Reduction of Almond Hull Rot Disease Caused by *Rhizopus stolonifer* by Early Termination of Preharvest Irrigation

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ABSTRACT

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Preharvest termination of weekly irrigation prior to harvest from late June to mid-August 1990 and 1991 was studied for control of almond hull rot disease caused by *Rhizopus stolonifer*. When trees were irrigated within 2 wk of harvest, there was more infection of hulls by *R. stolonifer*, more leaf strikes per tree, and in 1991, more shoot and branch death per tree than when irrigation was discontinued earlier. Percent hull split incidence and hull moisture content increased as irrigation continued through the season, but these criteria did not explain differences in disease incidence among trees in the first six compared with the last two irrigation termination dates.

Additional keywords: cultural practices, *Prunus dulcis*

Hull rot is a sporadic but sometimes serious disease of almond, *Prunus dulcis* (Mill.) D. Webb, in California. It is generally caused by *Rhizopus stolonifer* (Ehrenb.:Fr.) Vuill. or *Monilinia fructicola* (G. Wint.) Honey, but sometimes *Monilinia laxa* (Aderhold & Ruhland) Honey, *Rhizopus circinans* Tiegh., and *Rhizopus arrhizus* A. Fischer also can elicit hull rot symptoms (4,7). Although all almond cultivars grown in California are potential hosts, the widely planted cultivar Nonpareil is the most susceptible (7,8). Vigorous, heavily cropped trees usually sustain the greatest damage, and no control measures have been developed (1,8).

The first symptom of hull rot, a grayish lesion that soon turns tan to brown on the mesocarp (hull) of the maturing almond fruit, is followed by necrosis and death of nearby leaves and part or all of the spur or shoot upon which the infected fruit is borne. In *R. circinans* infections, fumaric acid produced by the pathogen in the infected hull is transported to the subtending spur and kills the leaves (6). Leaf and shoot death associated with infection by other hull rot fungi is presumed to be caused in a similar manner. The dead leaves remaining attached to the twigs impart a scorched look to badly damaged trees. Internally, the vascular tissues leading to the infected fruit develop brown to black discoloration. Sporulation of *Rhizopus* spp. is easily visible between the hull and shell, and *M. fructicola* often sporulates on inner and outer hull surfaces. Infected fruit that remain attached to the tree after harvest (sticktights) must be removed because they can serve as overwintering sites for the navel orangeworm *Amyelois transitella* (Walker), a serious insect pest of almonds (10,11). Although the nutmeat is not harmed by hull rot infections, losses in yield accrue from sticktights and the destruction of productive wood (1).

As the almond fruit completes maturation, the hull dehisces along the ventral suture (5). This process, called hull split, begins in early July in Nonpareil trees planted in the southern end of the San Joaquin Valley. Most fruit have split hulls by late July, and essentially all have dehisced by harvest in mid-August. The hull opening (split) enlarges over several days, and the hull detaches from the pedicel and loses moisture. At harvest, hulls of most fruit are fully open, dry, and leathery. Healthy fruit remain attached to the tree by only a few vascular elements and are easily dislodged when the tree is shaken (3). Hull rot begins during hull split. Spores must be deposited on the inner hull surfaces to establish infection, because the pathogen cannot invade the outer hull surface (7). Air currents and insects are the suspected agents of spore dispersal (7,8).

Hull rot is most prevalent in orchards that have high yields and dense canopies and that are provided with ample water and nitrogen. Sudden outbreaks of hull rot often follow irrigations made just before harvest, suggesting that changes in irrigation practices might be useful in minimizing losses to hull rot. Therefore, we investigated the effects of irrigation termination dates on the incidence and severity of hull rot.

MATERIALS AND METHODS

Irrigation termination. Irrigation experiments were conducted in 8.9 ha of a commercial almond orchard in Kern County, California. The orchard was

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planted in 1981 with cultivars Nonpareil and Carmel in a 2:2 pattern on a 7.6 × 7.6 m spacing. All orchard practices except irrigation were standard for the region and maintained by the grower (9).

Microsprinklers delivered 23 mm of water in each 24-h irrigation. Before the irrigation experiment began each year, all trees received 525 mm of water in 1990 and 445 mm water in 1991, based on evaporative demand as estimated with California Irrigation Management Information System (CIMIS) modified Penman reference crop water use and almond crop coefficients (2). During the experiment, irrigations usually were applied twice weekly but occasionally occurred one or three times per week depending on evaporative demand or the need for other cultural practices in the orchard.

Eight irrigation treatments (intervals between the last irrigation and harvest) were applied to the same trees in 1990 and 1991. Irrigation was terminated at eight weekly intervals beginning in late June and ending just prior to harvest in mid-August. The intervals between the last irrigation and harvest were 51, 44, 37, 30, 22, 15, 8, and 1 days in 1990 and 52, 46, 39, 32, 25, 18, 11, and 4 days in 1991. The cumulative amounts of preharvest water applied are presented in Table 1. The last irrigation in commercial orchards usually occurs within 2 wk of harvest, a timing represented in our experiment by irrigation termination at 1 and 8 days (1990) and 4 and 11 days (1991) preharvest.

Each plot consisted of eight rows 12 trees long, and disease data were collected from the center eight (four pairs) Nonpareil trees per replicate in 1990 and 1991. There were three replicates of each irrigation treatment arranged in a randomized complete block design.

Trees were mechanically shaken to remove fruit on 16 August in both years. On 17 and 16 August 1990 and 1991, respectively, all leaf strikes per tree and the estimated length of dead wood present were determined. Most almond fruit are borne on short spurs, and the associated leaves tend to be clustered near them. The designation "leaf strike" used here describes a short spur with one or two clusters of dead leaves or a single cluster of dead leaves on a shoot. The length of fruiting wood or small limbs with more than two leaf strikes was estimated and included in the category "estimated length of dead wood." Fruit samples of approximately 3 kg were collected arbitrarily from beneath these trees, placed in paper bags, and transported to the laboratory, where 100 fruit from each sample were examined visually for the presence of lesions and visually or with a stereo microscope (30×) for growth of pathogens.

Each year, surface-disinfested tissue samples from 50 fruit with hull rot lesions, collected at harvest, were placed in petri dishes containing acidified (2.5 ml of a 25% lactic acid [v/v] per liter of medium) potato-dextrose agar and incubated in the laboratory at 22–23 C for 5 days to identify the organisms associated with the hull rot lesions.

Transformations were performed on data for number of leaf strikes and estimated length of dead wood per tree (log) and percent hull infection (arcsine) before two-way analysis of variance and mean separation by orthogonal contrasts.

Hull split incidence and hull moisture content. Beginning at early hull split each year, in July, four fruit collections were made at 34, 28, 21, and 10 days before harvest in 1990 and 30, 23, 17, and 12 days before harvest in 1991. Twenty fruit gathered arbitrarily from the periphery of each group of eight center trees were sealed in self-sealing plastic bags, stored on ice in an ice chest, and returned to the laboratory. Water from the microsprinklers hit only an occasional low branch on a few trees. All collected fruit were taken from areas well above the plane of sprinkler water. Hulls were considered split if any part of the suture had separated 1 mm or more. Hulls were removed from the nuts, weighed, and air-dried in a forced air oven (Soiltest Model L-72 C, Evanston, Illinois) at 65 C for 72 h to determine dry weights. Percent hull moisture content was calculated from these values.

Arcsine transformed data for percent hull split incidence and actual data for percent hull moisture content were analyzed as a split-plot analysis of variance with irrigation termination treatments the main plot and hull collection date the subplot factors.

Weather data. Data for 1990 and 1991 were obtained from a CIMIS station located approximately 2.5 km from the orchard where the experiments were conducted.

RESULTS AND DISCUSSION

R. stolonifer was the only hull rot pathogen observed or isolated from diseased fruit; therefore, all further mention of hull rot pathogens refers to this species.

Irrigation termination. As irrigations were continued through the season, there was a significant linear increase in the number of leaf strikes per tree and percent hull infection in both years and in

Table 1. Effect of preharvest termination of irrigation on incidence of hull rot disease, caused by *Rhizopus stolonifer*, of cv. Nonpareil almond trees, Kern County, California

Days between last irrigation and harvest		Total water applied (mm)[w]		No. leaf strikes per tree[x]		Est. length dead wood per tree (m)[x]		Percent infected hulls[y]	
1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
51	52	525	445	0.0	8.3	0.0	0.2	1.3	0.0
44	46	572	490	0.0	30.7	0.0	0.5	0.0	7.0
37	39	617	536	1.3	11.0	0.0	0.6	1.0	3.0
30	32	663	582	6.3	20.0	0.0	0.7	1.0	7.7
22	25	720	650	7.3	36.3	0.0	1.6	0.7	6.7
15	18	765	696	16.3	71.0	0.0	2.2	0.3	9.0
8	11	789	742	59.0	284.7	0.0	17.0	5.7	16.3
1	4	812	787	70.0	362.7	0.0	16.8	8.3	31.7
Significance of *F*, *P* =[z]									
Irrigation interval				0.001	0.001	...	0.001	0.001	0.001
Linear				0.001	0.001	...	0.001	0.001	0.001
1 and 8 vs. 15–51 days				0.001	...	...	...	0.001	...
4 and 11 vs. 18–52 days				...	0.001	...	0.001	...	0.001

[w] Before experiment began each year, 525 and 445 mm of water applied to all treatments in 1990 and 1991, respectively. Generally two 24-h irrigations of 23 mm of water each per week.

[x] Trees shaken 16 August 1990 and 1991; data collected 17 and 16 August 1990 and 1991, respectively.

[y] One hundred fruit per replicate collected 17 and 16 August 1990 and 1991, respectively.

[z] Three replicates of eight-tree plots arranged in a randomized complete block design. Analysis of variance and mean separation by orthogonal contrasts performed on log transformed data for number leaf strikes and estimated dead wood per tree and on arcsine transformed data for percent infected hulls. Actual data presented.

the estimated length of dead wood in 1991 (Table 1). These were reduced significantly when irrigation was not applied during the last 2 wk before harvest. Mitigation of disease severity by eliminating irrigations about 2 wk before harvest could be an important tool in a control strategy for hull rot. Fungicide programs for controlling hull rot are not available in California, and disease management is therefore dependent on manipulation of cultural practices such as irrigation frequency. Registration of fungicides for hull rot control is unlikely, given the difficulty in delivering a material to the susceptible inner hull surface and the desire to reduce fungicide use. Furthermore, fungicide residues on or in hulls, most of which are fed to livestock, would pose a problem. Tree growth and yield were reduced where irrigation ceased about 4 wk before harvest. Denial of water about 2 wk before harvest did not affect production (D. A. Goldhamer, *unpublished*) and is consistent with preparation of the orchard for harvest. Less stringent deficit irrigation schemes, which employ limitation of water over the irrigation season rather than the summary denial of water used in our experiments, also may be effective. These schemes are the subject of another study.

Table 2. Effect of preharvest irrigation termination on hull split incidence and hull moisture content of cv. Nonpareil almond fruit, Kern County, California

		Hull moisture content (%)[x]		Hull split incidence (%)[x]	
1990	**1991**	**1990**	**1991**	**1990**	**1991**
Days between last irrigation and harvest[y]					
51	52	74.2	71.4	0.0	5.4
44	46	76.3	74.5	7.9	25.6
37	39	74.9	73.2	8.3	21.6
30	32	77.4	76.0	7.9	38.8
22	25	78.3	75.2	20.4	64.8
15	18	79.0	77.3	32.5	69.4
8	11	79.3	79.0	48.3	70.4
1	4	78.9	79.9	38.3	61.4
Days between hull collection and harvest					
34	30	79.8	80.1	1.8	16.9
28	23	78.7	77.6	10.8	45.8
21	17	78.6	75.3	32.1	54.7
10	12	72.1	69.6	43.1	59.0
Significance of F, $P =$[z]					
Irrigation interval		0.025	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001
1 and 8 vs. 15–51 days		NS	...	NS	...
4 and 11 vs. 18–52 days		...	NS	...	NS
Weeks hulls collected		0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001
Irrigation × hull collection		0.032	0.001	0.001	0.001

[x] Twenty fruit from each of three replications collected four times at approximately weekly intervals beginning at early hull split (13 and 17 July 1990 and 1991, respectively). Means of data combined over four collection dates (for days between last irrigation and harvest) or eight irrigation treatments (for days between hull collection and harvest).

[y] Generally two 24-h irrigations of 23 mm water each per week. Each year, 525 and 445 mm water were applied to all treatments before experiment began in 1990 and 1991, respectively. Total amounts water applied are shown in Table 1.

[z] Three replications of eight-tree plots arranged in a randomized complete block design. Analysis of variance and orthogonal contrasts performed on actual data for hull moisture content and on arcsine transformed data for percent hull split. Actual data reported.

Percent hull split incidence and hull moisture content. The average percent hull split incidence and hull moisture content (data combined over the four collection dates) increased linearly as irrigation continued into the season, but these values did not differ significantly between the six longest and two shortest irrigation termination intervals (Table 2). Percent hull split incidence and hull moisture content increased linearly over time.

There were significant interactions between irrigation treatment and the interval between hull collection and harvest for percent hull split incidence and hull moisture content in both years. Where irrigation was discontinued early, 51–22 days preharvest in 1990 and 52–32 days preharvest in 1991, hull split culminated in lower percent hull split incidences at the final collection (Fig. 1). Hull moisture loss was least in 1990 in the longest (51 days) and shortest (1 day) and in 1991 in the two longest (52 and 46 days) and shortest (11 and 4 days) irrigation termination interval treatments (Fig. 2). In early irrigation termi-

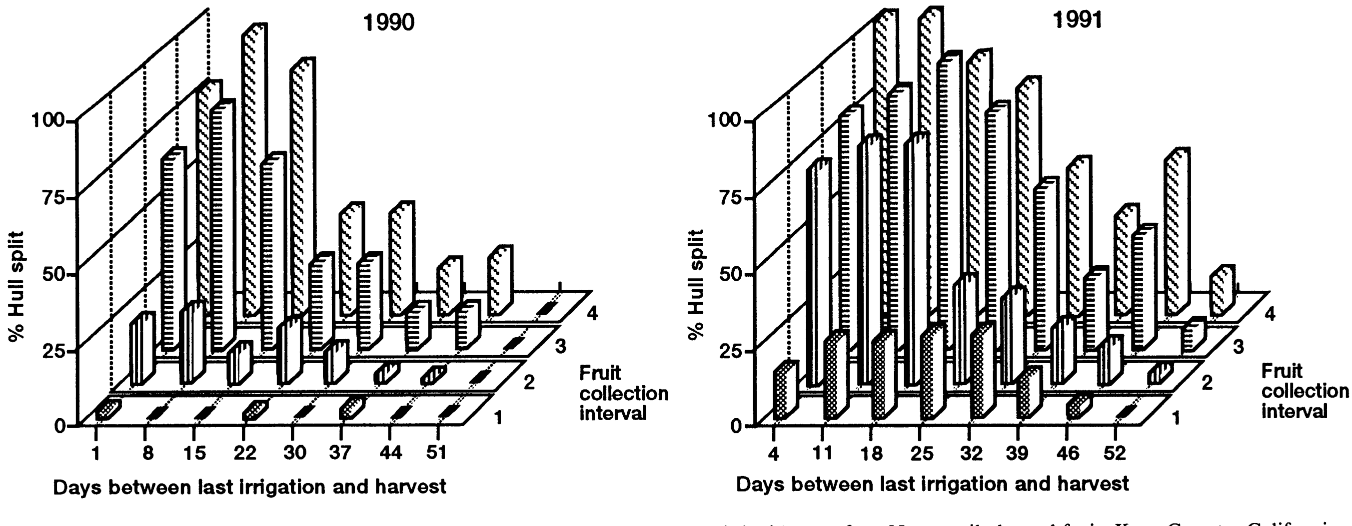

Fig. 1. Effect of interval between last irrigation and harvest on percent hull split incidence of cv. Nonpareil almond fruit, Kern County, California. Each 24-h irrigation delivered 23 mm of water; irrigations were applied generally twice weekly until preharvest termination. Twenty fruit were collected at four preharvest intervals from each of three replicates of each irrigation treatment. The four preharvest fruit collection intervals, numbers 1 through 4, were 34, 28, 21, and 10 in 1990 and 30, 23, 17, and 12 days in 1991. Trees were harvested 16 August 1990 and 1991. Hulls were considered split if any part of the suture had separated 1 mm or more.

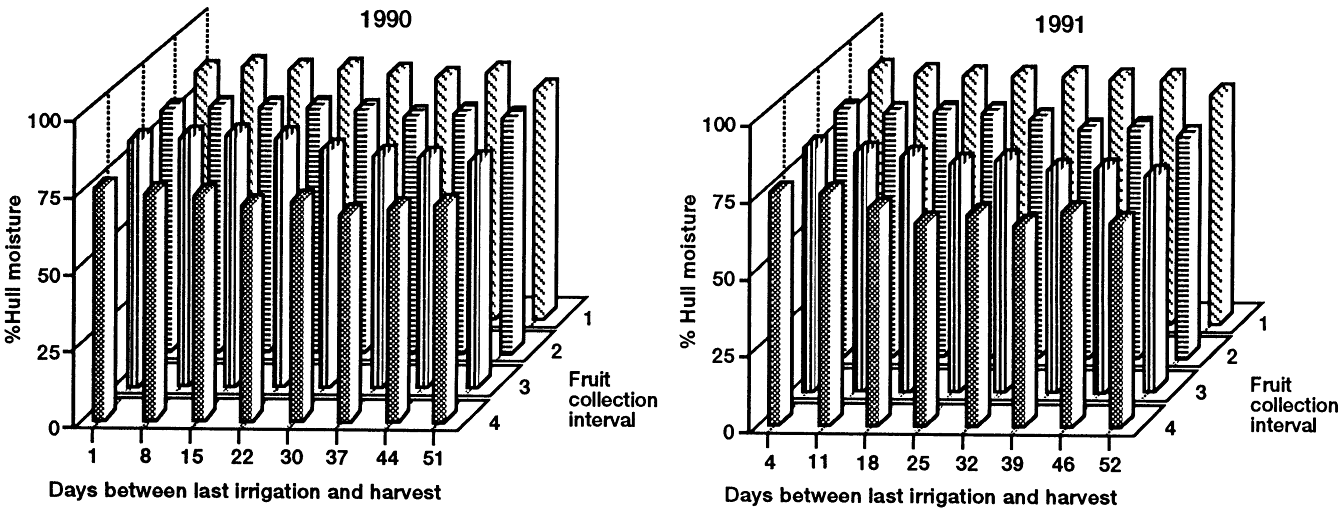

Fig. 2. Effect of interval between last irrigation and harvest on percent hull moisture content of cv. Nonpareil almond fruit, Kern County, California. Each 24-h irrigation delivered 23 mm of water; irrigations were applied generally twice weekly until preharvest termination treatment. Twenty fruit were collected at four preharvest intervals from each of three replicates of each irrigation treatment. The four preharvest fruit collection intervals, numbers 1 through 4, were 34, 28, 21, and 10 in 1990 and 30, 23, 17, and 12 days in 1991. Trees were harvested 16 August 1990 and 1991.

nation treatments, hulls apparently lost moisture before hull collections began and did not dry much thereafter, but held moisture where trees were watered later into the season.

Differences in hull split incidence do not explain entirely the effect of irrigation termination on disease incidence. On our last hull collection date each year, which was fewer than 14 days before harvest, half or fewer fruit were split where irrigation ended 22 (1990) or 32 (1991) or more days before harvest (Fig. 1). These low percentages of hull split may account for the low levels of disease found in those treatments. Where irrigations continued later into the season, hull split reached or exceeded 60 and 70% in 1990 and 1991, respectively, by 3 wk before harvest. Thus, most fruit in treatments irrigated later into the season were susceptible for at least 3 wk before harvest, but disease was reduced substantially only by ending irrigation at 15 (1990) or 18 (1991) days before harvest.

Changes in hull moisture content also do not account for the effects of irrigation termination on disease incidence. Although hulls retained moisture longer as irrigation continued through the season, the remarkable difference in disease incidence found between the longest six and shortest two irrigation termination treatments was not observed for hull moisture content.

Weather data. Average daily maximum and minimum temperatures in summer were higher in 1990 than in 1991. Through the course of the irrigation experiment (mid-June through mid-August), there were 56 and 38 days above 32.2 C, and 16 and 6 days surpassed 37.8 C, in 1990 and 1991, respectively. The high and low means for that period were 36.5 and 17.5 C in 1990 and 33.0 and 15.8 C in 1991. During hull split, the 5-wk period before harvest, temperatures exceeded 37.8 C on 12 and 2 days in 1990 and 1991, respectively. The mean high and low temperatures for this period were 37.1 and 19.1 C in 1990 and 33.7 and 16.2 C in 1991.

Hull rot was less severe in the warmer year 1990 than in 1991. Symptoms in 1990 were limited to individual leaf strikes (thus no data on estimated length of dead wood). Collapsed shoots and small limbs as well as individual leaf strikes were present in 1991.

How irrigation and weather affect hull rot is unclear. The physiological status of the tree, production and dissemination of inoculum, growth and sporulation of the pathogen, and the biology and movement of possible insect vectors each may be modified in some way by irrigation or weather or interactions among these factors. The epidemiology of hull rot has not been studied; greater knowledge of the disease would provide a basis for understanding the relationship between irrigation practices and disease control. Nonetheless, our work demonstrates that changes in preharvest irrigation practices can reduce the incidence of hull rot and help manage this disease.

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