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Bioactivity of selected essential oils from medicinal plants found in Fiji against the Spiralling whiteflies (*Aleurodicus dispersus* Russell)

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Key words: *Aleurodicus dispersus* Russell, essential oils, fumigant and repellent toxicity, GC-MS.

Abstract: The concentration of essential oil solutions [0.25%, 0.5% and 5% (v/v)] of five medicinal plants found in the South Pacific (Fiji) were subjected to the whitefly (*Aleurodicus dispersus* Russell) in order to assess eventual control activities, by both fumigant and repellent tests. The essential oil of *Ocimum tenuiflorum* L. exhibited the strongest fumigant activity against the Spiralling whiteflies with an LC_{50} value of 0.003% followed by the essential oil of *Cymbopogon citratus* (DC.) Stapf. (LC_{50} = 0.004%), *Cananga odorata* (Lam.) Hook F. and Thoms (LC_{50} = 0.050%), *Murraya koenigii* (L.) Spreng. (LC_{50} = 0.113%), and *Euodia hortensis* forma *hortensis* (LC_{50} = 0.114%). The essential oil of *M. koenigii* (RI=52%) and *C. citratus* (RI=52%) at 5% (v/v) concentration were found to have a higher repellent toxicity against the Spiralling whiteflies. The chemical composition of the selected essential oils was also determined using GC-MS. The trend in the chemical constituent of essential oils revealed that the phenolic and alcoholic compounds were the major groups of contributors to the tested activities. Thus, these data suggested that essential oils from the selected medicinal plants found in the South Pacific (Fiji) have the potential to be employed in the pesticidal activities.

1. Introduction

The whitefly, *Aleurodicus dispersus* Russell is commonly known as Spiralling whitefly, a native to the Caribbean region and Central America. The Spiralling whiteflies are thought to be widely spread in the Pacific Islands, America (North and South), Asia and Africa (Waterhouse and Norris, 1989). The Spiralling whiteflies were first discovered in Suva, Fiji Islands in April 1986 and since then was regarded as a serious pest (Kumar *et al.*, 1987; Waterhouse and Norris, 1989). These Spiralling whiteflies pose extreme threats to the agricultural and horticultural crops in glasshouses and fields worldwide (Oliveira *et al.*, 2001; Mani and Krishnamoorthy, 2002; Stansly and Natwick, 2010). Some specific plants that are usually attacked include cassava, pepper, papaya, mango, eggplant, citrus, guava, banana, coconut, breadfruit, tropical almond, sea grape, paper bark and rose (Russell, 1965; Kessing *et al.*, 1993; Neuenschwander, 1994; Reddy, 2015).

There are many synthetic chemicals i.e. pyriproxyfen, imidacloprid, buprofezin and pyridaben which are used by farmers to control the different species of whiteflies (Bi *et al.*, 2002; Toscano and Bi, 2007; Reddy, 2015). The use of synthetic chemicals has led to the development of resistance in the insects (Palumbo *et al.*, 2001; Horowitz *et al.*, 2007; Carabalí *et al.*, 2010; Li *et al.*, 2014). The use of synthetic chemicals also arouse major concern to the environment and human health through the bioaccumulation of chemical compounds in the food chains, resulting in severe physiological disorders and diseases (Oliva *et al.*, 2001; Baldi *et al.*, 2003; Briggs, 2003; Saiyed *et al.*, 2003; Lemaire *et al.*, 2004). As a result, an alternative search for chemical pesticides has led to the global effort to test the efficacy of various natural product for the pest control and crop protection.

Natural pesticides such as plant essential oil can represent an alternative in the crop protection (Coats, 1994; Isman, 2000; Koul *et al.*, 2008). The

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diverse use of essential oil can represent a good alternative due to its novel, safe and eco-friendly substitute for its effective insecticidal properties (Li *et al.*, 2014; Palanisami *et al.*, 2014). Several essential oils from medicinal plants have been screened for the repellence and toxicity against grain storage insects, fleas, ticks and lice (Leal and Uchida, 1998; Gandhi *et al.*, 2010; Olivero-Verbel *et al.*, 2010; Caballero-Gallardo *et al.*, 2011; Cheng *et al.*, 2012; Seo *et al.*, 2012; Vera *et al.*, 2014). However, very little information on the fumigant and repellent toxicity of essential oils from medicinal plants found in the South Pacific (Fiji) was available against the Spiralling whiteflies. The aim of this study was to assess if essential oils of determined medicinal plants could serve as bio-pesticides for the control of the whitefly pest. The chemical profile of selected essential oils was also studied in order to provide justification for the presence of active compounds in the tested activities.

2. Materials and Methods

Essential oils extraction and analysis

The plant materials from *Cananga odorata* (Lam.) Hook F. and Thoms (Makosoi flowers), *Cymbopogon citratus* (DC.) Stapf. (Lemongrass leaves), *Murraya koenigii* (L.) Spreng. (Curry leaves), *Ocimum tenuiflorum* L. (Tulsi leaves) and *Eudioa hortensis* forma *hortensis* (Uci leaves) were collected from Fiji islands in April to November, 2015. The selected plant materials were verified with the voucher specimens placed at University of the South Pacific Herbarium and Koronivia Research Station, Suva, Fiji Islands. The plant materials from the medicinal plants were hydro-distilled using Clevenger apparatus for 5-7 hours. A meniscus layer (essential oils) was formed in the collecting tube which was then collected in a vial. The samples were dried over anhydrous sodium sulphate (Na_2SO_4) and stored at 4°C.

The analysis of essential oils using Gas Chromatography equipped with Mass spectrometry (Agilent Technologies 6890) was performed using an HP-5MS non polar fused silica capillary column (0.25 mm, 30 m, 0.25 µm film thickness; Model Number: 19091S-433) with the following conditions: The oven temperature was programmed from 50°C to 325°C over 5 min, at equilibration time of 0.50 min. The transfer source and quadrupole temperatures were 150°C, 200°C, 230°C and 250°C respectively, operating at 71 eV ionization energy. For the front inlet the mode used was split with an initial temperature of 250°C at 42.5 kPa at a split ratio of 50:1 and split flow of 43.8 mL/min. Helium was used as a carrier gas at a constant linear velocity of 35 cm/sec, flow rate of 0.9 mL/min; the injected sample volume was 1.0 µL which was diluted in hexane (1000 µL). The analysis was carried at the Southern Cross University, Australia. The constituents of essential oils were identified based on mass spectra comparison of retention indices (RI) with standard compounds. For the reference purpose, the database search was done using Essoils and Adams library. For the purpose of semi-quantification, the normalized peak areas of reported compounds were used without any correction factors for establishing abundance. Retention Indices (RI) and abundance were calculated using the mean values of 3 injections (El Bouzidi *et al.*, 2011).

Breeding of Spiralling whiteflies

The adult Spiralling whiteflies were brought from a nearby farm (Rewa Province) without any insecticidal exposure. The collected Spiralling whiteflies were brought to the green house where they were introduced to the cassava plants [*Manihot esculenta* (Crantz)] in order for them to grow and multiply. The plants were maintained in the greenhouse for appropriately 6-7 months without any pesticide contact before carrying out the actual experiment. The adult Spiralling whiteflies were collected in petri dish using a small paintbrush. The conditions that were set in the laboratory were similar to the environment that they were found, that is, under the condition of 28±2°C, 75±5% RH and light regime of 14:10 h (L:D). The Spiralling whiteflies (*Aleurodicus dispersus* Russell) bred in the greenhouse were brought into the laboratory when required to carry out the fumigant and repellent test.

Fumigant toxicity assessment

The leaves of the cassava pot plants were enclosed with a clear pocket plastic bag (16 cm in length) with 50 whiteflies in each bag irrespective of their sex. The treatments [0.25%, 0.5% and 5% (v/v)] were introduced into each plastic bag using a filter paper (~2 cm in diameter) based on the randomisation. The filter paper discs (~2 cm in diameter) were impregnated on the side of the plastic bag. The control filter disc had Tween 20 (5%) (Purchased from Sigma-Aldrich, Australia) mixed with the distilled water. The mortality count results after 3, 6, 9, 12 and 24 hours were calculated.

Repellent toxicity assessment

A T-shaped olfactometer set was constructed in order to test the repellency on the adult Spiralling whiteflies. The setup consisted of a long glass tube (diameter of 50 cm). The external light source was placed between site 1 and site 2. Site 1 had the control leaf disc (2 cm in diameter) dipped in tween 20 (5%) solution, while site 2 had the leaf disc with selected concentration of the essential oil. The essential oil concentration for all the five plants tested were 0.25%, 0.5% and 5% (v/v). The test was performed on 50 adult whiteflies with 4 replicates for each concentration. After 6-8 hours the number of whiteflies were counted using a hand lens for each site (chamber). The Repellency Index (RI %) was calculated using the formula (Abdellaoui *et al.*, 2009):

$$RI \% = (C-T/ C+T) \times 100$$

where [C= whitefly counts on the control side of the olfactometer] and [T = whitefly counts on the treatment side of the olfactometer].

If the Repellency Index calculated (RI %) is positive, it means that the whiteflies were repelled with the tested concentration of essential oils and vice versa if the Repellency Index (RI %) calculated is negative.

Statistical analysis

Fumigant test assessment. A Factorial ANOVA (5x4x5 split plot design) using Tukey's HSD test was performed. Prior to performing ANOVA (significant at p=0.05), the percentage mortalities were transformed by the arcsine of the square root. The total mortalities were converted to percentage mortality. The Lethal concentration (LC_{50}) values for the mortality after 24 hours were assessed using Probit in XLSTAT software (version 2015.1) (Kabir *et al.*, 2007; Postelnicu, 2011). The morality was corrected using Abbott's formula for those that exceed 10% by natural mortality (Abbott, 1925).

Repellent test assessment. To evaluate the statistical difference at 5% level of significance between each essential oil with its respective control, an independent sample t-test was performed. The Probit analysis in XLSTAT software (version 2015.1) was also used to calculate the EC_{50} for the repelling effect of each essential oil (Padhy and Panigrahi, 2016, Olufayo and Alade, 2012).

3. Result and Discussion

Chemical analysis of the essential oils

A total of 88 compounds were detected in the selected essential oils from the medicinal plants, accounting for 92.76-97.88% of total composition as summarised in Table 1 and 2. The main chemical compounds identified in the essential oil of *C. odorata* were *trans*, *trans*-farnesol (29.71%), benzyl benzoate (21.69%), linalool (16.65%) and *trans*, *trans*-farnesyl acetate (6.93%). While for *M. koenigii* the major compounds identified were sabinene (43.80%), β-caryophyllene (16.52%), terpinen-4-ol (7.20%) and α-pinene (5.67%). In case of *E. hortensis,* menthofuran (55.17%) and evodone (25.91%) were the main compounds. The essential oil from *O. tenuiflorum* revealed the presence of eugenol (58.20%), germacrene D (11.68%) and *cis*-β-ocimene (10.79%) as the major compounds. The major compounds identified in the *C. citratus* essential oil were citronellal (45.09%), citronellol (19.11%), geraniol (13.57%) and elemol (6.15%).

Table 1 - Composition of essential oils (%) from *C. odorata* (Makasoi), *M. koenigi*i (Curry leaves), *E. hortenis* (Uci), *O. tenuiflorum* (Tulsi) and *C. citratus* (Lemon grass)

Chemical compounds	*Ocimum tenuiflorum* (%)	*Cymbopogon citratus* (%)	*Cananga odorata* (%)	*Euodia hortensis* forma *hortensis* (%)	*Murraya koenigii* (%)
α-thujene	0.61	-	0.31#	-	1.79
linalool	0.21	0.27	16.65	0.10#	-
myrcene	0.38	-	0.11	0.37	1.84
sabinene	0.43	-	0.58#	-	43.80
iso-pulegol	-	1:17	-	-	-
α-pinene	-	-	0.32	-	5.67
limonene	-	-	-	4.64	-
1-octen-3-ol	0.19#	-	-	-	-
citronellal	-	45.09	-	0.20	-
iso iso-pulegol	-	0.46#	-	-	-
β-pinene	-	-	-	-	1.55
α-terpinene	0.23#	-	-	-	2.64
decanal	-	0.14#	-	-	-
methyl benzoate	-	-	1.64	-	-
menthofuran	-	-	-	55.17	-
p-cymene	0:23	-	-	-	0.67
citronellol	-	19:11	-	0.13#	-
cis-β-ocimene	10.79	-	-	-	0.11
neral	-	0:55	-	-	-
ethyl benzoate	-	-	0.14	-	-
limonene-10-ol	-	-	-	0.60	-
trans-β-ocimene	0.43#	-	-	-	0.39
geraniol	-	13:57	0.74	-	-
terpinen-4-ol	1:01	-	0.15	-	7.20
evodone	-	-	-	25.97	-
β-phellandrene	-	-	-	-	0.69
ϒ-terpinene	0:37	-	-	-	4.82
geranial	-	0.74	-	-	-
methyl salicylate	-	-	3.15	-	-
α-copaene	1.98#	-	-	0.79	-
citronellic acid	-	0.37#	-	-	-

to be continued

Table 1 (continued)

Chemical compounds [z]	*Ocimum tenuiflorum* (%)	*Cymbopogon citratus* (%)	*Cananga odorata* (%)	*Euodia hortensis* forma *hortensis* (%)	*Murraya koenigii* (%)
methyl chavicol	-	-	0.45#	-	-
β-cubebene	-	-	-	0.26	-
allo-ocimene	0.17#	-	-	-	-
citronellyl acetate	-	1.05#	-	-	-
limonene-10-yl acetate	-	-	-	0.60	-
geranyl acetate	-	0.44	-	-	-
trans-anethole	-	-	0.27#	-	-
α-(2) gurjunene	-	-	-	0.59#	-
trans-sabinene hydrate	-	-	-	-	0.59
α-cubebene	0.18#	-	-	-	-
β-elemene	-	0.59#	-	-	-
δ-elemene	-	-	0.24#	-	-
β- caryophyllene	-	-	-	0.54	-
isoterpinolene	-	-	-	-	0.95#
eugenol	58.20	-	1.38	-	0.33#
germacrene D	11.68	0.79#	2.74	0.27#	0.14
trans-α-bergamotene	-	-	-	0.18#	-
trans-p-menth-2-en-1-ol	-	-	-	-	0.47#
δ-cadinene	1.44#	0.88	-	-	-
methyl eugenol	-	-	1.77	-	-
trans-β-farnesene	-	-	-	0.20#	-
β-bourbonene	0.93	-	-	-	-
elemol	-	6.15	-	-	-
β-caryophyllene	4.31	-	0.49	-	16.52
β-funebrene	-	-	-	0.23#	-
α-terpineol	-	-	-	-	0.28
4-α-hydroxyl germacral (10), 5-diene	-	1.15#	-	-	-
humulene	0.33#	-	-	0.29#	-
cis-piperitol	-	-	-	-	0.12#
β-copaene	0.35	-	-	-	-
ϒ-eudesmol	-	0.72#	-	-	-
β-selinene	-	-	0.31#	-	0.40#
trans-piperitol	-	-	-	-	0.17#
δ-cardinol	-	0.27#	-	-	-
α-germacrene	-	-	0.35#	-	0.18#
AR-curcumene	-	-	-	0.60	-
ϒ-muurolene	0.40#	-	-	-	-
α-cardinol	-	3.70	-	-	-
β- elemene	-	-	-	-	1.50
trans, trans-farnesol	-	-	29.71	-	-
cis, trans-farnesol	-	0.46#	-	-	-
bicyclogermacrene	-	-	-	0.41#	-
trans, trans-farnesal	-	-	0.43#	-	-
benzyl benzoate	-	0.21#	21.69	-	-
β-curcumene	-	-	-	0.56#	-
α-cardinene	0.55#	-	-	-	-
ϒ-cardinene	0.22#	-	-	-	-
trans, trans-farnesyl acetate	-	-	6.93	-	-
δ-cardinene	-	-	-	0.46#	-
α-selinene	-	-	-	-	0.78#
benzyl salicyate	-	-	2.21	-	-
caryophyllene oxide	0.24	-	-	-	0.75#
epi-1-cubenol	0.13#	-	-	-	-
trans-nerolidol	-	-	-	-	0.24#
α-cadinol	0.87#	-	-	-	-
intermedeol	-	-	-	-	0.27#
ϒ-curcumene	-	-	-	3.79#	-

(z) Compounds listed in order of elution from a HP-5MS non polar fused silica capillary column.

\# Indicate that the compounds were detected for the first time as compared to the literature.

Variability in the essential oils

The results obtained also showed variability in terms of the quality, quantity and composition of essential oils in all the selected plants when compared to the available literature, that is, *O. tenuiflorum* (Pino *et al.*, 1998; Naquvi *et al.*, 2012), *C. citratus* (Negrelle and Gomes, 2007; Olivero-Verbel *et al.*, 2010; Matasyoh *et al.*, 2011; Tyagi *et al.*, 2014), *C. odorata* (Katague and Kirch, 1963; Gaydou *et al.*, 1986; Murbach Teles Andrade *et al.*, 2013), *E. hortensis* (Brophy *et al.*, 1985) and *M. koenigii* (Raina *et al.*, 2002; Chowdhury *et al.*, 2008) (Table 1). The variability in the composition of essential oil is mainly due to the genetic variations, climatic, ecological locations, soil composition, plant organs, age and vegetative cycle stages of the plant (Pietschmann *et al.*, 1998; Masotti *et al.*, 2003; Stewart, 2005; Tchoumbougnang *et al.*, 2005; Angioni *et al.*, 2006; Koba *et al.*, 2007; Nascimento *et al.*, 2008; Katoch *et al.*, 2013; Erbil *et al.*, 2015; Ríos, 2016).

Table 2 - The major chemical groups present in the essential oils of *C. odorata*, *M. koenigii*, *E. hortensis*, *O. tenuiflorum*, and *C. citratus*

Chemical groups	*Cananga odorata* (%)	*Murraya koenigii* (%)	*Euodia hortensis* forma *hortensis* (%)	*Ocimum tenuiflorum* (%)	*Cymbopogon citratus* (%)
Monoterpenes	1.32	65.51	60.18	13.64	-
Ester	35.76	-	0.60	-	1.70
Alcohol and phenol	50.85	9.08	0.83	60.61	45.88
Sesquiterpenes	4.13	20:27	9.17	22.61	3.41
Aldehyde	0:43	-	0.20	-	46.52
ketones	-	-	25.97	-	-
Acid	-	-	-	-	0.37
Miscellaneous	0.27	-	-	-	-
Total (%)	92.76	94.86	96.95	96.86	97.88

Fumigant toxicity of selected essential oils

Among the five tested essential oils (Fig. 1 a-c), *O. tenuiflorum* essential oil showed the most robust fumigant effect against the Spiralling whiteflies with LC_{50} value of 0.003% followed by the essential oils of *C. citratus* (LC_{50} = 0.004%), *C. odorata* (LC_{50} = 0.050%), *M. koenigii* (LC_{50} = 0.113%), and *E. hortensis* (LC_{50} = 0.114%) (Table 3). Statistically, the fumigant activity of *O. tenuiflorum* and *C. citratus* essential oils at 0.5% and 5% (v/v) concentrations were significantly higher than the other species ($p=0.00$). The significant threshold was set at $p<0.05$. The mortality count of the Spiralling whiteflies were also higher at 5% (v/v) concentration for *C. odorata*, *E. hortensis* and *M. koenigii* essential oils as compared to 0.25% and 0.5% (v/v) concentrations. Generally the increasing concentrations of the tested essential oils led to increased mortality of whiteflies.

The robust effect of *O. tenuiflorum* essential oil

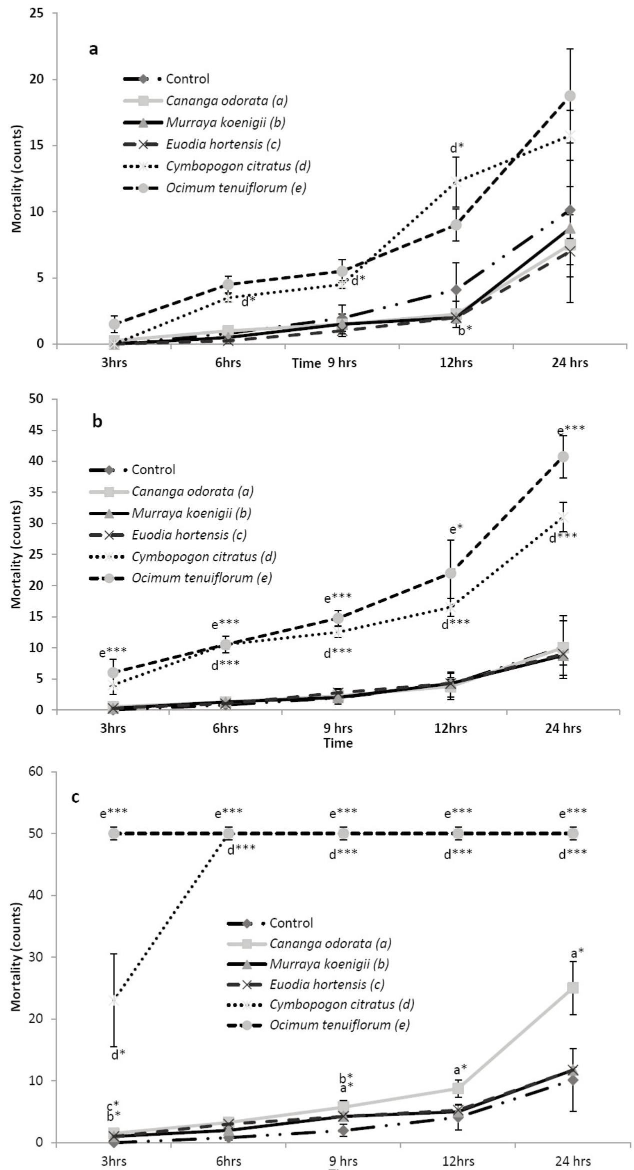

Fig. 1 - Fumigant effect (Mean±SE) of selected essential oils on the Spiralling whiteflies over different time intervals using different solution concentrations: (a) 0.25%; (b) 0.5%; (c) 5% (v/v). The alphabetical letters represent the respective essential oils and the asterisks indicate results statistically different from the control at $p<0.05$ (*), $p<0.01$ (**), $p<0.001$ (***) using Tukey's test.

could be attributed to the chemical constituents present in the oil. In this study, *O. tenuiflorum* essential oil had 60.61% of alcoholic and phenolic compounds as compared to *C. citratus* (45.88%), *C. odorata* (50.85%), *E. hortensis* (0.83%) and *M. koenigii* (9.08%). According to Isman (2000), eugenol compounds were found to be 7-9 times more toxic than terpenes and terpinene-4-ol. This confirms that *O. tenuiflorum* essential oils from the present study showed a strong fumigant effect due to eugenol (58.20%) compound. In previous studies, eugenols were also reported as a major cause of toxicity against the adult beetle (*Callosobruchus maculatus*) (Ajayi *et al.*, 2014), bean weevil (*Acanthoscelides obrectus*) (Regnault-Roger and Hamraoui, 1995), yellow fever mosquito (*Aedes aegypti*) (Sosan *et al.*, 2001) and rice weevil (*Sitophilus oryzae*) (Lee *et al.*, 2003).

Cymbopogon citratus essential oil also showed strong fumigant effect (Fig. 1 a-c). Such effect can be attributed to the major chemical compounds, alcohols and phenols (45.88%), especially citronellol (19.11%) and geraniol (13.57%). These major chemical compounds have showed toxicity and repellent effects on different pests (Fradin and Day, 2002; Ansari *et al.*, 2005; Choochote *et al.*, 2007; Paluch *et al.*, 2009; Sakulku *et al.*, 2009; Maia and Moore, 2011).

Similarly, the interaction of different chemical compounds could have played a major role in the repression of the fumigant effect. According to Chang *et al.* (2009), when linalool compound from the Basil oil (*Ocimum* family) was mixed with cuelure compounds, the level of toxicity on the tested insect (Melon fly, *Bactrocera cucurbitae*) decreased. The above scenario could explain why *C. odorata* essential oil had the second highest percentage of alcohol and phenol compounds (50.85%) while it was not able to produce a greater fumigant effect as compared to *C. citratus* (45.88%) essential oil.

Table 3 - Dose-effect analysis of the fumigant properties of essential oils on the Spiralling whiteflies after 24 hours at 0.25%, 0.5% and 5% (v/v) concentrations

Essential oils	Time (hours)	Equation	R^2	LC_{50}/EC_{50} (%)	$\chi^2_{statistic}$	P-value	df
Cananga odorata	24	y = 4.998 + 4.086x	0.750	0.050	118.149	<0.0001	1
Murraya koenigii	24	y = 3.408+ 3.933x	0.316	0.113	76.080	<0.0001	1
Euodia hortensis forma *hortensis*	24	y = 3.349+3.887x	0.586	0.114	78.574	<0.0001	1
Cymbopogon citratus	24	y = 8.725+3.764x	0.902	0.004	279.950	<0.0001	1
Ocimum tenuiflorum	24	y = 12.286+5.020x	0.651	0.003	253.512	<0.0001	1

The χ^2 probability ≤0.0001, indicated that the significant difference was brought by the log (concentration) variable and the repellency. Each test represents the mean of four replicates of 50 whiteflies.

Repellent toxicity of selected essential oils

The Table 4 revealed that none of the essential oils showed a very strong repelling effect on the Spiralling whiteflies. In order, based on the Repellency index (RI %) of selected essential oils at the highest concentration [5%(v/v)], we found *C. citratus* (52%), *M. koenigii* (52%), *O. tenuiflorum* (12%), *E. hortensis* (10%) and *C. odorata* (9%). A direct relationship was seen between the repellent effect and the concentration (Table 4). Statistically, it was found that only *C. citratus* had a strong significant difference (R^2 =0.611, p=0.00) at tested concentrations. The EC_{50} values in ascending order of the repellent effect of selected essential oils were 3.05% (*C. odorata*), 2.73% (*O. tenuiflorum*), 0.96% (*E. hortensis*), 0.43% (*C. citratus*) and 0.41% (*M. koenigii*).

The chemical analysis in this study revealed the presence of α-pinene (5.67%), β-pinene (1.55%) and myrcene (1.84%) only in the essential oil of *M. koenigii*. The other active compounds that might have contributed towards the repellent effect can be terpinene-4-ol (7.20%) and eugenol (0.33%). In previous report, these compounds were found to repel yellow fever mosquito (*Aedes aegypti*) (Coats *et al.*, 1991; Debboun *et al.*, 2014), bean weevil (*Callosobruchus chinensis*) (Haidri *et al.*, 2014) and two-spotted spider mites (Lee *et al.*, 1997).

The repellent activity of *C. citratus* and *M. koenigii* essential oils at the highest concentration [5% (v/v)] were similar. In agreement with Nerio *et al.* (2010), essential oil from *C. citratus* family were found to have promising repellent properties. The active compounds from previous studies such as α-pinene, limonene, citronellol, citronellal, camphor and thymol have shown higher repellent activity against ticks (*Amblyomma americanum*) and yellow fever mosquito *(Aedes aegypti*) (Nerio *et al.*, 2010; Debboun *et al.*, 2014). This study also reported the presence of citronellal (45.09%), citronellol (19.11%) and geraniol (13.57%) that may have caused the repellent effect (Table 1).

Interestingly, the essential oil activity of *O. tenuiflorum* showed a weak repellency against the Spiralling whiteflies, despite the fact that the mode of action of essential oils against the Spiralling whiteflies in both fumigant and repellent test are known to be similar. In fact, the mode of action of essential oils against the Spiralling whiteflies was via neurotoxicity and respiratory toxicity (Tanada and Kaya, 1993; Isman and Machial, 2006; Satar *et al.*, 2008; Li *et al.*, 2014; Tehri and Singh, 2015)**.** The weak repellent activity of *O. tenuiflorum* essential oil could be due the eugenol content (58.20%) which could have attracted the Spiralling whiteflies rather than repelling. In previous study, eugenol caused attractancy to the Japanese beetle (*Popillia japonica*) (Isman and Machial, 2006). The other chemical compounds from literature that were found to attract the insects were cinnamyl alcohol, 4-methoxy-cinnamaldehyde, cinnamaldehyde, geranylacetone and α-terpineol (Hammack, 1996; Petroski and Hammack, 1998). The overall trend of repellent effect of selected essential oils on the Spiralling whiteflies can be ranked as *C. citratus* and *M. koenigii* followed by *E. hortensis, O. tenuiflorum* and *C. odorata.*

4. Conclusions

All the five essential oils from medicinal plants

Table 4 - Summary of repellent effect (6-8 hours) on the adult whiteflies at different concentrations (Using Probit analysis)

Essential oils	Conc (v/v) (%)	RI (%)	Equation	R^2	EC_{50} (%)	$\chi^2_{statistic}$	P-value	Df
Cananga odorata	0.25	-29	y = -0.140+0.290x	0.0795	3.046	5.93	0.015	1
	0.05	-17						
	5	9						
Murraya koenigii	0.25	-13	y = 0.260+0.663x	0.3232	0.406	38.214	< 0.0001	1
	0.05	8						
	5	52						
Euodia hortensis forma hortensis	0.25	-10	y=0.003+0.188x	0.028	0.964	3.277	0.070	1
	0.05	-3						
	5	10						
Cymbopogon citratus	0.25	-9	y = -0.285+0.953x	0.6111	0.434	27.474	< 0.0001	1
	0.05	3						
	5	52						
Ocimum tenuiflorum	0.25	-18	y = -0.163+0.374x	0.1582	2.728	13.928	0.000	1
	0.05	-11						
	5	12						

The χ^2 probability ≤0.0001, indicated that the significant difference was brought by the log (concentration) variable and the repellency. Each test represents the mean of four replicates of 50 whiteflies.

tested against the Spiralling whiteflies showed fumigant and repellent effects. The strongest fumigant effect was shown by *O. tenuiflorum* essential oils, while for repellent test none of the essential oils showed strong effect. However the *M. koenigii* and *C. citratus* showed higher repellency when compared with other tested essential oils. In addition, the results presented in this study are the first given information on the chemical composition of essential oils from the South Pacific on the selected plant species. So far only *E. hortensis* essential oil composition data from Fiji is reported (Brophy *et al.*, 1985). The selected essential oils from medicinal plants showed potential for the development of possible natural form of controlling the whitefly but needs to be further evaluated to enhance their activity and safety to the humans.

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