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# Responses of *Carpophilus hemipterus* (Coleoptera: Nitidulidae) and Other Sap Beetles to the Pheromone of *C. hemipterus* and Host-Related Coattractants in California Field Tests

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**ABSTRACT** The aggregation pheromone of *Carpophilus hemipterus* (L.), previously isolated and identified using wind-tunnel bioassays, was field tested in California. A 4-d preliminary study in plantings of figs and stone fruits was followed by long-term studies in a date garden (12 mo) and a stone fruit orchard (11 wk). The pheromone was most effective in combination with host-related coattractants such as fermenting whole wheat bread dough or fermenting fig juice. In the date garden, for example, traps baited with pheromone plus bread dough caught an overall mean of 1,152 *C. hemipterus*, but those baited with only the pheromone or dough caught only 23 and 3 per trap, respectively. A semisynthetic volatile mixture of methanol, methyl butyrate, propanal, and apple cider vinegar was nearly as effective as fermenting dough as a coattractant and is a practical, longer-lasting alternative to dough. The pheromone was formulated on rubber septa, which were replaced every 2 wk. There was a 45% decrease in trap catch due to aging of septa from wk 1 to wk 2, but the septa retained activity into the second week despite daily maximum temperatures >40°C. In the date garden, peak response to the traps occurred during June (65% of the total catch), although temperatures were favorable for beetle flight throughout most of the year. In all experiments, both sexes responded similarly. Four other nitidulid species responded significantly to the pheromone of *C. hemipterus*: *C. mutilatus* Erichson, *C. lugubris* Murray, *C. obsoletus* Erichson, and *C. (Urophorus) humeralis* (F.). Two other nitidulid species in the study plots, *C. freemani* Dobson and *Haptoncus luteolus* (Erichson), responded poorly or not at all to the pheromone.

**KEY WORDS** *Carpophilus* spp., attractant, pheromone, host volatiles

THE DRIEDFRUIT BEETLE, *Carpophilus hemipterus* (L.), is a worldwide pest of a wide variety of fruits and grains, both before and after harvest (Hinton 1945). In California, *C. hemipterus* and related nitidulid beetles have been persistent pests of figs, dates, and stone fruits (e.g., Lindgren & Vincent 1953, Tate & Ogawa 1975, Smilanick 1979, and Warner et al. 1990). Impact on crop value is primarily due to the presence of the beetles in products for sale (e.g., dried fruits) and to the transmission by the beetles of harmful microorganisms into the crop. Control by mass trapping has been tried in fig orchards by using fermenting fig baits and was shown to be economically feasible (Warner 1961). A synthetic version of the fermenting fruit volatiles has been developed as a bait for field use (Smilanick et al. 1978). Although synthetic compounds are in principle far easier to use than the natural fruit baits, and large numbers of beetles were captured in the study, attractants of this type are not in general use today.

Although using attractants in the management of nitidulids appears promising, having still more potent attractants would be desirable. A likely improvement for beetle attractants would be the inclusion of the pheromones of the species. An aggregation pheromone has been identified and synthesized for *C. hemipterus* (Bartelt et al. 1990a). In the laboratory, the pheromone was most attractive when combined with a host-related coattractant. Our objectives in the study reported here were to determine whether the synthetic aggregation pheromone was active under field conditions and whether it was advantageous to combine host-type coattractants with the pheromone. The answers to these and related practical questions will determine whether the aggregation pheromone, as presently defined, can have a useful role in controlling or monitoring this pest.

Because a complex of nitidulid species occurs in the study areas, we also had an opportunity to

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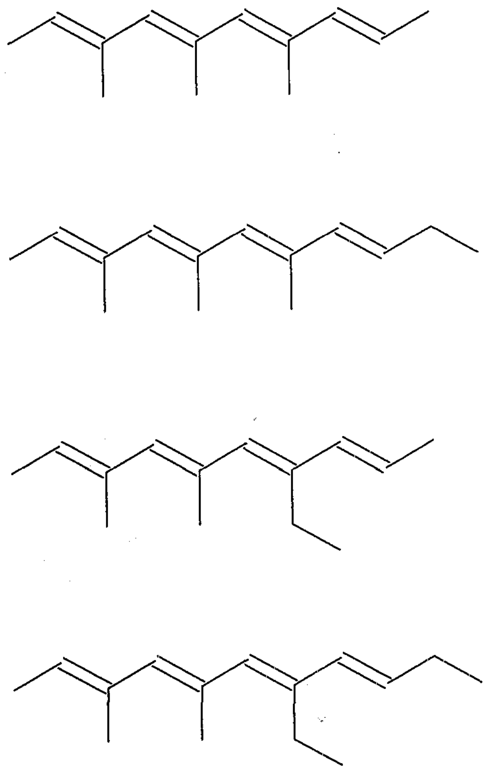

**Fig. 1.** Chemical structures of synthetic pheromone components for *C. hemipterus*.

look for cross-attraction to the *C. hemipterus* pheromone. The major reported species in California date gardens include *C. mutilatus* Erichson, *C. (Urophorus) humeralis* (F.), and *Haptoncus luteolus* Erichson (Lindgren & Vincent 1953, Warner et al. 1990). (Before its redescription by Dobson [1954], *C. mutilatus* was confused with *C. dimidiatus* [F.].) In addition to these, two other *Carpophilus* species are well known from fig orchards: *C. freemani* Dobson and *C. lugubris* Murray (Smilanick et al. 1978).

## Materials and Methods

**Pheromone.** The synthetic pheromone for *C. hemipterus* (Fig. 1) consists of four compounds: (2*E*,4*E*,6*E*,8*E*)-3,5,7-trimethyl-2,4,6,8-decatetraene (1), (2*E*,4*E*,6*E*,8*E*)-3,5,7-trimethyl-2,4,6,8-undecatetraene (2), (2*E*,4*E*,6*E*,8*E*)-7-ethyl-3,5-dimethyl-2,4,6,8-decatetraene (3), and (2*E*,4*E*,6*E*,8*E*)-7-ethyl-3,5-dimethyl-2,4,6,8-undecatetraene (4). The compounds were prepared as described previously (Bartelt et al. 1990c); except for preliminary chromatography on open columns of silica gel and distillation, they were used without purification. The trimethyl tetraenes were 83–84% pure, and the ethyl-dimethyl tetraenes were 71–73% pure. Impurities were generally other geometrical isomers.

A hexane solution of the pheromone was prepared in which components 1, 2, 3, and 4 were present in 100:12:7:3 proportions, respectively, and in which the total concentration of tetraene was 50 $\mu$g/$\mu$l. Septa (natural rubber, 15 mm long by 11 mm diam., Aldrich Chemical Co., Milwaukee, WI) were prepared for use as field baits by applying 10 $\mu$l of this mixture (500 $\mu$g of tetraene) and 300 $\mu$l of methylene chloride and allowing the liquid to soak in. The septa were then aired in a fume hood for ≈1 h, transferred to tightly covered bottles, and stored in a freezer until needed.

**Host-Related Coattractants.** In the initial study, the coattractant was fermenting fig juice. Dried figs were added to water (1:2 ratio wt/wt) and kept at room temperature for 4 d, after which the mixture bubbled vigorously and smelled strongly of ethanol. The fermentation was caused by microorganisms naturally present with the figs. The juice was placed in the traps after straining out the fruit. Freshly prepared fig juice was used for each day of the study. Our fig juice differed from the "fig paste" used as a beetle attractant by Smilanick et al. (1978) primarily in that the solids were not strained from the fig paste.

Two other coattractant types that were less time-consuming to manipulate were used in the subsequent, longer-term field studies. One of these was the semisynthetic volatile mixture (SVM). This was developed empirically by one of us (P.F.D.) based on structure-activity wind tunnel studies with *C. hemipterus* (Dowd & Bartelt 1991). The volatiles were emitted from three 5-ml vials held in the bait compartment of the trap. The first vial held a 10:1 (vol/vol) mixture of apple cider vinegar and methanol. The mixture was added to enough dry 7.5% polyacrylamide gel so that the swollen gel filled the vial. The volatiles were allowed to evaporate through a small (2-mm) hole drilled through the plastic vial cap. The second vial was filled with methyl butyrate. The opening of the vial was covered with a 1.5-mm-thick disk of red rubber, which was held in place with a plastic cap manufactured with a 9-mm hole in the center. The ester vapor slowly penetrated the rubber disk and emerged through the hole in the vial cap. The third vial contained propanal and was covered as was the second vial, except that a teflon-lined gas chromatograph (GC) septum was used in place of the red rubber. The teflon side was outward, and aldehyde vapor that penetrated the rubber septum could escape only at the sides, around the threads of the cap. Propanal has very high volatility, and this configuration kept the evaporation at an appropriate level for effectiveness in the field. All three vials were kept upright, so that the contained liquids were not in contact with the caps. The vials were refilled as needed (every 2 or 3 wk during summer and less often during cooler weather) so that liquid was always present.

The second type of coattractant used in the long-term studies was fermenting whole-wheat bread dough. This bait is an effective nitidulid attractant (e.g., Juzwik & French 1986, Lin & Phelan 1991) and was included as a "natural" host-type volatile source against which to compare the SVM. The dough was a 4:1:2 mixture of whole-wheat flour, sugar, and water (vol/vol/vol) to which dried baker's yeast was added to start fermentation. Approximately 15 ml of this mixture, held in a 30-ml plastic cup, was used for baiting traps. Fermentation usually caused expansion to about 30 ml, so that the dough did not normally spill out of the upright cup. The dough baits were replaced weekly throughout the experiments.

**Traps.** Two types of traps were used. Cup traps were used only for the initial study and were open, white plastic containers 10 cm tall by 10 cm in diam. (≈0.5 liter capacity). To bait the trap with pheromone, a wire stand was placed in the bottom of the container, and a pheromone-treated rubber septum was attached to the wire so that the septum was above the center of the cup and at the level of the rim. Either water or fermenting fig juice was added to each cup to a depth of ≈1 cm. A drop of detergent (to break surface tension) and a 0.5-cm cube of insecticide (Shell No-Pest-Strip) were also added. The traps were placed directly on the ground. Attracted beetles alighted on the containers, crawled down inside, and became trapped when they contacted the surface of the liquid.

The wind-oriented pipe trap (Dowd et al. 1992) was employed for the longer-term studies. These traps were constructed from PVC plumbing pipe and screen wire. They were oriented to the wind by a fin so that the openings were always accessible to beetles approaching the traps from downwind. Attracted beetles entered the trap through a cone-shaped piece of screen and were trapped in a glass vial attached to the bottom of the trap. No killing agent was used. A screen partition in the trap prevented attracted beetles from contacting the bait. The traps were suspended ≈1 m above the ground from a wire. These traps were preferred for prolonged studies because they required far less care and maintenance than the cup traps.

**Preliminary Study.** On 19–21 September 1989, a preliminary study was conducted in three fig orchards in the Fresno area, and on 22 September, additional data were obtained in a stone fruit orchard at the Kearney Agricultural Center of the University of California at Parlier, CA. The intent was to gain initial information about the interaction of pheromone and food-type coattractants under field conditions. At the time of the study the fig harvest was nearly over, but some drying fruits were still dropping from the trees, and considerable numbers of figs were present on the ground. In the stone-fruit planting also, large numbers of fruits (peaches and plums) were present on the ground. The test sites were known to have populations of *C. hemipterus* (site evaluation by H.H.S.), and the beetles were especially abundant at the Kearney Agricultural Center. A rain storm on 18 September thoroughly moistened the soil in the orchards; 19–22 September was a period of sunny weather, and by 21 September, the soil surface had become quite dry again.

Cup traps were used, and the four treatments were fermenting fig juice plus pheromone, fig juice only, pheromone only, and control. (Water was the trapping agent in the treatments without fig juice.) The four treatments were arranged in blocks, with ≈5 m between traps. Each trap was set in partial shade, ≈1 m from a tree trunk. There were five blocks at each test site. These studies ran for ≈7 h each day, from ≈0900 to 1600 hours, after which the *C. hemipterus* were collected from the traps and the traps were taken from the field and cleaned. At the end of each day, the pheromone septa were returned to a common container and stored in a freezer; the following day the septa were randomly reused for the next set of tests.

Preliminary tests with the pheromone of *C. freemani* were done concurrently in these orchards (Bartelt et al. 1990b).

**Long-Term Study in a Date Garden.** This study was conducted from 11 May 1990 to 17 May 1991 in a garden of 'Deglet Noor' dates at Rancho Eileen, near Oasis, CA. The purpose was to evaluate the effectiveness of the pheromone with two different coattractants throughout an entire year. The trees in the garden were relatively short; bunches of dates were between 1.5 and 5 m above the ground. Large numbers of fallen dates were present on the ground at all times of the year. Many of these were frequently wetted by the drip irrigation system, and they provided a constant food source for nitidulid populations. Beginning late in June and continuing until the harvest in winter, the food supply on the ground was supplemented by additional dates dropping from the bunches on the trees. Fallen fruit from the interplantings of citrus trees provided another resource for the beetles. Although nitidulids were abundant in the garden, *C. hemipterus* was a proportionally minor species.

The traps were arranged in four linear blocks, with five traps per block. Each trap was positioned ≈1 m above the ground, suspended by a wire from a wooden support attached to a tree trunk. In each block, traps were separated by 20 m. (Traps were hung in every second date tree.) The blocks were also separated by 20 m. Four treatments were present in every block: pheromone plus SVM, pheromone only, SVM only, and control. The fifth traps in blocks 2 and 3 were baited with pheromone plus fermenting dough; the fifth traps in blocks 1 and 4 were baited with dough only. The dough-containing treatments provided a "natural" standard against which the SVM could be evaluated. The pheromone septa were replaced every 2 wk, but the replacement schedule was staggered, so that the septa in blocks 1 and 2 were replaced one week, and those in blocks 3 and 4 the next week, and so on. Because septa of two ages (0–1 wk and 1–2 wk) were always present in the garden, changes in septum potency over time could be evaluated. From May to November 1990, captured beetles were removed from the traps twice each week, usually on Tuesday and Friday. All bait replacements (pheromone, dough, SVM) were made on Fridays, so that Tuesday trap collections represented 0–4-d-old ("fresh") dough and the Friday trap collections represented 4–7-d-old ("old") dough. Traps were rerandomized each Friday. From November until the end of the study, the traps were tended just once per week. Because of trap vandalism, no data were obtained for the last 2 wk of March 1991, and blocks 3 and 4 were terminated on 4 April.

Samples of fallen dates were collected during mid-October and early December to gain information about the species composition of the nitidulids using this resource.

**Eleven-Week Study in a Stone-Fruit Planting.** The final study was conducted from 19 July to 3 October 1990 in a planting of peach and plum trees at the University of California Kearney Agricultural Center, Parlier, CA. The objective was to evaluate the treatments of the long-term study at a second location. Nitidulids were also abundant at this site, but unlike the date garden, *C. hemipterus* was the dominant species. The treatments, trap types, and experimental design were the same as for the long-term experiment in the date garden, except that the traps were checked once per week. A study that evaluated the synthetic pheromone for *C. freemani* was done concurrently (Bartelt et al. 1990b). A sample of fruit was collected from the ground during mid-August and examined to gain information about the relative abundance of the nitidulid species in the orchard.

**Statistical Analysis.** Analysis of variance (ANOVA) was used to evaluate experimental factors; counts of captured beetles were transformed to the $\log(x+1)$ scale before analysis to stabilize variance. In all but the initial study there were unbalanced factors and treatment replications; therefore, ANOVA for these was performed using a multiple regression program. Effects due to treatments, septum age, dough age, and interactions of these, as well as effects due to blocks and trapping periods were incorporated into the analyses by using indicator variables. *F* tests for differences among two or more treatments were calculated by using the "extra of sum of squares" principle (Draper & Smith 1966). For a test between two treatments, this was identical in result to a *t* test using the pooled residual error. Further details of analyses are given with results.

**Identification of Species.** Preliminary identification of captured nitidulids was by means of the keys presented by Dobson (1954), Okumura & Savage (1974), and Connell (1991). Series of specimens were then submitted to the USDA-ARS Systematic Entomology Laboratory, Beltsville, MD, for confirmation or correction.

## Results

**Preliminary Study.** The results for the preliminary field study (19–22 September 1989) are presented in Table 1. By ANOVA there were highly significant overall differences among treatments ($F = 214$; df = 3, 108; $P << 0.0001$), but there was also a significant interaction between treatments and replications of the experiment ($F = 12.6$; df = 24, 108; $P << 0.0001$). (Each location and date was considered as a replication.) Therefore the treatment means for each location and date are presented separately in Table 1.

Synergistic activity of fig juice and pheromone was evident on the first day of the study at all three fig orchards. The presence of pheromone increased the response to the fig juice by factors ranging from 6.7 to 23, depending on the orchard. However, the nature of the response changed over time. By the third day of the study, the pheromone plus fig juice treatment was not significantly more attractive than fig juice alone in two of the three orchards (Pacific Ag. and Greenleaf). Only at Montgomery Farms did the initial trend persist.

Both sexes responded to the treatments about equally. In the fig orchards, the beetles captured in the pheromone plus fig juice, fig juice, and pheromone treatments were 45, 54, and 40% females, respectively.

In the stone-fruit orchard on the final day of the preliminary study, the trap catches were high for both treatments containing fig juice (Table 1). The large numbers reflected the abundance of *C. hemipterus;* many adult and larval nitidulids could be seen when the peaches and plums on the ground were turned over. However, the pheromone did not enhance the attractiveness of the fig juice in this replication of the experiment. The pheromone by itself had significant activity relative to the control, but the magnitude of this response was far less than that for fig juice.

**Long-Term Studies.** The overall data for *C. hemipterus* in the date garden are presented in Table 2. The results were consistent with those of the first day of preliminary tests (Table 1) in that dramatic synergism occurred between pheromone and "host"-related baits. Although the

**Table 1. Mean captures ($n = 5$) of *C. hemipterus* in preliminary field study with synthetic pheromone for *C. hemipterus*, conducted 19–22 September 1989, in the Fresno area**

| Orchard (crop) | Treatment[a] | Date | | | |
|---|---|---|---|---|---|
| | | 19 Sept. | 20 Sept. | 21 Sept. | 22 Sept. |
| Pacific Ag. (figs) | Pheromone + fig | 3.9a (2–5) | 10.7a (9–14) | 1.1ab (0–4) | — |
| | Fig | 0.5b (0–1) | 7.8a (2–19) | 1.3a (0–4) | — |
| | Pheromone | 0.0b | 0.0b | 0.2bc (0–1) | — |
| | Control | 0.0b | 0.0b | 0.0c | — |
| Greenleaf (figs) | Pheromone + fig | 9.5a (5–13) | 7.6a (5–10) | 2.5a (0–8) | — |
| | Fig | 1.0b (0–3) | 1.6b (0–5) | 1.8a (0–7) | — |
| | Pheromone | 0.8bc (0–4) | 0.3c (0–1) | 0.1b (0–1) | — |
| | Control | 0.0c | 0.0c | 0.0b | — |
| Montgomery Farms (figs) | Pheromone + fig | 18.3a (10–38) | — | 11.3a (8–18) | — |
| | Fig | 0.6c (0–4) | — | 0.5c (0–3) | — |
| | Pheromone | 3.2b (1–15) | — | 1.9b (0–5) | — |
| | Control | 0.0c | — | 0.0c | — |
| Kearney Ag. Center (stone fruits) | Pheromone + fig | — | — | — | 90.8a (73–110) |
| | Fig | — | — | — | 113.0a (86–178) |
| | Pheromone | — | — | — | 3.6b (1–6) |
| | Control | — | — | — | 0.7c (0–3) |

For each location and date, means followed by the same letter are not significantly different (LSD, $P < 0.05$; analysis done in $\log(x+1)$ scale). Ranges of trap catches shown in parentheses whenever means >0.

[a] Synthetic pheromone for *C. hemipterus* denoted by "Pheromone"; fermenting fig juice denoted by "Fig". Treatments in "cup" traps placed on ground. Pheromone-only and control traps contained water in place of fig juice.

pheromone-plus-dough treatment caught about twice as many beetles as the pheromone-plus-SVM treatment, the difference was not quite significant ($P = 0.15$). The difference between these treatments (Table 2) was due in large part to one especially large catch by a pheromone-plus-dough trap (687 beetles on 19 June). The responses to the pheromone alone or to either type of coattractant alone were very low. The controls did not catch a single *C. hemipterus* during the entire year.

In the stone-fruit planting, the captures of *C. hemipterus* showed the same trends as in the date garden, but the overall numbers were lower (Table 2, right-hand column). Again, both sexes were attracted to the treatments about equally. During the final week of the study, one trap baited with only the *C. hemipterus* pheromone captured 214 *C. hemipterus*. This value was completely inconsistent with the remainder of the data set and exceeded the total over all other trap catches for the entire experiment. This data point was omitted from the analysis (Table 2), but its possible significance is discussed below. It did rain at the site of the experiment during the final week (H.H.S., personal observation).

**Table 2. Overall mean captures[a] of *C. hemipterus* in long-term studies in date garden (Oasis) and stone-fruit planting (Parlier)**

| Treatment[b] | Location | |
|---|---|---|
| | Date garden (12 mo) | Stone-fruit planting (11 wk) |
| Pheromone + SVM | 557.0a (460– 604) | 28.8a (13–49) |
| SVM | 0.8c (0– 1) | 0.5bc (0– 2) |
| Pheromone + dough | 1152.0a (864–1440) | 27.5a (25–30) |
| Dough | 3.0c (2– 4) | 3.0b (1– 5) |
| Pheromone | 22.5b (6– 68) | 3.0b[c] (0– 9) |
| Control | 0.0d | 0.0c |
| Overall % females | 48% | 64% |

In each column, means followed by the same letter are not significantly different ($P < 0.05$, $t$ tests in $\log(X+1)$ scale).

[a] Captures on per-trap basis for entire duration of studies. Ranges of captures given in parentheses whenever means $\geq 0$. Wind-oriented pipe traps were used for the study.

[b] Synthetic pheromone for *C. hemipterus* denoted by "Pheromone"; semisynthetic volatile mixture denoted by "SVM"; "Dough" represents whole-wheat bread dough inoculated with baker's yeast; "Control" was blank trap. For both treatments containing dough, $n = 2$ at each location; for all other treatments, $n = 4$.

[c] Outlier removed from data set: pheromone-only trap of block 4. During the eleventh week of the study, this trap caught 214 *C. hemipterus;* during the rest of the study it caught none.

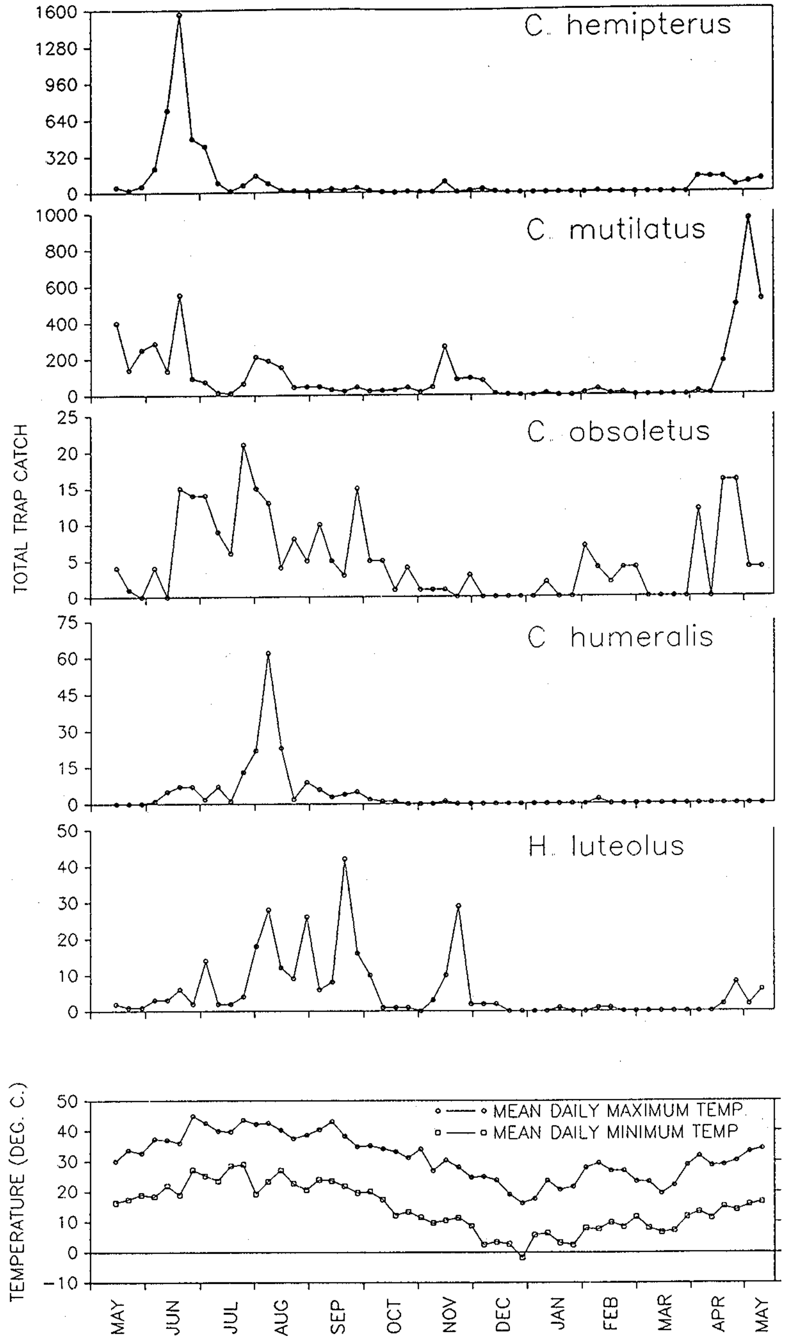


**Fig. 2.** Seasonal trap response patterns for five nitidulid species in a date garden near Oasis, CA, and corresponding temperature data. Each point in the trap-catch graphs is a 1-wk total over all traps and treatments. Each point in the temperature graph is a mean daily maximum or minimum for the 1-wk trapping period. Temperature data are for Thermal, CA; Thermal and the date garden are both in the Coachella Valley and are ≈15 km apart. Source of weather data: *Los Angeles Times*.

The pattern of trap catch over time for *C. hemipterus* in the date garden is shown in Fig. 2 (top). There was one major peak of trap catch activity: 65% of the total capture occurred during June. Although, there were several other time periods with sizeable trap catches (July–August, November, and April–May), these were not comparable with the late-spring peak. The trap-catch

**Table 3. Mean trap catches[a] of *C. hemipterus* showing effects of septum age and dough age on trap catch in date garden**

| Treatment[b] | Septum age 0–1 wk: Tuesday collection (dough age 0–4 d) | Septum age 0–1 wk: Friday collection (dough age 4–7 d) | Septum age 1–2 wk: Tuesday collection (dough age 0–4 d) | Septum age 1–2 wk: Friday collection (dough age 4–7 d) |
|---|---|---|---|---|
| Pheromone + SVM | 19.3 (0–135) *9.2*b | 23.3 (0–147) *7.4*bc | 12.0 (0– 72) *6.0*bc | 13.0 (0–85) *5.1*cd |
| Pheromone + dough | 97.0 (0–687) *20.3*a | 33.6 (0–289) *4.3*cd | 19.1 (0–103) *7.1*bc | 6.3 (0–36) *2.8*d |
| Contrasts[c]: | | | | |
| 0–1-wk septa vs 1–2-wk septa: | $P < 0.0001$ | | | |
| Pheromone + SVM vs pheromone + dough: | $P = 0.99$ | | | |
| Tuesday vs Friday collections: | $P < 0.0001$ | | | |
| Treatment by collection-day interaction: | $P = 0.004$ | | | |
| Other two-factor and three-factor interactions: | $P \geq 0.27$ | | | |

[a] Means on a per-trap and per-check basis for period 22 May–17 Aug. 1990; $n = 26$ for pheromone + SVM treatment and $n = 13$ for pheromone + dough treatment. Numerical means are followed by ranges, in parentheses. Analysis was conducted in the $\log(x + 1)$ scale; means from the analysis, after conversion back to numerical scale, are listed in italics below the numerical means and ranges. (The $\log(x+1)$ scale gives less weight to the larger, more variable values; hence means from the $\log(x+1)$ scale are always smaller than the numerical means.) Means followed by the same letter are not significantly different ($t$ tests, $P < 0.05$).

[b] "Pheromone" is synthetic pheromone for *C. hemipterus;* semisynthetic volatile mixture and fermenting whole-wheat bread dough denoted by "SVM" and "dough," respectively.

[c] Effects of treatments, septum age, and trap check time analyzed by 1 df orthogonal contrasts; ANOVA in $\log(x + 1)$ scale.

pattern was very different from the temperature pattern in the date-growing region (Fig. 2, bottom).

**Changes in Bait Potency Over Time.** The experimental design and the frequency of trap collections at the date garden permitted evaluation of bait components as a function of bait age. The two treatments with pheromone plus coattractant were analyzed for the 13-wk period of 22 May to 14 August 1990, during which 81% of the *C. hemipterus* were captured (Table 3). Overall, traps with 0–1-wk-old septa captured 1.8 times as many *C. hemipterus* as the comparable traps with 1–2-wk-old septa (1 df contrast; $P < 0.0001$). The two coattractants (dough and SVM) performed similarly overall (1 df contrast; $P = 0.99$), but the coattractants aged differently, producing a significant interaction with trap collection day (1 df contrast; $P = 0.004$). Over both septum ages, the pheromone plus dough bait attracted 3.5 times as many beetles when the dough was "fresh" (0–4 d) as when it was "old" (4–7 d). On the other hand, the pheromone plus SVM treatment remained more constant over time; the difference between the Tuesday and Friday collections was not significant ($P > 0.5$ for both septum ages).

In the stone-fruit planting, captures of *C. hemipterus* were 1.2 times higher with 0–1-wk-old septa than with those that were 1–2 wk old, but the difference was not significant ($P = 0.24$, means not shown).

**Nitidulids in Fruit Samples.** Based on samples of dates collected from the ground, *C. mutilatus* was the most abundant nitidulid in the date garden, which was also the situation reported by Lindgren & Vincent (1953). In early October, 97 dates yielded 150 *C. mutilatus,* two *C. hemipterus,* 10 *H. luteolus,* and one *Stelidota geminata* (Say). Approximately 50 larvae were also found but were not identified. In mid-December, 196 dates were examined, and 557 *C. mutilatus* and two *C. hemipterus* were found.

*C. hemipterus* was the dominant nitidulid species at the stone-fruit planting employed for the final study. In a sample of fruit taken from the ground in mid-August, 94 *C. hemipterus,* 61 *H. luteolus,* nine *C. freemani,* and one *C. humeralis* were found. *C. mutilatus* was not encountered in this fruit sample.

**Trap Catches of Other Species.** Four species of nitidulid beetles were captured in the date garden study besides *C. hemipterus* (Table 4). *C. mutilatus* was the major one of these, and dough was the most attractive single bait for it. Surprisingly, the response to dough was significantly enhanced by addition of *C. hemipterus* pheromone. The pheromone alone was correspondingly more attractive than controls, and the combination with SVM was more attractive than SVM alone, although the overall numbers were lower. SVM was developed specifically for *C. hemipterus,* and it was not nearly as effective for *C. mutilatus* as the dough. *C. obsoletus* and *C. humeralis* were captured in relatively low numbers, but as with *C. mutilatus,* they responded synergistically to the *C. hemipterus* pheromone plus host volatiles. Of these, only *C. obsoletus* was captured in traps baited with just the pheromone. *C. obsoletus* has been reported only rarely from California dates (e.g., Stickney et al. 1950), but it is clearly established where our study was conducted. Finally, *H. luteolus* was captured fairly frequently during the experi-

**Table 4. Overall mean trap catches[a] of nitidulid species other than *C. hemipterus* to the pheromone of *C. hemipterus* and coattractants during the long-term studies**

| Treatment[b] | Species (study crop) | | | | | | |
|---|---|---|---|---|---|---|---|
| | *C. mutilatus* (dates) | *C. obsoletus* (dates) | *C. lugubris* (stone fruits) | *C. freemani* (stone fruits) | *C. humeralis* (dates) | *Haptoncus luteolus* (dates) | *Haptoncus luteolus* (stone fruits) |
| Pheromone + SVM | 94.0c (76–130) | 25.8a (10–39) | 2.8b (1–5) | 0.0c | 32.0a (8–70) | 0.0b | 0.3b (0–1) |
| SVM | 4.3e (1–11) | 0.0c | 0.0d | 0.0c | 2.0b (0–4) | 0.0b | 0.5b (0–2) |
| Pheromone + dough | 1451.5a (1,055–1,848) | 57.5a (21–94) | 34.0a (20–48) | 12.5a (9–16) | 24.0a (21–27) | 44.5a (38–51) | 97.5a (89–106) |
| Dough | 658.5b (454–863) | 0.5c (0–1) | 1.0bc (1–1) | 3.0b (0–6) | 1.0bc (0–2) | 93.5a (56–131) | 112.0a (82–142) |
| Pheromone | 26.5d (11–46) | 4.3b (2–9) | 0.3cd (0–1) | 0.0c | 0.0c | 0.3b (0–1) | 0.0b |
| Control | 0.0f | 0.0c | 0.0d | 0.0c | 0.0c | 0.3b (0–1) | 0.0b |
| Overall % females | 50% | 64% | 65% | 34% | 41% | — | — |

[a] Means on a per-trap basis for entire studies (12 mo in date garden and 11 wk in stone-fruit planting); $n = 2$ for treatments with dough; $n = 4$ for all other treatments. Traps were of wind-oriented funnel type. In each column, means followed by the same letter are not significantly different ($P < 0.05$, $t$ tests in $\log(x + 1)$ scale). Ranges of trap catches given in parentheses whenever means $> 0$.

[b] Synthetic pheromone for *C. hemipterus* denoted by "Pheromone"; "SVM" and "dough" represent semisynthetic volatile mixture and fermenting whole-wheat bread dough, respectively.

ment, but the responses were almost always to treatments containing dough; the *C. hemipterus* pheromone had no demonstrable effect on *H. luteolus*.

Three species in addition to *C. hemipterus* were captured in the stone-fruit planting: *C. lugubris*, *C. freemani*, and *H. luteolus* (Table 4). *C. lugubris* responded relatively well to the pheromone of *C. hemipterus* in combination with bread dough, but SVM baits were less effective. *C. freemani* occurred somewhat more frequently in traps baited with the *C. hemipterus* pheromone plus dough than in those baited only with dough, but no traps with SVM caught *C. freemani*. As in the date garden, *H. luteolus* responded only to traps containing dough and appeared not to be influenced by the pheromone of *C. hemipterus*.

The trap catch patterns over time for the additional species in the date garden are presented in Fig. 2. The pattern for *C. mutilatus* was similar to that for *C. hemipterus*, except that the June peak was not so pronounced. *C. obsoletus* was never caught in large numbers, but the species appeared in traps during most of the year; catches tended to follow the temperature cycle. *C. humeralis* was captured primarily during summer, with the peak occurring during August. *H. luteolus* responded to the traps during most of the summer and fall; there was also a peak in April–May 1991.

## Discussion

**Activity of Materials.** The experiments verified that the aggregation pheromone of *C. hemipterus*, which was originally isolated by using laboratory wind-tunnel bioassays, was active in the field as well. Furthermore, as in the laboratory (Bartelt et al. 1990a, Dowd & Bartelt 1991), the pheromone was more effective in combination with host-type coattractants than by itself. The synergistic response of *C. hemipterus* was very similar in pattern to those seen earlier in the field with *C. lugubris* (Bartelt et al. 1991) and *C. freemani* (Bartelt et al. 1990b). Certain fermenting materials have long been known to be attractive to nitidulid beetles, but the dramatic magnification of this attraction by the aggregation pheromones would allow the beetles to find others of their kind for mating, even in the midst of an abundant host resource.

*C. hemipterus* is apparently rather flexible in what constitutes an acceptable host-type coattractant for the aggregation pheromone. The species has a very wide range of hosts (Hinton 1945) and undoubtedly responds to a correspondingly wide range of host volatiles under natural conditions. In our study, *C. hemipterus* responded to three different coattractants: fermenting fig juice, whole-wheat bread dough, and SVM. Other mixtures of chemicals have been reported previously as being attractive to *C. hemipterus* in the field (Smilanick et al. 1978) and in a wind tunnel (Dowd & Bartelt 1991, Phelan & Lin 1991). (Our SVM has no components in common with the mixtures of Smilanick et al. [1978] or Phelan & Lin [1991].) From a practical point of view, a wide variety of such blends could probably be successful coattractants for pest management use, and we have demonstrated that an empirical, wind tunnel–based approach can lead to materials of acceptable field activity.

SVM had an advantage over the "standard," fermenting dough as a coattractant because it was more consistent and required maintenance much less often than dough (only every 2 or 3 wk, even in the intense summer heat in the desert). Certainly, a coattractant for use in practical pest management would need to last as long as possible without being tended. Freshly prepared dough did have higher activity than SVM, but the dough quickly lost its effectiveness, because of either drying out or exhaustion of the resources for fermentation (Table 3). Nevertheless, the initial superiority of dough demonstrated that there was potential for the further improvement of SVM.

The rubber septum pheromone formulations survived the intense desert heat remarkably well. Although there was an overall 45% decrease in trap catch between the first week and second week that the septa were in the field, the 1–2-wk-old septa were still clearly active. Undoubtedly, pheromone formulations with better emission/stability properties will be found, but rubber septa provide a workable, "baseline" formulation for use in the present and with which to compare new formulations in the future.

**Inconsistencies.** One very striking pattern in this study was that the trap catches of *C. hemipterus* were often low, even when there was strong evidence for a large field population being present. This was especially true for the 11-wk study at the Kearney Agricultural Center. Based on fruit samples, *C. hemipterus* was about 10 times more abundant than *C. freemani*, but the mean numbers of *C. hemipterus* captured in traps (e.g., 27.5 to *C. hemipterus* pheromone plus dough) were less than 1/10 as large as the mean captures of *C. freemani* to its pheromone plus dough (599, Bartelt et al. 1990b). Both the fallen-fruit sample and the single, very high catch to the pheromone-only treatment during the last week of the study indicated that a large population of *C. hemipterus* was present during the study, but the beetles did not respond to the traps. Similarly, the captures of *C. hemipterus* in the date garden were quite low after the June activity peak (Fig. 2), even though nitidulid populations are normally expected to build throughout the summer (Warner et al. 1990). High trap catches did not invariably follow from high beetle populations.

A number of factors probably influenced the responses of *C. hemipterus* to the traps. The first is food supply. It was noted in the laboratory that well-fed beetles tended not to fly and that a starvation period was required before flight bioassays could be conducted (Bartelt et al. 1990a, Dowd & Bartelt 1991). If the ground is littered with fallen fruit at an acceptable stage for beetle colonization, then field trap catches might be expected to be low. This is consistent with the poor response during the 11-wk study in the stone-fruit planting, but it does not explain the major, June activity peak in the date garden.

A second factor is precipitation. Rainfall seemed to trigger beetle flight activity. During the preliminary study, which was initiated the day after an unusual, late-summer storm, the beetles were frequently seen in flight (R.J.B., personal observation), and the numbers responding to the traps were high, especially at the Kearney Agricultural Center, where the beetles were most abundant. In the 11-wk study, one pheromone-only trap had an uncharacteristically massive catch shortly after a rainfall. Because this occurred during the final week of the study, it is unknown whether a period of general flight activity was beginning or whether this trap catch was an isolated incident. Precipitation was recorded at Thermal, CA, on 28–29 May 1990, which was just before the major trap catch peak began in the date garden. (Rainfall was not recorded again at Thermal until January 1991, when cooler temperatures might have inhibited flight.) Soil moisture would seem important when a new generation of adult beetles is ready to emerge from pupation underground. It would be expected that newly emerged, virgin beetles would be especially inclined to seek others of their kind and would therefore be particularly responsive to the aggregation pheromone.

A third factor is competition from natural pheromone sources. If beetles have colonized the fruit on the ground, then they are presumably releasing pheromone as well. High natural pheromone levels would render the synthetic compounds in the traps less effective. In this case one would expect the pheromone plus coattractant treatments to work as well as the coattractants alone. A pattern like this seemed to develop over time during the preliminary study (Table 1).

Finally, there may be an innate, annual flight activity pattern, upon which these other factors are superimposed. The striking pattern of trap catches of *C. hemipterus* during June in the date garden (Fig. 2) was observed again in June 1991 (unpublished data), and Barnes & Kaloostian (1940) observed a similar pattern in trap catches of *C. hemipterus* (a dramatic peak in June and July) over a raisin-drying yard during a long-term study in Fresno, CA. (Their method was to capture flying beetles with a mechanized net rather than to attract them to baits.) If such a tendency exists, then the 11-wk study was set out too late in the year to obtain large, consistent catches. There appeared to be some tendency for different species to fly most actively at different times of the year (e.g., *C. hemipterus* versus *C. humeralis* in Fig. 2). Such differences could help avoid competition for host resources.

**Implications for Control of *C. hemipterus*.** When the beetles were flying, the pheromone caused dramatic increases in the responses to host-type baits, and it is suggested that the aggregation pheromone could become an important tool in the management of this species. From the studies reported here, the pheromone appears most effective early in the year, when flight activity is high but food supplies are low or of poor quality. Pheromone/host-volatile/insecticide baits used at that time could reduce populations in a meaningful way. Sanitation (removal of fallen fruit from the plantings), as recommended by Warner et al. (1990) and earlier workers, is an important accompanying step. It would do little good to reduce spring beetle populations if the survivors still had abundant food supplies in which to multiply throughout the summer.

**Cross-Attraction.** Multiple nitidulid species at the test sites gave us information about cross-attraction. In the date garden, the most abundant species, *C. mutilatus,* did respond significantly to the pheromone of *C. hemipterus* (Table 4). The ratio of captures by pheromone plus dough to dough-only for *C. mutilatus* was far less dramatic than for *C. hemipterus,* but the data suggest that the pheromone of *C. hemipterus* could serve as a kairomone for *C. mutilatus. C. mutilatus* might be inclined to take over or co-colonize suitable host sites first discovered by *C. hemipterus.* On the other hand, SVM, which was optimized for *C. hemipterus,* was far less effective for *C. mutilatus* than dough. Thus, the preferences of the species for host volatiles are clearly not entirely parallel, and this difference could aid in keeping the species in separate niches, despite some degree of pheromonal cross-attraction.

*C. lugubris, C. obsoletus,* and *C. humeralis* also showed synergistic attraction to the *C. hemipterus* pheromone. Of these, only *C. obsoletus* responded to the pheromone alone. For the last two species, the dough and SVM were equally effective coattractants, but for *C. lugubris,* the dough was superior (Table 4). *H. luteolus* was captured in the traps in both long-term studies, but virtually only when dough was present. The pheromone of *C. hemipterus* appeared not to affect *H. luteolus.*

The 11-wk study gave us a more comprehensive view of cross-attraction and species specificity because of the concurrent study with the pheromone of *C. freemani* (Bartelt et al. 1990b). *C. freemani* responded significantly to the pheromone of *C. hemipterus* in combination with dough, but the response was only 1/50 of the response to the pheromone of *C. freemani* plus dough: 12.5 *C. freemani* per trap (Table 4) versus 599 (Bartelt et al. 1990b). There was no attraction of *C. hemipterus* to the pheromone of *C. freemani* (unpublished data). Thus cross-attraction was minor relative to the species-specific responses. A similar situation is also expected for *C. mutilatus, C. lugubris, C. obsoletus,* and *C. humeralis* if the pheromones of these are tested concurrently with the *C. hemipterus* pheromone.

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## References Cited

**Barnes, D. F. & G. H. Kaloostian. 1940.** Flight habits and seasonal abundance of dried-fruit insects. J. Econ. Entomol. 33: 115–119.

**Bartelt, R. J., P. F. Dowd, R. D. Plattner & D. Weisleder. 1990a.** Aggregation pheromone of driedfruit beetle, *Carpophilus hemipterus*: wind-tunnel bioassay and identification of novel tetraene hydrocarbons. J. Chem. Ecol. 16: 1015–1039.

**Bartelt, R. J., P. F. Dowd, H. H. Shorey & D. Weisleder. 1990b.** Aggregation pheromone of *Carpophilus freemani* (Coleoptera: Nitidulidae): a blend of conjugated triene and tetraene hydrocarbons. Chemoecology 1: 105–113.

**Bartelt, R. J., D. Weisleder & R. D. Plattner. 1990c.** Synthesis of nitidulid beetle pheromones: alkyl-branched tetraene hydrocarbons. J. Agric. Food Chem. 38: 2192–2196.

**Bartelt, R. J., P. F. Dowd & R. D. Plattner. 1991.** Aggregation pheromone of *Carpophilus lugubris*: new pest management tools for the nitidulid beetles, pp. 27–40. *In* P. A. Hedin [ed.], Naturally occurring pest bioregulators. ACS Symposium Series No. 449. American Chemical Society, Washington, DC.

**Connell, W. A. 1991.** Sap beetles (Nitidulidae, Coleoptera), pp. 151–174. *In* J. R. Gorham [ed.], Insect and mite pests in food: an illustrated key, vol. 1. U.S. Dep. Agric. and U.S. Dep. Health and Human Services Agric. Handb. 655.

**Dobson, R. M. 1954.** The species of *Carpophilus* Stephens (Col. Nitidulidae) associated with stored products. Bull. Entomol. Res. 45: 389–402.

**Dowd, P. F. & R. J. Bartelt. 1991.** Host-derived volatiles as attractants and pheromone synergists for driedfruit beetle, *Carpophilus hemipterus.* J. Chem. Ecol. 17: 285–308.

**Dowd, P. F., R. J. Bartelt & D. T. Wicklow. 1992.** A novel insect trap useful in capturing sap beetles (Coleoptera: Nitidulidae) and other flying insects. J. Econ. Entomol. 85: 772–778.

**Draper, N. R. & H. Smith. 1966.** Applied regression analysis. Wiley, New York.

**Hinton, H. E. 1945.** A monograph of beetles associated with stored products, vol. 1. British Museum of Natural History, London.

**Juzwik, J. & D. W. French. 1986.** Relationship between nitidulids and *Ceratocystis fagacearum* during late summer and autumn in Minnesota. Plant Dis. 70: 424–426.

**Lin, H. & P. L. Phelan. 1991.** Identification of food volatiles attractive to dusky sap beetle, *Carpophilus lugubris* (Coleoptera: Nitidulidae). J. Chem. Ecol. 17: 1273–1286.

**Lindgren, D. L. & L. E. Vincent. 1953.** Nitidulid beetles infesting California dates. Hilgardia 22: 97–118.

**Okumura, G. T. & I. E. Savage. 1974.** Nitidulid beetles most commonly found attacking dried fruits in California. Nat. Pest Control Operator News 34: 4–7.

**Phelan, P. L. & H. Lin. 1991.** Chemical characterization of fruit and fungal volatiles attractive to dried-fruit beetle, *Carpophilus hemipterus* (L.) (Coleoptera: Nitidulidae). J. Chem. Ecol. 17: 1253–1272.

**Smilanick, J. M. 1979.** Colonization of ripening figs by *Carpophilus* spp. J. Econ. Entomol. 72: 557–559.

**Smilanick, J. M., L. E. Ehler & M. C. Birch. 1978.** Attraction of *Carpophilus* spp. (Coleoptera: Nitidulidae) to volatile compounds present in figs. J. Chem. Ecol. 4: 701–707.

**Stickney, F. S., D. F. Barnes & P. Simmons. 1950.** Date palm insects in the United States. U.S. Dep. Agric. Circ. 846.

**Tate, K. G. & J. M. Ogawa. 1975.** Nitidulid beetles as vectors of *Monilinia fructicola* in California stone fruits. Phytopathology 65: 977–983.

**Warner, R. M. 1961.** Area baiting program 1960 results. Proc. Calif. Fig Inst. 15: 36–40.

**Warner, R. L., M. M. Barnes & E. F. Laird. 1990.** Reduction of insect infestation and fungal infection by cultural practice in date gardens. Environ. Entomol. 19: 1618–1623.

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