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ARTHROPODS AND MEDICAL ENTOMOLOGY - ORIGINAL PAPER

Chemical composition, *Aedes* mosquito larvicidal activity, and repellent activity against *Triatoma rubrofasciata* of *Severinia monophylla* leaf essential oil

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Abstract

Aedes aegypti and *Ae. albopictus* are key vectors in the spread of arboviruses such as dengue, chikungunya, yellow fever, and Zika. *Triatoma rubrofasciata* is an "assassin bug" whose populations and association with humans have dramatically increased and may represent a serious health concern. Control of insect vectors is a logical course of action to prevent the spread of these insect-borne infections. This work presents the leaf essential oil composition, mosquito larvicidal activities, and insect-repellent activity of *Severinia monophylla*. The essential oil of *S. monophylla* from Vietnam was obtained by hydrodistillation and analyzed by gas chromatography and mass spectrometry. The major components were sabinene, β-caryophyllene, bicyclogermacrene, germacrene D, (*E*)-nerolidol, globulol, and linalool. The leaf essential oil showed remarkable larvicidal activity against *Ae. aegypti* with LC_{50} (48 h) of 7.1 μg/mL and *Ae. albopictus* with LC_{50} (48 h) of 36 μg/mL. The essential oil also showed repellent activity on *T. rubrofasciata* at a concentration of 0.5%.

Keywords Dengue fever · Trypanosomiasis · Sabinene · β-Caryophyllene · Vector control · Vietnam

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Introduction

Aedes mosquitoes are important insect vectors of arboviruses such as dengue (Gubler 1998), yellow fever (Barrett and Higgs 2007), chikungunya (Dhimal et al. 2015), and Zika (Benelli and Mehlhorn 2016). Dengue fever is widespread in Vietnam and epidemics are becoming more frequent and widespread (Quyen et al. 2018). In addition, chikungunya and Zika infections have recently been reported in Vietnam (Quyen et al. 2017).

Triatoma rubrofasciata (De Geer) is a pan-tropical reduviid "assasin bug" most commonly found in Asia, Oceania, Africa, and Central America (Claver and Yaqub 2015), but *T. rubrofasciata* populations and a propensity for feeding on humans have been increasing in Vietnam (Dujardin et al. 2015). *Triatoma rubrofasciata* has been associated with black rats, *Rattus rattus* (L.), and is the vector of the rat trypanosome, *Trypanosoma conorhini* (Donovan). Human infections with *T. conorhini* are not yet known, but *T. rubrofasciata* can serve as the host of *Trypanosoma cruzi* (Chagas), the causative agent of Chagas disease (Patterson et al. 2001).

Insecticide resistance in *Aedes* mosquitoes has been increasing worldwide and could lead to a re-emergence of

mosquito-borne diseases (Vontas et al. 2012; Liu 2015; Smith et al. 2016). Furthermore, insecticide resistance is emerging in many insect vectors of human diseases (Hemingway and Ranson 2000; Naqqash et al. 2016), including triatomids (Lardeux et al. 2010; Mougabure-Cueto and Picollo 2015). In addition to insecticide resistance, environmental impacts of synthetic insecticides have been a chronic problem for several decades (Kamrin 1997; Goulson 2013). Recent reports have pointed out the consequences of insecticide use on non-target organisms such as imidacloprid on honey bee (*Apis mellifera*) (Suchail et al. 2000), damselfly (*Ischnura senegalensis*) (Sugita et al. 2018), fathead minnow (*Pimephales promelas*), or the amphipod (*Hyalella azteca*) (Lanteigne et al. 2015). There is a clear need for complementary vector control methods and essential oils may provide renewable and environmentally safe alternatives to synthetic insecticides (Silva et al. 2008; Benelli 2015; Masetti 2016; Pavela and Benelli 2016).

Severinia monophylla Tanaka is a perennial shrub belonging to the Rutaceae (Wunderlin 1998). The mature plant is 1–2 m tall with green branchlets, leaves, and spines. The spines are erect and 3–4 cm long. The leaves are simple with short petiole. The petioles are about 3–4 mm long (Pham 2002). The leaf blades are elliptic, ovate, or obovate with size about 3–5 cm long and 2–3 cm wide, cuneate to rounded or cordate at the base, rounded or obcordate at the apex, entire or slightly sinuate margins, with oil glands. The secondary veins are several and reach up to the margins. The inflorescences are axillary with 1–6 white flowers. The fruits are 1 cm in diameter, green when young, and black when ripe, with two seeds. In Vietnam, the plant fruits appear from November to January. *Severinia monophylla* is distributed from northern to central Vietnam. The leaves and branchlets of *Paramignya monophylla* are used as a traditional herbal medicine in Vietnam to treat fever, sore throat, and poisonous snakebite (Do 2004).

There has been some debate regarding the nomenclature and speciation of *Severinia monophylla* and several suggested synonyms have appeared, including *Severinia monophylla* Tanaka, *Atalantia buxifolia* (Poir.) Oliv. ex Benth., *Severinia buxifolia* (Poir.) Ten., *Atalantia monophylla* DC., *Paramignya monophylla* Wight, and *Luvunga monophylla* (DC.) Mabb. (Tanaka 1931; Airy-Shaw 1939; Nair and Barrie 1995; Brummitt 1998). Many authors had proposed to combine or reject names and all of them had strong scientific evidences. Currently, Kew Royal Botanic Gardens (Royal Botanic Gardens 2018) and Missouri Botanical Garden (Missouri Botanical Garden 2018) have accepted *Severinia monophylla* Tanaka as the correct species name and without any synonyms (Wunderlin 1998). The description of this plant (see above) is based on our specimens and Pham (Pham 2002). In this work, we present the essential oil compositions of *S. monophylla* collected from two different locations, Hoa Vang and Hoa Khanh Nam, Da Nang city, Vietnam, the mosquito larvicidal activities against *Aedes aegypti* (L.) and *Ae. albopictus* (Skuse), and the nymphal-repellent activities against *Triatoma rubrofasciata*. To our knowledge, there are no previous reports on the insecticidal or other bioactivity properties of the essential oil from this plant.

Materials and methods

Plant material

Mature leaves of *Severinia monophylla* were harvested from plants growing in Hoa Vang district, Da Nang city (16°00′ 44.2″ N, 108°05′17.9″ E), and Hoa Khanh Nam district, Da Nang city (16°02′56.4″ N, 108°09′36.5″ E), in April 2018. The plants were identified by Dr. Pham Van The, and a voucher specimen (PVTDN02-2017) has been deposited with the Herbarium of Hanoi University (HNU) of Science, Vietnam National University. Plant materials were air-dried at room temperature (≈ 25 °C), the dried plant materials were shredded and hydrodistilled for 4 h using a Clevenger-type apparatus.

Gas chromatography-mass spectrometry

Each of the essential oils of *Severinia monophylla* was analyzed by GC-MS using a Shimadzu GC-MS-QP2010 Ultra operated in the electron impact (EI) mode (electron energy = 70 eV), scan range = 40–400 amu, scan rate = 3.0 scans/s, and GC-MS solution software. The GC column was a ZB-5 fused silica capillary column with a (5% phenyl)-polymethylsiloxane stationary phase and a film thickness of 0.25 μm. The carrier gas was helium with a column head pressure of 552 kPa and flow rate of 1.37 mL/min. Injector temperature was 250 °C and the ion source temperature was 200 °C. The GC oven temperature program was programmed for 50 °C initial temperature, temperature increased at a rate of 2 °C/min to 260 °C. A 5% *w/v* solution of the sample in CH_2Cl_2 was prepared and 0.1 μL was injected with a splitting mode (30:1). Identification of the oil components was based on their retention indices determined by reference to a homologous series of *n*-alkanes (C_8-C_{40}), and by comparison of their mass spectral fragmentation patterns with those reported in the literature (Adams 2007), and stored in our in-house Sat-Set library (Satyal 2015).

Mosquito larvicidal assay

Larvae of *Ae. aegypti* were collected from a mosquito colony maintained at the Laboratory of Parasitology and Entomology of Duy Tan University, Da Nang, Vietnam. For the assay, aliquots of the essential oil of *S. monophylla* (Hoa Vang) dissolved in DMSO (1% stock solution) were placed in a 500-mL

beaker and added to water that contained 25 larvae (third and early fourth instar). With each experiment, a set of controls using DMSO was also run for comparison. Mortality was recorded after 24 h and again after 48 h of exposure during which no nutritional supplement was added. The experiments were carried out 25 ± 2 °C. Each test was conducted with four replicates with four concentrations (50, 25, 12.5, and 5.0 μg/mL). Median lethal concentrations (LC_{50}) were determined by log-probit analysis using XLSTAT v. 2018.5 (Addinsoft, Paris, France). Larvicidal activities against *Ae. albopictus* (reared from wild populations) were determined similarly with concentrations of 100, 50, 25, and 12.5 μg/mL.

Repellent activity against *Triatoma rubrofasciata*

The first and second nymphal instars of *Triatoma rubrofasciata*, obtained from the Laboratory of Parasitology and Entomology of Duy Tan University, Da Nang, Vietnam, were used for the assays. The insect-repellent assays were carried out following the method of Ferrero and co-workers (Ferrero et al. 2006). Circular white filter paper #1 disks (9 cm in diameter) were cut in half. One half was treated with 0.5 mL of acetone (control) and the other half was treated with 0.5 mL of a 0.5% (*w*/*v*) solution of *S. monophylla* leaf essential oil (Hoa Vang) in acetone. After evaporation of the solvent, the two halves were fitted together and placed in a Petri dish. Five nymphs were place in the center of each Petri dish (four replicates) and their distribution was recorded after 1 h, 24 h, 48 h, and 72 h. Insect repellency is expressed as % repellency (PR) = $[(100 \times N_{UT} / N_{total}) - 50] \times 2$, where N_{UT} is the number of insects occupying the untreated filter paper and N_{total} is the total number of insects (Lima et al. 2011).

Data analysis

The acute larvicidal effects on *Ae. albopictus* and *Ae. aegypti* were recorded 24 h and 48 h after treatment. The data obtained were subjected to log-probit analysis (Finney 2009) to obtain LC_{50} values, LC_{90} values, 95% confidence limits, and chi-square values using XLSTAT v. 2018.5 (Addinsoft, Paris, France). Insect repellency of *T. rubrofasciata* is expressed as % repellency (PR) = $[(100 \times N_{UT} / N_{total}) - 50] \times 2$, where N_{UT} is the number of insects occupying the untreated filter paper and N_{total} is the total number of insects (Lima et al. 2011).

Results and discussion

Chemical composition

The leaf essential oils of *S. monophylla* were obtained in 0.53 and 0.60% yields, respectively. The essential oil compositions are presented in Table 1. The major components in *S. monophylla* leaf oils were sabinene (19.0 and 22.6%), β-caryophyllene (14.8 and 10.9%), bicyclogermacrene (8.9 and 9.2%), germacrene D (7.0 and 7.6%), (*E*)-nerolidol (4.3 and 6.2%), globulol (3.5 and 6.4%), and linalool (1.1 and 6.5%). Monoterpene (29.6 and 35.4%) and sesquiterpene (44.9 and 33.6%) hydrocarbons were the major essential oil classes. A total of 101 compounds were identified in the essential oils accounting for 99.1% and 100% of the compositions. The compositions of *S. monophylla* leaf oil in this study are markedly different from that reported previously by Tan Duc and co-workers (Duc et al. 2008). These workers found linalool, α-terpineol, linalyl acetate, and nerolidyl acetate in the leaf essential oil.

There have been several reports on the leaf essential oil compositions of *Atalantia monophylla*. Das and Swamy characterized *A. monophylla* leaf oil from Tamil Nadu, southern India, and found (*E*)-asarone (28.8%), sabinene (13.2%), methyl eugenol (12.7%), 1,2-dimethoxy-4-(2-methoxyethenyl)benzene (11.6%), and β-pinene (5.3%) to be the major components (Das and Swamy 2013). Nattudurai and co-workers also characterized *A. monophylla* leaf oil from Tamil Nadu, India, and reported eugenol (19.8%), sabinene (19.6%), 1,2-dimethoxy-4-(2-methoxyethenyl)benzene (9.8%), (*Z*)-asarone (7.0%), and methyl eugenol (5.5%) as the major components (Nattudurai et al. 2017). Thirugnanasampandan et al. reported sabinene (23.8%), (*E*)-asarone (19.6%), β-pinene (13.4%), and myrcene (10.4%) as the predominant constituents in the leaf oil of *A. monophylla* from the Western Ghats of southern India (Thirugnanasampandan et al. 2017).

Severinia buxifolia leaf essential oil from southern California contained α-santalene (24.4%), (*E*)-β-santalol (20.8%), limonene (18.9%), germacrene B (10.6%), and β-caryophyllene (6.7%) as the major components (Scora and Ahmed 1994). Similarly, the leaf oil of *S. buxifolia* from western Cuba contained (*E*)-β-santalol (26.9%), α-santalene (22.2%), bicyclogermacrene (5.3%), and spathulenol (5.2%) as the major components (Pino et al. 2006). *Severinia buxifolia* leaf oil from Florida was rich in α-santalene (34.6%), β-caryophyllene (17.3%), (Z)-α-santalol (13.7%), bicyclogermacrene (6.6%), and β-santalene (5.1%) (Hijaz et al. 2016). A seasonal variation study of the leaf essential oil of *S. buxifolia* from Gaza, Egypt, showed that limonene (19.2–35.5%), (*Z*)-α-santalol (13.7–29.2%), α-santalene (8.1–20.9%), γ-elemene (5.5–7.8%), and β-caryophyllene (3.0–5.1%) dominated the composition (2018) (Safaa et al. 2018).

Phenylpropanoids are conspicuous components of *A. monophylla* leaf essential oils, but are absent in *S. monophylla*; santalene and santalols are abundant in *S. buxifolia*, but are absent in *S. monophylla*. Therefore, the chemical compositions of the leaf essential oils of

Table 1 Chemical compositions of *Severinia monophylla* leaf essential oils from Hoa Khanh Nam and Hoa Vang, Vietnam

RI[a]	RI[b]	Compound	Percent composition	
			Hoa Khanh Nam	Hoa Vang
924	924	α-Thujene	0.1	tr
931	932	α-Pinene	0.4	0.7
971	969	Sabinene	19.0	22.6
976	974	β-Pinene	2.3	4.2
987	988	Myrcene	1.4	1.2
1002	998	Octanal	0.1	–
1005	1002	α-Phellandrene	0.3	0.3
1016	1014	α-Terpinene	0.3	0.2
1023	1020	*p*-Cymene	0.2	0.2
1028	1024	Limonene	2.9	3.2
1029	1025	β-Phellandrene	1.5	2.0
1033	1032	(*Z*)-β-Ocimene	tr	–
1044	1044	(*E*)-β-Ocimene	0.2	–
1056	1054	γ-Terpinene	0.8	0.8
1068	1065	*cis*-Sabinene hydrate	tr	–
1073	1060	(2*E*)-Octen-1-ol	tr	–
1084	1086	Terpinolene	0.1	tr
1098	1095	Linalool	1.1	6.5
1103	1100	Nonanal	0.1	–
1168	1163	(2*E*)-Nonen-1-ol	1.5	2.6
1173	1165	1-Nonanol	tr	–
1179	1174	Terpinen-4-ol	0.4	1.2
1204	1201	Decanal	2.2	1.9
1209	1211	Octyl acetate	0.2	–
1277	1268	(2*E*)-Decen-1-ol	0.1	–
1306	1305	Undecanal	0.1	–
1331	–	Bicycloelemene	0.7	0.6
1334	1335	δ-Elemene	tr	–
1346	1345	α-Cubebene	0.2	tr
1372	1367	1-Undecanol	0.1	–
1374	1374	α-Copaene	0.3	tr
1376	1379	Geranyl acetate	0.1	tr
1383	1387	β-Bourbonene	1.0	1.0
1386	1387	β-Cubebene	0.2	–
1388	1389	β-Elemene	1.9	0.7
1408	1408	Dodecanal	1.0	0.6
1418	1417	β-Caryophyllene	14.8	10.9
1429	1430	β-Copaene	0.3	tr
1431	1432	*trans*-α-Bergamotene	0.1	tr
1437	1439	Aromadendrene	0.1	–
1443	1448	*cis*-Muurola-3,5-dine	0.1	tr
1448	1451	*trans*-Murrola-3,5-diene	0.2	–
1450	1454	(*E*)-β-Farnesene	tr	0.4
1454	1452	α-Humulene	3.5	2.5
1459	1458	Alloaromadendrene	0.7	tr
1461	1465	*cis*-Muurola-4(14),5-diene	0.1	–
1467	1464	9-*epi*-β-Caryophyllene	0.2	–

Table 1 (continued)

RI[a]	RI[b]	Compound	Percent composition	
			Hoa Khanh Nam	Hoa Vang
1471	1461	*cis*-Cadina-1(6),4-diene	0.2	–
1474	1475	*trans*-Cadina-1(6),4-diene	0.1	–
1481	1484	Germacrene D	7.0	7.6
1486	1496	Viridiflorene (Ledene)	0.2	–
1488	1489	β-Selinene	0.1	–
1490	1493	*trans*-Muurola-4(14),5-diene	0.7	–
1492	1491	(*E*)-Methylisoeugenol	0.1	–
1495	1500	Bicyclogermacrene	8.9	9.2
1497	1500	α-Muurolene	0.2	tr
1506	1505	β-Bisabolene	0.1	–
1511	1511	δ-Amorphene	0.1	–
1514	1514	Cubebol	0.3	0.3
1516	1522	δ-Cadinene	1.2	0.7
1520	1521	*trans*-Calamenene	0.9	tr
1531	1533	*trans*-Cadine-1,4-diene	0.8	tr
1535	1537	α-Cadinene	0.1	–
1550	1551[c]	Isocaryophyllene oxide	0.1	–
1560	1561	(*E*)-Nerolidol	4.3	6.2
1567	1566[c]	1,5-Epoxysalvial-4(14)-ene	tr	–
1569	1567	Palustrol	0.1	–
1571	–	Sesquirosefuran	0.1	–
1576	1577	Spathulenol	2.6	3.7
1581	1582	Caryophyllene oxide	1.6	1.2
1585	1590	Globulol	3.5	6.4
1593	1592	Viridiflorol	0.9	–
1602	1602	Ledol	1.3	0.4
1608	1608	Humulene epoxide II	0.2	tr
1621	1618	Junenol	tr	–
1624	1630	Muurola-4,10(14)-dien-1β-ol	0.1	–
1626	1627	1-*epi*-Cubenol	0.3	–
1631	1629[c]	*iso*-Spathulenol	0.2	–
1632	1639	*allo*-Aromadendrene epoxide	0.1	–
1635	1639	Caryophylla-4(12),8(13)-dien-5β-ol	0.3	tr
1640	1644	α-Muurolol	0.3	tr
1642	1640	τ-Muurolol	0.1	–
1645	1647	Muurola-4,10(14)-dien-1α-ol	0.1	–
1654	1652	α-Cadinol	0.3	tr
1657	1658	Selin-11-en-4α-ol	0.1	–
1660	–	13-*nor*-Eremophil-1(10)-en-11-one	tr	–
1668	1668	14-Hydroxy-9-*epi*-β-caryophyllene	0.1	–
1682	–	Germacra-4(15),5,10(14)-trien-1β-ol	0.2	tr
1685	1685	Germacra-4(15),5,10(14)-trien-1α-ol	0.1	–
1692	1688	Shyobunol	tr	–
1698	1699	*epi*-Nootkatol	tr	–
1706	1713	(2*E*,6*Z*)-Farnesal	tr	–
1712	1714	(2*E*,6*Z*)-Farnesol	0.1	–
1716	–	Eudesma-4,11-dien-2-ol	tr	–

Table 1 (continued)

RI[a]	RI[b]	Compound	Percent composition	
			Hoa Khanh Nam	Hoa Vang
1729	1733	Isobicyclogermacrenal	tr	–
1734	1740	(2*E*,6*E*)-Farnesal	tr	–
1737	1740	Mint sulfide	tr	–
1834	1835[c]	Neophytadiene	tr	–
1838	1841[c]	Phytone	tr	–
1963	1968	Sandaracopimara-8(14),15-diene	tr	–
2104	2109[c]	(*E*)-Phytol	0.1	tr
		Monoterpene hydrocarbons	29.6	35.4
		Oxygenated monoterpenoids	1.6	7.7
		Sesquiterpene hydrocarbons	44.9	33.6
		Oxygenated sesquiterpenoids	17.4	18.2
		Others	5.6	5.1
		Total Identified	99.1	100.0

[a] Retention index determined with reference to a homologous series of *n*-alkanes on a ZB-5 column

[b] Retention indices from Adams (2007) unless otherwise indicated

[c] Retention indices from Satyal (2015)

A. monophylla, *S. buxifolia*, and *S. monophylla* are consistent with treating these plants as individual separate species.

Mosquito larvicidal activity

The mosquito larvicidal activities of the leaf essential oil from *S. monophylla* from Hoa Vang are summarized in Table 2. Due to limited supply of the essential oil from Hoa Khanh Nam, only the oil from Hoa Vang was used in the larvicidal assay. The larvicidal activity of *S. monophylla* leaf oil compares well with those observed for other essential oils (Dias et al. 2014; Pavela 2015). An investigation by Das et al. on the larvicidal activity of *Atalantia monophylla* leaf essential oil had shown LC_{50} (24 h) = 87.4 ± 4.2 μg/mL and LC_{50} (48 h) = 83.5 ± 5.2 μg/mL against *Ae. aegypti*; the life stage (instar) was not reported, however (Das et al. 2015). A later report by Baskar and co-workers found *Ae. aegypti* (4th instar) larvicidal activity of *A. monophylla* leaf oil of LC_{50} = 14.97 μg/mL, but the exposure duration was not reported (Baskar et al. 2018). Based on the results of this current study, *Ae. albopictus* is more tolerant than *Ae. aegypti* to *S. monophylla* essential oil. A previous study comparing the activities of several insecticides against *Ae. aegypti* and *Ae. albopictus* has shown comparable differences in susceptibilities; *Ae. albopictus* is more tolerant than *Ae. aegypti* (Gómez et al. 2011).

Several of the major components of *S. monophylla* leaf oil had previously shown larvicidal activity (LC_{50} < 100 μg/mL) against *Ae. aegypti*, including sabinene (LC_{50} 21.2–74.1 μg/mL), linalool (LC_{50} 38.6–96.6 μg/mL), germacrene D (LC_{50} 18.8–63.6 μg/mL), β-caryophyllene (LC_{50} 88.3 μg/mL), and (*E*)-nerolidol (LC_{50} 9.0–17.0 μg/mL) (Dias et al. 2014).

Table 2 Mosquito larvicidal activities of *Severinia monophylla* leaf essential oil against third instar *Aedes aegypti* and *Aedes albopictus* larvae

Mosquito species	Treatment time	LC_{50}, μg/mL[a] (fiducial limits)	LC_{90}, μg/mL[a] (fiducial limits)	Regression equation	χ^2	*P*
Ae. aegypti	24 h	16.41 (13.78–20.40)	69.86 (46.86–137.48)	$y = -2.475 + 2.037x$	51.3	< 0.001
Ae. aegypti	48 h	7.06 (5.54–8.46)	28.78 (22.20–43.27)	$y = -1.782 + 2.100x$	55.6	< 0.001
Ae. albopictus	24 h	38.26 (34.34–43.50)	84.53 (68.96–114.63)	$y = -5.891 + 3.722x$	79.5	< 0.001
Ae. albopictus	48 h	36.22 (32.35–41.38)	85.44 (68.84–118.04)	$y = -5.360 + 3.438x$	79.7	< 0.001

[a] The mortality after 24 h and after 48 h for the DMSO control was 0%

Table 3 *Triatoma rubrofasciata* nymphal-repellent activities of *Severinia monophylla* leaf essential oil

Replicate	Number *T. rubrofasciata*	1 h N_{EO}/N_{UT} (PR%)[a]	24 h N_{EO}/N_{UT} (PR%)	48 h N_{EO}/N_{UT} (PR%)	72 h[b] N_{EO}/N_{UT} (PR%)
R_1	5	1/4 (60%)	1/4 (60%)	0/5 (100%)	1/4 (60%)
R_2	5	1/4 (60%)	0/5 (100%)	0/5 (100%)	3/2 (− 20%)
R_3	5	2/3 (20%)	1/4 (60%)	1/4 (60%)	0/5 (100%)
R_4	5	2/3 (20%)	1/4 (60%)	1/4 (60%)	2/3 (20%)
Average	5	1.5/3.5 (40%)	0.75/4.25 (70%)	0.5/4.5 (80%)	1.5/3.5 (40%)

[a] N_{EO}, the number of bugs occupying the essential oil–treated half; N_{UT}, the number of bugs occupying the untreated half; PR%, percent repellency

[b] None of the *T. rubrofasciata* insects died within 72 h

Sabinene (Cheng et al. 2013) and β-caryophyllene (Govindarajan et al. 2016) have both demonstrated larvicidal activity against *Ae. albopictus* (LC_{50} = 39.5 and 44.8 μg/mL, respectively). Furthermore, the sabinene-rich essential oil of *Cupressus macrocarpa* (Giatropoulos et al. 2013) and the β-caryophyllene-rich essential oil of *Pinus halapensis* (Koutsaviti et al. 2014) showed larvicidal activities against *Ae. albopictus* with LC_{50} values of 54.6 and 70.2 μg/mL, respectively. Thus, the relatively high concentrations of these components likely account for the larvicidal activity of *S. monophylla* leaf essential oil.

There are several targets for insecticides, including acetylcholinesterase (AChE), nicotinic acetylcholine receptor (nAChR), γ-butyric acid (GABA) receptor, voltage-gated sodium channel (VGSC), glutamate-gated chloride channel (CluCl), octopamine receptor, and ryanodine receptor (RyR) (Casida and Quistad 2000; Hemingway and Ranson 2000; Rattan 2010; Karatolos et al. 2011; Dambolena et al. 2016; ffrench-Constant et al. 2016; Jankowska et al. 2018).

Several EOs have shown AChE inhibitory activity (Rattan 2010). For example, *Cupressus macrocarpa*, *Rosmarinus officinalis* (Abou-Taleb et al. 2016), *Tagetes filifolia* (Olmedo et al. 2015), *Citrus aurantium* (Zarrad et al. 2015), *Dysphania ambrosioides* (Pavela et al. 2018), and *Cannabis sativa* (Benelli et al. 2018) essential oils have shown both insecticidal and AChE inhibitory activities, and numerous essential oil components have been shown to be effective AChE inhibitors (Kang et al. 2013). Of the main components in *S. monophylla* essential oil, sabinene (Menichini et al. 2009) and linalool (López and Pascual-Villalobos 2010) have shown AChE inhibitory activity. β-Caryophyllene, however, has shown only weak or no AChE inhibition (Dohi et al. 2009; Bonesi et al. 2010; Yeom et al. 2015).

Another insecticidal protein target that has been identified as an essential oil target is the octopamine receptor (Enan 2001, 2005; Ochocka et al. 2002; Rattan 2010; Dambolena et al. 2016). Linalool apparently does not affect the octopamine receptor (Gross et al. 2013). However, linalool has been shown to block voltage-gated sodium channels (Narusuye et al. 2005; Leal-Cardoso et al. 2010) as well as interact with insect GABA receptors (Tong and Coats 2012).

It is likely that *S. monophylla* essential oil affects several different insect targets (Pavela and Benelli 2016). Furthermore, synergistic effects of the essential oil components (Tak and Isman 2017) likely also play a role in the larvicidal activity of *S. monophylla* oil. A potential model for synergistic effects of essential oil components has been demonstrated by Scalerandi and co-workers in *Musca domestica* (Scalerandi et al. 2018). These workers have shown that the major components of essential oils are preferentially metabolically oxidized by insects, while the components in lesser concentrations, then, act as toxicants.

Triatoma rubrofasciata repellent activity

The nymphal repellency of *S. monophylla* leaf essential oil from Hoa Vang against *T. rubrofasciata* is presented in Table 3. The essential oil showed *Triatoma*-repellent activities of 40% after 1 hour, 70% after 24 h, 80% after 48 h, and 40% after 72 h. These repellent activities are comparable to previously published nymphal-repellent essential oils against *Triatoma infestans* (Klug) and other members of the Triatominae; for a recent review, see Benelli and Pavela (2018). For example, the essential oils from several medicinal plants from the Andes of Argentina were screened for repellent activity against nymphs of *T. infestans*. At essential oil concentrations of 0.5% demonstrated *Triatoma*-repellent activity ranging from 17.3 to 86.7% (Lima et al. 2011). Likewise, essential oils from different *Tagetes* spp. showed repellent activity against *T. infestans*, at concentrations of 0.5%, ranging from 28 to 95% (López et al. 2011).

The major components in *S. monophylla* leaf essential oil are likely responsible for the insect-repellent activity. Sabinene showed 60% repellent activity after 24 h at a concentration of 0.034% against the grain weevil, *Sitophilus granarius* (L.) (Benelli et al. 2012), although it was only marginally insecticidal against the rice weevil, *Sitophilus oryzae* (L.) (Park et al. 2003). β-Caryophyllene has shown insect-repellent activity against fire ants, *Solenopsis invicta* (Buren)

(Wheeler et al. 2003) and against grain weevils, *S. granarius* (65% repellent at a concentration of 0.011% after 24 h) (Benelli et al. 2012). Furthermore, (*E*)-nerolidol also showed insect-repellent (Wheeler et al. 2003) and insecticidal (Satyal et al. 2013) activity against *S. invicta*. Both (*E*)-nerolidol and linalool have shown larvicidal activity against *T. infestans* (Laurent et al. 1997), and linalool has shown mosquito repellent activity (Dekker et al. 2011).

Conclusion

Severinia monophylla leaf essential oil showed good larvicidal activity against both species of *Aedes* mosquito, although *Ae. aegypti* was more susceptible than *Ae. albopictus*. The essential oil, therefore, represents a low-cost and environmentally friendly vector control agent to prevent the spread of the arbovirus infections. Additionally, *S. monophylla* leaf oil demonstrated *Triatoma*-repellent activity against *T. rubrofasciata* and may be useful in dissuading the bug from infesting human as well as livestock living areas. Thus, this work provides evidence that essential oils, which are available to developing countries where neglected tropical diseases are prevented, may be important alternatives to environmentally damaging and persistent insecticides. However, although the larvicidal and repellent activities of *S. monophylla* essential oil are encouraging, there is additional work needed. The practicality of using this and other essential oils in the field needs to be examined, and the potential toxicology on non-target organisms needs to be assessed (Masetti 2016; Pavela and Benelli 2016).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Abou-Taleb HK, Mohamed MIE, Shawir MS, Abdelgaleil SAM (2016) Insecticidal properties of essential oils against *Tribolium castaneum* (Herbst) and their inhibitory effects on acetylcholinesterase and adenosine triphosphatases. Nat Prod Res 30:710–714. https://doi.org/10.1080/14786419.2015.1038999

Adams RP (2007) Identification of essential oil components by gas chromatography/mass spectrometry, 4th edn. Allured Publishing, Carol Stream

Airy-Shaw HK (1939) Notes on the nomenclature of certain Rutaceae-Aurantioideae. Bull Misc Inf (Royal Bot Gard Kew) 1939:290–293

Barrett ADT, Higgs S (2007) Yellow fever: a disease that has yet to be conquered. Annu Rev Entomol 52:209–229. https://doi.org/10.1146/annurev.ento.52.110405.091454

Baskar K, Sudha V, Nattudurai G, Ignacimuthu S, Duraipandiyan V, Jayakumar M, al-Dhabi NA, Benelli G (2018) Larvicidal and repellent activity of the essential oil from *Atalantia monophylla* on three mosquito vectors of public health importance, with limited impact on non-target zebra fish. Physiol Mol Plant Pathol 101:197–201. https://doi.org/10.1016/j.pmpp.2017.03.002

Benelli G (2015) Research in mosquito control: current challenges for a brighter future. Parasitol Res 114:2801–2805. https://doi.org/10.1007/s00436-015-4586-9

Benelli G, Mehlhorn H (2016) Declining malaria, rising of dengue and Zika virus: insights for mosquito vector control. Parasitol Res 115:1747–1754. https://doi.org/10.1007/s00436-016-4971-z

Benelli G, Pavela R (2018) Beyond mosquitoes—essential oil toxicity and repellency against bloodsucking insects. Ind Crop Prod 117:382–392. https://doi.org/10.1016/j.indcrop.2018.02.072

Benelli G, Flamini G, Canale A et al (2012) Repellence of *Hyptis suaveolens* whole essential oil and major constituents against adults of the granary weevil *Sitophilus granarius*. Bull Insectol 65:177–183

Benelli G, Pavela R, Lupidi G, Nabissi M, Petrelli R, Ngahang Kamte SL, Cappellacci L, Fiorini D, Sut S, Dall'Acqua S, Maggi F (2018) The crop-residue of fiber hemp cv. Futura 75: from a waste product to a source of botanical insecticides. Environ Sci Pollut Res 25:10515–10525. https://doi.org/10.1007/s11356-017-0635-5

Bonesi M, Menichini F, Tundis R, Loizzo MR, Conforti F, Passalacqua NG, Statti GA, Menichini F (2010) Acetylcholinesterase and butyrylcholinesterase inhibitory activity of *Pinus* species essential oils and their constituents. J Enzyme Inhib Med Chem 25:622–628. https://doi.org/10.3109/14756360903389856

Brummitt RK (1998) Report of the committee for spermatophyta: 46. Taxon 1998:441–444

Casida JE, Quistad GB (2000) Insecticide targets: learning to keep up with resistance and changing concepts of safety. Agric Chem Biotechnol 43:185–191

Cheng SS, Lin CY, Chung MJ, Liu YH, Huang CG, Chang ST (2013) Larvicidal activities of wood and leaf essential oils and ethanolic extracts from *Cunninghamia konishii* Hayata against the dengue mosquitoes. Ind Crop Prod 47:310–315. https://doi.org/10.1016/j.indcrop.2013.03.016

Claver MA, Yaqub A (2015) Morphometric analysis of tropicopolitan bug *Triatoma rubrofasciata* (De Geer) in two different parts of India. Int J Res Stud Biosci 3:130–138

Dambolena JS, Zunino MP, Herrera JM et al (2016) Terpenes: natural products for controlling insects of importance to human health - a structure-activity relationship study. Psyche (New York) 2016:4595823. https://doi.org/10.1155/2016/4595823

Das AK, Swamy PS (2013) Comparison of the volatile oil composition of three *Atalantia* species. J Environ Biol 34:569–571

Das AK, Suresh Kumar J, Swamy PS (2015) Larvicidal activity and leaf essential oil composition of three species of genus *Atalantia* from south India. Int J Mosq Res 2:25–29

Dekker T, Ignell R, Ghebru M, Glinwood R, Hopkins R (2011) Identification of mosquito repellent odours from *Ocimum forskolei*. Parasit Vectors 4:183. https://doi.org/10.1186/1756-3305-4-183

Dhimal M, Gautam I, Joshi HD, Hara RBO (2015) Risk factors for the presence of Chikungunya and dengue vectors (*Aedes aegypti* and *Aedes albopictus*), their altitudinal distribution and climatic

determinants of their abundance in central Nepal. PLoS Negl Trop Dis 9:e0003545. https://doi.org/10.1371/journal.pntd.0003545

Dias CN, Fernandes D, Moraes C (2014) Essential oils and their compounds as *Aedes aegypti* L. (Diptera: Culicidae) larvicide: review. Parasitol Res 113:565–592. https://doi.org/10.1007/s00436-013-3687-6

Do TL (2004) Medicinal plants and drugs from Vietnam. Medical Publishing House, Hanoi

Dohi S, Terasaki M, Makino M (2009) Acetylcholinesterase inhibitory activity and chemical composition of commercial essential oils. J Agric Food Chem 57:4313–4318. https://doi.org/10.1021/jf804013j

Duc T, Quynh LTN, Nghi NP et al (2008) Research on chemical composition and biological activity of *Severina monophylla* leaf. J Sci Technol Univ Da Nang 6:71–76

Dujardin JP, Lam TX, Khoa PT, Schofield CJ (2015) The rising importance of *Triatoma rubrofasciata*. Mem Inst Oswaldo Cruz 110:319–323. https://doi.org/10.1590/0074-02760140446

Enan E (2001) Insecticidal activity of essential oils: octopaminergic sites of action. Comp Biochem Physiol - C Toxicol Pharmacol 130:325–337. https://doi.org/10.1016/S1532-0456(01)00255-1

Enan EE (2005) Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils. Arch Insect Biochem Physiol 59:161–171. https://doi.org/10.1002/arch.20076

Ferrero AA, Werdin González JO, Sánchez Chopa C (2006) Biological activity of *Schinus molle* on *Triatoma infestans*. Fitoterapia 77:381–383. https://doi.org/10.1016/j.fitote.2006.03.004

ffrench-Constant RH, Williamson MS, Davies TGE, Bass C (2016) Ion channels as insecticide targets. J Neurogenet 30:163–177. https://doi.org/10.1080/01677063.2016.1229781

Finney D (2009) Probit analysis, Reissue Ed. Cambridge University Press, Cambridge

Giatropoulos A, Pitarokili D, Papaioannou F, Papachristos DP, Koliopoulos G, Emmanouel N, Tzakou O, Michaelakis A (2013) Essential oil composition, adult repellency and larvicidal activity of eight Cupressaceae species from Greece against *Aedes albopictus* (Diptera: Culicidae). Parasitol Res 112:1113–1123. https://doi.org/10.1007/s00436-012-3239-5

Gómez A, Seccacini E, Zerba E, Licastro S (2011) Comparison of the insecticide susceptibilities of laboratory strains of *Aedes aegypti* and *Aedes albopictus*. Mem Inst Oswaldo Cruz 106:993–996. https://doi.org/10.1590/S0074-02762011000800015

Goulson D (2013) An overview of the environmental risks posed by neonicotinoid insecticides. J Appl Ecol 50:977–987. https://doi.org/10.1111/1365-2664.12111

Govindarajan M, Rajeswary M, Hoti SL, Bhattacharyya A, Benelli G (2016) Eugenol, α-pinene and β-caryophyllene from *Plectranthus barbatus* essential oil as eco-friendly larvicides against malaria, dengue and Japanese encephalitis mosquito vectors. Parasitol Res 115:807–815. https://doi.org/10.1007/s00436-015-4809-0

Gross AD, Kimber MJ, Day TA et al (2013) Quantitative structure-activity relationships (QSARs) of monoterpenoids at an expressed American cockroach octopamine receptor. ACS Symp Ser 1141:97–110. https://doi.org/10.1021/bk-2013-1141.ch007

Gubler DJ (1998) Dengue and dengue hemorrhagic fever. Clin Microbiol Rev 11:480–496

Hemingway J, Ranson H (2000) Insecticide resistance in insect vectors of human disease. Annu Rev Entomol 45:371–391

Hijaz F, Nehela Y, Killiny N (2016) Possible role of plant volatiles in tolerance against huanglongbing in citrus. Plant Signal Behav 11:1–12. https://doi.org/10.1080/15592324.2016.1138193

Jankowska M, Rogalska J, Wyszkowska J, Stankiewicz M (2018) Molecular targets for components of essential oils in the insect nervous system - a review. Molecules 23:34. https://doi.org/10.3390/molecules23010034

Kamrin MA (1997) Pesticide profiles: toxicity, environmental impact, and fate. CRC Press, Boca Raton

Kang JS, Kim E, Lee SH, Park I-K (2013) Inhibition of acetylcholinesterases of the pinewood nematode, *Bursaphelenchus xylophilus*, by phytochemicals from plant essential oils. Pestic Biochem Physiol 105:50–56. https://doi.org/10.1016/j.pestbp.2012.11.007

Karatolos N, Pauchet Y, Wilkinson P, Chauhan R, Denholm I, Gorman K, Nelson DR, Bass C, ffrench-Constant RH, Williamson MS (2011) Pyrosequencing the transcriptome of the greenhouse whitefly, *Trialeurodes vaporariorum* reveals multiple transcripts encoding insecticide targets and detoxifying enzymes. BMC Genomics 12:56. https://doi.org/10.1186/1471-2164-12-56

Koutsaviti K, Giatropoulos A, Pitarokili D, Papachristos D, Michaelakis A, Tzakou O (2014) Greek *Pinus* essential oils: larvicidal activity and repellency against *Aedes albopictus* (Diptera: Culicidae). Parasitol Res 114:583–592. https://doi.org/10.1007/s00436-014-4220-2

Lanteigne M, Whiting SA, Lydy MJ (2015) Mixture toxicity of imidacloprid and cyfluthrin to two non-target species, the fathead minnow *Pimephales promelas* and the amphipod *Hyalella azteca*. Arch Environ Contam Toxicol 68:354–361. https://doi.org/10.1007/s00244-014-0086-7

Lardeux F, Depickère S, Duchon S, Chavez T (2010) Insecticide resistance of *Triatoma infestans* (Hemiptera, Reduviidae) vector of Chagas disease in Bolivia. Trop Med Int Heal 15:1037–1048. https://doi.org/10.1111/j.1365-3156.2010.02573.x

Laurent D, Vilaseca LA, Chanttraine J-M et al (1997) Insecticidal activity of essential oils on *Triatoma infestans*. Phyther Res 11:285–290

Le Quyen D, Le NT, Van Anh CT et al (2018) Epidemiological, serological, and virological features of dengue in Nha Trang City, Vietnam. Am J Trop Med Hyg 98:402–409. https://doi.org/10.4269/ajtmh.17-0630

Leal-Cardoso JH, da Silva-Alves KS, Ferreira-da-Silva FW, dos Santos-Nascimento T, Joca HC, de Macedo FHP, de Albuquerque-Neto PM, Magalhães PJC, Lahlou S, Cruz JS, Barbosa R (2010) Linalool blocks excitability in peripheral nerves and voltage-dependent Na^+ current in dissociated dorsal root ganglia neurons. Eur J Pharmacol 645:86–93. https://doi.org/10.1016/j.ejphar.2010.07.014

Lima B, López S, Luna L, Agüero MB, Aragón L, Tapia A, Zacchino S, López ML, Zygadlo J, Feresin GE (2011) Essential oils of medicinal plants from the central Andes of Argentina: chemical composition, and antifungal, antibacterial, and insect-repellent activities. Chem Biodivers 8:924–936

Liu N (2015) Insecticide resistance in mosquitoes: impact, mechanisms, and research directions. Annu Rev Entomol 60:537–559. https://doi.org/10.1146/annurev-ento-010814-020828

López MD, Pascual-Villalobos MJ (2010) Mode of inhibition of acetylcholinesterase by monoterpenoids and implications for pest control. Ind Crop Prod 31:284–288. https://doi.org/10.1016/j.indcrop.2009.11.005

López SB, López ML, Aragón LM et al (2011) Composition and anti-insect activity of essential oils from *Tagetes* L species (Asteraceae, Helenieae) on *Ceratitis capitata* Wiedemann and *Triatoma infestans* Klug. J Agric Food Chem 59:5286–5292. https://doi.org/10.1021/jf104966b

Masetti A (2016) The potential use of essential oils against mosquito larvae: a short review. Bull Insectol 69:307–310

Menichini F, Tundis R, Loizzo MR, Bonesi M, Marrelli M, Statti GA, Menichini F, Conforti F (2009) Acetylcholinesterase and butyrylcholinesterase inhibition of ethanolic extract and monoterpenes from *Pimpinella anisoides* V Brig. (Apiaceae). Fitoterapia 80:297–300. https://doi.org/10.1016/j.fitote.2009.03.008

Missouri Botanical Garden (2018) Tropicos.org. In: Tropicos.org. www.tropicos.org. Accessed 27 Jul 2018

Mougabure-Cueto G, Picollo MI (2015) Insecticide resistance in vector Chagas disease: evolution, mechanisms and management. Acta Trop 149:70–85. https://doi.org/10.1016/j.actatropica.2015.05.014

Nair KN, Barrie FR (1995) (1168) Proposal to change the listed type of *Atalantia* Corrêa (Rutaceae), nom. cons. Taxon 1995:429–432

Naqqash MN, Gökçe A, Bakhsh A, Salim M (2016) Insecticide resistance and its molecular basis in urban insect pests. Parasitol Res 115: 1363–1373. https://doi.org/10.1007/s00436-015-4898-9

Narusuye K, Kawai F, Matsuzaki K, Miyachi E (2005) Linalool suppresses voltage-gated currents in sensory neurons and cerebellar Purkinje cells. J Neural Transm 112:193–203. https://doi.org/10.1007/s00702-004-0187-y

Nattudurai G, Baskar K, Paulraj MG, Islam VIH, Ignacimuthu S, Duraipandiyan V (2017) Toxic effect of *Atalantia monophylla* essential oil on *Callosobruchus maculatus* and *Sitophilus oryzae*. Environ Sci Pollut Res 24:1619–1629. https://doi.org/10.1007/s11356-016-7857-9

Ochocka JR, Asztemborska M, Sybilska D, Langa W (2002) Determination of enantiomers of terpenic hydrocarbons in essential oils obtained from species of *Pinus* and *Abies*. Pharm Biol 40:395–399

Olmedo R, Herrera JM, Lucini EI et al (2015) Essential oil of *Tagetes filifolia* against the flour beetle *Tribolium castaneum* and its relation to acetylcholinesterase activity and lipid peroxidation. Agriscientia 32:113–121

Park IK, Lee SG, Choi DH, Park JD, Ahn YJ (2003) Insecticidal activities of constituents identified in the essential oil from leaves of *Chamaecyparis obtusa* against *Callosobruchus chinensis* (L.) and *Sitophilus oryzae* (L.). J Stored Prod Res 39:375–384. https://doi.org/10.1016/S0022-474X(02)00030-9

Patterson JS, Schofield CJ, Dujardin JP, Miles MA (2001) Population morphometric analysis of the tropicopolitan bug *Triatoma rubrofasciata* and relationships with Old World species of *Triatoma*: evidence of New World ancestry. Med Vet Entomol 15: 443–451. https://doi.org/10.1046/j.0269-283X.2001.00333.x

Pavela R (2015) Essential oils for the development of eco-friendly mosquito larvicides: a review. Ind Crop Prod 76:174–187

Pavela R, Benelli G (2016) Essential oils as ecofriendly biopesticides? Challenges and constraints. Trends Plant Sci 21:1000–1007. https://doi.org/10.1016/j.tplants.2016.10.005

Pavela R, Maggi F, Lupidi G, Mbuntcha H, Woguem V, Womeni HM, Barboni L, Tapondjou LA, Benelli G (2018) *Clausena anisata* and *Dysphania ambrosioides* essential oils: from ethno-medicine to modern uses as effective insecticides. Environ Sci Pollut Res 25: 10493–10503. https://doi.org/10.1007/s11356-017-0267-9

Pham HH (2002) Cay Co Vietnam - an illustrated flora of Vietnam 2. Tre Publishing House, Ho Chi Minh

Pino JA, Marbot R, Fuentes V (2006) Aromatic plants from western Cuba. VI. Composition of the leaf oils of *Murraya exotica* L., *Amyris balsamifera* L., *Severinia buxifolia* (Poir.) Ten. and *Triphasia trifolia* (Burm. f.) P. Wilson. J Essent Oil Res 18:24–28

Quyen NTH, Kien DTH, Rabaa M et al (2017) Chikungunya and Zika virus cases detected against a backdrop of endemic dengue transmission in Vietnam. Am J Trop Med Hyg 97:146–150. https://doi.org/10.4269/ajtmh.16-0979

Rattan RS (2010) Mechanism of action of insecticidal secondary metabolites of plant origin. Crop Prot 29:913–920. https://doi.org/10.1016/j.cropro.2010.05.008

Royal Botanic Gardens K (2018) The plant list. http://www.theplantlist.org/. Accessed 27 Jul 2018

Safaa AN, Mostafa AAK, Maha MS, Mohamed SH (2018) The impact of seasonal variation on the volatile oil profile of leaves of *Severinia buxifolia* (Poir.) and its antimicrobial activity. J Pharmacogn Phyther 10:56–63. https://doi.org/10.5897/JPP2018.0488

Satyal P (2015) Development of GC-MS database of essential oil components by the analysis of natural essential oils and synthetic compounds and discovery of biologically active novel chemotypes in essential oils. Ph.D. dissertation, University of Alabama in Huntsville

Satyal P, Paudel P, Poudel A, Dosoky NS, Pokharel KK, Setzer WN (2013) Bioactivities and compositional analyses of *Cinnamomum* essential oils from Nepal: *C. camphora*, *C. tamala*, and *C. glaucescens*. Nat Prod Commun 8:1777–1784

Scalerandi E, Flores GA, Palacio M, Defagó MT, Carpinella MC, Valladares G, Bertoni A, Palacios SM (2018) Understanding synergistic toxicity of terpenes as insecticides: contribution of metabolic detoxification in *Musca domestica*. Front Plant Sci 9:1579. https://doi.org/10.3389/fpls.2018.01579

Scora RW, Ahmed M (1994) The leaf oils of *Severinia buxifolia* (Poir.) Tenore. J Essent Oil Res 6:363–367

Silva WJ, Dória GAA, Maia RT, Nunes RS, Carvalho GA, Blank AF, Alves PB, Marçal RM, Cavalcanti SCH (2008) Effects of essential oils on *Aedes aegypti* larvae: alternatives to environmentally safe insecticides. Bioresour Technol 99:3251–3255. https://doi.org/10.1016/j.biortech.2007.05.064

Smith LB, Kasai S, Scott JG (2016) Pyrethroid resistance in *Aedes aegypti* and *Aedes albopictus*: important mosquito vectors of human diseases. Pestic Biochem Physiol 133:1–12. https://doi.org/10.1016/j.pestbp.2016.03.005

Suchail S, Guez D, Belzunces LP (2000) Characteristics of imidacloprid toxicity in two *Apis mellifera* subspecies. Environ Toxicol Chem 19: 1901. https://doi.org/10.1897/1551-5028(2000)019<1901:COITIT>2.3.CO;2

Sugita N, Agemori H, Goka K (2018) Acute toxicity of neonicotinoids and some insecticides to first instar nymphs of a non-target damselfly, *Ischnura senegalensis* (Odonata: Coenagrionidae), in Japanese paddy fields. Appl Entomol Zool 53:519–524. https://doi.org/10.1007/s13355-018-0583-7

Tak JH, Isman MB (2017) Penetration-enhancement underlies synergy of plant essential oil terpenoids as insecticides in the cabbage looper, *Trichoplusia ni*. Sci Rep 7:42432. https://doi.org/10.1038/srep42432

Tanaka T (1931) Notes on the Dutch Indian species of Rutaceae-Aurantieae (Revisio Aurantiacearum - V.). Meded s Rijks Herb Leiden 69:4–18

Thirugnanasampandan R, Gunasekar R, Gogulramnath M (2017) Chemical composition analysis, antioxidant and antibacterial activity evaluation of *Atalantia monophylla* Correa. Pharm Res 7:S52–S56

Tong F, Coats JR (2012) Quantitative structure-activity relationships of monoterpenoid binding activities to the housefly GABA receptor. Pest Manag Sci 68:1122–1129. https://doi.org/10.1002/ps.3280

Vontas J, Kioulos E, Pavlidi N, Morou E, della Torre A, Ranson H (2012) Insecticide resistance in the major dengue vectors *Aedes albopictus* and *Aedes aegypti*. Pestic Biochem Physiol 104:126–131. https://doi.org/10.1016/j.pestbp.2012.05.008

Wheeler GS, Massey LM, Southwell IA (2003) Dietary influences on terpenoids sequestered by the biological control agent *Oxyops vitiosa*: effect of plant volatiles from different *Melaleuca quinquenervia* chemotypes and laboratory host species. J Chem Ecol 29:189–208. https://doi.org/10.1023/a:1021941000399

Wunderlin RP (1998) A guide to the vascular plants of Florida. University Press of Florida, Gainesville

Yeom H-J, Jung C-S, Kang J, Kim J, Lee JH, Kim DS, Kim HS, Park PS, Kang KS, Park IK (2015) Insecticidal and acetylcholine esterase inhibition activity of Asteraceae plant essential oils and their constituents against adults of the German cockroach (*Blattella germanica*). J Agric Food Chem 63:2241–2248. https://doi.org/10.1021/jf505927n

Zarrad K, Ben Hamouda A, Chaieb I et al (2015) Chemical composition, fumigant and anti-acetylcholinesterase activity of the Tunisian *Citrus aurantium* L. essential oils. Ind Crop Prod 76:121–127. https://doi.org/10.1016/j.indcrop.2015.06.039