	DynAmic 6 fl oz	@	@	@	1.3	c
8	Mixtures	Fontelis + Teb	20 fl oz + 8 oz	---	@	@	@	1.5	c
9		Quash + Sercadis	2.5 oz + 3.5 fl oz	DynAmic 6 fl oz	@	@	@	0.5	c
10	Pre-mixtures	Luna Experience	8 fl oz	BreakThru 6 fl oz	@	@	@	2.8	c
11		Fervent	15 fl oz	DynAmic 6 fl oz	@	@	@	1.5	c
12	Rotation	Indar	6 fl oz	DynAmic 6 fl oz	@	---	---	3.2	c
		Fontelis	20 fl oz	---	---	@	---		
		Inspire Super	20 fl oz	DynAmic 6 fl oz	---	---	@		

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

** - For brown rot, the number of strikes per tree was counted for each of four single-tree replications.

Thus, the significance of these findings is that advancements are being made to improve the performance of biologicals and natural products against brown rot. CR-7 was very exciting because of the extremely low rate used. The 52-mg (3 mg per gal = $3x10^6$ cfu) rate is equivalent to 3×10^4 spores in 100 gal/A or (30,000 spores/A). Still, Dart (capric/caprylic acids), EcoSwing, and GWN 10474 were also very effective against brown rot blossom blight under low disease pressure (Table 2). This information will help the industry, especially the organic segment, move toward new, highly effective alternatives as compared to using copper- and sulfur-based products. These materials, however, showed moderate to low efficacy against gray mold (Table 3) and low efficacy against shot hole (data not shown). Although gains have been made in the activity of biologicals for managing brown rot, other products will need to be developed for other pathogens due to the specificity of the evaluated treatments against *Monilinia* spp. (brown rot pathogens).

Table 3. Efficacy of natural products and conventional fugncides for management of gray mold of cv. Sonora almond at UC Davis.

				Application	Gray mold**	
No.	Program	Treatment*	Rate/A	2-19 FB	Incidence (%)	LSD
1	---	Control	---	---	66.2	a
2	Biologicals	Ecoswing	32 fl oz	@	40.9	b
3		Dart XF 17001	0.35%	@	35.6	bc
4	Single	Quash	3 oz	@	10.5	efg
5		Fontelis	20 fl oz	@	25.4	d
6		V-10424	3 fl oz	@	10.0	efg
7		V-10484	6 oz	@	29.4	cd
8	Mixtures	Quash + Sercadis	2.5 + 3.5 fl oz	@	16.1	e
9		Sercadis + Fluxapyroxad	4.5 fl oz	@	12.9	ef
10		Fontelis + Teb 45DF	20 fl oz + 8 oz	@	8.9	fg
11		Quash + V-10484	2.5 + 3.75 oz	@	5.5	g
12	Pre-mixture	Fervent	15 fl oz	@	2.1	h

* - Treatments were applied using an air-blast sprayer at a rate of 100 gal/A on 2-19 (full bloom).
** - Gray mold was evaluated on flower petals that were collected after the FB application and incubated on moist vermiculite in the laboratory. Incidence is the average percentage of infected petals per total petals evaluated.

Table 4. Evaluation of the pre- and post-infection activity of biologicals and fungicides for control of brown rot blossom blight of cvs. Drake

				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.	Program	Fungicide	(100 gal/A)	%	LSD^	(%	LSD	%	LSD	(%	LSD
1	---	Control	---	90.7	a	100.0	a	99.3	a	92.1	a
2	Biologicals	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	Single	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	Mixtures	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	Pre-	EXP-AD	13.7 fl oz	2.9	bc	2.8	ef	3.1	def	0.0	c
14	mixtures	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 with *M. laxa*.

Pre- and post-infection activity was evaluated for biologicals including natural products and conventional fungicides listed above in laboratory assays. All premixtures, tank mixtures, and some of the single active ingredients had very high pre- and post-infection activity against brown rot on cvs. Drake and Wood Colony (Table 4). This indicates that most of the conventional fungicide treatments are highly effective as preventative and curative treatments when applications are made soon after infection periods (i.e., within 24 h). In these assays, the biologicals and natural products were ineffective or performed poorly. The tests were developed to evaluate conventional fungicides under ideal continuous wetness periods and temperatures to support the growth of *Monilinia* species. Perhaps a new assay needs to be developed that does not provide continuous but rather fluctuating wet and dry periods and cycling temperatures that reflect day/night conditions during almond bloom. Perhaps this will slow down the pathogen and give the biologicals and natural products an advantage under less favorable conditions.

For **hull rot**, we will continue to evaluate orchards for the presence of *R. stolonifer, Monilinia* spp.*,* and *Aspergillus niger*. As in previous years, hull rot was predominantly caused by *R. stolonifer* in Butte, Colusa, Sutter, San Joaquin, and Stanislaus Co. *M. fructicola* was found mostly in Stanislaus Co., whereas *A. niger* was much less commonly present in these central to northern regions of the state. In 2020 *R. stolonifer* was also the major cause of hull rot in Kern Co.

Studies on the management of hull rot were done in orchards where *R. stolonifer* is the main pathogen. Fungicides containing FC 3, 11, 19, (possibly in premixtures with FC 7), or undisclosed experimentals, as well as Cinetis and the alkalizing foliar fertilizer dipotassium-phosphate (di-KPO_4) continued to perform well reducing the disease between 60-75% in orchards where minimal irrigation was done, where nitrogen applications were minimized or stopped in June and July, and fungicides were applied at the beginning of hull split. (Fig. 5). Large-scale trials with grower-applied Banx, di-KPO_4, or Merivon confirmed the benefits of these treatments on a large scale (Table 6). The role of nutrients like Di-KPO_4 and Cinetis (Utilize) is to possibly neutralize fumaric acid that is produced by hull rot pathogens and is responsible in part for dieback of branches. Additionally, these nutrients may balance the overuse of nitrogen with the other macronutrients (i.e., potassium and phosphate). Phytotoxicity was not observed in any treatments over the years.

Hull rot management should always include cultural methods including proper nitrogen fertilization and irrigation practices. For Nonpareil and other susceptible cultivars (e.g., Monterey), a two-spray program is suggested at pre-hull split in early/mid-June (targeting *Monilinia* pathogens) and at early hull split (targeting the *Rhizopus* and possibly the *Aspergillus* pathogens). Soil-applied treatments to reduce inoculum and stimulate SAR effects were not as effective as foliar treatments for managing hull rot (data not shown).

Table 5. Efficacy of fungicide treatments for management of hull rot of cv. Nonpareil almond - Colusa Co.

					Application date				Strikes/tree**	
No.	Program	Treatment*	Rate (/A)	Additive	7-3	7-10	7-10	7-30	No.	LSD^
1	---	Control	---	---	---	---	---	---	35.5	a
2	Fertilizers	Utilize	12 fl oz	---	@	---	@	---	8.0	cd
3		Cinetis (GA142)	24 fl oz	---	@	---	@	---	9.8	cd
4		Cinetis (GA142)	24 fl oz	---	---	@	---	---	8.3	cd
		Cinetis (GA142) + Ph-D + DynAmic	24 fl oz + 6.2 oz	---	---	---	@	---		
5		DiKPO4	48 oz	---	@	---	@	---	6.8	d
6		DiKPO4 + Cinetis	48 oz + 24 fl oz	---	---	@	---	---	8.0	cd
7		Aluminum sulfate hydrate + DiKPO4	125 + 48 oz	---	---	---	@	@	21.3	b
8	Single	Aproach	8 fl oz	NIS	---	---	@	@	11.3	bcd
9	Mixtures	Quash + Ph-D	8 fl oz + 8 oz	NIS	---	---	@	@	12.5	bcd
10		Aproach + Bumper	8 + 8 fl oz	NIS	---	---	@	@	8.5	cd
11		V-449 + Intuity	3.5 fl oz + 2 fl oz	NIS	---	---	@	@	9.8	cd
12	Pre-	Luna Sensation	7.8 fl oz	NIS	---	---	@	@	18.3	bc
13	mixtures	Luna Experience	8 fl oz	NIS	---	---	@	@	5.3	d
14		Quadris Top	14 fl oz	NIS	---	---	@	@	10.8	cd
15		Merivon	6.5 fl oz	NIS	---	---	@	@	10.5	cd
16		EXP-AD	14 fl oz	NIS	---	---	@	@	8.0	cd
17		EXP-AF	7 fl oz	NIS	---	---	@	@	11.8	bcd

* - Treatments were applied using an airblast sprayer at 100 gal/A.

Table 6. Efficacy of fungicide and fertilizer treatments for management of hull rot of cv. Nonpareil almond in commercial field trials - Yolo Co.

	Treatment*	Rate (/A)	Application 7-2-20	Strikes/tree** No.	LSD^
Trial 1	Control	---	---	28.7	a
	Merivon	6.5 fl oz	@	21.4	a
	Banx	48 oz	@	12.1	b
Trial 2	Control	---	---	21.2	a
	Merivon	6.5 fl oz	@	12.9	b
	$DiKPO_4$	48 oz	@	8.4	b

* - Treatments were applied using an airblast sprayer at 100 gal/A.

Objective 2 - Establish baseline sensitivities of fungal pathogens against new fungicides.

Laboratory baseline studies were done for 25 isolates of *M. fructicola* and 25 isolates of *M. laxa* (data not shown) for 5 DMI (FC 3) fungicides and 5 SDHI (FC 7) fungicides currently or pending registration on almond in California (Table 7). Information shown for *M. fructicola* was similar for *M. laxa*. For the DMIs, values ranged from 0.1 to 45 ppb and for the SDHIs, values ranged from 1 to 132 ppb. The SDHI fungicides had more outliers possibly indicating a higher chance of selecting for resistance in a population. These average values and ranges shown for individual fungicides will be used for comparing future isolates to determine if shifts in sensitivity have occurred that indicate selection of resistance.

Table 7. Summary of baseline sensitivities to DMI (left) and SDHI (right) fungicides for 25 isolates of *M. fructicola*.

Fungicide	Range (µg/ml)	Average (µg/ml)
Mefentrifluconazole	0.0001 – 0.0028	0.0006
Metconazole	0.0006 – 0.006	0.0026
Propiconazole	0.009 – 0.045	0.013
Tebuconazole	0.005 – 0.017	0.010
Tetraconazole	0.0054 – 0.038	0.017

Fungicide	Range (µg/ml)	Average (µg/ml)
Fluopyram	0.005 – 0.132	0.022
Fluxapyroxad	0.004 – 0.050	0.020
Isofetamid	0.003 – 0.132	0.022
Pydiflumetofen	0.001 – 0.031	0.004
Pyraziflumid	0.001 – 0.027	0.005

*- Values obtained using the spiral gradient dilution assay. Values are effective concentrations to inhibit 50% of mycelial growth as compared to growth in the absence of each fungicide.

Objective 3 - Evaluate almond genotype susceptibility to the natural incidence of foliar diseases at UC Davis.

In comparative evaluations of natural host susceptibility of 23 almond genotypes and cultivars to diseases in an orchard planted at UC Davis, differences to brown rot, shot hole, and rust were observed over four years from 2017 to 2020 (Fig. 1A). Susceptibility to brown rot blossom blight varied over a wide range but was mostly consistent for each genotype over the 4-yr period. Wood Colony along with p16.013, 8-201, Durango, and UCD 8-160 were the most susceptible, whereas Nonpareil, Capitola, Folsom, Sterling, Supareil, Jeanette, and the numbered genotypes y121-42-99, p13.019, and UCD 8-27 were the least susceptible. Overall, all genotypes (varieties) were more susceptible to shot hole (Fig. 1B) and rust (data not shown). Less susceptible to these two latter diseases were Capitola, Supareil, Sterling, 2-19e Total (Kester), UCD 8-160, and UCD 7-159.

This information is significant to growers and breeders who know the genetic lineage of the genotypes and cultivars. Growers that have higher disease pressure to brown rot blossom blight due to higher rainfall may select more brown rot blossom blight-resistant varieties similar to Nonpareil. This information could then be cross-referenced to yield data (farm advisor trials) to make informed decisions concerning productivity and disease management in new established orchards. The breeder could use this information to make future selections that are disease-resistant and high-yielding. This could potentially make the almond industry more sustainable with lower disease management inputs and profitable yielding varieties.

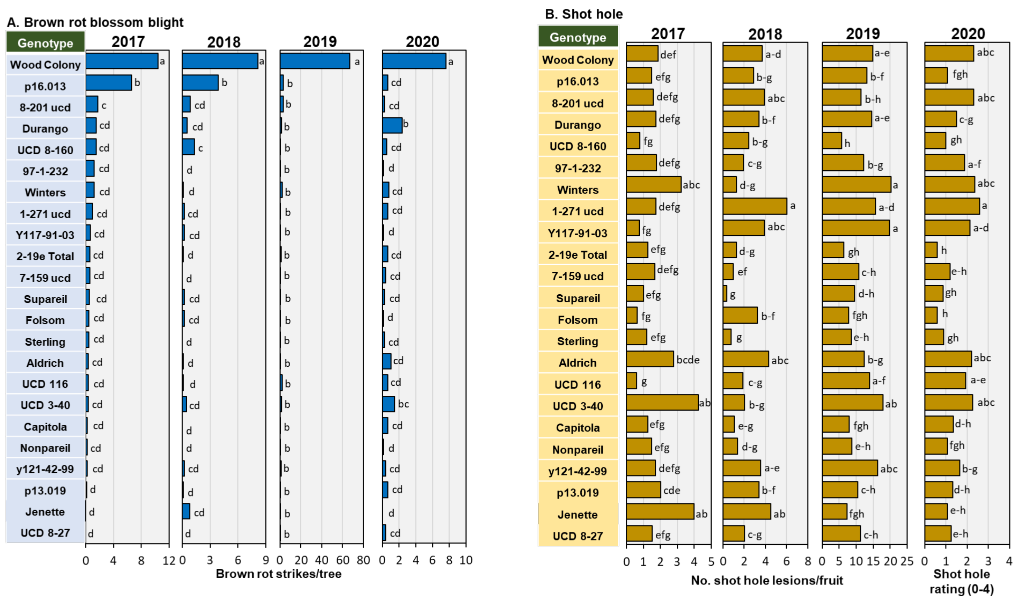

Fig. 1. Evaluation of almond genotype susceptibility to brown rot (A) and shot hole (B) for four consecutive years for 23 genotypes.

D. Outreach Activities – oral presentations given in 2019 and 2020

1. Jan. 9, 2019: Managing diseases in almonds. Bayer CropScience 2019 Tree, Nut, and Vine Meeting, Universal Studies, Universal City, CA. 150 people. Mainly PCAs.
2. Jan. 17, 2019: Almond Disease Management - Colusa Co. Williams, CA. 35 people. Growers and PCAs.
3. Jan. 18-19, 2019: Diseases - Key economic pests, identification, biology, and treatments in almond. Independent PCA Symposium. Monterey, CA. 65 people. Mainly PCAs.
4. Jan. 21, 2019: IPM of Almond Diseases. Syngenta Crop Protection, Bakersfield CA Pre-recorded. 45 people. Growers and PCAs.
5. Jan. 29, 2019: Almond flower, foliar, and fruit diseases and their management- Spring time and Summer diseases. Cortez, CA. 45 people. Growers and PCAs.
6. Feb. 5, 2019: Bloom and foliar diseases. UCCE Annual Almond Production Meeting, Woodland, CA. 45 people. Growers and PCAs.
7. June 25, 2019: Epidemiology and management of almond hull rot. Tulare International Agri-Center, Tulare, CA. 50 people. Growers and PCAs.
8. Nov. 5-7, 2019. Almond diseases and their management. 2019 UC Almond Short Course. Visalia Convention Center, Visalia, CA. 100 people. Growers and PCAs. State and International audience.
9. Jan. 17, 2020: Key economic pests, identification, biology, and treatments in almond. Bayer Crop Science Annual Almond Disease Management Meeting, Monterey, CA. 70 people. Growers and PCAs.
10. Jan. 21, 2020: Almond foliar diseases. North Valley Nut Conference, Orland, CA. 250 people. Growers and PCAs as well as regulators and industry representatives.

11. Jan. 22, 2020: Fungal and bacterial almond disease management during bloom. UCCE Colusa Winter Almond Meeting, Williams, CA. 35 people. Growers and PCAs.
12. Jan 29, 2020: Key economic diseases, identification, biology, and treatments in almond. Bayer Crop Science Chico Tree Nut Meeting, Chico, CA. 250 people. Growers and PCAs as well as regulators and industry representatives.
13. Feb. 5, 2020: Almond flower, foliar, and fruit diseases and their management. Yolo-Solano-Sacramento Almond Meeting, 50 people. Growers and PCAs.
14. June 18, 2020: Almond hull rot and new strategies for the management of this complex summer disease. Zoom meeting sponsored by ReDox Ag. 150 people. Growers and PCAs and industry representatives.

E. Materials and Methods:

I. ***Disease management strategies*** – We evaluated new fungicides and developed efficacy data based on spectrum of activity, systemic action, and persistence. Standard fungicide trials were established in experimental (UC Davis, KARE) and commercial orchards in the spring of each season using selected registered and experimental fungicides (one or several fungicides from each class – DMIs, anilinopyrimidines (APs), QoIs, SDHIs, chitin synthase inhibitors (CSIs), and guanidines, as well as pre-mixtures. Natural compounds (Serenade, Fracture, and others) were evaluated. Treatments were applied in the field using an air-blast sprayer (100 gal/A) or in the laboratory using an air-nozzle sprayer. Experimental design was a completely randomized block with 4 single-tree replications per treatment. Plots were evaluated for brown rot, gray mold, and shot hole. Using a minimum number of applications, programs based on rotations or mixtures of fungicides that belong to different classes were evaluated to reduce the potential of fungicide resistance development in the pathogen population.

The pre- and post-infection activities of fungicides against blossom blight were evaluated in laboratory studies. For this, blossoms were collected at pink bud, allowed to open and either inoculated with a conidial suspension of *M. laxa* (20K conidia/ml) and treated after 24 h with fungicides or natural products using a hand sprayer (post-infection activity), or treated and then inoculated after 24 h (pre-infection activity). Three replications of 8 blossoms were used for each fungicide. The incidence of stamen infection was determined for each blossom after 4 to 5 days at 20 C. All data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures of SAS 9.4. Information on these characteristics of fungicides were used to develop effective programs for brown rot and other foliar and fruit diseases of almond and used in the IPM website.

Field plots for hull rot management were established in commercial orchards with a known history of the disease. Trials were done where *Rhizopus or Monilinia* spp. or both species were the causal pathogens of hull rot. Surveys for Aspergillus hull rot were also conducted in several counties in cooperation with farm advisors and PCAs. Treatments (QoIs, DMIs, SDHIs, pre-mixtures) were applied at early or late hull split at locations where *R. stolonifer* is the pathogen. Earlier timings (similar to an Alternaria leaf spot management program) were done where *M. fructicola* has been the main pathogen in the past. When both pathogens were present two applications were done in early- or mid-June and at early hull split. Selected fungicides were applied using an adjuvant. The incidence of hull rot strikes was evaluated at or immediately after harvest.

Additionally, we evaluated alkalinizing treatments (alkaline fertilizers such as dipotassium phosphate, Banx) applied at different rates and timings at or before hull split. These treatments are systemic in the host tissue by themselves. We also tested them in combination with fungicides that we previously identified effective against hull rot. The direct effect on tissue acidity was determined by measuring the pH of plant tissues with a surface electrode. All data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures of SAS.

II. ***Develop baseline sensitivities*** **of fungal pathogen populations against new fungicides and determine shifts in fungicide sensitivity**. Sensitivity assays for populations of *Monilinia* spp. to selected new experimental and registered fungicides were done using the spiral gradient dilution method. To determine the presence of any field resistance, isolates of *Monilinia, Wilsonomyces,* and *Botrytis* spp. were evaluated from locations in California where outbreaks have occurred after fungicide application.

III. ***Field evaluations of almond cultivar susceptibility***. In an orchard at UC Davis, almond new and currently common cultivars, and genotypes (mostly from Dr. T. Gradziel's program) were evaluated annually. From early spring to early summer trees were wetted using a raised sprinkler irrigation system to create favorable conditions for the occurrence of diseases. Trees were evaluated for naturally occurring foliar and fruit diseases including brown rot, rust, shot hole, and scab. Data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures of SAS.

F. Publications that emerged from this work (online publications)

1. Adaskaveg, J. E., and Michailides, T. J. 2021. Efficacy and Timing of Fungicides, Bactericides, and Biologicals for Deciduous Tree Fruit, Nut, Strawberry, and Vine Crops (PDF). *In production*. http://ipm.ucanr.edu/PDF/PMG/fungicideefficacytiming.pdf

2. Ziram: Re-Registration Eligibility Decision Review. Support letter posted on EPA website. 2020-21. https://www.regulations.gov/docket?D=EPA-HQ-OPP-2015-0568

3. Prepared several disease chapters for the Almond Production Manual.

4. Haviland, D. R., Symmes, E. J., Adaskaveg, J. E., Duncan, R. A., Roncoroni, J. A., Gubler, W. D., Hanson, B., Hembree, K. J., Holtz, B. A., Stapleton, J. J., Tollerup, K. E., Trouillas, F. P., and Zalom, F. G. Revised continuously. *UC IPM Pest Management Guidelines: Almond*. UC ANR Publication 3431. Oakland, CA. https://www2.ipm.ucanr.edu/agriculture/almond/