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Efficacy of plant essential oils for repelling against American cockroach adults (*Periplaneta americana* L.)

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Abstract The combination of four plant essential oils (EOs) from star anise, citronella grass, lemon grass, and cinnamon was evaluated for repelling American cockroaches by the dual-choice method. A combination of star anise + citronella grass had a repellency rate of 95%. In contrast, combinations of star anise + lemon grass and star anise + cinnamon were effective between 73% and 69%, but the synthetic chemical repellent (12% DEET) was less effective at 59%. Therefore, the essential oils formulae had a high potential for effective use and, further, are harmless for healthiness and the environment. Thus, they can replace more toxic synthetic insecticides.

Keywords: American cockroach, Cinnamon, Citronella grass, Lemon grass, Star anise

Introduction

Cockroaches are insect pests spread all around the world: 30 species live in habitation and 16 species cause illness (Nasrin *et al*., 2021). The cockroaches are synanthropic and universal insect pests, that cause intolerance response in people (Yeom *et al*., 2013). They are spreaders of pathogens (Gonzalez *et al.*, 2016). Cockroaches are in habitats, industries, woodworking facilities, and the environment (Nasrin *et al*., 2021).

The American cockroach, *Periplaneta americana,* is a usual insect pest - generally found in homes, eateries, educational institutions, and health centers (Schal and Hamilton, 1990). They are omnivorous, feeding on real leather, wrappers, gums, pelts, and furs (Nasrin *et al.,* 2021). Over the world, they are generally controlled by synthetic insecticides (Alzogaray *et al*., 2011). These

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synthetic chemicals, which are stomach poisons and insect growth regulators, often leave residual chemicals (Gore and Schal, 2004). The long-term use leads to human wellness hazards, residual toxicants, and cockroaches-resistant (Nasrin *et al*., 2021).

Many synthetic insecticides effectively repel against cockroaches (Prakash *et al*., 1990). DEET or CAS 134-62-3 is a synthetic chemical repellent for repelling insects. Forty years ago, it was used to defend living creatures from insect pests (Taylor *et al.,* 1993). At present, utilizing pesticides against pests has multiple problems, including pest resistance, pollution of habitats, non-target species, and virulence to persons (Campos *et al.,* 2019). Thus, plant essential oils were developed to effectively reduce or replace synthetic insecticides (Campolo *et al.,* 2020).

Essential oils are secondary phytochemicals, liable for the aroma of many plants, that have been shown as potential alternatives to chemical insecticides (Omara *et al*., 2013). These plant oils are active against insect pests (Isman, 2006): their properties include insecticides against cockroaches and other insects as well as fumigants, inhibiting feeding and repelling effects, and inhibiting reproductive (Omara *et al.,* 2013). The main constituents of plants can quickly degrade, leading to low pesticide residues and low residual toxicity against valuable species (Hashem *et al*., 2020). Hence, plant extracts could be potential alternatives against cockroaches (Ferrero *et al*., 2006). Previous research on essential oils against cockroaches revealed that catnip oil effectively repelled adult male German cockroaches (Peterson *et al*., 2002). Two essential oil components - citral and eugenol also repelled cockroaches (Vartak *et al*., 1994). Additionally, the kaffir lime strongly repelled two cockroach species (German and American cockroach) and was more effective than naphthalene (Thavara *et al*., 2007).

This research investigation was evaluated the repellency of adult American cockroaches from several combinations.

Materials and methods

Rearing of adult cockroaches

The adult stage of cockroaches was collected from Hua Ta Khe market, Lat Krabang, Thailand (13.4323° N, 100.4720° E) and reared in glass jars (225 mm diameter × 350 mm) at 25±2 °C at School of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand (13.8436° N, 100.5077° E). They were fed with 10% glucose syrup soaked in cotton and

dog food mixed with milk powder. Newly born adults were used. The materials used in Table 1.

Table 1. Materials used

Material	Source	Notes
Adult American cockroach	Hua Ta Khe market	13.4323° N, 100.4720° E
Glucose syrup	Mitr Phol, Thailand	Sucrose 50%, glucose 25%, fructose 35%
Dog food	Mars Petcare. Thailand	Pedigree
Milk powder	Nestle (Thai) company limited	Carnation
Star anise Citronella grass Lemon grass Cinnamon	Sigma-Aldrich, Thailand.	Essential oil
DEET	SBL Supply group, Thailand	N,N-diethylphenylacetamide Chemical insecticide

Plant essential oils preparation

Essential oils (EOs) of star anise, citronella grass, lemon grass, and *Cinnamomum verum* were used in formulations listed in Table 2.

Table 2. The combination and concentration of combinations

Combination	Concentration
star anise + cinnamon	1% star anise EO + 1% cinnamon EO + 98% ethyl alcohol
star anise + lemon grass	1% star anise EO + 1% lemon grass EO+ 98% ethyl alcohol
star anise + citronella grass	1% star anise EO + 1% citronella grass EO+ 98% ethyl alcohol

Other chemical preparation

The positive and negative controls were 12% (w/w) DEET, a common insecticide and 70% (v/v) ethanol see Table 1.

Repellency test in lab conditions

An 85 mm diameter × 340 mm open-top, plastic test bottle was used as a cockroaches plastic test bottle for the repellency test. A piece of cotton wool that filled the zone of the base of the plastic test bottle was placed at the bottom of the plastic test bottle. It was separated into two equal zones, a treatment zone, and a control zone. 3 mL treatment was dropped by the treatment zone, whereas the control zone was left empty. For the positive control treatment, 3 mL DEET, a common synthetic chemical repellent was dropped into the treatment area.

Identical sets of food and drink cups were placed in both the treatment and control zones to ensure that no cockroach would starve. For each treatment, five adult cockroaches were placed in the plastic test bottle. Repellency was measured and recorded as the number of cockroaches that moved away from the treatment zone, or the number of cockroaches that remained in the control zone. After 30, 60, 90, 120, 150, and 180 minutes, counts from the repellency test were recorded (five times). The outcomes were converted into a repellency index (RI) using (Thavara *et al.,* 2007; Sittichock *et al*., 2013):

$$RI = (NS–NC)/(NS+NC)$$

where NS was the number of insects in the treatment at the time of observation, and NC was the number in the control zone.

The repellency (PR%) for each essential oil was calculated from:

$$PR = [1- (NS)/(NS+NC)] \times 100\%,$$

where NS was the number of insects in the treatment area at the time of observation and NC was the number in the control zone.

Statistical analysis

A paired *t*-test (using SPSS version 25) was used to determine the significant difference at $p<0.05$ in the means of cockroaches in the treatment and control zones.

Results

Repellency activity

After testing the formulas against adult cockroaches, the combination of 1% star anise + 1% citronella grass was most effective at 150 minutes, repelling 95% of adults, followed by the combination of 1% star anise and 1% lemon grass repelling 73%, whereas 1% star anise + 1% cinnamon repelled 69%. DEET was effective, repelling 63%. The relationship between effectiveness vs time showed correlation coefficients, R^2, between 0.49 and 0.73 (Table 3).

Table 3. Repellent rates for American cockroaches after exposure to essential oil combinations

Treatment	Repellency rate (%) ±SD (min)						R^2	Regression equation of time
	30	60	90	120	150	180		
Star anise + cinnamon	58±13^{b}	68±24^{ab}	69±25^{a}	68±28^{a}	69±27^{a}	69±27^{a}	0.49	Y=1.6286x +61.133
Star anise + lemon grass	63±29^{ab}	65±26^{b}	67±28^{a}	71±29^{a}	73±30^{a}	73±30^{a}	0.95	Y=2.2286x +60.867
Star anise + citronella grass	84±13^{a}	92±7^{a}	92±7^{a}	93±7^{a}	95±6^{a}	95±9^{a}	0.73	Y=1.8571x +85.333
12% DEET	66±12^{ab}	65±11^{b}	74±11^{a}	64±18^{a}	64±18^{a}	63±17^{a}	0.86	Y = -2.4x +88.733
70% ethanol	0	0	0	0	0	0	0	0

Repellency index

The repellency index of the 1% star anise + 1% citronella grass combination showed it was slightly more effective as a repellent than DEET at 1.5 after 180 min, whereas the other two ranged between 1.1 and 1.2 (Figure 1).

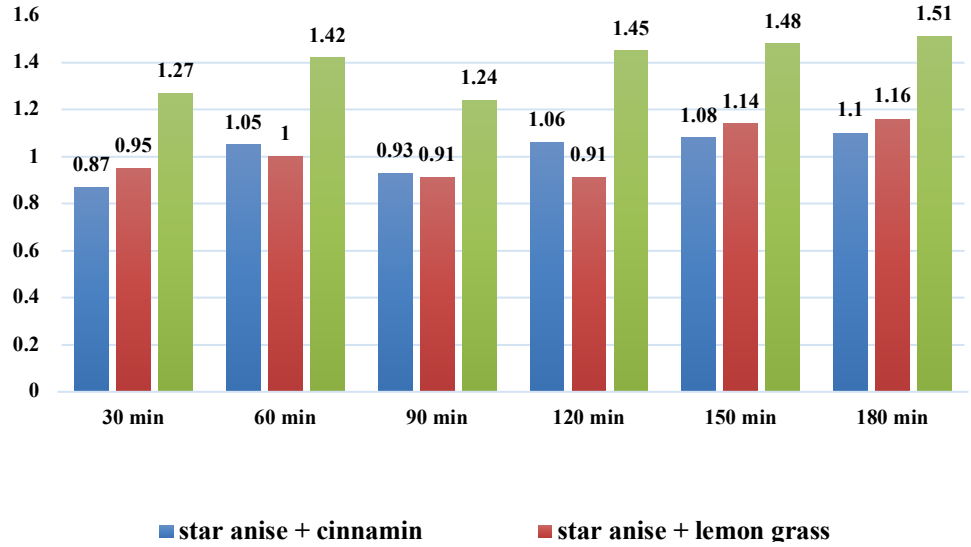

Figure 1. Repellency indexes of American cockroaches for the tested combinations

To conclude, ranked according to their repellency against adult cockroaches, the selected plant essential oils were ranked as follows:
star anise + citronella grass > star anise + lemon grass > star anise + cinnamon

Discussion

Star anise and citronella grass essential oil combinations showed a better-than-DEET repelling effect on adult cockroaches, as compared to more combinations. It showed that the repellency index at 180 minutes of the star anise and citronella grass combination was 1.51, it was higher than the other combinations and thus, it revealed a higher repelling activity than DEET. The linear regression result revealed the relation between time and the repelling rate of American cockroaches. Regressions for repellency effectiveness versus time showed R^2 coefficients between 0.49 and 0.73. Previous studies showed that the essential oils from lemon grass, cinnamon, blue gum, star anise, and makhwaen had ovicidal and repelling activity against American cockroaches by topical method (Soonwera *et al*., 2022). Chang and Ahn (2001) also showed a high repelling of star anise essential oil for adult German cockroaches. Sittichock *et al.* (2013) also determined that the Thai local plants dissolved in soybean oil and ethyl alcohol had high repellencies - between 66-100% - on American cockroaches. In addition, the lemon grass had high repelling activity on yellow fever mosquitoes and malaria mosquitoes (Sritabutra *et al.,* 2011). Furthermore, at 0.21 mg/cm^2 of lemon grass essential oil had high repelling activity on the yellow fever mosquito, malaria mosquito, and southern house mosquito (Phasomkusolsil and Soonwera, 2012). Moreover, the citral from lemon grass had the highest toxicity on larva of housefly by contact with LC_{50} of 0.002 mL/cm^3 and fumigant toxicity method with and 3.3 mL/cm^3(Kumar *et al*., 2012). The major constituent of lemon grass, star anise, and nutmeg oil had a high insecticidal activity against houseflies in knockdown and mortality effect (Aungtikun *et al.*, 2021). Lei *et al.* (2023) showed that the major constituent in star anise had trans-anethole. Metabolism of trans-anethole showed in growth inhibition, dehydration, laying inhibition, feeding inhibition, and neurotoxin in insect pests (Park *et al*., 2016): it inhibited the Acetylcholinesterase enzymes (Peter *et al*., 2021). Further, it strongly repelled insect pests, when applied coated on polyethylene terephthalate film (Choi *et al*., 2006). The major constituents in citronella grass oil had citronellal and geraniol (Nyamador *et al*., 2020).

As a repelling, DEET revealed a lower activity on American cockroaches than these combinations. On the other hand, as a repellant, DEET was highly effective, continuing, and showed low harmful against other insects (Frances, 2006). Its effectiveness was shown in hematophagous and non-hematophagous

insects (Reeder *et al*., 2001). Similarly, Komiyama *et al*. (1981) revealed that it repelled German and smoky brown cockroaches at 2.5 grams per square meter for 3 weeks and adult and nymphs of smoky brown cockroaches at 5 grams per square meter for 2 weeks. In addition, DEET was active against German cockroaches at 700 micrograms per square centimeter for 20 minutes (Sfara *et al*., 2013). However, now DEET has difficulty eliminating some insects because they have developed resistance to synthetic insecticides. Lutz *et al*. (2014) revealed that, in many studies, when the insect pests were revealed to high concentrations for a long time repellency decreased. First instar nymphs of German cockroaches became resistant to DEET (Mengoni and Alzogaray, 2018). Although DEET could be depended on for long-term effects, it was a less success repelling, because it was eliminated with raindrops and degraded in intense heat (Fradin and Day, 2002).

In conclusion, star anise and citronella grass essential oil formulae were toxic to adult American cockroaches. Thus the combination was an important alternative against cockroaches and reducing health deterioration.

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