Appl Biol Chem (2016) 59(1):3–8
DOI 10.1007/s13765-015-0115-x

Online ISSN 2468-0842
Print ISSN 2468-0834

ARTICLE

Insecticidal toxicities of naphthoquinone and its structural derivatives

Min-Gi Kim[1] · Hoi-Seon Lee[2]

Received: 3 August 2015 / Accepted: 14 August 2015 / Published online: 26 August 2015

Abstract Insecticidal toxicities of bioactive constituent from *Diospyros kaki* roots and its structural derivatives were evaluated against the larvae of *Aedes aegypti*, *Culex pipiens pallens*, and *Ochlerotatus togoi*. Bioactive constituent of *D. kaki* roots was isolated by some chromatographic methods and identified as 5-hydroxy-2-methyl-1,4-naphthoquinone. Based on the LC_{50} values of 5-hydroxy-2-methyl-1,4-naphthoquinone structural derivatives, 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone (0.89, 0.80, and 1.04 μg/mL) had the most potent insecticidal activity, followed by 2,3-dibromo-1,4-naphthoquinone (1.32, 1.28, and 1.94 μg/mL), 5,8-dihydroxy-1,4-naphthoquinone (3.57, 3.34, and 5.04 μg/mL), 2,3-dichloro-1,4-naphthoquinone (4.76, 3.89, and 5.33 μg/mL), 5-hydroxy-2-methyl-1,4-naphthoquinone (5.66, 5.43, and 6.09 μg/mL), and 2,2′-bi(3-hydroxy-1,4-naphthoquinone) (33.93, 32.82, and 36.17 μg/mL) against *Ae. aegypti*, *Cx. pipiens pallens*, and *Oc. togoi*, respectively. In this regard, 5-hydroxy-2-methyl-1,4-naphthoquinone and its structural derivatives could be suitable as insecticidal agents to control the larvae of the three mosquito species.

Keywords *Aedes aegypti* · *Culex pipiens pallens* · Naphthoquinone derivatives · Insecticidal toxicities · *Ochlerotatus togoi*

✉ Hoi-Seon Lee
hoiseon@chonbuk.ac.kr

[1] Organic Agriculture Division, Department of Agricultural Environment, National Academy of Agricultural Sciences, Rural Development Administration, Wanju 565-851, Republic of Korea

[2] Department of Bioenvironmental Chemistry, College of Agriculture and Life Science, Chonbuk National University, Jeonju 561-756, Republic of Korea

Introduction

Mosquito is the most important intermediator with respect to human disease and global distribution (James 1992). They function as vectors for various diseases, which are dengue fever, encephalitis, and filariasis (Rajeswary and Govindarajan 2013). These diseases are accompanied by economic losses, particularly in tropical and subtropical countries (James 1992). Synthetic mosquito larvicides, such as growth regulators (methoprene) and organophosphates (chlorpyrifos and temephos), have been used for several decades to control the larvae of mosquitoes (Yang et al. 2002). Despite their effectiveness, continuous use of synthetic larvicides has caused undesirable effects, such as reducing biological control by natural enemies, development of larvicide resistance, and toxicity to non-target and beneficial organisms (Park and Shin 2005). The problems have been needed for the new development of safer insecticides for the larvae of mosquitoes (Yang et al. 2002).

Plant substances may be an alternative source of insecticides and larvicides because they constitute the rich materials of biological compounds (Lee 2002; Lee et al. 2013; Yang et al. 2013). In particular, a variety of plant species with chemical defense mechanisms against herbivores could provide a new source of control agents against a wide spectrum of insect vectors (Kim et al. 2002; Yang et al. 2002). Various studies have focused on essential oils, phytochemicals, and plant extracts, such as mosquito control agents (Tabanca et al. 2013). Therefore, it is established that natural products derived from plants have the potential as alternatives to conventional repellents, insecticides, and larvicides (Ali et al. 2013; Tabanca et al. 2013). *Diospyros kaki* (Ebenaceae) is native to Korea, China, and Japan and 90 % of its production occurs in

eastern Asia (Sunity and Himanshu 2011). *D. kaki* has been continuously used as traditional medicine because of its active compounds, such as carotenoids, epicatechin, gallocatechin, and polyphenols (George and Redpath 2008; Sunity and Himanshu 2011). *D. kaki* roots contain abundant phenolic compounds, including anthocyanidin, chlorogenic acid, quinones, syringic acid, and tannin (Sattar et al. 1992; Suzuki et al. 2005). Phenolic compounds possess biological effects, such as anticarcinogenic, antimutagenic, insecticidal, and radioprotective activities (Bachrach and Wang 2002; Lee and Lee 2008; Pu et al. 2013). Although various studies have reported on the compounds derived from *D. kaki* roots, the insecticidal activity of an active compound from *D. kaki* roots against mosquito larvae has not been reported previously. In this regard, the objective of the present study is to isolate the bioactive compound from *D. kaki* roots and evaluate the insecticidal toxicities of the bioactive compound and its structural derivatives against the three types of the mosquito species.

Materials and methods

Chemicals

2.2′-Bi(3-hydroxy-1,4-naphthoquinone) and pirimiphos-methyl were purchased from Fluka (Switzerland). 2,3-Dibromo-1,4-naphthoquinone, 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone, 2,3-dichloro-1,4-naphthoquinone, and 5,8-dihydroxy-1,4-naphthoquinone were provided by Sigma-Aldrich (USA).

Sample preparation

Diospyros kaki roots were supplied from the Jeonju market in Korea during spring 2012 and dried at 30 °C. After washing, the roots (2 kg) were homogenized with a grinder and then extracted with methanol in an incubator at 25 °C for 48 h. The methanol extract (628 g, yield 31.4 %) was filtered and consecutively divided with hexane, chloroform, ethyl acetate, butanol, and distilled water. Five fractions were concentrated at 45 °C using a vacuum evaporator and the distilled water fraction was freeze-dried.

Isolation and identification

Chromatographic methods were used to isolate the insecticidal compound of the chloroform fraction partitioned from the methanol extract of *D. kaki* roots (Lee and Lee 2008). The chloroform fraction (9 g) was loaded on an open column, containing a silica gel (70–230 mesh, 500 × 701 mm; Merck, USA) and sequentially eluted with a mixture of organic solvents consisting of hexane:chloroform (3:7, 1:9, and 0:10, v:v). All fractions were analyzed using thin layer chromatography and the fractions with similar thin layer chromatography patterns were combined. As a result, six fractions (DK1–DK6) were produced. The active DK1 fraction (4.4 g) was again chromatographed using a silica gel column and a mixed organic solvent consisting of hexane:chloroform (3:7, v:v), and six fractions (DK11–DK16) were obtained. The active DK11 fraction (1.2 g) was isolated using prep HPLC (JAI Co., Ltd., Japan), following the analytical conditions: JAI GS column (GS310 500 + GS310 500 mm, 20 × 500 mm, Japan); mixed organic solvents consisting of hexane:chloroform:isopropanol (30:70:2, v:v:v); flow rate of 5 mL/min; and UV detection at an absorbance of 268 nm. As a result, five fractions (DK111–DK115) were obtained. The active DK114 fraction (940 mg) was chromatographed on a JAI W column (W 253 500 mm, 20 × 500 mm) under the same conditions. Finally, the active DK1144 fraction (380 mg) was isolated. The structure of the DK1144 fraction was measured by spectroscopic methods. ^{1}H and ^{13}C distortionless enhancement by polarization transfer (DEPT) nuclear magnetic resonance spectra were documented with the JNM-ECA 600 spectrometer (JEOL Ltd., Japan) using $CDCl_3$ at 600 and 150 MHz, respectively. Tetramethylsilane served as the chemical shifts, and internal standards are given in delta (δ, parts per million). A spectrum of absorbance was obtained using an ultraviolet spectrometer (model: DR 4000, HACH, Korea).

Mosquitoes and bioassay

The mosquito species were *Ae. aegypti*, *Cx. pipiens pallens*, and *Oc. togoi* supplied from Seoul National University in 2012. Each larva was reared in a plastic tray (200 × 350 × 70 mm) and was provided with a sterile diet consisting of chick chow powder: yeast (4:1, v:v). The mosquito adults were supplied with a blood from the mouse and 10 % sucrose solution. The mosquito larvae and adults were maintained on a light:dark photoperiod (16:8 h) at 28 °C and 70 % relative humidity. The insecticidal activities of active component and its structural derivatives against the larvae of the three mosquito species were conducted using the standard method modified by WHO (2009). Twenty-fourth-instar larvae were placed in distilled water (24.5 mL), containing an each sample (0.5 mL), was added in a 30 mL cup. For comparison, pirimiphos-methyl, which is one of the commercial insecticides, was used as the positive control. The negative control was prepared from distilled water (24.5 mL) and dimethyl sulfoxide solution (0.5 mL), which were added with mosquito larvae. All treatments were replicated five

times and were incubated for 24 h at 28 °C. Percent mortalities were investigated and transformed to arcsine square root values for variance analysis with SPSS statistical software (version 18.0, SPSS Inc., USA). Treatment means were compared with Scheffe's test ($p < 0.05$). Means values of untransformed data are reported. LC_{50} values in all treatments were calculated by probit analysis.

Results and discussion

The insecticidal activity of the methanol extract from *D. kaki* roots against the larvae of the three mosquito species is shown in Table 1. The *D. kaki* extract exhibited 100 % mortality against *Cx. pipiens pallens*, *Ae. aegypti*, and *Oc. togoi* at 100 μg/mL. Based on the 50 and 25 μg/mL concentrations, the methanol extract of *D. kaki* roots had potent larvicidal activity against *Cx. pipiens pallens* (85.7 and 40.3 % mortality), followed by *Ae. aegypti* (72.7 and 28.6 % mortality) and *Oc. togoi* (60.5 and 9.8 % mortality). A previous study reported that plants are particularly suitable for crop protection because of the presence of defense chemicals with more than one mode of action (Jiang et al. 2002). Furthermore, the methanol extract (600 g) of *D. kaki* roots was partitioned using the polarity of several solvent systems to obtain the five fractions of hexane (22 g, yield 3.7 %), chloroform (67 g, yield 11.2 %), ethyl acetate (188 g, yield 31.3 %), butanol (109 g, yield 18.2 %), and distilled water (83 g, yield 13.8 %). The chloroform fraction possessed excellent larvicidal toxicities (86.5, 100, and 69.5 % mortality at 50 μg/mL) against *Cx. pipiens pallens*, *Ae. aegypti*, and *Oc. togoi*, respectively. Therefore, the chloroform fraction partitioned from the *D. kaki* extract was isolated using some chromatographic methods to identify bioactive compound.

Silica gel column and prep HPLC were conducted to isolate the insecticidal compound of the chloroform fraction. The DK1144 fraction was isolated as the bioactive compound in *D. kaki* roots and the DK1144 structure was identified by some spectroscopic methods, such as ^{1}H, ^{13}C, and DEPT NMR spectra. The DK1144 fraction was characterized as 5-hydroxy-2-methyl-1,4-naphthoquinone ($C_{11}H_8O_3$) (Fig. 1A); EI-MS (70 eV) *m/z* M^+ 188 (100), 173 (17), 160 (19), 131 (18), 120 (11), 92 (9), 63 (5); ^{1}H NMR ($CDCl_3$, 600 MHz) δ 2.086–2.090 (d, 3H, $J = 1.6$ Hz), 6.693–6.697 (d, 1H, $J = 1.6$ Hz), 7.124–7.148 (m, 1H, $J = 9.6$ Hz), 7.470–7.488 (d, 1H, $J = 7.2$ Hz), 7.508–7.523 (d, 1H, $J = 6.0$ Hz); ^{13}C NMR ($CDCl_3$, 150 MHz) δ 16.54 (CH), 113.98 (C), 118.16 (CH), 123.02 (CH), 130.89 (C), 134.28 (CH), 134.94 (CH), 148.44 (C), 159.96 (C), 183.54 (C), 189.03 (C). The analytical result of 5-hydroxy-2-methyl-1,4-naphthoquinone was consistent with the NMR data of previously reported study (Lee and Lee 2008).

The insecticidal toxicity of 5-hydroxy-2-methyl-1,4-naphthoquinone was evaluated against the three mosquito

Table 1 Insecticidal toxicities of the methanol extract from *D. kaki* roots and the five fractions against the three mosquito larvae

Materials	Concentration (μg/mL)	Mortality (mean ± SE %)		
		Ae. aegypti	*Cx. pipiens pallens*	*Oc. togoi*
Methanol extract	100	100	100	100
	50	72.7 ± 1.6	85.7 ± 2.0	60.5 ± 1.5
	25	28.6 ± 1.6	40.3 ± 1.8	9.8 ± 1.2
Hexane fraction	100	0	0	0
	50	0	0	0
	25	0	0	0
Chloroform fraction	100	100	100	100
	50	86.5 ± 2.5	100	69.5 ± 1.8
	25	31.5 ± 1.5	56.4 ± 2.2	14.7 ± 2.4
Ethyl acetate fraction	100	15.5 ± 1.7	31.4 ± 2.5	4.5 ± 1.5
	50	0	0	0
	25	0	0	0
Butanol fraction	100	25.4 ± 2.2	40.5 ± 1.6	10.4 ± 2.3
	50	0	0	0
	25	0	0	0
Distilled water fraction	100	0	0	0
	50	0	0	0
	25	0	0	0

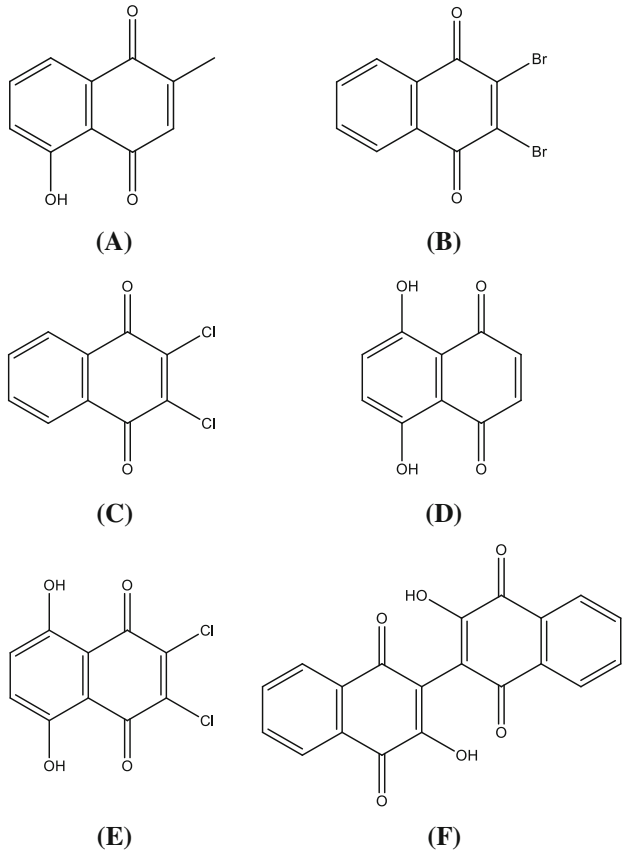

Fig. 1 Structures of 5-hydroxy-2-methyl-1,4-naphthoquinone derivatives: (**A**) 5-hydroxy-2-methyl-1,4-naphthoquinone, (**B**) 2,3-dibromo-1,4-naphthoquinone, (**C**) 2,3-dichloro-1,4-naphthoquinone, (**D**) 5,8-dihydroxy-1,4-naphthoquinone, (**E**) 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone, (**F**) 2,2′-bi(3-hydroxy-1,4-naphthoquinone)

larvae (Table 2). The LC_{50} values of 5-hydroxy-2-methyl-1,4-naphthoquinone (A) were 5.66, 5.43, and 6.09 μg/mL against *Ae. aegypti*, *Cx. pipiens pallens*, and *Oc. togoi*, respectively. The larvicidal toxicity of 5-hydroxy-2-methyl-1,4-naphthoquinone (A) has not been reported, and these findings indicate that the sensitivity of 5-hydroxy-2-methyl-1,4-naphthoquinone (A) against *Cx. pipiens pallens* was the highest among the three mosquito species. According to previous study, the resistance of natural substances derived from plants against *Ae. aegypti* and *Oc. togoi* was higher than that of a biomaterial against *Cx. pipiens pallens* because of the influence of phytochemicals (pellitorine, guineensine, and retrofractamide A) and biochemical factors (detoxifying enzyme, acetylcholinesterase, and penetration of sodium channel) (Yang et al. 2013; Kim et al. 2008).

The structural toxicity relationships of 5-hydroxy-2-methyl-1,4-naphthoquinone (A) and its structural derivatives, including 2,2′-bi(3-hydroxy-1,4-naphthoquinone) (F), 2,3-dibromo-1,4-naphthoquinone (B), 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone (E), 2,3-dichloro-1,4-naphthoquinone (C), and 5,8-dihydroxy-1,4-naphthoquinone (D) were determined (Table 2; Fig. 1). Based on the LC_{50} values of-5-hydroxy-2-methyl-1,4-naphthoquinone derivatives against *Ae. aegypti*, it was found that 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone (E) (0.89 μg/mL) had the most potent larvicidal toxicity, followed by 2,3-dibromo-1,4-naphthoquinone (B) (1.32 μg/mL), 5,8-dihydroxy-1,4-naphthoquinone (D) (3.57 μg/mL), 2,3-dichloro-1,4-naphthoquinone (C) (4.76 μg/mL), and 2,2′-bi(3-hydroxy-1,4-naphthoquinone) (F) (33.93 μg/mL); 2,3-Dichloro-5,8-dihydroxy-1,4-naphthoquinone (E) (0.80 μg/mL) possessed the strongest larvicidal toxicity against *Cx. pipiens pallens*, followed by 2,3-dibromo-1,4-naphthoquinone (B) (1.28 μg/mL), 5,8-dihydroxy-1,4-naphthoquinone (D) (3.34 μg/mL), 2,3-dichloro-1,4-naphthoquinone (C) (3.89 μg/mL), and 2,2′-bi(3-hydroxy-1,4-naphthoquinone) (F) (32.82 μg/mL). In the case of *Oc. togoi*, 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone (E)

Table 2 Insecticidal toxicities of 5-hydroxy-2-methyl-1,4-naphthoquinone derivatives and commercial insecticide against the three mosquito larvae

Compounds	Mosquito species	LC_{50} (μg/mL)	95 % confidence interval
5-Hydroxy-2-methyl-1,4-naphthoquinone	*Ae. aegypti*	5.66	5.60–5.78
	Cx. pipiens pallens	5.43	5.33–5.51
	Oc. togoi	6.09	5.98–6.18
2,3-Dibromo-1,4-naphthoquinone	*Ae. aegypti*	1.32	1.27–1.44
	Cx. pipiens pallens	1.28	1.20–1.40
	Oc. togoi	1.94	1.88–2.06
2,3-Dichloro-1,4-naphthoquinone	*Ae. aegypti*	4.76	4.71–7.93
	Cx. pipiens pallens	3.89	3.78–3.99
	Oc. togoi	5.33	5.29–5.39
5,8-Dihydroxy-1,4-naphthoquinone	*Ae. aegypti*	3.57	3.51–3.63
	Cx. pipiens pallens	3.34	3.27–3.40
	Oc. togoi	5.04	4.96–5.11
2,3-Dichloro-5,8-dihydroxy-1,4-naphthoquinone	*Ae. aegypti*	0.89	0.81–0.92
	Cx. pipiens pallens	0.80	0.74–0.87
	Oc. togoi	1.04	0.98–1.09
2,2′-Bi(3-hydroxy-1,4-naphthoquinone)	*Ae. aegypti*	33.93	33.81–34.05
	Cx. pipiens pallens	32.82	32.62–33.05
	Oc. togoi	36.17	35.96–36.31
Pirimiphos-methyl	*Ae. aegypti*	0.18	0.15–0.22
	Cx. pipiens pallens	0.13	0.10–0.19
	Oc. togoi	0.24	0.18–0.28

(1.04 μg/mL) showed excellent larvicidal toxicity, followed by 2,3-dibromo-1,4-naphthoquinone (B) (1.94 μg/mL), 5,8-dihydroxy-1,4-naphthoquinone (D) (5.04 μg/mL), 2,3-dichloro-1,4-naphthoquinone (C) (5.33 μg/mL), and -2,2′-bi(3-hydroxy-1,4-naphthoquinone) (F) (36.17 μg/mL). The larvicidal toxicities of the 5-hydroxy-2-methyl-1,4-naphthoquinone structural derivatives were less than those of pirimiphos-methyl (0.18, 0.13, and 0.24 μg/mL) against *Ae. aegypti*, *Cx. pipiens pallens*, and *Oc. togoi*. Nevertheless, 5-hydroxy-2-methyl-1,4-naphthoquinone (A) and its structural derivatives could be suitable as natural insecticidal agents to control mosquito larvae.

2,3-Dibromo-1,4-naphthoquinone (B) possessed potent insecticidal toxicity against the three mosquito larvae when 1,4-naphthoquinone contained Br, Cl, and OH functional groups, followed by 5,8-dihydroxy-1,4-naphthoquinone (D) and 2,3-dichloro-1,4-naphthoquinone (C). However, when combined with an OH functional group on 2, 3-dichloro-1,4-naphthoquinone (C), the larvicidal toxicities of 2,3-dichloro-5,8-dihydroxy-1,4-naphthoquinone (E) were approximately 5.35, 4.86, and 5.13 times more effective than those of 2,3-dichloro-1,4-naphthoquinone (C) against *Ae. aegypti*, *Cx. pipiens pallens*, and *Oc. togoi*, respectively. In contrast, when a CH_3 functional group was on 5-hydroxy-1,4-naphthoquinone, the insecticidal toxicities of 5-hydroxy-2-methyl-1,4-naphthoquinone (A) were less than those of 5,8-dihydroxy-1,4-naphthoquinone (D) against the three mosquito larvae. These findings indicate that the presence of some functional groups on 1,4-naphthoquinone influenced insecticidal toxicity against the *Cx. pipiens pallens*, *Ae. aegypti*, and *Oc. togoi* larvae. In particular, when the Cl and OH functional groups were placed on 1,4-naphthoquinone at the same time, insecticidal toxicity against the three mosquito larvae was the highest among compounds. In previous study, Ribeiro et al. (2009) have reported the insecticidal toxicities of 1,4-naphthoquinone structural derivatives against the *Ae. aegypti* larvae. Based on the LC_{50} values against *Ae. aegypti*, it was found that 3-bromo-5-hydroxy-1,4-naphthoquinone (0.873 μg/mL) possessed the potent larvicidal toxicity, followed by 5-hydroxy-1,4-naphthoquinone (3.587 μg/mL), 3-bromo-5-methoxy-1,4-naphthoquinone (5.752 μg/mL), and 3-bromo-5-acetoxy-1,4-naphthoquinone (7.287 μg/mL). These findings indicated that 1,4-naphthoquinone structural derivatives, containing Br and OH functional groups on 1,4-naphthoquinone, had the potent insecticidal effects against the mosquito larvae. From these results, the present study suggest that 1,4-naphthoquinone structural derivatives are insecticidal agents against the mosquito larvae.

Acknowledgments This research was carried out with the support of Cooperative Research Program for Agriculture Science & Technology Development (Project title: Development of integrated pest management techniques using natural products in the grain storage, Project No: PJ01004502), Rural Development Administration, Republic of Korea.

References

Ali A, Murphy CC, Demirci B, Wedge DW, Sampson BJ, Khan IA, Baser KHC, Tabanca N (2013) Insecticidal and biting activity of rose-scented geranium (*Pelargonium* species) individual compounds against *Stephanitis pyrioides* and *Aedes aegypti*. Pest Manage Sci 69:1385–1392

Bachrach U, Wang YC (2002) Cancer therapy and prevention by green tea: role of ornithine decarboxylase. Amino Acids 22:1–13

George AP, Redpath S (2008) Health and medicinal benefits of persimmon fruit: a review. Adv Hortic Sci 22:244–249

James AA (1992) Mosquito molecular genetics: the hands that feed bite back. Science 257:37–38

Jiang ZL, Zhang X, Feng JR (2002) A critical review of the essential oils and its application in plant protection. J Shaanxi Agric Sci 1:32–36

Kim DH, Kim SI, Chan KS, Ahn YJ (2002) Repellent activity of constituents identified in *Foeniculum vulgare* fruits against *Aedes aegypti* (Diptera: Culicidae). J Agric Food Chem 50:6993–6996

Kim NJ, Byun SG, Cho JE, Chung K, Ahn YJ (2008) Larvicidal activity of *Kaempferia galanga* rhizome phenylpropanoids towards three mosquito species. Pest Manag Sci 64:857–862

Lee HS (2002) Tyrosinase inhibitors of *Pulsatilla cernua* root-derived materials. J Agric Food Chem 50:1400–1403

Lee CH, Lee HS (2008) Acaricidal activity and function of mite indicator using plumbagin and its derivatives isolated from *Diospyros kaki* Thunb. roots (Ebenaceae). J Microbiol Biotechnol 18:314–321

Lee NH, Lee SM, Song DH, Yang JY, Lee HS (2013) Antimicrobial effect of emodin isolated from *Cassia tora* Linn. seeds against food-borne bacteria. J Appl Biol Chem 56:187–189

Park IK, Shin SC (2005) Fumigant activity of plant essential oils and components from garlic (*Allium sativum*) and clove bud (*Eugenia caryophyllata*) oils against the Japanese termite (*Reticulitermes speratus*). J Agric Food Chem 53:4388–4392

Pu F, Ren XL, Zhang XP (2013) Phenolic compounds and antioxidant activity in fruits of six *Diospyros kaki* genotypes. Eur Food Res Technol 237:923–932

Rajeswary M, Govindarajan M (2013) Mosquito larvicidal and phytochemical properties of *Ageratina adenophora* (Asteraceae) against three important mosquitoes. J Vector Borne Dis 50:141–143

Ribeiro KAL, de Carvalho CM, Molina MT, Lima EP, Lopez-Montero E, Reys JRM, de Oliveira MBF, Pinto AV, Santana AEG, Goulart MOF (2009) Activities of naphthoquinones against *Aedes aegypti* (Linnaeus, 1762) (Diptera: Culicide), vector of dengue and *Biomphalaria glabrata* (Say, 1818), intermediate host of *Schistosoma mansoni*. Acta Trop 111:44–50

Sattar A, Bibi N, Chaudry MA (1992) Phenolic compounds in persimmon during maturation and on tree ripening. Mol Nutr Food Res 36:466–472

Sunity S, Himanshu J (2011) *Diospyros kaki* (Ebenaceae): a review. Asian J Res Pharm Sci 1:55–58

Suzuki T, Someya S, Hu F, Tanokura M (2005) Comparative study of catechin compositions in five Japanese persimmons (*Diospyros kaki*). Food Chem 93:149–152

Tabanca N, Bernier UR, Ali A, Wang A, Demirci B, Blythe EK, Khan SI, Baser KHC, Khan IK (2013) Bioassay-guided investigation

of two *Monarda* essential oil for repellent activity against yellow fever mosquito *Aedes aegypti*. J Agric Food Chem 61: 8573–8580

World Health Organization (2009) Report of the WHO informal consultation on the evaluation on the testing of insecticides. World Health Organization, Geneva

Yang YC, Lee SG, Lee HK, Kim MK, Lee SH, Lee HS (2002) A piperidine amide extracted from *Piper longum* L. fruit shows activity against *Aedes aegypti* mosquito larvae. J Agric Food Chem 5:3765–3767

Yang JY, Cho KS, Chung NH, Kim CH, Suh JW, Lee HS (2013) Constituents of volatile compounds derivative from *Melaleuca alternifolia* leaf oil and acaricidal toxicities against house dust mites. J Korean Soc Appl Biol Chem 56:91–94