

Assessment of synthetic chemicals for disruption of *Rhynchophorus ferrugineus* response to attractant-baited traps in an urban environment

Salvatore Guarino · Ezio Peri · Paolo Lo Bue ·
Maria Pia Germanà · Stefano Colazza ·
Leonid Anshelevich · Uzi Ravid · Victoria Soroker

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Abstract The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera, Curculionidae), is one of the most severe pests of ornamental palm species in urban areas of Mediterranean countries. Aiming to discover inhibitory semiochemicals for RPW population management in urban environments, we conducted electroantennographic (EAG) screenings of 17 commercially available synthetic compounds, representing three groups of plant volatiles (isoprenoids, phenyl propanoid derivatives and fatty acid derivatives) known for their repellent effects toward insects. These tests were followed by trap-based screenings of EAG-active menthone, α -pinene and methyl salicylate, singly and in combination, under urban conditions. In EAG bioassays, RPW antennae of both sexes showed positive dose-dependent responses to 13 of the 17 synthetic chemicals with significant differences among them. In

field trapping experiments, conducted in the city of Palermo, Italy, from weeks 31 to 38 in 2010 and 2011, α -pinene, tested singly or in combination with methyl salicylate (2010) or menthone (2011), reduced trap catches by about 30% to 40%. Methyl salicylate and menthone alone were inactive. In conclusion, RPW is significantly affected by α -pinene. This isoprenoid is a promising disruptant for semiochemical-based management of this pest. In addition, identification of a large number of EAG-active chemicals could serve as a database for future design of active repellents or attractants of RPW adults.

Keywords EAG · Menthone · Methyl salicylate · α -pinene · Red palm weevil · Semiochemicals

Introduction

The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera, Curculionidae), is a severe pest of palm species (Arecaceae) (Dembilio *et al.* 2009; EPPO 2008; Giblin-Davis 2001; Rahalkar *et al.* 1978; Wattanapongsiri 1966). This insect is originally from Southeast Asia where it is a pest of coconut palms; following its accidental introduction into North Africa and Europe two decades ago, it has become established in countries of the coastal fringe of the Mediterranean basin (Buyukozturk *et al.* 2011; Dembilio *et al.* 2009; Giblin-Davis 2001). In 2009, it was reported in the western hemisphere, on the islands

S. Guarino · E. Peri · P. Lo Bue · M. P. Germanà ·
S. Colazza
Department DEMETRA, Università degli Studi di Palermo,
Viale delle Scienze edificio 5,
90128 Palermo, Italy

L. Anshelevich · V. Soroker (✉)
Agricultural Research Organization,
Department of Entomology, The Volcani Center,
Bet Dagan 50250, Israel
e-mail: sorokerv@agri.gov.il

U. Ravid
Agricultural Research Organization,
Newe Ya'ar Research Center,
Ramat Yishay 30095, Israel

of Curaçao, Aruba and the Netherlands Antilles, and in 2010, it was discovered in the Laguna Beach area of Orange County, California, USA (EPPO 2009; Ferry 2010; Roda *et al.* 2011). The list of palm species susceptible to RPW attack, as reported by the European Commission, is remarkable, but the insect is especially destructive to Canary Island and date palms, *Phoenix canariensis* Hort. ex Chabaud and *P. dactylifera* L., respectively (EU Decisions 2007/365/EC; 2008/776/EC and 2010/467/EU). The RPW is a concealed tissue borer: the larvae tunnel into leaves and stems, killing the single meristematic apex and causing palm death (Ferry & Gomez 2002). This type of damage makes it difficult to detect symptoms of RPW attack at an early stage of infestation and, consequently, the short period that might allow effective control measures can be missed (Faleiro 2006; Faleiro *et al.* 2002; Longo *et al.* 2008). The cryptic nature of the weevil, and the gaps in our knowledge of its biology and ecology, hamper the development of efficient and sustainable strategies for its control (Blumberg 2008; Soroker *et al.* 2005). Since the first reports of RPW in Europe, the main short-term strategy applied to reducing infestation has been to cut down the dead trees and destroy infested palm materials by pounding or burning (Faleiro *et al.* 2002; Longo *et al.* 2008). Recourse to broad-spectrum synthetic chemicals to control urban pest populations is undesirable due to the drawbacks of environmental pollution. Therefore, under urban conditions, new tactics to control RPW populations are clearly needed, such as non-toxic solutions based on manipulation of insect behavior by semiochemicals, as chemical cues often play a key role in insect orientation to a host (Witzgall *et al.* 2010). Most species of palm weevils (Curculionidae: Rhynchophorinae) use aggregation pheromones to facilitate mating (Giblin-Davis *et al.* 1996; Gunawardena *et al.* 1998; Rochat *et al.* 1991). Traps loaded with pheromone and supplemented with palm esters and fermenting mixtures of plant tissues and/or molasses preferentially attract RPW females. These traps are currently implemented in various countries for monitoring and mass-trapping in both agricultural and urban settings (Guarino *et al.* 2011; Hallett *et al.* 1999; Oehlschlager 2007; Soroker *et al.* 2005). However, as not much is known about weevil dispersal and host-selection strategy, there is some concern as to the potential role of traps in the

spread of RPWs. It is often claimed that massive distribution of powerful attractants can pose a danger to the palm trees near the lures. It is thus clear that RPW control based on semiochemicals might be improved by broadening our knowledge of behavior-modifying stimuli suitable for adult manipulation, for example, chemical compounds that repel them. In fact, pest insect populations can be controlled by “push and pull” or “stimulo-deterrent diversionary” strategies, which keep them away from plants by a combination of repellents that push them away and attractive pheromone-lured traps, which pull them in (Cook *et al.* 2007; Hassanali *et al.* 2008). This strategy has proven useful for the management of several species of bark beetle (Zhang & Schlyter 2004), and might be extended to the RPW. In particular, an ecological approach to repelling the weevil with chemical barriers of non-host volatiles via associational resistance, as recently shown for bark beetles (Schiebe *et al.* 2011), might be suggested. As the RPW is a problem in highly variable, man-made environments (plantations and urban areas), and the appropriate repellents are hard to predict, the approach taken in this study to identify repellents of RPW was to evaluate commercially available synthetic components representing the three groups of plant volatiles (isoprenoids, phenyl propanoid derivatives and fatty acid derivatives) known for their repellent effects toward insects and arachnids. Seventeen synthetic chemicals were screened on RPW adults by electroantennogram (EAG) bioassay. Then three of these chemicals—menthone, α -pinene and methyl salicylate—were tested singly or in combination in a field trapping experiment to assess their ability to disrupt the attractiveness of pheromone- and kairomone-baited traps.

Materials and methods

Insects RPW adults used for EAG analyses were from the north of Israel around the city of Nahariya (33°00' 37"N, 35°05'47"E), recovered from pheromone-baited traps and cut infested Canary Island palms. The insects were sexed and kept separated in groups of up to 50 individuals each. Weevil groups were maintained in an environmentally controlled room (25±1 °C, 70±10% RH, photoperiod 14:10 hL:D) on humidified coconut-fiber bedding in plastic cages (20×20×40 cm) with two 5-cm-diam mesh-covered holes, and fed fresh sugarcane.

Insects were kept under these laboratory conditions for at least 3 days prior to the EAG analyses.

Synthetic chemicals The 17 commercially available synthetic compounds used for the experiments belonged to three classes of plant volatiles: isoprenoids, phenyl propanoid derivatives and fatty acid derivatives. Among the isoprenoid compounds tested were: camphor, (*E*)-caryophyllene, citral, citronellol, *p*-cymene, geraniol, (*R*)-(+)-limonene, (*S*)-(-)-limonene, menthone, α -pinene, β -pinene and α -terpineol. The phenyl propanoid derivatives were benzyl acetate, benzaldehyde and methyl salicylate. The tested fatty acid derivatives were (*Z*)-3-hexen-1-ol and 1-octen-3-ol. Table 1 shows the chemical properties of these compounds, and gives a brief description

of their effects on insect behavior as reported in the literature.

EAG bioassays EAG assays were carried out in the laboratory of the Department of Entomology, ARO, The Volcani Center, Israel. Dose–response recordings were conducted using solutions of synthetic chemicals serially diluted 1:10 with hexane (HPLC-grade, 99%; Sigma Aldrich) to yield concentrations of 100 μ g, 10 μ g, 1 μ g, 100 ng and 10 ng per μ l. Hexane was used as a control. The antennae, excised from RPW adults and deprived of the scape, were suspended above two silver-wire electrodes using glass capillary tubes filled with a saline solution of 0.1 M KCl as described by Guarino *et al.* (2011). The recording electrode was inserted on the surface of the antennal

Table 1 Synthetic chemicals used for the EAG experiments with *Rhynchophorus ferrugineus* adults. Notes provide brief descriptions of their effects on insect behavior as reported in the literature

Compound class ^z / Compound	Source ^y	Chemical purity (%)	Boiling point (°C)	Notes
<i>Isoprenoids</i>				
camphor	D	95	204	Repellent to aphids (Hori 1998) and mosquitoes (Gillij <i>et al.</i> 2008)
(<i>E</i>)-caryophyllene	A	98.5	263	Repellent to mosquitoes (Gillij <i>et al.</i> 2008)
citral	B	97	229	Present in the essential oils of lemongrass, which is repellent to mosquitoes (Oyedele <i>et al.</i> 2002)
citronellol	C	66.8	225	Repellent to mosquitoes (Müller <i>et al.</i> 2008) and ticks (Tunón <i>et al.</i> 2006)
<i>p</i> -cymene	A	99.5	177	Present in the essential oils of <i>Curcuma longa</i> which is repellent to some stored product beetles (Tripathi <i>et al.</i> 2002).
geraniol	B	98	229	Repellent to mosquitoes (Müller <i>et al.</i> 2008; Tunón <i>et al.</i> 2006)
(<i>R</i>)-(+)-limonene	A	99	176	Repellent to weevils <i>Hylobius abietis</i> and <i>H. pinastri</i> (Norlander 1990)
(<i>S</i>)-(-)-limonene	A	99	176	Repellent to cigarette beetle, <i>Lasioderma serricorne</i> (F.) (Hori 2004)
menthone	B	97	207	Repellent to <i>Rhodnius prolixus</i> Stal. (Sfara <i>et al.</i> 2009)
α -pinene	A	99	155	Repellent to <i>Rhynchophorus palmarum</i> (Oehlschlager & Gonzalez 2001), and ticks (Tunón <i>et al.</i> 2006)
β -pinene	A	99	165	Toxic to the beetle <i>Tribolium castaneum</i> (Herbst) (Garcia <i>et al.</i> 2005)
α -terpineol	B	95	219	Repellent to aphids (Hori 1998) and <i>T. castaneum</i> (Herbst) (Garcia <i>et al.</i> 2005)
<i>Phenyl propanoid derivatives</i>				
benzyl acetate	A	99	206	Present in the essential oil of carnation plant which is repellent to mosquitoes and ticks (Tunón <i>et al.</i> 2006)
benzaldehyde	A	99	178	Repellent to the beetle <i>T. castaneum</i> (Herbst) (Saim & Meloan 1986)
methyl salicylate	B	99	223	Repellent to the leafhopper <i>Cicadulina storey</i> China (Oluwafemi <i>et al.</i> 2011)
<i>Fatty acid derivatives</i>				
(<i>Z</i>)-3-hexen-1-ol	A	99	156	Repellent to the bark beetle <i>Ips typographus</i> L. (Zhang <i>et al.</i> 1999)
1-octen-3-ol	B	98	175	Repellent to ants (Ômura <i>et al.</i> 2002)

^z Classification is derived from the biosynthetic pathway

^y A - Fluka; B - Sigma Aldrich; C - International Flavour and Fragrances; D - Riedel de Haen

club to provide optimal sensitivity to stimuli. A standard 1- μ l aliquot of each test concentration was pipetted onto a piece of filter paper (Whatman No. 1), exposed to air for 20 s to allow the solvent to evaporate, and then inserted into a glass Pasteur pipette. A stimulus-flow controller (model CS-05; Syntech, Hilversum, the Netherlands) was used to generate a 0.8-s stimulus at 1- to 2-min intervals, with a flow rate of 1.5 l min⁻¹. The signals generated by the antennae were passed through a high-impedance amplifier (model IDAC-232, Syntech) and recorded with specialized software (Syntech) as described by Alagarmalai *et al.* (2009). The same antenna was used to test blocks of increasing concentrations of the same compound. At the beginning and end of the series, 1 μ l pure hexane was puffed as reference. The responses elicited from the chemicals were subtracted from the means of the responses elicited by hexane. Each chemical was tested on eight antennae per sex, using one randomly selected antenna per weevil.

Trap catches in an urban environment

Experimental design Field trapping experiments were conducted in Palermo, Italy, where *R. ferrugineus* has been established for the last 7 years. The experimental plot was in an area of about 12 ha belonging to the military base “Ciro Scianna” (13°18'51"E, 38°0.5'40" N, WGS 84 F 33) (Fig. 1). This area was chosen because it resembles urban conditions while avoiding possible trap vandalism. The traps consisted of 10-l red plastic buckets with three rectangular openings (9×5 cm) located equidistantly on the wall at about 6 cm below the upper rim, and four circular openings (6.5 cm in diam) diametrically opposite on the lid (Intrachem Bio Italia SpA, Bergamo, Italy). The lower half of the trap was buried with the side openings at ground level to facilitate RPW adult access. Traps were baited with: (i) the aggregation pheromone Ferrugineol—[4S,5S]-4-methyl-5-nonanol (Rhyfer 220, Intrachem Bio Italia) released by a polyethylene dispenser at an average emission rate of 2 to 4 mg per day; (ii) 100 ml of ethyl acetate, released by a 100-ml bottle with the top nozzle filled by cotton wick at an average evaporation rate of 3600 to 4500 mg per day measured under field conditions at a mean daily temperature of 25.5±4.0°C; and (iii) a water solution of sugar beet (*Beta vulgaris* L. var. *saccharifera*) molasses, 2 l at 10%v/v. The dispenser of the aggregation

pheromone and the bottle with ethyl acetate were suspended about 10 cm below the trap lid, and the water-molasses solution filled the trap bottom. For the duration of the experiment, ethyl acetate and water-molasses solution were refilled weekly, whereas the aggregation pheromone dispenser was not changed. The experiment was laid out in randomized blocks. Twelve pheromone–kairomone–molasses-baited traps were distributed, 166±28 m (mean±SE) apart from each other. Traps were randomly divided into three blocks of four treatments (Fig. 1). The experiment consisted of two steps. Step 1: This step was designed to evaluate possible catch bias among the four three-trap units prior to treatment allocation (step 2). The 12 pheromone–kairomone–molasses-baited traps were inspected weekly from week 24 to week 29 in 2010 (3 traps×4 units×6 weeks =72 samples), and from weeks 23 to 29 in 2011 (3 traps×4 units×7 weeks =84 samples). Captured weevils were counted and sexed. Then, to eliminate possible odor contamination of the traps, they were left unloaded throughout week 29, and reloaded the week after (30th week) with the attractants and with the synthetic chemicals, as described in the next step. Step 2: Three synthetic chemicals—menthone, α -pinene and methyl salicylate—were tested singly or in combination to assess their ability to disrupt RPW attraction to pheromone- and kairomone-baited traps. The synthetic chemicals were allocated at random in each three-trap unit. The chemicals were provided in the amount of 10 ml released from a 15-ml falcon tube with a perforated lid. The actual daily evaporation rate of the synthetic chemicals was approx. 50 mg, measured under field conditions with a mean daily temperature of 25.5±4.0°C. The falcon tubes were suspended about 5 cm below the trap lid next to the other dispensers. In 2010, methyl salicylate and α -pinene were tested, and in 2011—menthone and α -pinene. Chemicals were tested singly or in combination and randomly assigned to each trap block, leaving one trap block with no additives as a positive control. The different combinations tested for each year are schematically presented in Fig. 1. Traps were inspected weekly, from week 31 to 38 in 2010 and in 2011 (4 traps×3 blocks×8 weeks =96 samples per year). Captured weevils were counted and sexed.

Statistical analysis The EAG dose–response data, given as means of antennal responses in mV after subtraction of the responses to the solvent, were analyzed

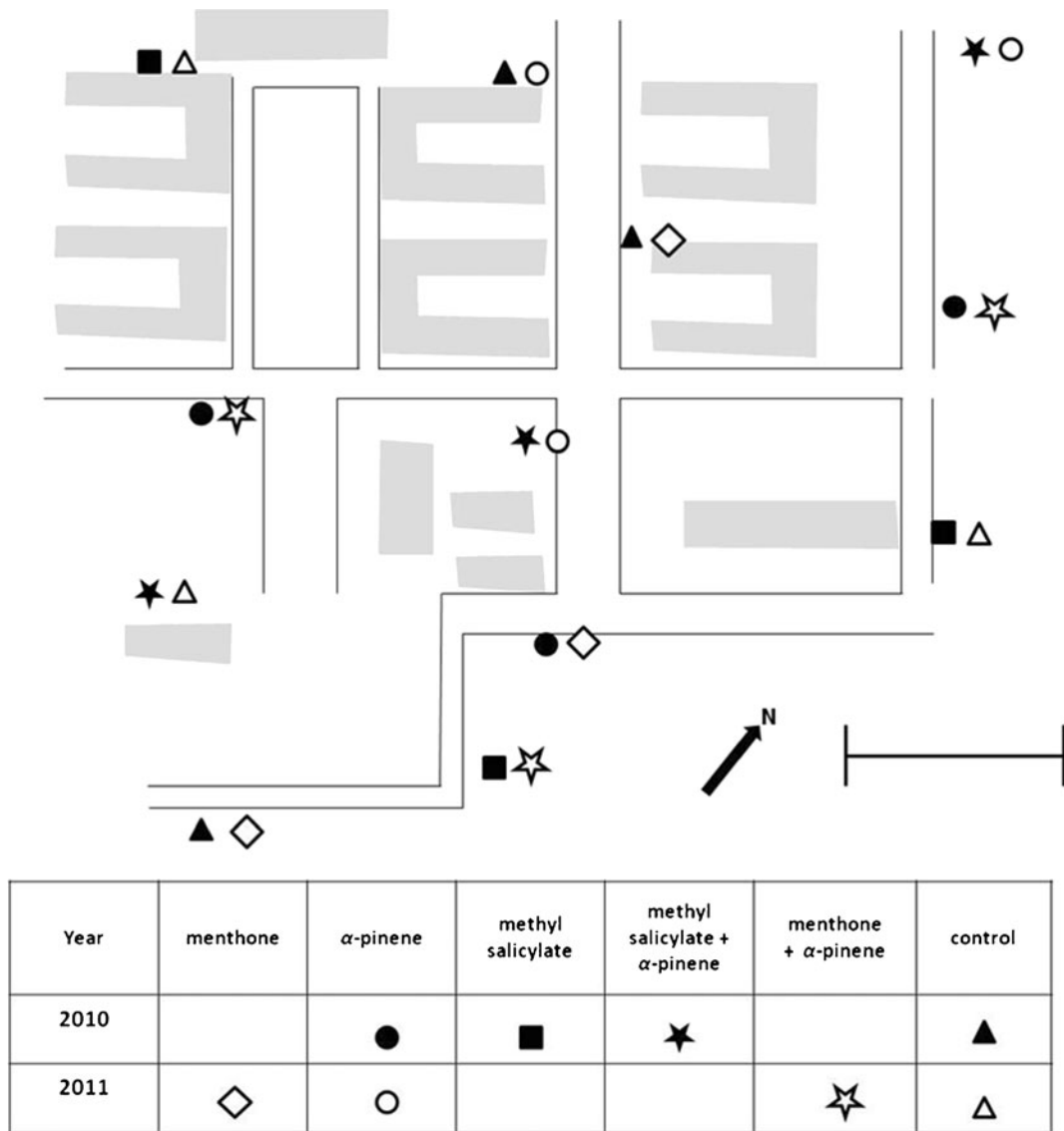


Fig. 1 Location of pheromone–kairomone–molasses-baited traps used for testing the repellent effects of menthone, α -pinene and methyl salicylate toward *Rhynchophorus ferrugineus* adults. The experiment was located in the city of Palermo, Italy. Twelve

traps were placed at densities of $0.97 \text{ trap ha}^{-1}$. The area used for installing the traps was approx. 12.29 ha . Gray rectangles represent buildings. Scale bar = 100 m

by ANOVA, followed by Bonferroni correction. Because we were interested primarily in how the treatments disrupt RPW attraction to the trap, catches of each trap on the inspection dates with the same treatment were pooled for the analysis. Data were analyzed using one-way ANOVA followed by Fisher's LSD test. The differences in the adult ratios from 1 for captured males and females were evaluated by χ^2 ; the differences in the sex ratio of the captured adults between the treatment traps and control traps were

analyzed using Goodman's post hoc procedure. All statistical analyses were performed using Statistica for Windows 6.0 (Statsoft Inc 2001).

Results

EAG bioassays Antennae of RPW adults showed positive dose-dependent responses to 13 of the 17 synthetic chemicals tested (Fig. 2). Statistically significant

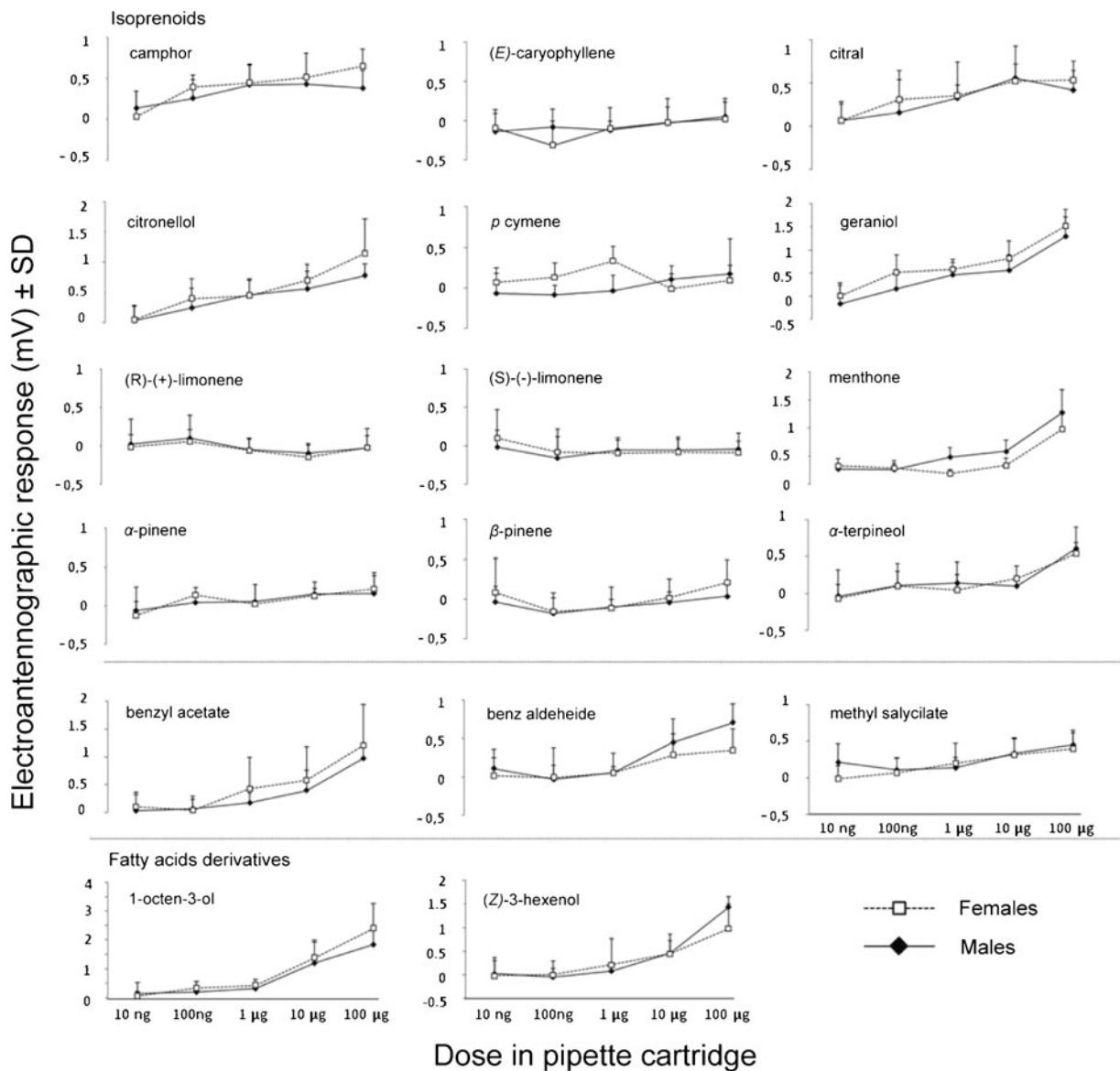


Fig. 2 EAG dose–response curves of *Rhynchophorus ferrugineus* adults to synthetic chemicals. EAG amplitudes were adjusted to control stimulus (hexane) and are presented as mean±SD. Each chemical was tested on eight individuals of each sex

differences in the EAG responses were observed among the chemicals (ANOVA, $F=26.4$; $df=16$; $P<0.001$) and between doses (ANOVA, $F=260.4$; $df=4$; $P<0.001$). The highest EAG response was recorded with 1-octen-3-ol at a dose of 100 μg . Camphor, citral, citronellol, geraniol, menthone, benzyl acetate, benzaldehyde, methyl salicylate, (*Z*)-3-hexen-1-ol and 1-octen-3-ol elicited EAG responses starting from a dose of 10 μg , whereas α -terpineol provided EAG

responses only at the maximum dose (100 μg). Female RPW antennae responded more strongly to *p*-cymene at 100 ng and 1 μg than male antennae ($n=16$; $P\leq 0.01$). Moreover, female antennae responded slightly more strongly to α -pinene than male antennae, and showed a significant response at a dose of 100 μg ($n=16$; $P\leq 0.03$). No responses were found to (*E*)-caryophyllene, (*S*)-(-)-limonene, (*R*)-(+)-limonene or β -pinene in either sex at any of the doses tested.

Trap catches in an urban environment

Step 1: The total number of RPW adults captured did not differ in either year among the four units (in 2010: $F=0.69$, $P=0.22$, $df=3$; in 2011: $F=1.50$, $P=0.2$, $df=3$; ANOVA followed by LSD test), showing that the trap selected to form the four trap units did not affect RPW catches. The total number of RPWs captured was 490 in 2010, and 365 in 2011. In both years, the number of females was consistently higher than the number of males, with a male/female sex ratio of 1:1.68 in 2010 ($\chi^2=27.94$; $P<0.001$) and 1:1.74 in 2011 ($\chi^2=27.94$; $P<0.001$).

Step 2: In 2010, the addition of α -pinene, singly or combined with methyl salicylate, significantly reduced the trap catches by approx. 30% and 47%, respectively, compared with the control traps ($F=4.79$; $P<0.005$, $df=3$; ANOVA followed by LSD test) (Fig. 3). The same trend was observed in 2011: in the traps in which α -pinene was added, alone or combined with menthone, the number of captured adults was reduced by approx. 37% and 30%, respectively, compared with the control traps ($F=6.89$; $P<0.001$; $df=3$; ANOVA followed by LSD test) (Fig. 3). The analysis also revealed that the number of captures in the traps supplemented with methyl salicylate (year 2010) and menthone (year 2011) were not significantly different from those in the control traps ($F=4.79$; $P=0.92$; $df=3$ and $F=6.89$; $P=0.65$; $df=3$ for methyl salicylate and menthone, respectively; ANOVA followed by LSD test) (Fig. 3). In both years, the sex ratio of adults captured in the different treatments did not differ statistically from the sex ratio of adults captured in the control traps (2010: $\chi^2=1.70$, $P=0.63$, $df=3$; 2011: $\chi^2=1.47$; $P=0.69$; $df=3$; Goodman's post hoc procedure). In 2010, the male/female sex ratios observed in the different treatments were 1/1.55 with α -pinene, 1/1.68 with methyl salicylate, and 1/2.15 with α -pinene combined with methyl salicylate, vs. 1/1.88 in the control traps. In 2011, the male/female sex ratios observed in the different treatments were 1/1.68 with α -pinene, 1/1.81 with menthone and 1/1.67 with α -pinene combined with menthone, vs. 1/1.40 observed in the control traps.

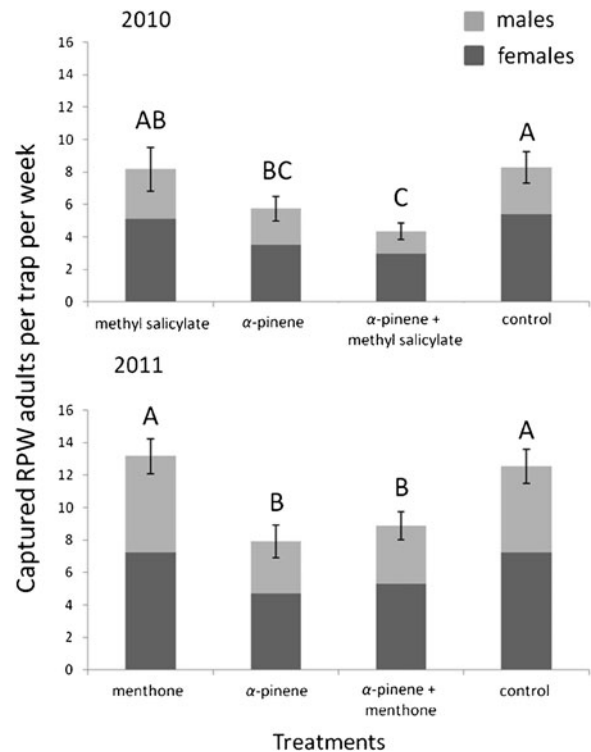


Fig. 3 Field responses of *Rhynchophorus ferrugineus* to traps baited with the aggregation pheromone, ethyl acetate and sugar beet molasses (*control*), with 10 ml of α -pinene, methyl salicylate or both α -pinene and methyl salicylate (in 2010) or with 10 ml of α -pinene, menthone or both α -pinene and menthone (in 2011). Experiments were carried out from weeks 31 to 38 of each study year in the city of Palermo, Italy. Bars indicate means \pm SE of adults captured per trap (three traps per treatment) during the 8 weeks. Columns labeled with a common letter do not differ significantly at $P<0.05$ (ANOVA followed by Fisher's LSD test)

Discussion and conclusions

How insects recognize their host and how manipulation of their chemical background can obscure such processes are vital questions for the development of novel semiochemical-based pest-protection strategies (Witzgall *et al.* 2010). Regardless of the recognition process, a prerequisite is compound detection by the peripheral olfactory system. The presented data show that, like many other phytophagous insects (Bruce & Pickett 2011), RPW adults possess a rather broadly tuned peripheral olfactory system. EAG bioassays on RPW adult antennae showed the high responsiveness of the receptors to molecules belonging to different classes of plant volatiles: isoprenoids, phenyl propanoid derivatives and fatty acid derivatives. Antennae

of both sexes responded to 13 of the 17 chemical compounds tested. Despite general differences in response levels, both sexes responded to the same compounds. In 1994, Gunawardena had already reported RPW's broad responsiveness to terpenoids. However, the specificity of the peripheral olfactory system of RPW is also evident, as in our experiments the adults did not respond to three of the ten tested isoprenoids and were able to sense α - but not β -pinene. The mechanism governing this discrimination is unclear but it seems to be independent of the chemical structure of the isoprenoid terminal group, as both hydrocarbon and oxygenated terpenes were active. Gunawardena (1994) suggested that the RPW is predisposed to sensing oxygenated compounds, such as alcohols and ketones, probably in accordance with the structure of their aggregation pheromone. This might explain the fact that all of the tested alcohols elicited antennal responses, with a particularly high response to the fatty acid derivatives 1-octen-3-ol and (*Z*)-3-hexen-1-ol. Another possibility is that these are components of natural host volatiles. In fact, (*Z*)-3-hexen-1-ol has been reported as a leaf volatile component of the dwarf palm *Chamaerops humilis* L. (Caissard *et al.* 2004), and is probably found among volatiles of other palm species as well.

Although the age and sexual maturity of wild insects used in the EAG experiments were unknown, the advantages in using wild collected weevils should not be underestimated since this represents the natural detection abilities of the weevil. Moreover, previous evaluations of trap-collected weevils indicated that most of the latter (over 80%) are sexually mature and ready to oviposit (Faleiro 2006; Lo Bue *et al.* 2010).

For the field experiments, we selected one non-host volatile that is strongly EAG active (menthone), one non-host volatile that is weakly EAG active (α -pinene) and a compound generally produced by stressed plants (methyl salicylate). The pheromone traps loaded with α -pinene, alone and in combination with menthone or methyl salicylate, exhibited low trapping of RPW adults. In particular, the mix of α -pinene and methyl salicylate showed the most promising results as a pheromone disruptant, reducing the weevil captures by approx. 40%. In contrast, the traps loaded with menthone or methyl salicylate alone caught a similar number of weevils as the control traps. From these results it seems that α -pinene is the major factor in RPW adult repellency, and it is possible that this

property can be enhanced by the addition of secondary compounds such as methyl salicylate, a typical plant defense compound (Kessler & Baldwin 2002). On the other hand, menthone did not have any influence on the number of weevil captures, used alone or in combination with α -pinene. The observed RPW repellency by a single molecule such as α -pinene, characteristic of the genus *Pinus* (Pinaceae), might support host avoidance based on taxonomically specific compounds. Why the same does not apply to menthone, which is quite specific to the genus *Mentha* (Labiatae), is still not clear. Many cases of negative responses to non-host volatiles have been reported among coleopteran species that feed on forest and ornamental plants (Mauchline *et al.* 2005; Zhang *et al.* 1999). For example, similar to our observations, α -pinene is known to be repellent to the Ambrosia beetles *Tryphodendron domesticum* (Oliver) and *Xyleborus dispar* (F.), which feed specifically on broad-leaved trees (Nijholt & Schönherr 1976; Schroeder & Lindelow 1989). Furthermore, studies on the North American coleopteran species *Dendroctonus frontalis* Zimmermann, *Ips grandicollis* (Eichhoff) and *Ips avulsus* (Eichhoff) have shown that bark beetles might avoid non-host trees because their response to pheromone is inhibited by several compounds among the green leaf volatiles (GLVs) (Dickens *et al.* 1991; 1992). Moreover, GLVs of non-host plants have been found to inhibit significantly the attraction of *Ips typographus* L. to its aggregation pheromone in laboratory bioassays and in a field test using pheromone traps (Zhang *et al.* 1999). Prior to this, only Oehlschlager & Gonzalez (2001), in experiments on *Rhynchophorus palmarum* (L.), revealed the repellent potency of one undisclosed compound toward palm weevils.

In conclusion, this study is the first to demonstrate that α -pinene, alone or with methyl salicylate, can disrupt pheromone attraction since catches in pheromone-baited traps significantly decreased. Further studies are in progress to assess whether these substances can indeed repel the RPWs from settling on the host and thereby protect the palm tree from infestation; or whether they merely hamper the impact of RPW aggregation pheromone. Interference with host detection is expected to play a significant role in RPW management, delaying, if not inhibiting, host exploitation via masking. As palm odors are also involved in this process, the efficiency of the repellents in protecting palms needs to be evaluated in the context of “push and pull strategy”

(Cook *et al.* 2007; Witzgall *et al.* 2010) to increase the efficiency of mass trapping and minimize the risks of RPW “spillover” onto susceptible hosts. The behavioral effects of other candidate repellents screened in this study warrant further evaluation.

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