Nitidulid Beetles as Vectors of Monilinia fructicola in California Stone Fruits

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ABSTRACT

Under hot, dry conditions in the Central Valley of California, brown rot development in stone fruits was closely associated with the presence of nitidulid beetles and fruit injury caused by the oriental fruit moth and/or natural splitting of the fruit endocarp. During 1971-73, on decaying stone fruits within orchard trees, *Carpophilus freemani* predominated in June, July, and August while the populations of *C. mutilatus* and *Haptonchus luteolus* were rare until August, but increased and became prevalent in September. Throughout the summer, *C. hemipterus* was present in trace numbers in the trees. In decaying fruit on the orchard floor, *C. mutilatus* was less abundant than the other species.

Carpophilus mutilatus and *H. luteolus* were important vectors of *Monilinia fructicola* in late-maturing peach and nectarine cultivars. They were active visitors of oriental fruit moth exit holes in healthy fruit, were contaminated in nature with viable conidia of *M. fructicola*, and transmitted the spores to injuries in fungicide-treated or untreated fruit, with resultant development of decay. Although *C. freemani* and *C. hemipterus* experimentally transmitted *M. fructicola* and were contaminated in nature with viable conidia, they were not important vectors since neither actively visited injured healthy fruit in furrow-irrigated orchards. Olfactometer tests showed that *C. freemani* preferred decaying to healthy fruit odors while the other species preferred the latter. Moisture was an important factor which influenced the attraction of all species to injured fruit.

These data establish two species of nitidulid beetles, *C. mutilatus* and *H. luteolus*, as effective vectors of *M. fructicola* in late-maturing stone fruit cultivars with injured fruit and may explain why recommended fungicide applications sometimes fail to control fruit decay in California orchards. Control of brown rot of fruit in the field was obtained by insecticide sprays aimed at reducing oriental fruit moth injuries.

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Additional key words: insect transmission, peaches, *Carpophilus* spp., *Sclerotinia fructicola*.

Association between brown rot of stone fruits incited by *Monilinia fructicola* (Wint.) Honey and *M. laxa* (Alderh. and Ruhl.) Honey with injury of fruit by insects has been reported from Europe (19), the United States (2, 13, 14, 15), and Australia (4, 6), with positive correlations established for the plum curculio (2, 14, 16) and the oriental fruit moth (2, 6, 12). Insecticide application to reduce damage in fruit by these insects was shown to lessen the brown rot problem (6, 12, 15). Various insects, including nitidulid beetles, were suspected of disseminating the brown rot fungi by carrying conidia externally on their bodies (6, 9. 10, 19). Nitidulid beetles contaminated with conidia were found within healthy fruit containing oriental fruit moth injuries in Australia (6), and Ogawa (10) reported transmission of *M. fructicola* conidia by the dried fruit beetle (*Carpophilus hemipterus* L.) to injured fruit in California.

Though evidence has accumulated on the role of nitidulid beetles in the spread of brown rot in stone fruits, no one has shown conclusively that transmission by beetles results in fruit decay, or the importance of this to disease development in orchards sprayed with protectant fungicides. This study investigated the role of nitidulid beetles in the epidemiology of brown rot in stone fruit under arid California conditions.

MATERIALS AND METHODS.—The nitidulid species studied were *C. hemipterus, C. mutilatus* Er., *C. freemani* Dobson and *Haptonchus luteolus* (Erichson) cultured from field collections made at the San Joaquin Valley Research and Extension Center, Parlier, California, or supplied by the Stored-Products Insects Laboratory, Agricultural Marketing Service, U.S. Department of Agriculture, Fresno, California. Culture containers were 1,150-ml, wide-mouth glass canning jars with insect screen tops. To prevent fungus and mite contamination a Whatman No. 40 filter paper was inserted beneath the screen. Cultures were fed twice-weekly with freshly soaked, autoclaved figs and subcultures started in fresh autoclaved field soil by transferring an infested fig from an established culture. Beetles were handled with an aspirator (Fig. 1-A) which was also used for CO_2 anesthetization when it was necessary to count out specific numbers of beetles.

Olfactometer tests on attraction of beetles to fruit.—The olfactometer used was similar to the one described by Howell and Goodhue (5) but modified for use with nitidulid beetles (Fig. 1-F, G). This apparatus was used to compare the relative attractiveness of two air streams of 13 mm/second velociety at 24-25 C and varying relative humidity (RH). To determine response to a particular stimulus, 30 beetles of mixed sex were placed in the olfactometer cage which was then darkened with aluminum foil. After 1 hour the foil was removed and a record taken of beetle numbers on each side of the cardboard division between air streams. Before the test, beetles were dispersed in the cage by blowing upon them,

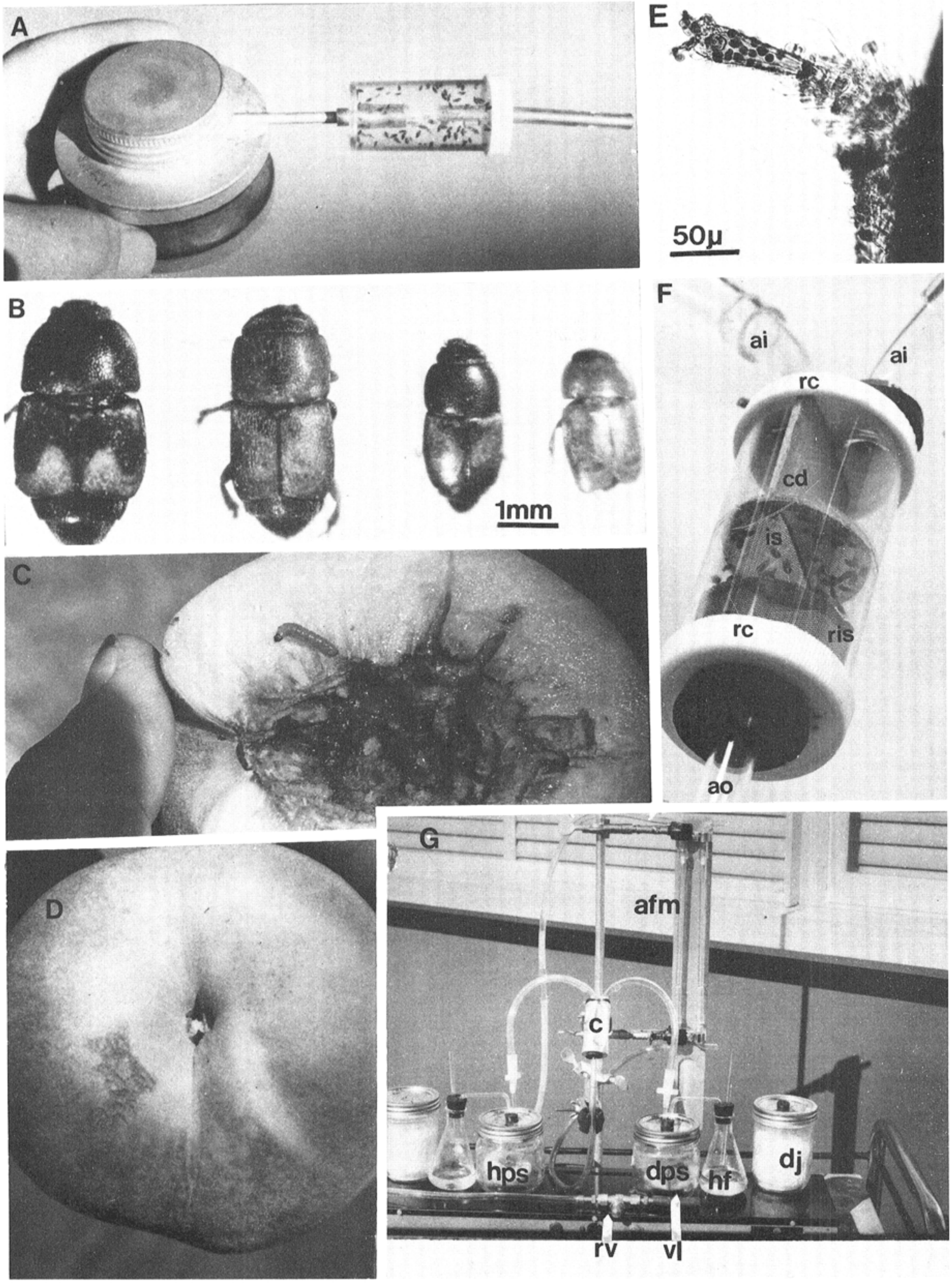

Fig. 1-(A to G). **A**) Aspirator used for collecting beetles and for anesthetizing with CO_2. **B**)Nitidulid species associated with peach brown rot decay: left to right, *Carpophilus hemipterus, C. mutilatus, C. freemani,* and *Haptonchus luteolus.* **C**) Mature peach (cultivar Carnival) opened to show an oriental fruit moth larva, feeding damage, and the exit tunnel. **D**) Mature peach (cultivar Halloween) showing the split-pit condition. **E**) Photomicrograph of *C. mutilatus* leg showing conidia of *Monilinia fructicola* lodged among bristles and adhering to tibia and tarsus. **F**) Olfactometer cage with beetles, actual size: cd = cardboard divider; is = insect screen; ai = airstream intake; ao = airstream outlet; rc = removable cap; ris = removable insect screen. **G**) Insect olfactometer apparatus: afm = air flow meter; hps = healthy peach slice; dps = decayed peach slice; hf = humidifying flask; rv = regulator valve; vl = vacuum line; dj = drying jar containing $CaCl_2$; c = aluminum foil cover over olfactometer cage.

TABLE 1. Presence of nitidulid species (*Carpophilus* and *Haptonchus* spp.) in stone fruit during harvests of 1971 to 1973

	Decaying fruits with beetles[a] (mean %)				
	Within tree				On ground
Nitidulid species	Jun	Jul	Aug	Sep	Jul-Sep
C. freemani	44.5	96.7	83.5	15.0	47.3
C. mutilatus	1.5	7.7	44.5	65.7	13.5
H. luteolus	0.0	0.0	28.3	61.7	60.8
C. hemipterus[b]	0.5	7.0	19.8	5.5	54.8
Fruit examined (no.)	266	103	125	615	1715

[a]Cultivars examined included Le Grand nectarines and Red Top peaches in June; Le Grand nectarines in July; Autumn Grand nectarines, Carnival and L 120 peaches in August; Halloween peaches and Autumn Rosa plums in September. Fruit maturity varied from green to ripe.

[b]When *C. hemipterus* infested tree fruit they never exceeded one or two/fruit, compared with consistently high numbers (30 or more) for other species.

and between runs the test and control air streams were interchanged. For each comparison, at least four runs were made. Beetles were dehydrated by fasting in dry vials for 6 hours, whereas hydrated beetles were those used immediately after removal from humid culture jars. Airstream humidity was varied by passing ambient air over anhydrous $CaCl_2$ (35% RH), glass-distilled water (92% RH) or various H_2SO_4-water mixtures as listed by Stevens (17). RH in the olfactometer was determined by inserting into the cage two copper-constantan thermocouples (one wrapped with wet cotton) attached to a temperature-reading potentiometer (Leeds and Northrup Model 8692). For ambient laboratory air drawn through the olfactometer, thermocouple measurements taken this way agreed with those taken in the laboratory with a ventilated psychrometer (Psychron Model 566). Before any olfactometer runs were made, the psychrometric thermocouples had to be removed since the beetles were strongly attracted by the water vapor from the wet thermocouple junction.

Field data were collected at Parlier in a mixed block of peach and nectarine cultivars with a natural infestation of oriental fruit moth (OFM), *Grapholitha molesta* (Busck). Supporting data were obtained in nearby commercial orchards. Data were taken at intervals throughout the 1971-73 peach harvest seasons which extended from May through September. Pesticides used in various trials included captan (Orthocide 50W), benomyl (Benlate 50W), 2,6-dichloro-4-nitro-aniline (Botran 75W), malathion (50% EC) and *O,O*-dimethyl-S-(2-methoxy-1,3,4-thiadiazol-5 (4H)-onyl-(4)-methyl)-dithiophosphate (Supracide 20% EC).

RESULTS.—*Association of beetles with fruit decay.*—Four species of nitidulid beetles, *Carpophilus hemipterus, C. mutilatus, C. freemani* and *Haptonchus luteolus* (Fig. 1-B), were consistently associated with brown rot of stone fruits in the Central Valley of California from 1971 to 1973. Table 1 shows which nitidulid species infested fruit with brown rot as the

TABLE 2. Association of nitidulid beetles and injury with brown rot of fruit in stone fruit trees

	Percent decaying fruit with beetles and/or injury						
	1972	1973					
Presence on fruit of	Peach[a]	Nectarine[a]		Peach[b]	Nectarine[b]		Plum[b]
	21 Sep	7 Jun	28 Jun	28 Jun	9 Jul	27 Jul	29 Sep
Injury + beetles	85.6	0.0	50.0	59.0	80.0	30.0	85.0
Injury with no beetles	13.5	79.4	21.0	14.0	0.0	5.0	5.0
Beetles	0.9	0.0	12.0	21.0	20.0	62.0	9.0
No beetles	0.0	20.6	17.0	6.0	0.0	3.0	1.0
No. of fruit recorded	228	136	34	58	30	60	100

[a]Oriental fruit moth (OFM) was the major cause of fruit injury.
[b]Split pits (fruit suture split open at stem) accounted for most injuries.

TABLE 3. Visitation by nitidulid beetles to oriental fruit moth exit holes and artificial openings in healthy fruit during 1972-73

	Injured fruit visited (mean %)					
	Natural openings[a]		Artificial openings[b]			
Nitidulid species	Aug	Sep	Jun	Jul	Aug	Sep
C. freemani	0.0	1.8	0.0	0.0	0.5	0.3
C. mutilatus	16.0	39.5	0.0	0.0	1.8	2.3
H. luteolus	32.0	32.3	0.0	0.0	1.1	14.8[c]
C. hemipterus	0.0	0.5	0.0	0.0	0.5	0.0
Total fruit	37	307	959	641	536	226
No. of tests	1	4	11	11	8	3

[a]Oriental fruit moth holes in Carnival and Halloween peaches.
[b]Artificially punctured fruit of Le Grand nectarine and L 120, Fay Elberta, Red Top, Carnival and Halloween peaches.
[c]Routine furrow irrigation was applied at the time of this test.

season progressed for the 3-year study period. During June, July, and August most decaying fruit were infested with *C. freemani,* but in August *C. mutilatus* and *H. luteolus* counts increased and by September these latter two species had prevailed. *Carpophilus hemipterus* was always present in very low numbers in tree fruit compared to other species, but was abundant on fallen fruit. *Carpophilus mutilatus* was less common on fallen decaying fruit than were the other species.

Observations on randomly harvested, decaying fruit during 1972 and 1973 (Table 2) showed that most of these fruit were both injured and infested with nitidulid beetles. The only exceptions were on 7 June 1973 when beetles had not yet appeared, and on 27 July 1973 when disease had reached epidemic levels and contact between healthy and decaying fruit appeared to be more important for initiating additional infections than were injuries. Thus, early in the season OFM injury was nearly always associated with green fruit rot, but once the beetles (*C. freemani*) had appeared they were usually present on decaying fruit whether or not the fruit was injured. OFM accounted for 70%, and split pits 30% of fruit injuries in unsprayed nectarines and Halloween peach trees during 1972 and 1973. Early in the season the OFM injuries were caused by newly hatched larvae entering the fruit close to the stem, while in maturing fruit of late cultivars, injury was caused by mature larvae that bored open tunnels from the pit to the fruit surface.

Visitation by beetles to injuries in healthy fruit.—The presence of bettles on and within decaying fruit suggested insect transmission of *M. fructicola,* but additional data were required to demonstrate beetle visitation to healthy fruit under conditions suitable for infection (7). Such conditions would be met by any injury which provided the required moisture for spore germination even when outside conditions were unfavorable. In this study, the major causes of injury were OFM larvae and splitting of the endocarp and mesocarp along the suture at the stem end (split pit) as shown in Fig. 1-C, D. OFM exit tunnels that remained open were found only in fruit of late season cultivars nearing harvest maturity. In immature fruit, any OFM injury was rapidly blocked by profuse gumming, making it inaccessible to beetles.

At intervals through the harvest period, Carnival and Halloween peach trees were searched for fruit showing OFM exit holes. These were picked, sliced open and presence of beetle recorded. Fruit with symptoms of decay were rejected. In addition, attached healthy fruit of early (Le Grand nectarine), middle (L 120 peach) and late (Halloween peach) season cultivars at all maturity stages were artificially punctured to the pit with a 2-mm diameter wire to simulate OFM damage. This was done in the morning, and 4-6 hours later each fruit was opened to record beetle presence. The common visitors to healthy, OFM-injured fruit, were *C. mutilatus* and *H. luteolus* (Table 3).

Fruit at any stage of development punctured in late June or July were not visited by *C. freemani* or *C. hemipterus* even though both species were abundant in decaying fruit at these times. Visitation to punctured fruit

TABLE 4. Olfactometer responses by nitidulid beetles (*Carpophilus* and *Haptonchus* spp.) to emanations from healthy and decayed peach fruit slices

Treatments				Mean numbers of beetles on each side							
				Le Grand nectarine		L 120 peach		Halloween peach			
Test side		Control		*C. freemani*		*C. mutilatus*		*H. luteolus*		*C. hemipterus*	
Fruit slices	RH (%)	Fruit slices	RH (%)	Test	Control	Test	Control	Test	Control	Test	Control
None	92	None	92	14.8	15.2	14.3	15.7	14.8	15.2	15.7	14.3
None	92	None	35	27.5	2.5	27.5	2.5	29.0	1.0	26.2	3.8
Healthy	92	None	92	4.0	26.0	0.7	29.3	9.0	21.0	11.4	18.6
Decayed	92	None	92	13.3	16.7	1.0[a]	29.0	4.7	25.3	1.8	28.2
Decayed	92	Healthy	92	25.9	4.1	2.1	27.9	1.5	28.5	2.3	27.7
Decayed	92	None	35	24.3	5.7	28.7	1.3	29.5	0.5	27.5	2.5
Healthy	92	None	35	...	...	28.0	2.0	29.7	0.3	26.0	4.0

[a]Datum derived from test of Halloween peach.

TABLE 5. Transmission of *Monilinia fructicola* by nitidulid beetles to fruit in caged peach trees

Transmitting beetle species	Separate tests	Total injured fruit exposed[a]		Fruit infected (%)			
				Injured fruit		Fruit stages[b]	
		Detached	Attached	Detached	Attached	Immature	Mature
Carpophilus							
hemipterus	3	180	...	11.7	...	6.7	13.3
freemani	9	358	119	7.8	5.9	6.6	8.3
mutilatus	10	461	151	16.3	9.9	10.6	21.5
Haptonchus							
luteolus	3	180	...	9.4	...	8.9	9.6

[a]Cultivars included Le Grand nectarine and Red Haven, Dixon, L 120, Fay Elberta, Carnival, and Halloween peaches.
[b]'Immature' is from pit-hardening to before harvest-mature stage. 'Mature' is harvest-mature to ripe.

increased as the season progressed, and was highest in cultivars harvested in September. This coincided with the buildup of *C. mutilatus* and *H. luteolus* populations.

Olfactometer tests on nature of attraction.—The basis of insect transmission of *M. fructicola* in peaches is the attraction of the vector to healthy fruit under conditions favoring spore germination and infection. The stimulus which may induce nitidulid beetles to seek out injuries in fresh and decayed fruit was investigated using an insect olfactometer. Table 4 summarizes the olfactometer response of all four species using dehydrated beetles. *Carpophilus freemani* was repelled by healthy nectarine slices, but not by decayed slices. When compared together, decayed slices were preferred over healthy slices. The other three species were repelled more by decayed than by healthy fruit slices, and preferred healthy over decayed. However, when either decayed or healthy fruit slices were placed in a humid air stream relative to the other side, these three species were attracted to the humid side regardless of fruit condition, showing that manipulation of RH could alter the response of the beetles. Also, when RH was lowered on one side relative to the other side, all species moved to the most humid side. In further tests, the attraction of dehydrated beetles to humidified air was found to be more rapid than that of hydrated beetles, confirming the importance of moisture in the attraction of these beetles.

Presence and longevity of viable spores of M. fructicola on beetles.—Plating beetles from sporulating decayed fruit on a selective agar medium (11) showed that 85% of 206 beetles of all species collected from sporulating fruit were contaminated with viable propagules, ranging from 1 to 2,095 with an average of 206 for each beetle.

In another test when 30 beetles of *C. mutilatus* and *H. luteolus* were removed from apparently uninfected OFM-injured fruit or the stem end of healthy fruit, 12 beetles yielded colonies of *M. fructicola*. Examination of beetles heated in cotton blue stain showed that conidia were present on body surfaces (Fig. 1-E).

To show that contamination of beetles by live fungus spores might persist under conditions of beetle flight, stationary contaminated beetles were exposed to an air stream considered to greatly exceed the wind conditions created by flying beetles. A cylindrical plastic tube, 20.3 mm in diameter, with insect screen at both ends was attached to the suction end of a vacuum cleaner and ambient air (25 C, 45% RH) was drawn through at a velocity of 55.3 km per hour. Fifty beetles were placed in the tube, and at intervals three beetles were removed to separate plates of selective agar medium for 10 minutes. When *C. mutilatus* was exposed in this manner, viable fungus was still recovered from beetles after exposure for as long as 64 minutes.

Transmission tests.—A series of tests to demonstrate transmission under field conditions was conducted from May through August 1973 in four insect-proof cages in the Armstrong field area at the University of California, Davis. Each cage enclosed a single 4-year-old Dixon peach tree. The only known source of *M. fructicola* spores were the contaminated beetles released in the cages. Fruit already present in these trees were injured and exposed without detaching them, but most experiments involved introducing to the cages healthy fruit of various cultivars and maturities which were punctured and laid at random on a wire rack 1.52 m high in the foliage center. Control fruit were either noninjured, injured and bagged to prevent beetle visitation, or injured and bagged with noncontaminated beetles. In any one test, 15-30 healthy fruit of various maturities were used for each treatment. In the morning, fruit were punctured to the endocarp with a sterile 2-mm diameter wire, placed on the rack, and approximately 200 beetles which had been artificially contaminated with spores, were released at the tree base. The following morning, detached fruit were individually sealed in clean plastic bags and incubated in the laboratory. After 2-4 days the incidence of brown rot developing from the puncture wounds was recorded. Attached fruit were left hanging, but removed upon the first symptoms of infection to the laboratory for further incubation and confirmation of the infecting organism.

Results are given in Table 5. All species transmitted spores to injured fruit at all stages of development from pit-hardening to ripe, but there was a consistent increase in transmission with fruit maturity and ripeness. Occasionally a ripe control fruit became infected with *Rhizopus stolonifer* (Ehr. ex Fr.) Lind., but otherwise control fruit remained free of disease.

To show that beetles can successfully transmit *M. fructicola* to injured fruit protected with fungicides, an inoculation hood in the laboratory with a filtered air supply was converted into an insect-proof cage. Harvest-mature or ripe Halloween peaches were dipped in a

TABLE 6. Control of brown rot of peaches in the field by insecticide [vs. oriental fruit moth (OFM)] and fungicide (vs. *Monilinia fructicola*) applications

Field sprays applied	Fruit count per tree (mean no.)	Percent of total fruit crop per tree with					
		Harvested from tree			Harvested from ground		
		Brown rot[a]	Nitidulid beetles	OFM injury	Brown rot[a]	Nitidulid beetles	OFM injury
Untreated	532	3.81 A	4.00	2.91	20.38 A	19.18	2.16
Benomyl[b]	631	2.96 A	3.39	2.40	12.03 B	13.63	2.83
Supracide[c] + benomyl[b]	616	1.43 B	1.80	0.97	6.70 C	7.22	0.61
Supracide[c]	645	1.35 B	1.64	1.12	7.78 BC	7.20	1.06

[a]Duncan's multiple range test ($P = .05$) (3). Treatments followed by the same letter do not differ significantly.
[b]Applied 10 and 4 weeks before harvest (harvested 22 September).
[c]Applied 10 and 9 weeks before harvest to coincide with the third flight of OFM.

benomyl-Botran aqueous suspension (300 and 1,200 μg/ml active ingredient, respectively) for 10 seconds. After being air dried, 30 fruit were punctured to the pit with a sterile 3.5-mm diameter cork borer, and spaced out on the floor of the cage with the injuries facing downwards. The controls consisted of 30 dipped and noninjured fruit placed among the injured fruit. Contaminated beetles (*C. mutilatus* and *H. luteolus* together) were released in the hood, and fresh filtered air was supplied intermittently. After 4 days all fruit were examined for brown rot development around the pit. It was found that beetles transmitted spores into 26 of 30 injured fruit, while the 30 noninjured fruit remained healthy.

Field control of fruit brown rot by insecticide and fungicide applications.—Since OFM, an important California insect pest (18) accounted for much of the injury associated with fruit brown rot, one would expect insecticide sprays to significantly reduce the amount of decaying fruit at harvest by reducing the number of injured fruit. Conversely, protective fungicides may have little effect in reducing brown rot, since beetles can carry spores through the fungicide-protected zone at the epidermis as shown in the previous experiment. In a block of mature Halloween trees that supported a severe infestation of OFM the previous season, insecticide sprays were compared with fungicide sprays for control of brown rot in a randomized-block, six-replicate trial with single tree plots. Supracide at 250 ml of product per 100 liters (1 qt per 100 gal) of water was applied by handgun at 9 and 10 weeks before harvest to coincide with the third flight period of OFM, and was aimed at reducing the number of fruit with open OFM exit holes at harvest. Benomyl at 30 g active ingredient per 100 liters (0.25 lb per 100 gal) of water was applied similarly at 10 and 4 weeks before harvest to reduce decay from *M. fructicola*. Controls included trees untreated, or sprayed with both materials. In two preharvest counts, fallen fruit were examined for open OFM holes, decay and beetles; and then removed from the trial area. All remaining fruit were recorded similarly when they were harvested at maturity. No rain fell during this trial.

Results given in Table 6 show that the percent of decayed fruit within insecticide-sprayed trees was significantly lower than for fungicide-sprays, which gave no protection. In fallen fruit harvested from under benomyl-sprayed trees in the third week after spraying, decay was reduced. This suggested a carryover of protection against superficial infections resulting from ground impact injury. However, when Supracide was also applied, protection was even better. Since untreated trees had no chemical protection from brown rot, fallen fruit from these trees were heavily infected. In all plots fruit decay in the tree was closely related to the combined presence of injury and beetle infestation. These results indicate that insecticide sprays to control OFM injury reduced brown rot by reducing beetle access, and therefore fungal access, to the unprotected mesocarp of the fruit.

DISCUSSION.—To be considered potential transmitters of *M. fructicola* to fruit, nitidulid beetles must be shown to both infest decaying fruit so that spores may be acquired, and also to visit injuries of healthy fruit in orchard trees where the spores may be deposited with a good chance of infection resulting. *Carpophilus mutilatus* and *H. luteolus* both fulfilled these requirements. Once they had become abundant in August, which occurred in the 3 years studied, they were consistently associated with decaying fruit in the trees, and also visited injuries in healthy fruit in significant numbers. Both beetles preferred healthy to decayed peach odors in olfactometer tests, but were also attracted to decaying peach if the alternative was a dry environment.

Carpophilus hemipterus and *C. freemani* also satisfied both requirements, but in contrast were less important as vectors since they rarely visited injuries of healthy fruit in the trees. The results indicate that *C. hemipterus* is mostly involved in spread of the fungus on fallen fruit since decaying fruit in the trees contained few individuals of this species. Observations further indicated that *C. hemipterus* was an active colonizer of freshly fallen ripe fruit that had split open upon impact. In contrast, *C. freemani* was a consistent inhabitant of decaying fruit, injured or not, both in the trees and on the ground, and in olfactometer tests was the only species studied that preferred decayed to healthy fruit odors, confirming the apparent preference for decaying fruit which this species exhibits in the field.

The overriding response to moisture exhibited by all species in the olfactometer tests helps to explain how *C. mutilatus* and *H. luteolus,* though more attracted to injuries in healthy fruit, could also be attracted under dry conditions to injured decaying fruit. Neither species is present in significant numbers until August, but by then decaying fruit are usually available both in and under trees. Nitidulid beetles are known to fly in the heat of the day during summer (1) when temperatures commonly reach 38-43 C (100-110 F), and under these conditions response to moisture should be strongly developed. Visitation to decaying fruit would be expected, and once in decaying fruit, the beetles would be readily induced to leave by any orchard operation that causes abnormal movement of such fruit. Irrigation may submerge fallen fruit and this also drives beetles out. In Table 3, the high level of visitation to punctured fruit by *H. luteolus* could be explained by the beetles leaving fallen fruit that became submerged during irrigation. Upon leaving a decayed fruit the beetles were almost always contaminated with conidia which were readily deposited by walking action onto the surface of agar medium and on injured peach surfaces in nature. Healthy fruit with open OFM injuries or split pits were more common in late-maturing cultivars, and both beetle species were found to visit these even though decaying fruit also were plentiful.

Moisture as a stimulus to nitidulid beetles was probably also involved in the results of Moller et al. (8), who studied Ceratocystis canker of stone fruits. They found that bark injuries made on trees when the soil was moist not only provided better infection courts for *Ceratocystis fimbriata,* but appeared to be more attractive to *C. freemani,* the main vector of the fungus. This suggests that considerable water loss to the atmosphere from bark injuries was necessary to provide the stimulus to attract the vector, and strengthens the conclusion for the present study that moisture constitutes an important part of the overall stimulus that attracts nitidulid beetles to injured fruit.

Nitidulid beetles are strong fliers, being recorded 7.07

km upwind of a release point within 2 days (20). Therefore, in the 1-hour period during which the fungus was shown to persist under simulated flight conditions, beetles may carry the fungus over a significant distance before introducing it into an injured fruit.

The ability of all species to carry conidia to injuries in healthy fruit was demonstrated in the transmission tests. Successful transmission by *C. freemani* and *C. hemipterus* may be explained by their attraction to moisture in the dry-cage environment since there was no alternative source such as decaying fruit for *C. freemani* or fallen injured fruit for *C. hemipterus*. Since neither species actively visited injured, healthy fruit in uncaged trees, they are probably not important as vectors in nature, though they cannot be completely excluded since situations might arise where the only attractive moisture source might be injured fruit in trees or fallen fruit on the ground.

Most significantly, *C. mutilatus* and *H. luteolus* demonstrated the ability to carry conidia past a fungicide barrier and into fruit by way of deep injuries such as insect tunnels, splits, or punctures. Prevention of split pits to control brown rot has not been achieved, but reduction of insect damage is possible, and control of OFM injury by spraying an insecticide resulted in a significant reduction of brown rot (Table 6) through a reduction of beetle access to fruit interiors. Similar results with OFM were obtained by Kable (6) in Australia.

Gaven (4) reported that nitidulid beetles in Australia are responsible for primary damage of peaches (penetration through intact epidermis and feeding in the mesocarp below). In the present study, incidence of primary damage was very low and never observed in the field until fruit were well past normal harvest maturity. Economic loss to the grower is therefore unlikely. In the laboratory, none of the four species of beetle penetrated sound peach epidermis until the fruit was ripe.

Since neither *C. mutilatus* nor *H. luteolus* was present in significant numbers until August when later cultivars normally mature, they contributed little to the early season build-up of brown rot. In contrast, during spring months newly hatched OFM larvae that penetrated small green fruit at the stem end appeared to play a major role in disease development by providing infection courts for the conidia already present on blighted twigs and blossoms. The possibility exists that OFM larvae become contaminated with conidia before entering the fruit. In late-maturing cultivars, the specificity of beetles for fruit injuries makes them an important disseminating agent for conidia of *M. fructicola*.

Thus, nitidulid beetles do not contribute to the early buildup of brown rot inoculum in the trees, but later in the season they can become important disseminating and inoculating agents, particularly in years with no rain and when fruit injury is widespread. This emphasizes the importance of good insect control. Long-distance spread of *M. fructicola* conidia by nitidulid beetles is a real possibility based on their considerable flying range.

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