

Field Attraction of the Vine Weevil *Otiorhynchus sulcatus* to Kairomones

Author(s) :Robert W.H.M. van Tol, Denny J. Bruck, Frans C. Griepink, and Willem Jan De Kogel

Source: Journal of Economic Entomology, 105(1):169-175. 2012.

Published By: Entomological Society of America

DOI: <http://dx.doi.org/10.1603/EC11248>

URL: <http://www.bioone.org/doi/full/10.1603/EC11248>

BioOne (www.bioone.org) is a nonprofit, online aggregation of core research in the biological, ecological, and environmental sciences. BioOne provides a sustainable online platform for over 170 journals and books published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Web site, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/page/terms_of_use.

Usage of BioOne content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

Field Attraction of the Vine Weevil *Otiorhynchus sulcatus* to Kairomones

ROBERT W.H.M. VAN TOL,¹ DENNY J. BRUCK,² FRANS C. GRIEPINK,¹
AND WILLEM JAN DE KOGEL¹

J. Econ. Entomol. 105(1): 169–175 (2012); DOI: <http://dx.doi.org/10.1603/EC11248>

ABSTRACT Root weevils in the genus *Otiorhynchus* are cited as one of the most important pests in the major nursery and small fruit production areas throughout the United States, western Canada, and northern Europe. A major problem in combating weevil attack is monitoring and timing of control measures. Because of the night-activity of the adult weevils growers do not observe the emerging weevils in a timely manner and oviposition often starts before effective control measures are taken. Several vine weevil electroantennogram-active plant volatiles were identified from a preferred host plant, *Euonymus fortunei*. Main compounds evoking antennal responses on the weevils' antennae were (*Z*)-2-pentenol, (*E*)-2-hexenol, (*Z*)-3-hexenol, methyl benzoate, linalool, (*E*)-4,8-dimethyl-1,3,7-nonatriene, methyl eugenol, and (*E*, *E*)- α -farnesene. Several of these compounds were tested alone and in mixtures on attractiveness for the vine weevil *Otiorhynchus sulcatus* (F.) in field-grown strawberry in Oregon. *O. sulcatus* were attracted to (*Z*)-2-pentenol ($\approx 3\times$ more than control) and a 1:1 ratio mixture of (*Z*)-2-pentenol and methyl eugenol ($4.5\times$ more than control). This is the first report of field-active attractants for *O. sulcatus* which holds promise for the development of new monitoring strategies for growers in the near future.

KEY WORDS *Otiorhynchus*, weevil, kairomone, plant odor, strawberry

The black vine weevil, *Otiorhynchus sulcatus* F. (Coleoptera: Curculionidae), is often cited as one of the most important pests in the major nursery and small fruit production areas throughout the United States, western Canada, and northern Europe (Moorhouse et al. 1992). Traditional management of this insect centers on the use of insecticide sprays targeted at adults in an attempt to avert egg-laying. However, growers continually have problems properly timing spray applications because of the invisibility of the two life-stages of the weevil, namely 1) adults are night-active feeding on leaves, 2) larvae live in soil eating living plant roots. Repeated insecticide applications targeting adults throughout the growing season kill a large percentage of beneficial insects resulting in secondary pest outbreaks. These sprays also make it impossible for growers to use augmentive or inundative control strategies for other insect pests using natural enemies. In addition, retailers are driving the movement toward residue-free soft fruit production that has also restricted control measures.

The root weevils, *Otiorhynchus* spp., are flightless univoltine weevils; many reproducing via thelytokous parthenogenesis (Downes 1922, Smith 1932, Suomalainen et al. 1987). Oviposition occurs at night with

eggs either dropped on the soil surface or inserted into crevices on plants (Smith 1932). Early instars begin by feeding on small roots while the later instars feed on larger roots, especially on the phloem and cambium tissues near the soil surface (La Lone and Clarke 1981). Adults are nocturnal and cause mainly esthetic damage to plants by notching the leaves. Overwintering occurs in the larval stage and pupation and transformation to adult occurs in the late spring to early summer. Adults may live and reproduce more than one year. The black vine weevil, *O. sulcatus* is the primary species afflicting crops globally. *O. sulcatus* is a univoltine, polyphagous insect that is a noxious pest of field and container-grown ornamentals as well as small fruit crops worldwide (Moorhouse et al. 1992). In the United States, the environmental horticulture industry (floriculture and nursery crops) is the third largest value crop behind corn and soybeans (USDA fact sheets, <http://www.nass.usda.gov>). *O. sulcatus* is thought to have a northern European origin and was first recorded in North America in 1835 (Smith 1932). All *Otiorhynchus* spp. appear to be omnivorous phytophages in that a number of plant hosts have been listed for each species. However, a number of studies have found that evidence of damage, particularly by adults, does not necessarily denote that the plant is a viable larval host. Even cultivars within the same species of host have shown differences in fecundity of *O. sulcatus* (Cram 1970a,b, 1980; Nielsen and Dunlap 1981; Cram and Daubeny 1982; Shanks and Doss 1986).

¹ Plant Research International, Wageningen-UR, P.O. Box 69, 6700 AB Wageningen, The Netherlands.

² Corresponding author: USDA-ARS, Horticultural Crops Research Laboratory, 3420 NW Orchard Avenue, Corvallis, OR 97330 (e-mail: denny.bruck@ars.usda.gov).

In both the eastern United States and in Europe, *O. sulcatus* appears to feed primarily on a number of angiosperms belonging to the plant orders Rosales, Primulales, Saxifragales, and to a lesser extent the Ericales. In those studies, strawberry was not the premier host (Smith 1932, Maier 1981, Nielsen and Dunlap 1981, Hanula 1988, van Tol et al. 2004, Fisher 2006).

A major problem in combating weevil attack is monitoring and timing of control measures. Because of the night-activity of the adults, growers do not observe the first emerging weevils in a timely manner and oviposition often starts before effective control measures are taken. Weevil presence is usually determined by monitoring weevil damage to the plants, but quantification and localization of the infested areas is quite labor intensive. To prevent weevil oviposition, growers spray broad-spectrum pesticides every 2–3 wks. Hence, integrated or biological control of other pests is only possible when growers monitor very intensively for weevil presence in the field and apply preferably nonpersistent and selective pesticides only at sites of infestation. Although integrated control of pests in nurseries is applied by some growers (Van der Horst and van Tol 1995, van Tol 1996), high costs of labor and mass-reared enemies prevent large-scale introduction and acceptance of this method. Selective attractants allow local qualitative and quantitative monitoring of weevils at an early stage of infestation. Because freshly emerged weevils have a preoviposition period of 3–4 wk, growers have the opportunity to control weevils before the onset of egg-laying. Localized and early control of the emerging weevils will reduce the number of pesticide applications and the amount of chemicals used. The selective monitoring of weevils will help the growers identify the sites that are at risk for grub infestation. Organic growers (primarily small fruits) have to rely completely on monitoring-based applications of entomopathogenic nematodes in autumn because they do not use synthetic pesticides and alternatives for adult control are not available at this time. For organic, integrated pest management (IPM) and conventional growers lure and kill could provide a solution.

O. sulcatus shows a clear preference for odors from specific host-plants like *Euonymus* and *Taxus* (van Tol and Visser 1998, 2002; van Tol et al. 2000, 2002a,b). In laboratory assays it was shown that these plants, when damaged by adult weevils, were more attractive than the undamaged plants. Extracts from *Euonymus* plants were attractive as well. In this study, we determined the specific components in the extract responsible for adult vine weevil attraction by combining two techniques (gas chromatography coupled with electroantennogram detection (GC-EAD) and gas chromatography coupled with mass-spectrometry (GC-MS)). The components involved in odor perception by the weevil antenna were identified and behavioral bioassays performed to determine which component(s) were behaviorally attractive for the weevil. Based on the laboratory results a selection of odors were tested in a strawberry field in Oregon on attractiveness for the vine weevil *O. sulcatus*.

Materials and Methods

Volatiles were collected from a bio-active extract of *Euonymus fortunei* 'Dart's Blanket' in paraffin oil and from cuttings of mechanically damaged and *O. sulcatus*-damaged *E. fortunei* Dart's Blanket. The antennal response to these plant odors by *O. sulcatus* were measured by GC-EAD. Compounds giving an electrophysiological response were tentatively identified by GC-MS. When the tentatively identified compound showed similar Kováts indices (Kováts, 1964) on our chromatographic system and identical mass spectral fragmentation pattern as the purchased synthetic reference compound, it was considered to be a positive identification. A selection of plant volatiles that gave an electrophysiological reaction on the antenna were tested as single compounds and in several mixtures of two or more compounds on bioactivity (R.W.H.M.v.T., unpublished data) using the olfactometer developed specifically to study vine weevil behavior (van Tol et al. 2002a). A small selection of compounds bioactive in the lab was tested under field conditions in strawberry.

Headspace Collection. A filtered 10-ml extract of *E. fortunei* Dart's Blanket in paraffin oil (Uvasol, Merck, Darmstadt, Germany) and four *O. sulcatus*-damaged and four mechanically damaged 20-cm long cuttings of field-grown *E. fortunei* Dart's Blanket were used for headspace collection. The extract was prepared by crushing 30 g of fresh leaves from the top 15 cm part of stems with 50 ml of paraffin oil on ice. The extract was crushed for ≈ 20 min followed by immediately filtering through Whatman No. 90 (diameter 15 cm) paper filter. The filtered *Euonymus* extract was stored cool until use. Cuttings of *Euonymus* were mechanically damaged with a scissor by four incisions per leaf three hours before headspace collection. The *O. sulcatus*-damaged *Euonymus* cuttings were prepared by offering 10 vine weevils 16 h before headspace collecting the cuttings. Weevils were removed and cuttings washed with deionized water before placing in a fresh 100 ml flask with water for headspace collection. For 3 d the *Euonymus* cuttings or a daily refreshed 10-ml paraffin oil extract of *Euonymus* in an open petri-dish were placed under a glass bell jar (5 liters) in a growth chamber at 20°C and under long day (L:D = 16:8 h) light conditions. Air was purified by passage through a charcoal filter and drawn at 0.2 liters min^{-1} through the jar. Volatiles were entrained for a total of 69 h. For the collecting of volatiles, Gerstel thermodesorption tubes, filled with 80 mg Tenax TA 20/35 mesh (Grace Alltech, Deerfield, IL), were used. Before use, these tubes were cleaned by rinsing them with 10 ml hexane and, subsequently, flushing them for one hour at 280°C with 20 ml min purified nitrogen. Each Tenax tube was refreshed after ≈ 8 h. The volatiles trapped on the Tenax were washed off with 15 ml hexane. The Tenax washings for each treatment were pooled and concentrated under argon to one extract ($\approx 200 \mu\text{l}$) before GC-EAD and GC-MS testing.

Coupled GC-EAD. GC-EAD measurements were carried out using an Interscience Trace GC-2000 (In-

terscience, Breda, The Netherlands) equipped with a cold on-column injector. The gas chromatograph was equipped with a Grace-Alltech 30 m EC-5 fused silica column, 0.25-mm ID and 0.25-mm film thickness. Conditions were: carrier gas, helium (constant flow 1.7 ml min⁻¹); temperature programming, 80°C (0.8 min hold) to 260°C (10 min hold) at 25°C min⁻¹; detector temperature, 250°C; the transfer line between the GC and the EAD (Syntech Laboratories, Hilversum, The Netherlands) followed the oven temperature. Over the antenna, a flow of purified, humidified air was maintained at a flow rate of 80 cm s⁻¹. The sample was equally split between a flame ionization detector (FID) and the EAG detector. Antennae were separated from the weevil heads and mounted between two glass electrodes filled with a Ringer's solution (6.4 mM KCl, 12 mM MgCl₂·0.6H₂O, 9.6 mM KOH, 12 mM NaCl, 20 mM KH₂PO₄, 1 mM CaCl₂, and 354 mM glucose in deionized water). Antennal preparation and EAG recording were performed according to the procedure described by Visser and Piron (1995) and van Tol et al. (2002b). The EAG recorder plus peripheral equipment were manufactured by Syntech Laboratories. Approximately five antennal preparations with limited background noise for each treatment showing responses to several compounds in the extract were used for comparison. Only EAG responses that were present in all preparations at the same retention time (Rt) were identified as an EAG positive response to a compound in the extract.

Gas Chromatography-Mass Spectrometry. Compounds giving an electrophysiological response were tentatively identified by GC-MS. When the tentatively identified compound showed similar Kováts indices on our chromatographic system and identical mass spectral fragmentation pattern as the purchased synthetic reference compound, it was considered to be a positive identification. GC-MS analyses were carried out on a Hewlett-Packard 5973 mass selective detector (70 eV) coupled to a Hewlett-Packard 6890 gas chromatograph equipped with a split/splitless injector. The gas chromatograph was equipped with an Alltech 30 m AT-5 fused silica column, 0.25 mm ID and 0.25 μm film thickness run in constant flow mode (1.3 ml/min Helium). Temperature programming: 50°C (2 min hold) to 300°C (8 min hold) at 5°C/min (AT-5 column); transfer line temperature, 300°C; injector temperature, 230°C. One microliter of concentrated headspace volatiles were injected manually into the GC-MS system for analysis. Injections were done in splitless mode only (1 μl).

Compounds and Treatments. A selection of single plant compounds (A = (Z)-2-pentenol and B = (E)-2-hexenol) and combinations of plant compounds (C = A + B in ratio 1:1, D = A + methyl eugenol in ratio 1:1, and E = A + B + methyl eugenol in ratio 1:1:1) were tested in a strawberry field (*Fragaria* × *ananassa* 'Tillamook') for attraction of *O. sulcatus*. Choice of compounds and mixtures were based on identification of EAD-active compounds from headspace of weevil-damaged *E. fortunei* Dart's Blanket plants and paraffin oil extract of the same *Euonymus*

plant species combined with bioassay results with the EAD-active compounds alone and in several mixtures (R.W.H.M.v.T., unpublished data). The compound (Z)-2-pentenol (purity 95%) was obtained from Bedoukian (Danbury, CT), (E)-2-hexenol (purity >96%) from Acros (Geel, Belgium), and methyl eugenol (purity >98%) from Sigma-Aldrich (St. Louis, MO). All chemicals were used without further purification. Single compounds and mixtures were introduced in dispensers before use and sealed. In each dispenser 0.4 ml of each compound was present.

Dispensers. Plant volatile dispensers were made of 1.5 ml LDPE Pasteur pipettes (Labo Scientific, Ede, The Netherlands). The compounds to be tested were introduced into the pipette, the tip of which was then sealed by heat. Before use, the tip of the pipette was cut off at 1 cm above the reservoir portion. The open tip of the dispenser had an internal diameter of 3.5 mm. This type of 'high release' pheromone/kairomone dispenser are developed and used by Pherobank (www.pherobank.com) for several years for the attraction of *Phyllopertha horticola* L. (Coleoptera: Scarabaeidae) and has also been successfully tested for attraction of the rosy apple aphid, *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphidae) (van Tol et al. 2009). Closed dispensers do not release high enough amounts of the plant volatiles through the polyethylene to attract these beetles and aphids compared with partially opened vials. The dispenser is a simple and cheap existing design which enables a high release profile especially for larger quantities of plant volatiles. The plant volatiles were commercial compounds presented singly or in a defined mixture in each dispenser.

Field Experiment. Experiments were performed in a commercial strawberry field in Oregon (Clackamas County, OR) in 2009. Five different treatments (A, B, C, D, and E) and one control were tested in the field. The control consisted of an empty dispenser. Dispensers with odors were placed in the top part of a boll weevil trap (Great Lakes IPM, Inc., Vestaburg, MI). Each trap contained one odor-filled or control (empty) dispenser located in the top capture assembly. Boll weevil traps were placed in the rows between the strawberry plants. Distance between each treatment was 10 m. Each treatment of trap-odor was coupled with a trap-control treatment at a distance of 10 m from each other and replicated four times for each field trial. Coupled odor-control set-up was performed to minimize effects of possible uneven weevil distribution throughout the fields. Dispensers were refreshed once a week. Traps and dispensers were placed in the fields and monitored for weevils' presence between May and August 2009. First weevils emerging from soil were found in the first week of June. Traps and plants surrounding each trap-dispenser combination were monitored for weevils weekly. Plants within the treatment row up to 60 cm distance from the dispenser in either direction were checked for weevil presence. Weevils found were removed from the field.

Statistics. The field tests were set-up as block designs where the blocks consisted of four plots. Each plot was divided into two subplots where one subplot was the trap-odor treatment and the other subplot was the trap-control treatment. The four subplots within a block were treated with the same odor. Each block therefore contained four identical odor traps coupled with four control traps. This set-up allows comparison of each odor with the control but not comparison between the different odors tested.

The total number of weevils for each weevil species per trap were analyzed using Generalized Linear Model with logarithmic link, Poisson distribution, and not fixed dispersion using the 12th version of the statistical package GenStat (Payne et al. 2009). The fixed part of the model consists of the additive effects of block/plot and odor (of which the control was an extra level). After the analysis, paired comparisons were performed on the transformed scale data with approximate *t*-tests between the odors and the control. Thereafter, estimates of the means of the weevils per trap are back transformed to the original scale with approximate standard errors.

Results

The headspace of mechanically damaged and weevil-damaged *E. fortunei* Dart's Blanket plants and the leaf extract in paraffin oil showed a different pattern in release of compounds (Fig. 1). All EAD-active compounds were present in all three headspace extracts and only differences in strength of antennal responses were found. The differences in strength are likely related to the amount of the specific compounds present in the headspace of the different treatments. The amounts of compounds and strength of the antennal responses were not quantified in this research. The results show that of the 14 EAD-active volatiles (*Z*)-2-pentenol, (*Z*)-3-hexenol and (*E*)-2-hexenol were present in larger quantities in the headspace of the *Euonymus* extract in paraffin oil than in the headspace of mechanically and weevil-damaged *Euonymus* leading to clearly stronger antennal responses for these compounds in the extract compared with the plant headspaces. High release of EAD-positive (*E*)-4,8-dimethyl-1,3,7-nonatriene in weevil-damaged *Euonymus* compared with the mechanically damaged plant and paraffin oil extract indicate that this compound is produced and released by the plants in increased amounts as a response to weevil damage. There was, however, no stronger antennal response to this compound in the weevil-damaged plants compared with the other treatments.

Results presented in Fig. 2 show the average number of weevils per replicate for each treatment after statistical analysis of the total number of each weevil species caught during the whole season. Except for an occasional weevil caught in the boll weevil trap all weevils were found in the plants surrounding the odor source. Treatment A (11.3, SE = 3.3, *P* = 0.01) and D (18.2, SE = 10.9, *P* = 0.03) caught significantly more *O. sulcatus* than the control (4.3, SE = 0.7). The treat-

ments B (4.3, SE = 2.6, *P* = 1.0), C (7.9, SE = 3.6, *P* = 0.22), and E (3.3, SE = 1.3, *P* = 0.56) were not significantly different from the control.

Discussion

This is the first report of a successful attraction of weevils in the genus *Otiorhynchus* to a synthetic kairomone consisting of plant volatiles (U.S. Patent Application Serial No. 13/157,944). Three compounds from the spindle tree *E. fortunei* Dart's Blanket, attractive for *O. sulcatus* (van Tol et al. 2002a), and sensed by their antenna play a key role in attraction. Of these compounds (*Z*)-2-pentenol alone and in combination with methyl eugenol appear to be attractive for *O. sulcatus* in strawberry. For two other weevil species in the same genus (*O. ovatus* and *O. rugosotriatus*), present in the strawberry test field, there were strong indications for attraction to a mixture of (*Z*)-2-pentenol and (*E*)-2-hexenol (Treatment C) but not to the *O. sulcatus* attractive treatments.

Many weevils in the genus *Otiorhynchus* are polyphagous and are parthenogenetic. Unless these weevil species also produce an aggregation pheromone it is likely that plant odors play a role in host-plant finding and/or aggregation (e.g., feeding-induced release of plant compounds attracting conspecifics). In previous research (van Tol et al. 2002a, 2004) attraction to frass and preference for feeding damaged plant species has been shown. It was, however, still unknown what compounds were actually involved in attraction. Likely plant compounds produced by most plant species (e.g., the so-called green leaf volatiles) play a role in attraction for these polyphagous insects. Indeed, EAD profile of *O. sulcatus* (van Tol et al. 2002b) showed strong antennal responses to typical green leaf volatiles with strongest responses to the C6 alcohols but not the C6 aldehydes, acetates or ketones. In this research the headspace of a preferred *O. sulcatus*-damaged host-plant (*E. fortunei*) and an attractive host-plant extract (R.W.H.M.v.T., unpublished data) tested on weevils' antennal response via GC-EAD coupled with GC-MS analysis revealed responses to two of these C6 alcohols present in the headspace of the plants, namely (*Z*)-3-hexenol and (*E*)-2-hexenol but also to a C5 alcohol, (*Z*)-2-pentenol. In laboratory and field tests only (*Z*)-2-pentenol appeared to play a role in attraction of *O. sulcatus* when combined with methyl eugenol. Pentenols are compounds found in several plant species released in substantial amounts when exposed to pathogen attack (Heiden et al. 1999) and after freeze-thaw wounding of plants (Fall et al. 2001). To our knowledge ours is the first report of any insect species responding behaviorally to pentenols; however, the related C5 alcohol 2-pentanol has been identified as a component of the alarm pheromone of the giant hornet *Vespa mandarinia* Smith (Hymenoptera: Vespidae) (Ono et al. 2003). Hedin (1972) described the presence of several C5 alcohols, including pentenols, in distillable oil from adult boll weevils *Anthonomus grandis* Boheman (Coleoptera: Curculionidae) in trace amounts but none of these compounds have ever been iden-

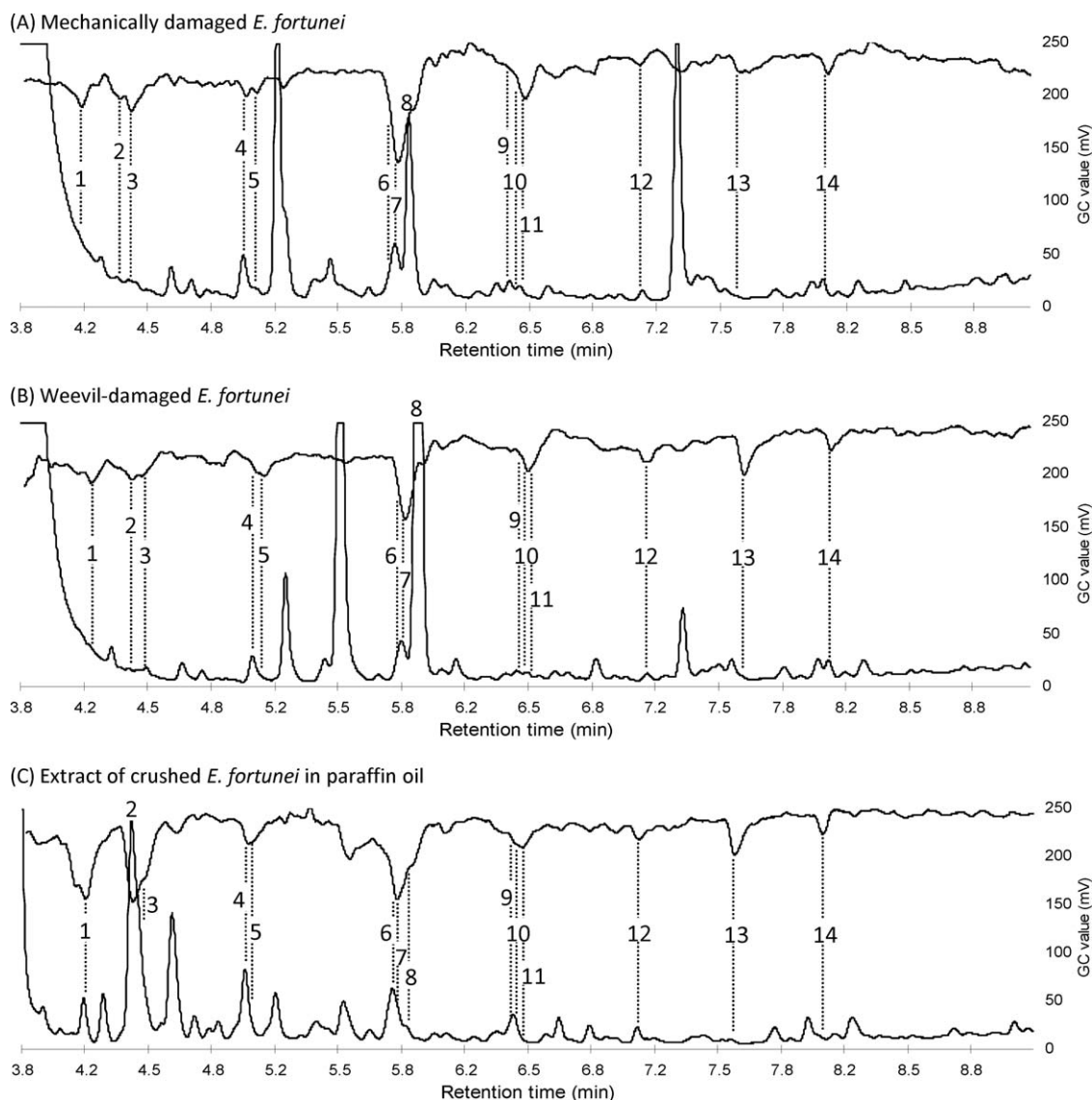


Fig. 1. Responses (top lines in A, B, and C) of *O. sulcatus* antennae to components (bottom lines in A, B, and C) in the headspace extract of (A) mechanically damaged, (B) weevil-damaged, and (C) crushed extract in paraffin oil of leaves of *E. fortunei* Dart's Blanket; (1) (*Z*)-2-pentenol, (2) (*Z*)-3-hexenol, (3) (*E*)-2-hexenol, (4) 1-octen-3-ol, (5) unidentified, (6) methyl benzoate, (7) linalool, (8) (*E*)-4,8-dimethyl-1,3,7-nonatriene, (9) estragole, (10) 4-*tert* butyl cyclohexanol, (11) 2-phenoxy ethanol, (12) (*E*)- β -ocimene, (13) methyl eugenol, (14) (*E, E*)- α -farnesene.

tified as attractants for this weevil species. The other compound, attractive in conjunction with (*Z*)-2-pentenol for *O. sulcatus* (methyl eugenol) occurs naturally in plants from over 200 species in 32 families (Tan 2000). Methyl eugenol is a well-known attractant for several fruit fly species firstly identified as such by Metcalf et al. (1975) and later also identified by others (LeBlanc et al. 2009) as an attractant for several flower-associated insects (honey bees, syrphid flies, nitidulid beetles, and endemic crambid moths) but not to any insect species in the Curculionidae.

Whether attraction and preference for certain plant species by *O. sulcatus* is related to the presence,

amounts and ratio of one or more of the identified plant compounds remains unclear. Publications identifying highly volatile C5 alcohols in traceable amounts in the headspace and/or distillates from plants attractive for *O. sulcatus* are very rare. In strawberry foliage 1-penten-3-ol (Himanen et al. 2005) has been found and in the headspace of strawberry fruits 2-pentanone and 2-pentanol (Hakala et al. 2002, Urruty et al. 2002). Our research shows that the three *Otiorhynchus* species present in the strawberry test field preferred different single compounds and/or mixtures of compounds but more testing is needed to optimize the composition and

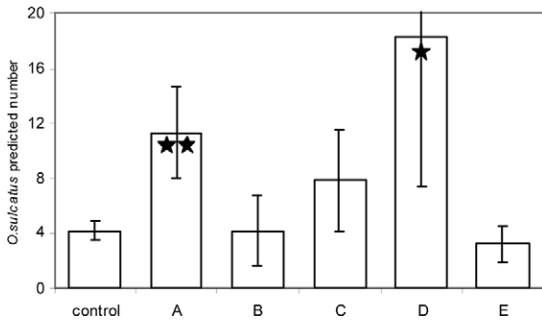


Fig. 2. Number of adult *O. sulcatus* caught in traps and surrounding strawberry plants on a commercial nursery in Oregon baited with (A) (Z)-2-pentenol, (B) (E)-2-hexenol, (C) (Z)-2-pentenol + (E)-2-hexenol (ratio 1:1), (D) (Z)-2-pentenol + methyl eugenol (ratio 1:1), and (E) (Z)-2-pentenol + (E)-2-hexenol + methyl eugenol (ratio 1:1:1). Treatments with asterisks (* $P = 0.03$, ** $P = 0.01$) are significantly different from the control treatment.

ratio of the attractive compounds for each species within this insect genus.

Apart from optimizing the odor composition, the development of trap devices is essential to use the odors for monitoring in the field. We tested several commercial available traps for weevil species but none were effective (R.W.H.M.v.T., unpublished data). *Otiorhynchus* weevils are night active feeders and are attracted to the host plants near the odor source at night while the traps tested are designed to act as daytime hiding locations and are not attractive for the weevils to enter during feeding. Currently new trap devices are being constructed and tested to improve capture.

Acknowledgments

We are grateful for the technical and field support by Bevely Thomas, Lacey Schultz, Kelly Donahue, and Amanda Lake (USDA-ARS), Leo Poleij, Henk Swarts, and Olga Smit-Bakker (Plant Research International) as well as the statistical support by Jac Thissen (Plant Research International-Biometris). This research was funded by the Northwest Nursery Crop Research Center (NNCRC), the Dutch Ministry of Agriculture (BO part of national research program LNV), and Plant Research International (KB program 2008-2010).

References Cited

Cram, W. T. 1970a. Unacceptability of cultivars of highbush blueberry by adult black vine weevils (Col.: Curculionidae). *J. Entomol. Soc. B. C.* 67: 3-6.

Cram, W. T. 1970b. Acceptability of cultivars of highbush blueberry at varying temperatures by adult black vine weevils (Col.: Curculionidae). *J. Entomol. Soc. B. C.* 67: 6-7.

Cram, W. T. 1980. Fecundity of the black vine weevil, *Otiorhynchus sulcatus* (Coleoptera: Curculionidae), fed foliage from some current cultivars and advanced selections of strawberry in Br. Colombia. *J. Entomol. Soc. B. C.* 77: 25-26.

Cram, W. T., and H. A. Daubeny. 1982. Responses of black vine weevil adults fed foliage from genotypes of strawberry, red raspberry, and red raspberry-blackberry hybrids. *HortScience* 17: 771-773.

Downes, W. 1922. The strawberry root weevil with notes on other insects affecting strawberries. Pamphlet 5. New Series. Canadian Department of Agriculture, Ottawa, Ontario, Canada.

Fall, R., T. Karl, A. Jordan, and W. Lindinger. 2001. Biogenic C5 VOCs: release from leaves after freeze-thaw wounding and occurrence in air at a high mountain observatory. *Atmos. Environ.* 35: 3905-3916.

Fisher, J. R. 2006. Fecundity, longevity and establishment of *Otiorhynchus sulcatus* (Fabricius) and *Otiorhynchus ovatus* (Linnaeus) (Coleoptera: Curculionidae) from the Pacific North-west of the United States of America on selected host plants. *Agric. Forest Entomol.* 8: 281-287.

Hakala, M. A., A. T. Lapveteläinen, and H. P. Kallio. 2002. Volatile compounds of selected strawberry varieties analyzed by purge-and-trap headspace GC-MS. *J. Agric. Food Chem.* 50: 1133-1142.

Hanula, J. L. 1988. Oviposition preference and host recognition by the black vine weevil, *Otiorhynchus sulcatus* (Coleoptera: Curculionidae). *Environ. Entomol.* 17: 694-698.

Hedin, P. A., A. C. Thompson, R. C. Gueldner, and J. P. Minyard. 1972. Volatile constituents of the boll weevil. *J. Insect Physiol.* 18: 79-86.

Heiden, A. C., K. Kobel, R. Koppmann, G. Schuh, and J. Wildt. 1999. Emission of oxygenated volatile organic compounds from plants: emission from lipoxygenase activity. *American Geophysical Union*, (abstr.) A12A-01.

Himanen, S., T. Vuorinen, T. Tuovinen, and J. K. Holopainen. 2005. Effects of cyclamen mite (*Phytonema pallidus*) and leaf beetle (*Gallerucella tenella*) damage on volatile emission from strawberry (*Fragaria × ananassa* Duch.) plants and orientation of predatory mites (*Neoseiulus cucumeris*, *N. californicus*, and *Euseiulus finlandicus*). *J. Agric. Food Chem.* 53: 8624-8630.

Kováts, E. 1964. The Kovats retention index system. *Anal. Chem.* 36: 31A-35A.

La Lone, R. S., and R. G. Clarke. 1981. Larval development of *Otiorhynchus sulcatus* (Coleoptera, Curculionidae) and effects of larval density on larval mortality and injury to Rhododendron. *Environ. Entomol.* 10: 190-191.

LeBlanc, L., D. Rubinoff, and R. I. Vargas. 2009. Attraction of nontarget species to fruit fly (Diptera: Tephritidae) male lures and decaying fruit flies in traps in Hawaii. *Environ. Entomol.* 38: 1446-1461.

Maier, C. T. 1981. Reproductive success of the black vine weevil, *Otiorhynchus sulcatus* (F.), fed different foliar diets and evaluation of techniques for predicting fecundity. *Environ. Entomol.* 10: 928-932.

Metcalf, R. L., W. C. Mitchell, T. R. Fukuto, and E. R. Metcalf. 1975. Attraction of the oriental fruit fly, *Dacus dorsalis*, to methyl eugenol and related olfactory stimulants. *Proc. Natl. Acad. Sci. U.S.A.* 72: 2501-2505.

Moorhouse, E. R., A. K. Charnley, and A. T. Gillespie. 1992. A review of the biology and control of the vine weevil, *Otiorhynchus sulcatus* (Coleoptera: Curculionidae). *Ann. Appl. Biol.* 121: 431-454.

Nielsen, D. G., and M. J. Dunlap. 1981. Black vine weevil: reproductive potential on selected plants. *Ann. Entomol. Soc. Am.* 74: 60-65.

Ono, M., H. Terabe, H. Hori, and M. Sasaki. 2003. Components of giant hornet alarm pheromone. *Nature* 424: 637-638.

- Payne, R. W., S. A. Harding, D. A. Murray, D. M. Soutar, D. B. Baird, A. I. Glaser, I. C. Channing, S. J. Welham, A. R. Gilmour, R. Thompson, and R. Webster. 2009. The Guide to GenStat Release 12, Part 2: Statistics. VSN International, Hemel Hempstead, Hertfordshire, United Kingdom.
- Shanks, C. H., and R. P. Doss. 1986. Black vine weevil (Coleoptera: Curculionidae) feeding and oviposition on leaves of weevil-resistant and -susceptible strawberry clones presented in various quantities. *Environ. Entomol.* 15: 1074–1077.
- Smith, F. F. 1932. Biology and control of the black vine weevil. U.S. Dep. Agric. Tech. Bull. 325.
- Suomalainen, E., A. Saura, and J. Lokki. 1987. Cytology and evolution in parthenogenesis. CRC, Inc., Boca Raton, FL.
- Tan, K. H. 2000. Behaviour and chemical ecology of *Batrocera* flies, pp. 647–656. In K. H. Tan (ed.), Area-wide control of fruit flies and other pests. Penerbit University, Penang, Malaysia.
- Urruty, L., J.-L. Giraudel, S. Lek, P. Roudeillac, and M. Montury. 2002. Assessment of strawberry aroma through SPME/GC and ANN methods. Classification and discrimination of varieties. *J. Agric. Food Chem.* 50: 3129–3136.
- van der Horst, M. J., and R.W.H.M. van Tol. 1995. Integrated pest management in nursery stock in The Netherlands. *Med. Fac. Landbouww. Rijksuniv. Gent.* 60: 759–762.
- van Tol, R.W.H.M. 1996. Prospects for biological control of black vine weevil in nursery stock. *Mitt. Biol. Bundesanstalt* 316: 69–75.
- van Tol, R.W.H.M., and J. H. Visser. 1998. Host-plant preference and antennal responses of the black vine weevil (*Otiorhynchus sulcatus*) to plant volatiles. *Proc. Sect. Exp. Appl. Entomol.* 9: 35–40.
- van Tol, R.W.H.M., J. H. Visser, and M. W. Sabelis. 2000. Responses of the black vine weevil (*Otiorhynchus sulcatus*) to weevil and host-plant odours. *Proc. Sect. Exp. Appl. Entomol., N.E.V. Amsterdam.* 11: 109–114.
- van Tol, R.W.H.M., and J. H. Visser. 2002. Olfactory antennal responses of the vine weevil *Otiorhynchus sulcatus* to plant volatiles. *Entomol. Exp. Appl.* 102: 49–64.
- van Tol, R.W.H.M., J. H. Visser, and M. W. Sabelis. 2002a. Olfactory responses of the vine weevil, *Otiorhynchus sulcatus*, to tree odours. *Physiol. Entomol.* 27: 213–222.
- van Tol, R.W.H.M., and J. H. Visser. 2002b. Olfactory antennal responses of the black vine weevil (*Otiorhynchus sulcatus*) to plant volatiles. *Entomol. Exp. Appl.* 102: 49–64.
- van Tol, R.W.H. M., J. H. Visser, and M. W. Sabelis. 2004. Behavioural responses of the vine weevil, *Otiorhynchus sulcatus*, to semiochemicals from conspecifics, *Otiorhynchus salicicola*, and host plants. *Entomol. Exp. Appl.* 110: 145–150.
- van Tol, R.W.H. M., H.H.M. Helsen, F. C. Griepink, and W. J. De Kogel. 2009. Female-induced increase of host-plant volatiles enhance specific attraction of aphid male *Dyspaphis plantaginea* (Homoptera: Aphididae) to the sex pheromone. *Bull. Entomol. Res.* 99: 593–602.
- Visser, J. H., and P.G.M. Piron. 1995. Olfactory antennal responses to plant volatiles in apterous virginoparae of the vetch aphid *Megoura viciae*. *Entomol. Exp. Appl.* 77: 37–46.

Received 22 July 2011; accepted 12 September 2011.