# Pheromone trapping protocols for the Asian palm weevil, Rhynchophorus ferrugineus (Coleoptera: Curculionidae)

(*Keywords: Rhynchophorus ferrugineus*, ferrugineol, Rhynchophorinae, pheromone trapping)

REBECCA H. HALLETT*‡, A. CAMERON OEHLSCHLAGER†§ and JOHN H. BORDEN‡

‡*Centre for Pest Management, Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6*
§*Department of Chemistry, Simon Fraser University, Burnaby, BC, Canada V5A 1S6*

**Abstract.** Protocols for pheromone-based mass-trapping of the Asian palm weevil, *Rhynchophorus ferrugineus* (Olivier), are presented. The aggregation pheromone, ferrugineol (4-methyl-5-nonanol) released at 3 mg per 24 h was numerically, but not statistically, superior to lower doses, and this rate is recommended for operational trapping programmes. Trap captures were maximized by placing traps at ground level or 2 m high. Vane traps were superior to bucket traps. Insecticide-free traps containing funnels to prevent weevil escape were equally as effective as traps using insecticide to retain weevils. Synergism between ferrugineol and host palm volatiles was demonstrated and necessitates the inclusion of palm material in traps for maximum trapping efficacy. Both the Asian palm weevil and coconut rhinoceros beetle, *Oryctes rhinoceros*, were captured in the same traps without interference between their respective pheromones. These results have led in part to pheromone-based mass-trapping of the Asian palm weevil throughout the Middle East where the weevil is a serious introduced pest of date palms.

## 1. Introduction

The Asian palm weevil, *Rhynchophorus ferrugineus* (Olivier) (= *R. vulneratus* = *R. schach*) (Hallett, 1996) is one of the most destructive pests of coconut, *Cocos nucifera* L., in South and Southeast Asia (Sivapragasam *et al.*, 1990; Sadakathulla, 1991). During the last decade, multiple introductions of *R. ferrugineus* to the Middle East from Pakistan and India have occurred and the Asian palm weevil (APW) is now a serious pest of date palms, *Phoenix sylvestris* Roxb., in the Arab Gulf States (Bokhari and Abuzuhari, 1992) and Egypt (RHH, ACO, personal observation).

Often, palm weevil infestations are not detected before damage caused by larval mining in the trunk is extensive, and it is not possible for the tree to recover (Sivapragasam *et al.*, 1990). In date palms, the only visible sign of attack may be oozing of palm sap from the trunk, and infestations are often not discovered until trees are blown over.

Current control methods include surveys to identify infested palms, removal, burning or burial of heavily infested trees, injection of insecticides into infested palms diagnosed as recoverable, and spraying of insecticides on all palms in infested areas. Burning of palm trunks is often incomplete, so that larvae and pupae survive and complete development. Delay between detection and destruction of an infested tree permits emergence and migration of adult weevils prior to destruction. Transporting infested trees and off-shoots for burning introduces the weevil to new areas.

Use of fumigant insecticides within infested trunks is unsatisfactory as penetration of insecticidal gas throughout the trunk is hampered by thick plugs of larval frass (Abraham *et al.*, 1998). Soaking of palm trunks with insecticides every 2 months has been recommended to prevent egg laying (Abraham *et al.*, 1998). However, these practices result in the use of high volumes of insecticide and have potentially negative environmental and public health impacts.

Ferrugineol (4-methyl-5-nonanol) is a major aggregation pheromone of the APW (Hallett *et al.*, 1993), and has been used in conjunction with 4-methyl-5-nonanone (Abozuhairah *et al.*, 1996) in mass-trapping programmes throughout the Middle East since 1995. Mass-trapping with rhynchophorol, 6-methyl-2(*E*)-hepten-4-ol, has been shown to reduce populations of the American palm weevil, *R. palmarum* (L.); concurrently, the incidence of red ring disease, which is vectored by the weevil, was also reduced in Costa Rican oil palm plantations (Chinchilla *et al.*, 1993; Oehlschlager *et al.*, 1993, 1995).

In many countries, traps made of palm stems or petioles have been used to capture *Rhynchophorus* spp. (Abraham and Kurian, 1975; Abraham *et al.*, 1989; Morin *et al.*, 1986; Sivapragasam *et al.*, 1990). Such traps are not entirely satisfactory, because they are labour-intensive, require weekly replacement, and their attractiveness varies considerably with environmental conditions (Chinchilla and Oehlschlager, 1992; Nagnan *et al.*, 1992). Host kairomones have been identified for *R. palmarum* (Nagnan *et al.*, 1992), *R. phoenicis* F. (Gries *et al.*, 1994) and *R. cruentatus* F. (Weissling *et al.*, 1992; Giblin-Davis *et al.*, 1994) and *R. ferrugineus* (Oehlschlager, unpublished data). A synergistic interaction between palm volatiles and ferrugineol was suggested in an earlier study (Hallett *et al.*, 1993a).

Since palm weevils rely on wounds to gain access to stem tissue for oviposition, it is possible that APW responds to the pheromones and/or frass produced by coconut rhinoceros beetle adults (CRB), *Oryctes rhinoceros* (L.), feeding in palm crowns. A pheromone-based mass-trapping programme for CRB has been developed (Hallett *et al.*, 1995; Chung, 1996;

*To whom correspondence should be addressed at: Department of Environmental Biology, University of Guelph, Guelph, ON, Canada N1G 2W1. Fax: +1 (519) 837-0442.
†Present address: ChemTica Natural, S.A., Apdo 159-2150, San Jose, Costa Rica.

*International Journal of Pest Management* ISSN 0967-0874 print/ISSN 1366-5863 online © 1999 Taylor & Francis Ltd
http://www.tandf.co.uk/JNLS/tpm.htm
http://www.taylorandfrancis.com/JNLS/tpm.htm

Hallett, 1996; Ho, 1996) and adopted operationally in Malaysia. Knowledge of interactions between APW and CRB may influence how operational trapping programmes are developed and implemented.

Trapping protocols for APW in date palm plantings in desert regions have been established by other researchers in the Middle East (Abozuhairah *et al.*, 1996). Herein we present the results of studies designed to develop pheromone-based mass-trapping protocols for APW in coconut plantations in the humid tropics, where CRB co-exists with APW. Results of a trap design experiment for use in date palm plantings are also presented.

## 2. Materials and methods

Release devices and release rates for Experiments 1–7 are given in table 1. All experiments were of randomized complete block design. Unless otherwise indicated, inter-trap and inter-block distances were 24 and 70 m, respectively.

### 2.1. Pheromone dose response

Experiment 1 was conducted to determine the activity and optimal dose of ferrugineol at Pakuwon Coconut Research Station, Pakuwon, West Java, Indonesia (14–27 August 1992; $N=20$). Ferrugineol was released at 0, 0.3, 1.0, and 3.0 mg per 24 h from standard white bucket traps (figure 1) (Oehlschlager *et al.*, 1993) attached 2 m high to coconut palms. All traps contained 2 kg of 1-day-old coconut palm wood pieces (approx. $5\times5\times20$ $cm^3$) treated with Basudin 60EC (diazinon; Ciba-Geigy), 0.24% a.i. in water, to retain captured weevils.

### 2.2. Trap height

To determine optimum trap height Experiment 2 was conducted at Pakuwon (30 October–13 November 1993; $N=10$). Standard white bucket traps were placed at ground level, or at 2, 5, or 10 m above ground. All traps were attached to coconut palms and contained ferrugineol and 1 kg palm wood treated with 0.3% a.i. solution of diazinon.

### 2.3. Trap design

Efficacy of the standard white bucket trap was compared in Experiment 3 with three insecticide-free trap designs (funnel trap; vane trap with funnel and low pheromone placement; vane trap with funnel and high pheromone placement) (figure 1). Traps with high pheromone placement had lures suspended in a slot 24 cm above the bucket rim, while those with low pheromone placement had lures suspended in a slot at the level of the bucket rim. This experiment was conducted at Bah

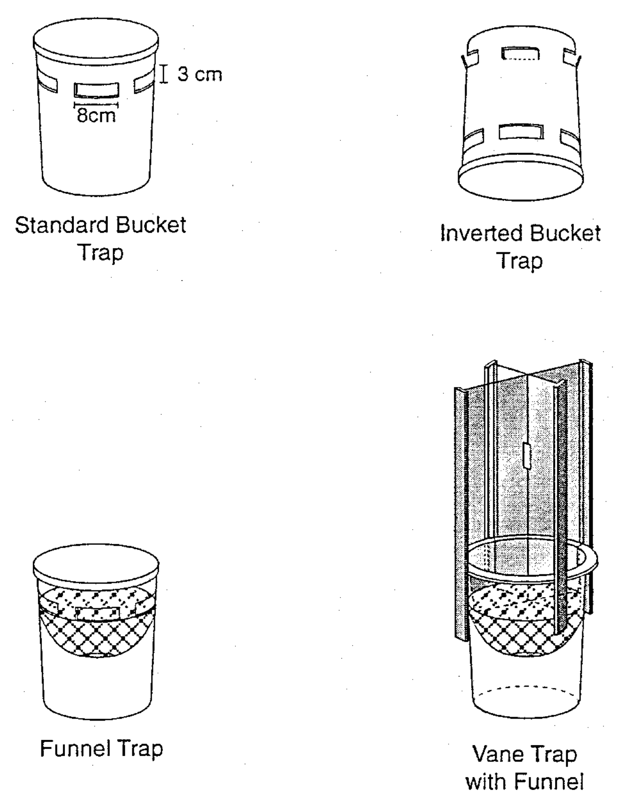


*Figure 1. Traps of different designs used for capturing* R. ferrugineus. Standard bucket trap*: 20 L white bucket with four slots around rim just below lid and four openings on lid to allow weevil entry and dissemination of volatiles (Oehlschlager* et al.*, 1993b); lures suspended 3–4 cm below lid of bucket.* Inverted bucket trap*: same as standard bucket trap, except trap inverted; four flaps around top of trap for weevil entry, and lure suspended from inside top of trap.* Funnel trap*: same as standard bucket trap, except with funnel inserted below side entry slots in order to prevent escape by captured weevils.* Vane trap with funnel*: same buckets as above, used without lid, with two unpainted metal vanes at right angles to each other to increase barrier surface and multi-directionality of trap; fitted with funnel below vanes to prevent weevil escape; lure suspended from central slot in vanes.*

*Table 1. Summary of semiochemical release rates and release devices used in seven experiments on the Asian palm weevil*

| Experiment | Semiochemical | Release rate (mg per 24 h)[a] | Release device[b] | Chemical source[c] |
|---|---|---|---|---|
| 1 | Ferrugineol | 0.3 | 400 μl microcentrifuge tube | SFU |
| | Ferrugineol | 1 | 1.5 ml microcentrifuge tube | SFU |
| | Ferrugineol | 3 | Three 1.5 ml microcentrifuge tubes | SFU |
| 2–6 | Ferrugineol | 3 | Polymer membrane bag lure | CT |
| 7 | Oryctelure | 3 | Polymer membrane bag lure | CT |
| | Ferrugineol | 3 | Polymer membrane bag lure | CT |

[a]Release rates of ferrugineol from microcentrifuge tubes estimated under laboratory conditions of 25° and 50% RH, unless otherwise noted.
[b]Capped polyethylene 400 μl and 1.5 ml microcentrifuge tubes (Quality Scientific Plastics, USA, and Gordon Technologies, Mississauga, Ontario, respectively) with two 3 mm diameter holes drilled 1 cm below top. Heat-sealed polymer membrane bag lures from Chem Tica International, Costa Rica.
[c]CT=Chem Tica International; SFU=Department of Chemistry, Simon Fraser University.

Lias Estate, London Sumatra Indonesia Plantation Company, North Sumatra, Indonesia (18 February–19 March 1994; *N*=10). All traps contained ferrugineol and half coconut husks (fresh, young coconuts with flesh removed). Only coconut husks in the standard bucket traps were treated with insecticide (0.3% a.i. diazinon).

The funnel and vane + funnel traps were compared in Experiment 4 with vane + funnel traps with black painted vanes at Bah Lias Estate (11–25 April 1994; *N*=15) in a mixed cocoa-coconut planting. Intertrap and interblock distances were 45 m. All traps contained ferrugineol and half coconut husks.

In short date palms, the presence of unsevered leaf axils minimized contact between standard bucket traps and the trunk. Black buckets were more readily obtainable than white buckets in the United Arab Emirates (UAE). Consequently, the standard trap (white upright) was compared with three other trap designs in Experiment 5 (inverted white bucket, upright black bucket and inverted black bucket) (figure 1) in Ras Al Kaimeh, UAE (12–20 June 1993; *N*=10). White buckets available in the UAE were very glossy such that weevils could not easily climb into the traps. Thus, surfaces of all white traps were roughened to permit APW to enter the traps. Inverted bucket traps had entry holes near the top and bottom of bucket and all traps contained ferrugineol and date palm tissue soaked in 0.3% a.i. solution of Lannate.

### 2.4. *Pheromone–host volatile interactions*

To examine synergism between host volatiles and ferrugineol and to determine whether the inclusion of host plant material would improve the trapping programme, Experiment 6 was conducted at Pakuwon (4–11 August 1993 and 8–14 October 1993; *N*=20) using standard bucket traps baited with ferrugineol and coconut palm tissue (1 kg), ferrugineol and insecticide-treated sponge (or towel), palm tissue alone, and sponge (or towel) alone. In all cases, palm tissue, sponges and towels were treated with a 0.3% a.i. solution of diazinon. Sponges and towels were used in 10 replicates each.

### 2.5. *Dual trapping*

To determine whether APW and CRB could be caught in the same traps, Experiment 7 tested vane + funnel traps containing either the CRB aggregation pheromone (ethyl 4-methyloctanoate, oryctalure), ferrugineol or both, set out in a mixed cocoa/coconut planting at Bah Lias Estate (27 April–7 June 1994; *N*=28).

### 2.6. *Statistical analyses*

In all field experiments, no significant differences were found in the responses of male and female beetles ($\chi^2$ test, $P > 0.05$), so catches were pooled by sex for analysis. Data were transformed by $\log_e$ (x+1) if they were not normally distributed and were subjected to ANOVA (General Linear Modelling) (Minitab, 1989). If replicates were run at different times or locations, data were analysed for time × treatment or location × treatment interactions. Following ANOVA, multiple pairwise comparisons were made using Bonferroni *t*-tests. If homoscedasticity was not achieved by transformation, data were analysed by $\chi^2$ tests (Zar, 1984). In these cases, treatment, sex, and species comparisons were also performed using $\chi^2$ tests.

Due to the synonymization of *R. ferrugineus* and *R. vulneratus* (Hallett, 1996), all data for the two colour morphs were pooled.

## 3. Results

### 3.1. *Pheromone dose response*

In Experiment 1, all doses of ferrugineol were significantly and equally more attractive to *R. ferrugineus* than palm alone (figure 2). However, capture rates at the highest dose (3.0 mg per 24 h) were nearly 1.5 times greater than at the lower dose (0.1 mg per 24 h). Therefore a release rate of 3 mg per 24 h, was used in all other experiments.

### 3.2. *Trap height*

Bucket traps at ground level caught significantly more weevils than at 5 m high, while those at 2 m were intermediate in effectiveness between those at ground level and at 5 m high (Experiment 2, figure 3). Traps at 10 m caught no weevils.

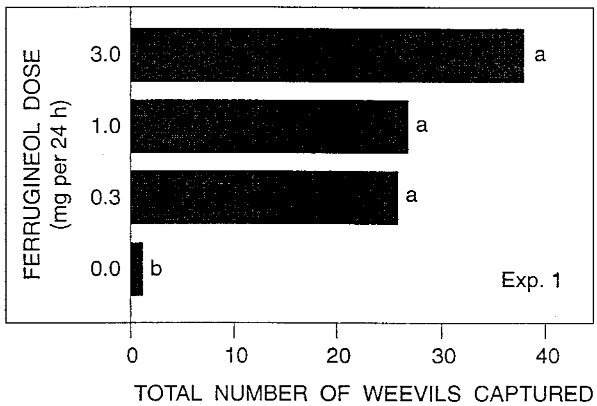


*Figure 2. Total number of captured* R. ferrugineus *in traps baited with palm wood alone (control) and in combination with ferrugineol at 3 release rates; Pakuwon, West Java, 22–27 August 1992;* N=*10 (Experiment 1). Bars with the same letter are not significantly different,* $\chi^2$ *test,* $P < 0.05$.

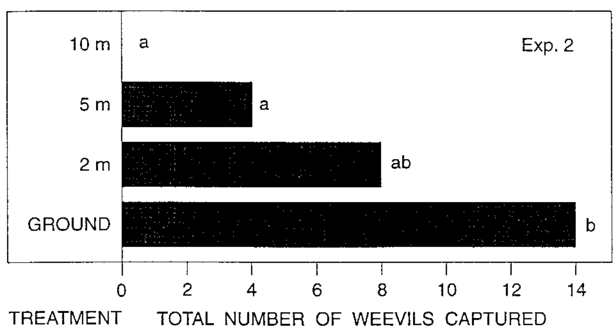


*Figure 3. Efficacy of traps at different heights in capturing* R. ferrugineus *(Experiment 2). Traps contained ferrugineol (3 mg per 24 h) and palm wood; Pakuwon, West Java, 30 October–3 November 1993,* N=*10. Bars with the same letter are not significantly different,* $\chi^2$ *test,* $P < 0.05$. *Trap captures were too low to permit comparison of traps at 5 and 10 m, but all other pairwise comparisons were made.*

### 3.3. Trap design

All four types of traps examined in Experiment 3 were equally effective (figure 4). Painting the sheet metal vanes black in Experiment 4 resulted in significantly more weevils being captured than in funnel traps (figure 4). Unpainted vane traps were intermediate in effectiveness.

In the UAE, black inverted bucket traps were most attractive, followed by black upright traps (figure 5, Experiment 5). No weevils were captured in white bucket traps regardless of their position.

### 3.4. Pheromone–host volatile interactions

Captures of APW in Experiment 6 were greatest in traps containing both ferrugineol and palm (figure 6), and were more than the sum of catches in traps containing these components individually. Captures were highest 3–5 days after cutting of palm tissue.

### 3.5. Dual trapping

While there were significant differences between treatments for both APW and CRB, no differences were found for either

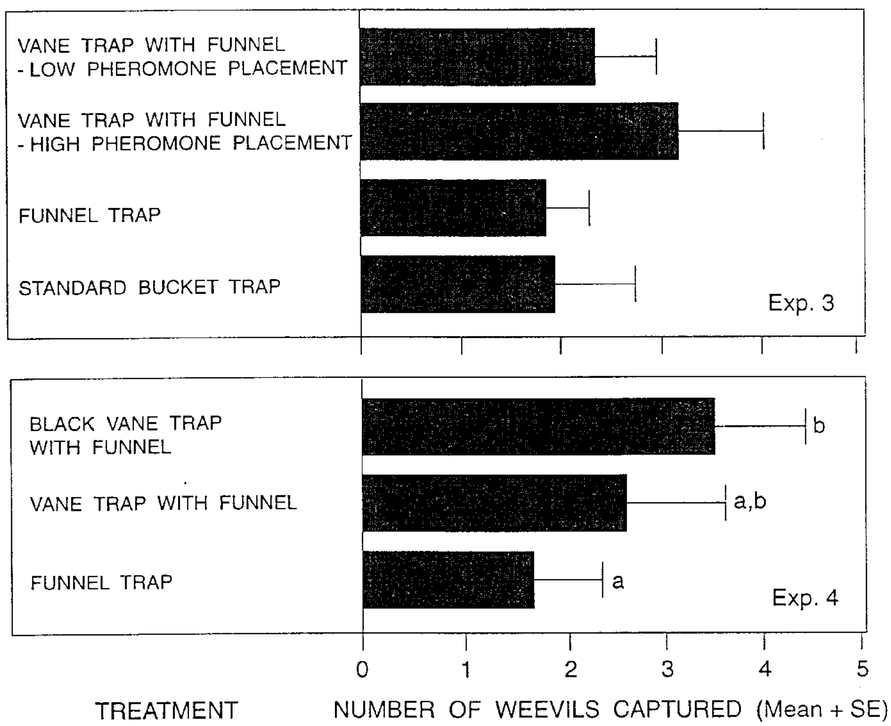


*Figure 4.* *Efficacy of different trap types in capturing* R. ferrugineus *at Bah Lias Estate, North Sumatra. Experiment 3: Vane + funnel traps with high or low pheromone placement compared to funnel and standard bucket traps, 18 February– 19 March 1994,* N=10. *Between-treatment differences not significant, ANOVA on data transformed by* $\log_e (x+1)$, $F=0.56$, $df=3,15$, $P=0.653$. *Experiment 4: Black or unpainted vane + funnel traps compared to funnel traps, 11–25 April 1994,* N=15. *Between-treatment differences significant, ANOVA on data transformed by* $\log_e (x+1)$, $F=3.47$, $df=2,24$, $P<0.05$. *All traps contained ferrugineol (3 mg per 24 h) and fresh halved coconut husks. Bars with the same letter are not significantly different, Bonferroni t-tests,* $P<0.05$.

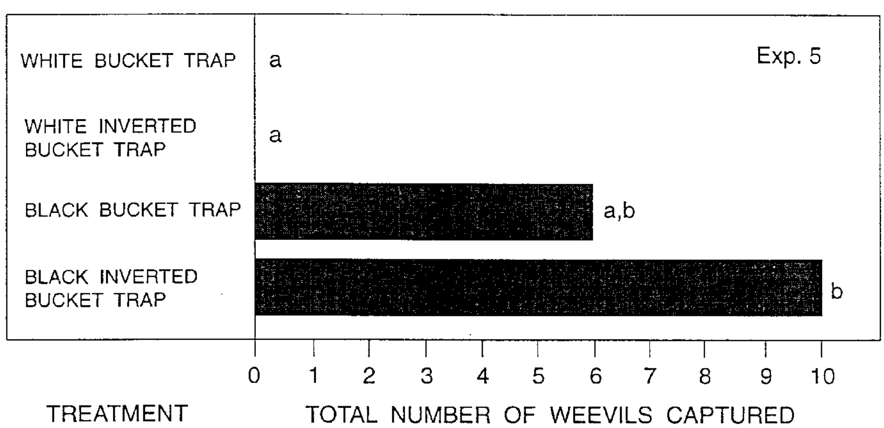


*Figure 5.* *Comparison of trapping efficacy of traps of different colour and orientation in capturing* R. ferrugineus *in Ras Al Kaimeh, UAE, 12–20 June 1993;* N=10 *(Experiment 5). Bars with the same letter are not significantly different,* $\chi^2$*-test,* $P<0.05$.

species in Experiment 7 between traps containing their own pheromone and those containing both pheromones (figure 7). Traps containing the pheromone of one species were not attractive to beetles of the other species.

## 4. Discussion

Since ferrugineol released at 3 mg per 24 h (under laboratory conditions, 25°C), was most attractive to the APW (figure 2), this release rate is recommended for operational use. Lures patterned after the 3 mg per 24 h lure are now used operationally in the Middle East. These lures release 3–10 mg per day depending on the season (V.A. Abraham, unpublished data).

The decline in efficacy of trapping APW when traps were > 2 m high (figure 3) appears to be in contrast to findings for *R. palmarum*, for which no differences in trapping efficacy were found for bucket traps placed on palms at heights between 0 and 3.3 m (Oehlschlager *et al.*, 1993). However, Oehlschlager *et al.* (1993) did find that when traps were placed between palms, those on the ground were significantly more effective than traps placed on poles.

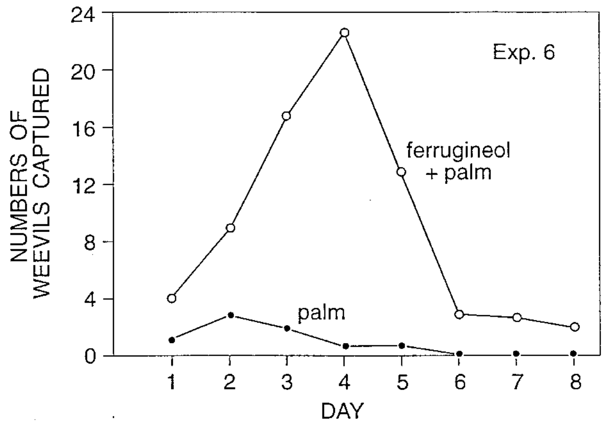


*Figure 6. Daily captures in Experiment 6 of* R. ferrugineus *in standard bucket traps containing ferrugineol and insecticide-treated palm tissue as compared to insecticide-treated palm tissue alone. In the same experiment, one weevil was captured on day 8 in a trap baited with ferrugineol plus an insecticide-treated sponge and none were captured in any trap containing only an insecticide-treated sponge (or towel). Treatment differences significant,* $\chi^2 = 178.21$, *df= 3,* $P < 0.001$.

Traps previously developed for *Rhynchophorus* spp. include traps made from palm logs or split palm petioles (Sivapragasam *et al.*, 1990), sandwich traps and bucket traps (Oehlschlager *et al.*, 1993). Oehlschlager *et al.* (1993) also evaluated the efficacy of McPhail traps (White and Elson-Harris, 1992) and multiple-funnel traps (Lindgren, 1983), but found that bucket traps were most effective in trapping the American palm weevil.

The greater response of the APW to black than white buckets (figure 5) and to vane traps with black-painted vanes over those with reflective unpainted vanes (figure 4) may result from higher pheromone release rates from black traps due to heating of the vanes. Alternately, it may suggest that vision is important in host selection by these species. Visual discrimination between acceptable and unacceptable host silhouettes has been hypothesized in the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Borden *et al.*, 1986) and demonstrated in the white pine weevil, *Pissodes strobi* Peck (VanderSar and Borden, 1977a), which selects feeding and oviposition sites by positive phototaxis and negative geotaxis (VanderSar and Borden, 1977b).

Inclusion of palm material in traps is essential (figure 6) as host volatiles have a striking synergistic effect on APW response to ferrugineol. Unfortunately, palm or other plant material require frequent replacement for maximum trapping efficacy. Studies to identify longer-lasting food sources and host kairomones are underway in the Gulf States where this weevil is a problem.

The absence of a reciprocal inhibiting effect of either the pheromone of APW or CRB on the other species (figure 7) suggests that these species do not interact competitively when colonizing the same host. Lack of heterospecific pheromone interference means that wherever both CRB and APW are considered to be problems, the same traps can be used to capture both species, without any increase in the cost of trapping system maintenance. Trapping of two species together or alone with equal efficiency has also been demonstrated for *Metamasius hemipterus* and *R. palmarum* (Chinchilla *et al.*, 1996) and *M. hemipterus* and *Cosmopolites sordidus* (Oehlschlager *et al.*, 1998).

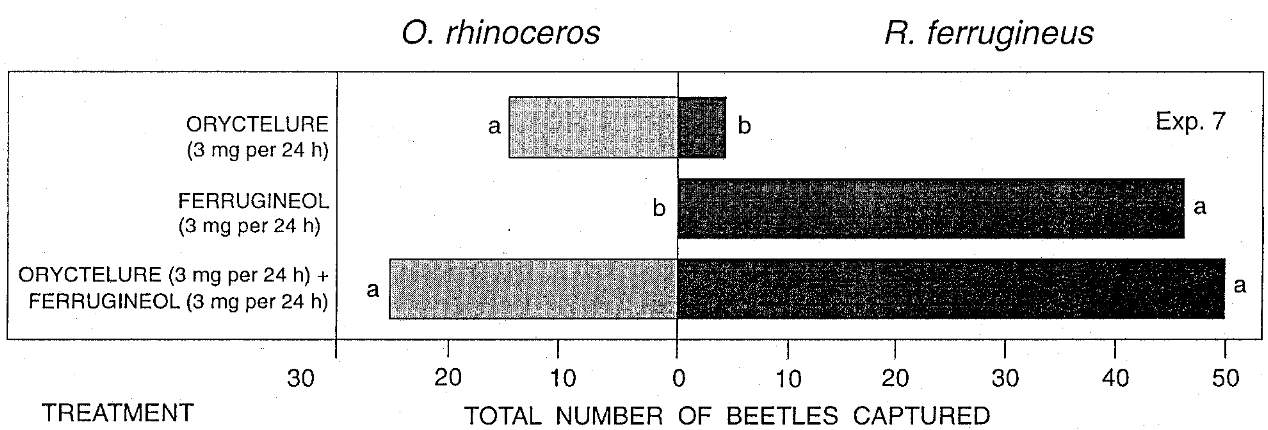


*Figure 7. Attraction of* R. ferrugineus *and* O. rhinoceros *to traps baited with oryctelure, ferrugineol or both (Experiment 7, Bah Lias Estate, 27 April–7 June 1994, N=28). Between treatment differences significant for* R. ferrugineus ($\chi^2 = 39.347$, *df= 2,* $P < 0.001$) *and* O. rhinoceros ($\chi^2 = 25.721$, *df= 2,* $P < 0.001$). *Bars followed by the same letter are not significantly different,* $\chi^2$ *test,* $P < 0.05$.

The capture of a few APWs in traps containing only oryctalure may be indicative of a slight cross-attraction. Cross-attraction would be expected when one species exploits the pheromone of a co-inhabiting species in order to colonize a host most efficiently (Birch, 1984). Strong cross-attraction may not occur because the CRB may also release aggregation pheromone in its breeding sites (e.g. rotting trunks, compost piles), which are unsuitable for palm weevil brood production.

The low trap captures in some experiments should not be used as an argument against a mass-trapping control programme for these palm pests. Large insects generally have low population densities, e.g. 23 – 57 *R. palmarum* per ha in a large Costa Rican oil palm plantation (Chinchilla *et al.*, 1993). Moreover, the capture of a single female can have a tremendous impact because each female is capable of laying several hundred eggs (Kalshoven, 1950). If trapping is continued over several generations, eventually emerging weevils that have not yet started new infestations may be captured, and damage rates may be reduced rapidly. In the UAE, Saudi Arabia, and Oman, where APW is causing severe damage to date palms, mass-trapping is considered to be a viable method of control. Trapping is being conducted by local Ministries of Agriculture and is supported by local governments, the Food and Agriculture Organization of the United Nations and by the Arab Organization for Agricultural Development. At least one Gulf country (UAE) has significantly decreased reliance on spraying insecticides to kill weevils outside palms (A. Azziz, personal communication). Mass-trapping of the American palm weevil, *R. palmarum*, has been credited with reducing weevil populations, maintaining them at a low density, and also reducing the incidence of the nematode-caused red ring disease, which is vectored by *R. palmarum* (Chinchilla *et al.*, 1993; Oehlschlager *et al.*, 1995).

We have demonstrated that the APW can be captured effectively in an insecticide-free trap, and that pheromone-based trapping for APW and CRB can be superimposed. Development of an optimally effective and persistent host kairomonal stimulus would further improve the trapping program. Even without effective kairomones, the potential for control of *R. ferrugineus* by mass-trapping with pheromones is great.

## Acknowledgements

Field sites and technical assistance were kindly provided by the Government of Indonesia Pakuwon Coconut Research Station, London Sumatra Indonesia Plantation Company, and by the Ministry of Agriculture and Fisheries, United Arab Emirates. Dr N.P.D. Angerilli, Eastern Indonesia University Development Project, Simon Fraser University, and Dr A. Rauf, Bogor Agricultural Institute, provided logistical support. Pheromones were donated by ChemTica International, San Jose, Costa Rica. This research was supported by an International Development Research Centre Young Canadian Researchers Award and by a Natural Sciences and Engineering Research Council, Canada, Postgraduate Fellowship to RHH and Research Grant to ACO.

## References

ABOZUHAIRAH, R. A., VIDYASAGAR, P. S. P. V., and ABRAHAM, V. A., 1996. Integrated management of red palm weevil, *Rhynchophorus ferrugineus* F., in date palm plantations of the Kingdom of Saudi Arabia. 20th International Congress of Entomology, Florence, Italy, August 1996, Paper 17-033.

ABRAHAM, V. A. and KURIAN, C., 1975. An integrated approach to the control of *Rhynchophorus ferrugineus* F. The red weevil of coconut palm. Fourth Session of the FAO Technical Working Party on Coconut Production, Protection and Processing. Kingston, Jamaica, 14 – 25 September 1975.

ABRAHAM, V. A., ABDULLA KOYA, K. M. and KURIAN, C., 1989. Integrated management of red palm weevil (*Rhynchophorus ferrugineus* F.) in coconut gardens. *Journal of Plantation Crops*, **16**(suppl.), 159 – 162.

ABRAHAM, V. A., AL SHUAIBI, M. A., FALEIRO, J. R., ABOZUHAIRAH R. and VIDYASAGAR, P. S. P. V. 1998. An integrated management approach for red palm weevil *Rhynchophorus ferrugineus* Oliv. a key pest of date palm in the Middle East. *Agricultural Science*, **3**, 77 – 83.

BIRCH, M. C., 1984. Aggregation in bark beetles. In W.J. Bell and R.T. Carde (eds) *Chemical Ecology of Insects* (London: Chapman & Hall), pp. 331 – 353.

BOKHARI, U. G. and ABUZUHARI, R., 1992. Diagnostic tests for redpalm weevil, *Rhynchophorus ferrugineus* infested datepalm trees. *Arab Gulf Journal of Scientific Research*, **10**, 93 – 104.

BORDEN, J. H., HUNT, D. W. A., MILLER, D. R. and SLESSOR, K. N., 1986. Orientation in forest Coleoptera: an uncertain outcome of responses by individual beetles to variable stimuli. In T.L. Payne, M.C. Birch, C.E.J. Kennedy (eds) *Mechanisms in Insect Olfaction*. (Oxford: Clarendon Press) pp. 97 – 109.

CHINCHILLA, C. M. and OEHLSCHLAGER, A. C., 1992. Captures of *Rhynchophorus palmarum* in traps baited with the male-produced aggregation pheromone. *ASD Oil Palm Papers*, **5**,1 – 8.

CHINCHILLA, C. M., OEHLSCHLAGER, A. C. and GONZALEZ, L. M., 1993. Management of red ring disease in oil palm through pheromone-based trapping of *Rhynchophorus palmarum*. Proceedings, 1993 PORIM International Oil Palm Congress, 20 – 25 September 1993, Kuala Lumpur, Malaysia.

CHINCHILLA, C. M., OEHLSCHLAGER, A. C. and BULGARELLI, J. 1996. A pheromone based trapping system for *Rhynchophorus palmarum* and *Metamasius hemipterus*. *ASD Oil Palm Papers*, **9**,11 – 17.

CHUNG, G. F. 1996. The bioefficacy of the aggregation pheromone in mass trapping of rhinoceros beetles (*Oryctes rhinoceros* L.) in Malaysia. 2nd MAPPS/ISP Seminar, 15 November 1996, Lumut Perak, Malaysia, pp.18 – 26.

GIBLIN-DAVIS, R. M., WEISSLING, T. J., OEHLSCHLAGER, A. C. and GONZALEZ, L. M., 1994. Field response of *Rhynchophorus cruentatus* (Coleoptera: Curculionidae) to its aggregation pheromone and fermenting plant volatiles. *Florida Entomologist*, **77**, 164 – 177.

GRIES, G., GRIES, R., PEREZ, A. L., GONZALEZ, L. M., PIERCE, H. D. JR., OEHLSCHLAGER, A. C., RHAINDS, M., ZEBEYOU, M. and KOUAME, B., 1994. Ethyl propionate: synergistic kairomone for African palm weevil, *Rhynchophorus phoenicis* L. (Coleoptera: Curculionidae). *Journal of Chemical Ecology*, **20**, 889 – 897.

HALLETT, R. H., 1996, Aggregation pheromones of coleopteran pests of palms. PhD thesis, Simon Fraser University, Burnaby, B.C., Canada.

HALLETT, R. H., GRIES, G., GRIES, R., BORDEN, J. H., CZYZEWSKA, E., OEHLSCHLAGER, A. C., PIERCE, H. D. JR., ANGERILLI, N. P. D. and RAUF, A., 1993. Aggregation pheromones of two Asian palm weevils, *Rhynchophorus ferrugineus* and *R. vulneratus*, *Naturwissenschaften*, **80**, 328 – 331.

HALLETT, R. H., PEREZ, A. L., GRIES, G., GRIES, R., PIERCE, H. D., JR., YUE, J., OEHLSCHLAGER, A. C., GONZALEZ, L. M. and BORDEN, J. H., 1995. Aggregation pheromone of coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae). *Journal of Chemical Ecology*, **21**, 1549 – 1570.

HO, C. T. 1996. The integrated management of *Oryctes rhinoceros* (L.) populations in the zero burning environment. PORIM International Oil Palm Congress, Kuala Lumpur, Malaysia, September 1996, Paper A-28.

KALSHOVEN, L. G. E., 1950. *Pests of Crops in Indonesia*. P.T. Ichtiar Baru-Van Hoeve, Jakarta. Revised and translated by P.A. Van der Laan (1981).

LINDGREN, B. S., 1983. A multiple funnel trap for scolytid beetles (Coleoptera). *The Canadian Entomologist*, **115**, 299 – 302.

MINITAB, 1989. Release 7.1, Standard Version, Minitab Inc.

MORIN, J. P., LUCHINI, F., ARAUJO, J. C. A., FERREIRA, J. M. S. and FRAGA, L. S., 1986. *Rhynchophorus palmarum* control using traps made from oil palm cubes. *Oleagineux*, **41**, 57 – 62.

NAGNAN, P., CAIN, A. H. and ROCHAT, D., 1992. Extraction and identification of volatile compounds of fermented oil palm sap (palm wine), candidate attractants for the palm weevil. *Oleagineux*, **47**, 135 – 142.

OEHLSCHLAGER, A. C., ALPIZAR, D., FALLAS, M., GONZALEZ, L. M. and JAYARAMAN, S. 1998. Pheromone-based mass trapping of the banana weevil, *Metamasius hemipterus*, in plantain and banana. International Society of Chemical Ecology 15th Annual Meeting, Ithaca, New York, June 1998, Abstract O-20.

OEHLSCHLAGER, A. C., CHINCHILLA, C. M., GONZALEZ, L. M., JIRON, L. F., MEXZON, R. and MORGAN, B., 1993. Development of a pheromone-based trapping system for the American palm weevil, *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae). *Journal of Economic Entomology*, **86**, 1381 – 1392.

OEHLSCHLAGER, A. C., MCDONALD, R. S., CHINCHILLA, C. M. and PATSCHKE, S. N., 1995. Influence of a pheromone-based mass trapping system on the distribution of *Rhynchophorus palmarum* (Coleoptera: Curculionidae) in oil palm. *Environmental Entomology*, **24**, 1005 – 1012.

SADAKATHULLA, S., 1991. Management of red palm weevil, *Rhynchophorus ferrugineus* F., in coconut plantations. *Planter*, **67**(786), 415 – 419.

SIVAPRAGASAM, A., ARIKIAH, A. and RANJIT, C. A., 1990. The red stripe weevil, *Rhynchophorus schach* Olivier (Coleoptera: Curculionidae): an increasing menace to coconut palms in Hilir Perak. *Planter*, **66**, 113 – 123.

VANDERSAR, T. J. D. and BORDEN, J. H., 1977a. Visual orientation of *Pissodes strobi* Peck (Coleoptera: Curculionidae) in relation to host selection behaviour. *Canadian Journal of Zoology*, **55**, 2042 – 2049.

VANDERSAR, T. J. D. and BORDEN, J. H., 1977b. Role of geotaxis and phototaxis in the feeding and oviposition behavior of overwintered *Pissodes strobi*. *Environmental Entomology*, **6**, 743 – 749.

WEISSLING, T. J., GIBLIN-DAVIS, R. M., GRIES, G., GRIES, R., PEREZ, A. L., PIERCE, H. D. JR. and OEHLSCHLAGER, A. C., 1994. Aggregation pheromone of the palmetto weevil, *Rhynchophorus cruentatus* (F.) (Coleoptera: Curculionidae). *Journal of Chemical Ecology*, **20**, 505 – 515.

WHITE, J. M. and ELSON-HARRIS, M. M., 1992. *Fruit Flies of Economic Significance* (Oxford: CAB International).

ZAR, J. H., 1984. *Biostatistical Analysis*. (New Jersey: Prentice-Hall).