

Behavioral and antennal responses of *Lobesia botrana* (Lepidoptera: Tortricidae) to volatiles from the non-host plant *Schinus molle* L. (Anacardiaceae)

Diego Silva¹, Tomislav Curkovic², and Ricardo Ceballos^{1*}

¹Instituto de Investigaciones Agropecuarias, INIA Quilamapu, Av. Vicente Méndez 515, Chillán, Chile.

*Corresponding author (rceballos@inia.cl).

²Universidad de Chile, Facultad de Ciencias Agronómicas, Av. Santa Rosa 11315, Santiago, Chile.

Received: 5 November 2018; Accepted: 6 December 2018; doi:10.4067/S0718-58392019000100165

ABSTRACT

Lobesia botrana (Lepidoptera: Tortricidae), the grapevine moth, is one of the major pest on grapes. Current control is based on spraying insecticides and/or mating disruption technique, using female sex pheromone, affecting only adult male's conduct. Behavioral active compounds as plants kairomones influence the interaction of phytophagous insects with plants, providing chemical cues to feed or lay eggs. Through electroantennography (EAG) and olfactory experiments, we investigated the role of volatiles of the non-host plant *Schinus molle* L. on behavior of *L. botrana*. Steam distilled essential oil (EO) from *S. molle* leaves was characterized by gas chromatography coupled to mass spectrometry (GC-MS). The most abundant compounds were limonene (17.61%), α -phellandrene (14.32%), β -caryophyllene (8.82%) and δ -cadinene (9.39%). Electrical responses of *L. botrana* at $1 \times 10^2 \mu\text{g mL}^{-1}$ EO were not different from control for females (0.81 mV) and males (1.22 mV). At 1×10^3 and $1 \times 10^4 \mu\text{g mL}^{-1}$ EO we found a significant increment for females to 1.28 and 1.57 mV, and 1.28 and 1.69 mV for males, respectively. In tube-Y olfactometer, at $1 \times 10^2 \mu\text{g mL}^{-1}$ EO the choice did not differ from the control for females ($P = 0.7630$) and males ($P = 0.4054$). Females were attracted to odor source at $1 \times 10^3 \mu\text{g mL}^{-1}$ ($P = 0.0043$) and at $1 \times 10^4 \mu\text{g mL}^{-1}$ ($P = 0.0011$). Males were attracted to the dose of $1 \times 10^3 \mu\text{g mL}^{-1}$ ($P = 0.0278$) and at $1 \times 10^4 \mu\text{g mL}^{-1}$ ($P = 0.0017$). We found that non-host plant volatiles elicited electrophysiological and behavioral responses and that *L. botrana* can discriminate between doses.

Key words: EAG, insect behavior, olfactometer, plant volatiles.

INTRODUCTION

Plant volatiles are essential to phytophagous insects, providing relevant information on hosts search, feeding, egg laying and evading non-host plants (Bruce and Pickett, 2011; Dicke, 2015). Insects' mechanisms to recognize plants volatiles in both host and non-host commonly rely on blends of compounds at specific ratios (Bruce and Pickett, 2011). Non-host plant volatiles (NHPVs) may disrupt the olfactory process in finding the host by a masking, deterrent or repellent effect. The insect repellency elicited by NHPVs has been reported for several species (Zhang and Schlyter, 2010; Bruce and Pickett, 2011). The tea green leafhopper, *Empoasca vitis* (Hemiptera), was repelled by NHPVs of *Corymbia citriodora* (Myrtaceae), *Lavandula pinnata* (Lamiaceae) and *Rosmarinus officinalis* (Lamiaceae) (Zhang et al., 2014). The scolytid *Ips typographus* uses an active avoidance of specific volatiles as 1-hexanol, (*Z*)-3-hexen-1-ol, and (*E*)-2-hexen-1-ol, 3-octanol, and 1-octen-3-ol (Zhang and Schlyter, 2010). Furthermore, pheromone detection is also affected by NHPVs. Terpenoids as NHPVs disrupted male *Plutella xylostella* (Lepidoptera) ability to navigate on pheromone plume and female

calling behavior was adversely affected (Wang et al., 2016). The polyphagous European grapevine moth, *Lobesia botrana* (Lepidoptera), has shown attraction to host plant volatiles (kairomones) and to NHPVs. This may explain *L. botrana* behavioral plasticity (Ioriatti et al., 2011). *Lobesia botrana* displayed oviposition preference for the NHPVs (S)-(-)-perillaldehyde and isoeogonolone, released by *Perilla frutescens* plant (Cattaneo et al., 2014). NHPVs from *Tanacetum vulgare* (Asteraceae) plants have shown inhibited oviposition and mating behavior, and adult longevity reduction on *L. botrana* (Gabel and Thiéry, 1994).

Pepper tree, *Schinus molle* L. (Anacardiaceae), native from the Andean region, has been used as an ancestral source in ethno-medicine (López et al., 2014; Abderrahim et al., 2018). Moreover, its essential oil, mainly from leaves and fruits, has revealed insecticidal and repellent activity to several pests (Wimalaratne et al., 1996; Benzi et al., 2009; Abdel-Sattar et al., 2010; Huerta et al., 2010). *Schinus molle* essential oil (EO) from fruits was an attractant to *Acyrtosiphon pisum* (Homoptera: Aphididae) (Kasmi et al., 2017), and the EO obtained from leaves was repellent to *Blatta orientalis* (Blattodea: Blattidae) (Deveci et al., 2010).

In this study, through electroantennographic and olfactory bioassays, the behavioral activity of females and males *L. botrana* in response to essential oil of *S. molle* was investigated. Gas chromatography coupled to mass spectrometry was used to identify volatile components of the essential oil.

MATERIALS AND METHODS

Insects

Adults of *L. botrana* were obtained from a laboratory colony established at Instituto de Investigaciones Agropecuarias, INIA LA Cruz, Quillota, Chile. The colony is yearly refreshed and larvae are fed *ad libitum* on artificial diet (Southland Products Inc., Lake Village, Arkansas, USA) at 23 ± 1 °C and 16:8 h photoperiod with a 75% RH. To ensure virginity, at pupae stage the individuals are separated by sex in transparent plastic boxes until bioassays.

Essential oil and chemical analyses

In autumn 2017 we collected leaves from ornamental *S. molle* plants in Chillán, Ñuble Region, Chile; 289 g air-dried leaves were milled and boiled for 8 h to obtain the essential oil by hydrodistillation using a type Clevenger apparatus. We added Na_2SO_4 to remove water from samples and then were stored at 8 °C under complete darkness. An aliquot (1 mg mL^{-1} diluted in hexane) of the essential oils (EO) was injected on a gas chromatographer equipped with a capillary column (Rxi-5ms: 5% diphenyl-95% dimethylpolysiloxane; 30 m \times 0.25 mm ID \times 1.0 μm ; Restek Corporation, Bellefonte, Pennsylvania, USA), coupled to a mass spectrometer (GC-MS QP2010 Plus, Shimadzu, Tokyo, Japan). Using helium as carrier gas (1.4 mL min^{-1}) the ionization was performed by electron impact (70 eV) and the acquisition in the mass range from 35 to 500 m/z . The GC oven was set up to 40 °C and then increased at the rate of 7 °C min^{-1} until reach 250 °C. EO volatiles were identified by comparing the mass spectrum with NIST05 library (Standard Reference Data, NIST, Gaithersburg, Maryland, USA) and commercially available standards.

Electroantennographic recordings

We evaluated the sensitivity of *L. botrana* to volatiles from *S. molle* EO with an electroantennographic (EAG) bioassay. The recordings were achieved using a Syntech EAG system (Syntech, Hilversum, The Netherlands). Excised antennae from unmated adults of *L. botrana*, 2 to 4 d old, were mounted between glass electrodes filled with 0.1 M KCl and 0.1% polyvinylpyrrolidone (Ceballos et al., 2015). The antennae were extirpated above the scape with a scalpel. The distal segment was cut with dissection scissors to improve the connection. Three concentrations of EO in hexane (at 1×10^2 , 1×10^3 and 1×10^4 $\mu\text{g mL}^{-1}$), were applied onto a filter paper strip (1 cm \times 10 cm; Whatman N°1 paper), were delivered to the antennal preparation at 30 mL s^{-1} for 2 s using a stimulus controller (CS-55, Syntech, Hilversum, The Netherlands) with a period of at least 60 s for recovery of antennal receptors. Data acquisition and analysis were carried out with EAG version 2014 software (Syntech, Hilversum, The Netherlands). Five antennae, from both males and females, were stimulated three times.

Olfactometric bioassays

The behavioral response of *L. botrana* (2 to 4 d old) to volatiles of *S. molle* was carried out using a glass Y-tube olfactometer (21 cm long with 3 cm id). Glass odor chambers (3 cm id and 15 cm high) were connected to the end of Y-tube arms to deliver the stimulus using filtered air 280 at mL min⁻¹ with a positive pressure air-pump. A volume of 10 µL of diluted EO (1×10², 1×10³ and 1×10⁴ µg mL⁻¹) was loaded onto a filter paper strip (1×7.5 cm), allowing 30 s to solvent evaporation, and then laid inside one odor chamber; hexane was used as control in the opposite odor chamber. One individual at a time was allowed to move freely inside the olfactometer for 6 min. The first choice, made by the insect trespassing beyond 6 cm from the intersection area of the Y-tube to any arm, was considered a positive election. The insects were tested once using a clean olfactometer under artificial fluorescent light (30-40 lux) at 23 ± 1 °C, 50 ± 3% RH (Cattaneo et al., 2014). Thirty replicates for each sex and EO concentration were conducted using a completely randomized experimental design.

Statistical analysis

The mean EAG amplitudes in response to hexane (control) and EO were compared by Student's t test (P < 0.05). To compare the EAG amplitudes elicited by the different concentration of EO volatiles, data were standardized by subtracting the average of the hexane-signal before and after the corresponding stimulus-signal and submitted to ANOVA followed by Tukey's HSD (honestly significant difference) test (P < 0.05) (Ceballos et al., 2015). The proportions of choice in the olfactometric bioassays were analyzed through Pearson's Chi-square test followed by Marascuilo's procedure for comparing multiple proportions (P < 0.05).

RESULTS AND DISCUSSION

Chemical characterization of essential oil of *S. molle*

Most volatile constituents of EO of *S. molle*, obtained by steam distillation of leaves, are terpenes mainly monoterpenes such as limonene (17.61%), α-phellandrene (14.32%), β-pinene (1.55%), β-myrcene (1.66%), sesquiterpenes as β-caryophyllene (8.82%), β-elemene (1.34%) and sesquiterpenoids δ-cadinene (9.39%), and α-amorphene (1.24%) (Table 1). Other studies on the chemical composition of EO from *S. molle* have shown the presence of limonene and

Table 1. Chemical composition of volatile fraction of essential oil of *Schinus molle*.

Compound	Abundance	Insect (behavioral role)*	Reference
	%		
Alcohol			
3-Hexanol	1.95		
Monoterpenes			
α-Pinene	3.25	<i>Cydia strobilella</i> (A) <i>Chilasa epycides</i> (R)	Jakobsson et al., 2016 Omura et al., 2006
Camphene	2.94	<i>Papilio glaucus</i> (A)	Frankfater et al., 2009
β-Pinene	1.55	<i>Cydia strobilella</i> (A)	Jakobsson et al., 2016
β-Myrcene	1.66	<i>Cydia strobilella</i> (A)	Jakobsson et al., 2016
α-Phellandrene	14.32	<i>Thyrinteina arnobia</i> (A)	Batista-Pereira et al., 2006
m-Cymene	3.39	<i>Dysdercus cingulatus</i> (R)	Farine et al., 1992
Limonene	17.61	<i>Lobesia botrana</i> (K) <i>Thyrinteina arnobia</i> (A)	Gabel et al., 1992 Batista-Pereira et al., 2006
Sesquiterpenes			
1,3,6-Heptatriene, 2,5,6-trimethyl	1.55	<i>Chilasa epycides</i> (R)	Omura et al., 2006
β-Elemene	1.34	<i>Papilio paris</i> (R) <i>Papilio polytes</i> (R)	Omura et al., 2006
β-Caryophyllene	8.82	<i>Lobesia botrana</i> (A) <i>Chilasa epycides</i> (R)	Tasin et al., 2005 Omura et al., 2006
Germacrene-B	6.65	<i>Papilio glaucus</i> (A) <i>Chilasa epycides</i> (R)	Frankfater et al., 2009 Omura et al., 2006
Sesquiterpenoids			
α-Amorphene	1.24	<i>Atrophaneura aristolochiae</i> (A)	Honda and Hayashi, 1995
δ-Cadinene	9.39		
Elemol	3.17	<i>Trialeurodes ricini</i> (A)	Hussein et al., 2017

*Behavioral role based on the right column reference: (A) Attractant, (R) repellent and (K) kairomone.

α -phellandrene as common major constituents in leaves in range of 0.79% to 15.6% and 1.3% to 45.6%, respectively (Baser et al., 1997; Benzi et al., 2009; Santos et al., 2009; Deveci et al., 2010; Abderrahim et al., 2018). The composition presented in Table 1, responds to 78.8% of the total composition of the EO (1.08% w/w from 289 g DM).

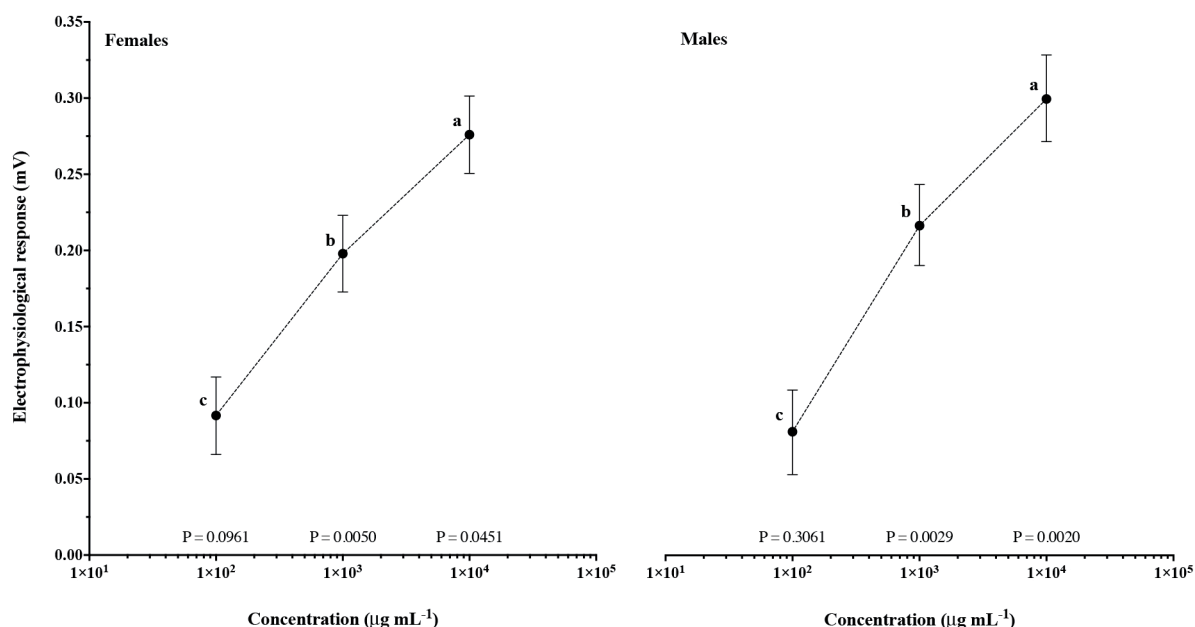
Electroantennographic responses of *L. botrana* to *S. molle* volatiles

Volatiles compounds from EO of *S. molle* elicited a higher electrical amplitude on adults of *L. botrana*, except at the lowest dose evaluated. At $1 \times 10^2 \mu\text{g mL}^{-1}$ the EAG response elicited by the EO was not different from hexane (control) for females ($t = 1.722$; $P = 0.096$; $\text{CI}_{95\%} [-0.017; 0.200]$) and males ($t = 1.044$; $P = 0.305$; $\text{CI}_{95\%} [-0.077; 0.237]$) (Figure 1). However, at $1 \times 10^3 \mu\text{g mL}^{-1}$ we found a significant increment in the EAG responses for females ($t = 3.057$; $P = 0.0050$; $\text{CI}_{95\%} [0.066; 0.332]$) and males ($t = 3.444$; $P = 0.002$; $\text{CI}_{95\%} [0.063; 0.087]$). Similarly, the electrophysiological response at $1 \times 10^4 \mu\text{g mL}^{-1}$ was large for females ($t = 2.099$; $P = 0.045$; $\text{CI}_{95\%} [0.007; 0.659]$) and males ($t = 3.498$; $P = 0.002$; $\text{CI}_{95\%} [0.123; 0.470]$). Furthermore, the electrical amplitude registered from the antennas in response to the EO showed an increment with dose for both females ($F = 53.3$; $P < 0.001$; $\eta^2 = 0.722$) and males ($F = 61.7$; $P < 0.001$; $\eta^2 = 0.746$) (Figure 1).

Behavioral response of *L. botrana* to *S. molle* EO volatiles

In Y-tube olfactometer females and males of *L. botrana* were significantly attracted to *S. molle* volatiles, except at the lowest studied dose (Figure 2). At $1 \times 10^2 \mu\text{g mL}^{-1}$ the frequency of choice did not differ noticeably from the control for females ($X^2 = 0.09$; $P = 0.7630$; $\text{CI}_{95\%} [0.0951; 0.3731]$) and males ($\text{CI}_{95\%} [0.1418; 0.4445]$; $X^2 = 0.69$; $P = 0.4054$). Females were notably attracted to odor source at $1 \times 10^3 \mu\text{g mL}^{-1}$ ($\text{CI}_{95\%} [0.4551; 0.7813]$; $X^2 = 8.17$; $P < 0.0043$) and at $1 \times 10^4 \mu\text{g mL}^{-1}$ ($\text{CI}_{95\%} [0.4878; 0.8077]$; $X^2 = 10.67$; $P < 0.0011$). Similarly, males were attracted to dose of $1 \times 10^3 \mu\text{g mL}^{-1}$ ($\text{CI}_{95\%} [0.4232; 0.7541]$; $X^2 = 4.84$; $P = 0.0278$) and at $1 \times 10^4 \mu\text{g mL}^{-1}$ ($\text{CI}_{95\%} [0.5212; 0.8334]$; $X^2 = 9.85$; $P = 0.0017$).

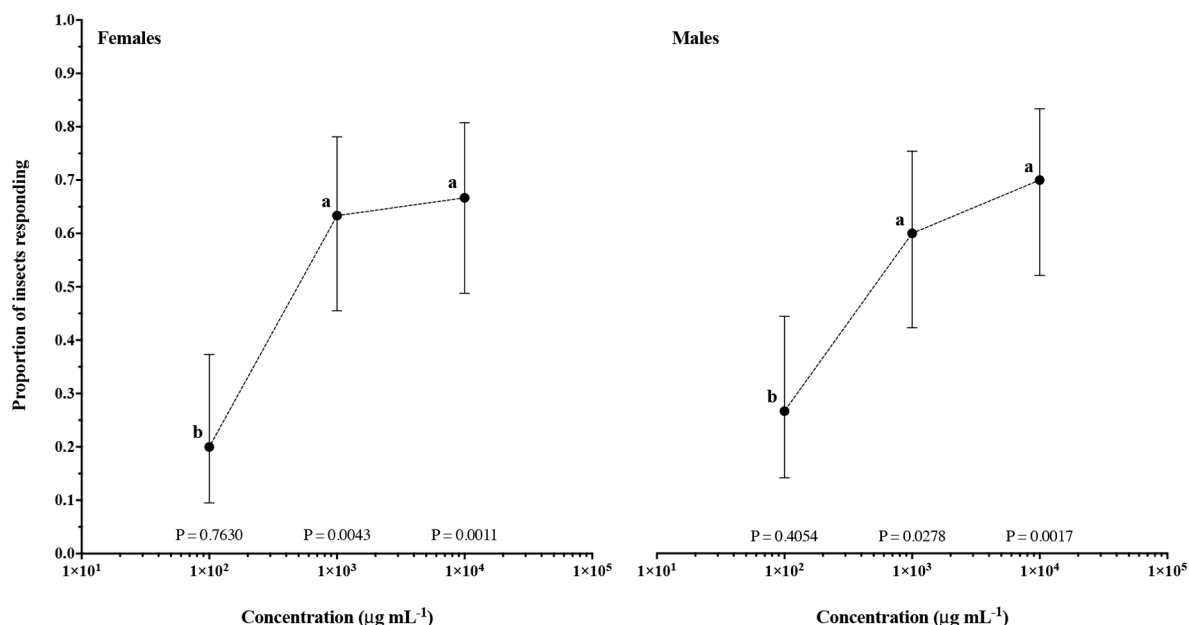
Figure 1. Electroantennographic amplitude of *Lobesia botrana* (average and $\text{CI}_{95\%}$) to different dose of *Schinus molle* essential oil diluted in hexane.



Means sharing a letter do not differ significantly according Tukey's test ($P < 0.05$). Data were standardized by subtracting the average of the immediately prior and afterward controls to the essential oil signal. $P < 0.05$, according Student's t -test, next to X-axis indicate significant differences between essential oil and hexane (control) for each dose.

$\text{CI}_{95\%}$: Confidence interval 95%.

Figure 2. Behavioral response of *Lobesia botrana* (proportion and CI_{95%}) to different dose of *Schinus molle* essential oil diluted in hexane.



Proportions sharing a letter do not differ significantly according Marascuilo's procedure ($P < 0.05$). $P < 0.05$, according Chi-square test, next to X-axis indicate significant differences between essential oil and hexane (control) for each dose.
 CI_{95%}: Confidence interval 95%.

Most studies on chemical constituents of *S. molle* have been oriented to its medicinal use. However, insecticidal, repellent and fumigant activity for *S. molle* has been found for different herbivorous insects (Chirino et al., 2001; Ruffinengo et al., 2005; Abdel-Sattar et al., 2010; Devci et al., 2010). On the other hand, the electroantennographic responses of *L. botrana* to host-plants volatiles have been extensively studied on *Daphne gnidium*, the putative ancestral host in Europe and *Vitis vinifera* (Tasin et al., 2005; Maher and Thiéry, 2006; von Arx et al., 2011). *Lobesia botrana* relation with non-host plants, mediated by volatiles compounds, has been studied on *Tanacetum vulgare* and *Perilla frutescens* (Cattaneo et al., 2014). The characterization of volatiles compounds emitted by *T. vulgare* and *P. frutescens* showed that *p*-cymene, *d*-limonene, α -thujene, α -thujone, β -thujone, thujyl alcohol, terpine-4-ol, *Z*-verbenol, piperitone, (*S*)-(-)-perillaldehyde and isogomaketone were electrophysiological active on both males and females *L. botrana* (Gabel et al., 1992; Masante-Roca et al., 2007; Cattaneo et al., 2014). However, to our knowledge, literature on EO of *S. molle* and behavioral response of *L. botrana* seems insufficient. Our findings reveal that volatiles compounds from EO of *S. molle* stimulated olfactory receptors and induced electrophysiological responses on both females and males *L. botrana*. Additionally, we found a dose-dependent relationship between the amplitude of antennal deflection and the attraction behavior exhibited in the Y-tube olfactometer. Experiments on plant volatile perception by *L. botrana* allowed to find *E*-(β)-caryophyllene, *E*-(β)-farnesene and *E*-(4,8)-dimethyl-(1,3,7)-nonatriene (DMNT) as physiologically active compounds used as chemical cues in host finding and oviposition site selection (Tasin et al., 2006; Ioriatti et al., 2011).

CONCLUSIONS

The volatile profile of the essential oil (EO) of *Schinus molle*, obtained by steam hydrodistillation of leaves, was electrophysiological and behavioral active on *Lobesia botrana*. At concentration of 1 × 10³ and 1 × 10⁴ µg mL⁻¹ EO was behavioral active to females and males *L. botrana*. Our results suggest that composition and compounds ratio in the volatile compounds profile are responsible for the attraction of females and males *L. botrana*.

ACKNOWLEDGEMENTS

Financial funding was provided by Instituto de Investigaciones Agropecuarias, INIA project 502655.

REFERENCES

- Abdel-Sattar, E., Zaitoun, A.A., Farag, M.A., Gayed, S.H., and Harraz, F.M. 2010. Chemical composition, insecticidal and insect repellent activity of *Schinus molle* L. leaf and fruit essential oils against *Trogoderma granarium* and *Tribolium castaneum*. *Natural Product Research* 24:226-235. doi:10.1080/14786410802346223.
- Abderrahim, A., Belhamek, K., Chalard, P., and Figuéredo, G. 2018. Correlation between chemical composition and antioxidant activity of the essential oils from leaves and berries of *Schinus molle* L. growing in two areas of Bejaia (Algeria). *Journal of Food Measurement and Characterization* 12:1123-1134. doi:10.1007/s11694-018-9727-2.
- Baser, K.H.C., Kürkcüoğlu, M., Demircakmak, B., Uülker, N., and Beis, S.H. 1997. Composition of the essential oil of *Schinus molle* L. grown in Turkey. *Journal of Essential Oil Research* 9:693-696. doi:10.1080/10412905.1997.9700813.
- Batista-Pereira, L.G., Fernandes, J.B., Correa, A.G., da Silva, M.F.G.F., and Vieira, P.C. 2006. Electrophysiological responses of eucalyptus brown looper *Thyrineina arnobia* to essential oils of seven *Eucalyptus* species. *Journal of the Brazilian Chemical Society* 17:555-561. <https://dx.doi.org/10.1590/S0103-50532006000300019>.
- Benzi, V., Stefanazzi, N., and Ferrero, A.A. 2009. Biological activity of essential oils from leaves and fruits of pepper tree (*Schinus molle* L.) to control rice weevil (*Sitophilus oryzae* L.) *Chilean Journal of Agricultural Research* 69:154-159. doi:10.4067/S0718-58392009000200004.
- Bruce, T.J., and Pickett, J.A. 2011. Perception of plant volatile blends by herbivorous insects-finding the right mix. *Phytochemistry* 72:1605-1611. doi:10.1016/j.phytochem.2011.04.011.
- Cattaneo, A.M., Bengtsson, J.M., Borgonovo, G., Bassoli, A., and Anfora, G. 2014. Response of the European grapevine moth *Lobesia botrana* to somatosensory-active volatiles emitted by the non-host plant *Perilla frutescens*. *Physiological Entomology* 39:229-236. doi:10.1111/phen.12067.
- Ceballos, R., Fernández, N., Zúñiga, S., and Zapata, N. 2015. Electrophysiological and behavioral responses of pea weevil *Bruchus pisorum* L. (Coleoptera: Bruchidae) to volatiles collected from its host *Pisum sativum* L. *Chilean Journal of Agricultural Research* 75:202-209. doi:10.4067/s0718-58392015000200009.
- Chirino, M., Cariac, M., y Ferrero, A.A. 2001. Actividad insecticida de extractos crudos de drupas de *Schinus Molle* L. (Anacardiaceae) sobre larvas neonatas de *Cydia Pomonella* L. (Lepidoptera- Tortricidae). *Boletín de Sanidad Vegetal Plagas* 27(3):305-314.
- Deveci, O., Sukan, A., Tuzun, N., and Kocabas, E.E.H. 2010. Chemical composition, repellent and antimicrobial activity of *Schinus molle* L. *Journal of Medicinal Plants Research* 4:2211-2216. <https://doi.org/10.5897/JMPR10.326>.
- Dicke, M. 2015. Herbivore-induced plant volatiles as a rich source of information for arthropod predators: fundamental and applied aspects. *Journal of the Indian Institute of Science* 95:35-42.
- Farine, J.P., Bonnard, O., Brossut, R., and Le Quere, J.L. 1992. Chemistry of pheromonal and defensive secretions in the nymphs and the adults of *Dysdercus cingulatus* Fabr. (Heteroptera, Pyrrhocoridae). *Journal of Chemical Ecology* 18:65-76. doi:10.1007/BF00997165.
- Frankfater, C., Tellez, M.R., and Slaterry, M. 2009. The scent of alarm: ontogenetic and genetic variation in the osmeterial gland chemistry of *Papilio glaucus* (Papilionidae) caterpillars. *Chemoecology* 19:81-96. doi:10.1007/s00049-009-0013-y.
- Gabel, B., and Thiéry, D. 1994. Non-host plant odor (*Tanacetum vulgare*; Asteracea) affects the reproductive behavior of *Lobesia botrana* Den. et Schiff (Lepidoptera: Tortricidae). *Journal of Insect Behavior* 7:149-157. doi:10.1007/BF01990077.
- Gabel, B., Thiery, D., Suchy, V., Marion-Poll, F., Hradsky, P., and Farkas, P. 1992. Floral volatiles of *Tanacetum vulgare* L. attractive to *Lobesia botrana* Den. et Schiff. females. *Journal of Chemical Ecology* 18:693-701. doi:10.1007/BF00994607.
- Honda, K., and Hayashi, N. 1995. Chemical nature of larval osmeterial secretions of papilionid butterflies in the genera *Parnassius*, *Sericinus* and *Pachliopta*. *Journal of Chemical Ecology* 21:859-867. doi:10.1007/BF02033466.
- Huerta, A., Chiffelle, I., Puga, K., Azúa, F., and Araya, J.E. 2010. Toxicity and repellence of aqueous and ethanolic extracts from *Schinus molle* on elm leaf beetle *Xanthogaleruca luteola*. *Crop Protection* 29:1118-1123. doi:10.1016/j.cropro.2010.04.010.
- Hussein, H.S., Salem, M.Z.M., and Soliman, A.M. 2017. Repellent, attractive, and insecticidal effects of essential oils from *Schinus terebinthifolius* fruits and *Corymbia citriodora* leaves on two whitefly species, *Bemisia tabaci*, and *Trialeurodes ricini*. *Scientia Horticulturae* 216:111-119. <https://doi.org/10.1016/j.scienta.2017.01.004>.
- Ioriatti, C., Anfora, G., Tasin, M., De Cristofaro, A., Witzgall, P., and Lucchi, A. 2011. Chemical ecology and management of *Lobesia botrana* (Lepidoptera: Tortricidae). *Journal of Economic Entomology* 104:1125-1137. doi:10.1603/ec10443.
- Jakobsson, J., Svensson, G.P., Löfstedt, C., and Anderbrant, O. 2016. Antennal and behavioural responses of the spruce seed moth, *Cydia strobilella*, to floral volatiles of *Norway spruce*, *Picea abies*, and temporal variation in emission of active compounds. *Entomologia Experimentalis et Applicata* 160:209-218. doi:10.1111/eea.12474.

- Kasmi, A., Hammami, M., Raelison, E.G., Abderrabba, M., Bouajila, J., and Ducamp, C. 2017. Chemical composition and behavioral effects of five plant essential oils on the green pea aphid *Acyrtosiphon pisum* (Harris) (Homoptera: Aphididae). *Chemistry and Biodiversity* 14(5):e1600464. doi:10.1002/cbdv.201600464.
- López, A., Castro, S., Andina, M.J., Ures, X., Munguía, B., Llabot, J.M., et al. 2014. Insecticidal activity of microencapsulated *Schinus molle* essential oil. *Industrial Crops and Products* 53:209-216. doi:10.1016/j.indcrop.2013.12.038.
- Maher, N., and Thiéry, D. 2006. *Daphne gnidium*, a possible native host plant of the European grapevine moth *Lobesia botrana*, stimulates its oviposition. Is a host shift relevant? *Chemoecology* 16:135-144. doi:10.1007/s00049-006-0339-7.
- Masante-Roca, I., Anton, S., Delbac, L., Dufour, M.-C., and Gadenne, C. 2007. Attraction of the grapevine moth to host and non-host plant parts in the wind tunnel: effects of plant phenology, sex, and mating status. *Entomologia Experimentalis et Applicata* 122:239-245. doi:10.1111/j.1570-7458.2006.00510.x.
- Omura, H., Honda, K., and Feeny, P. 2006. From terpenoids to aliphatic acids: Further evidence for late-instar switch in osmeterial defense as a characteristic trait of swallowtail butterflies in the tribe *Papilionini*. *Journal of Chemical Ecology* 32:1999-2012. doi:10.1007/s10886-006-9124-x.
- Ruffinengo, S., Eguaras, M., Floris, I., Faverin, C., Bailac, P., and Ponzi, M. 2005. LD50 and repellent effects of essential oils from Argentinian wild plant species on *Varroa destructor*. *Journal of Economic Entomology* 98:651-655. doi:10.1603/0022-0493-98.3.651.
- Santos, A.C.A.d., Rossato, M., Agostini, F., Serafini, L.A., Santos, P.L.d., Molon, R., et al. 2009. Chemical composition of the essential oils from leaves and fruits of *Schinus molle* L. and *Schinus terebinthifolius* Raddi from Southern Brazil. *Journal of Essential Oil Bearing Plants* 12:16-25. doi:10.1080/0972060X.2009.10643686.
- Tasin, M., Anfora, G., Ioriatti, C., Carlin, S., De Cristofaro, A., Schmidt, S., et al. 2005. Antennal and behavioral responses of grapevine moth *Lobesia botrana* females to volatiles from grapevine. *Journal of Chemical Ecology* 31:77-87. doi:10.1007/s10886-005-0975-3.
- Tasin, M., Backman, A.C., Bengtsson, M., Ioriatti, C., and Witzgall, P. 2006. Essential host plant cues in the grapevine moth. *Naturwissenschaften* 93:141-144. doi:10.1007/s00114-005-0077-7.
- von Arx, M., Schmidt-Busser, D., and Guerin, P.M. 2011. Host plant volatiles induce oriented flight behaviour in male European grapevine moths, *Lobesia botrana*. *Journal of Insect Physiology* 57:1323-1331. doi:10.1016/j.jinsphys.2011.06.010.
- Wang, F., Deng, J., Schal, C., Lou, Y., Zhou, G., Ye, B., et al. 2016. Non-host plant volatiles disrupt sex pheromone communication in a specialist herbivore. *Scientific Reports* 6:32666-32666. doi:10.1038/srep32666.
- Wimalaratne, P.D., Slessor, K.N., Borden, J.H., Chong, L.J., and Abate, T. 1996. Isolation and identification of house fly, *Musca domestica* L., repellents from pepper tree, *Schinus molle* L. *Journal of Chemical Ecology* 22:49-59. doi:10.1007/BF02040199.
- Zhang, Z., Luo, Z., Gao, Y., Bian, L., Sun, X., and Chen, Z. 2014. Volatiles from non-host aromatic plants repel tea green leafhopper *Empoasca vitis*. *Entomologia Experimentalis et Applicata* 153:156-169. doi:10.1111/eea.12236.
- Zhang, Q.H., and Schlyter, F. 2010. Inhibition of predator attraction to kairomones by non-host plant volatiles for herbivores: A bypass-trophic signal. *PLOS ONE* 5(6):e11063. doi:10.1371/journal.pone.0011063.