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Author(s) : Whitney A. Qualls, Rui-De Xue, J. Adam Holt, Mike L. Smith and Jeanne J. Moeller

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Field Evaluation of Commercial Repellents Against the Floodwater Mosquito *Psorophora columbiae* (Diptera: Culicidae) in St. Johns County, Florida

WHITNEY A. QUALLS,¹ RUI-DE XUE, J. ADAM HOLT, MIKE L. SMITH, AND JEANNE J. MOELLER

Anastasia Mosquito Control District, 500 Old Beach Road, St. Augustine, Florida 32080

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ABSTRACT Three plant-based repellents—REPEL LEMON Eucalyptus Insect Repellent Lotion (active ingredient [AI] 30% oil of eucalyptus), Bite Blocker Xtreme Sportsman Organic Insect Repellent ([AI] 3% soybean oil, 6% geranium oil, and 8% castor oil), and Bite Blocker BioUD Insect Repellent ([AI] 7.75% 2-undecanone)—were evaluated against OFF! ([AI] 15% *N,N*-diethyl-*m*-toluamide or *N,N*-diethyl-3-methyl-benzamide, also called DEET) at a field site in Elkton, FL, to determine the mean protection time provided against *Psorophora columbiae* (Dyar & Knab). These products provided different protection times against biting *Ps. columbiae*. REPEL provided the longest protection time (330 min) followed by Bite Blocker Xtreme Sportsman (163 min), Bite Blocker BioUD (140 min), and OFF! (130 min). This study provides the first information about plant-based insect repellent protection times against *Ps. columbiae*.

KEY WORDS *Psorophora columbiae*, DEET, eucalyptus oil, plant-based insect repellents

Psorophora columbiae (Dyar & Knab) (Diptera: Culicidae) is an aggressive and prolific floodwater mosquito that poses a nuisance both to residents and animals in St. Johns County (SJC), FL. Kuntz and colleagues (1982) reported that the major blood source of *Ps. columbiae* was domestic livestock. However, a decrease in the real-estate market since 2006 in SJC has led to an increase in vacant residential developments that provide an ideal *Ps. columbiae* breeding habitat (R.-D.X., personal observation). As a result, *Ps. columbiae* populations have dramatically increased in these undeveloped, cleared residential neighborhoods increasing human exposure to this voracious biter. After a 0.5-m rainfall event in 2009, >2,500 service requests were reported during a 2-wk period to the Anastasia Mosquito Control District (AMCD), SJC, FL. The majority of these requests came from residents living adjacent to partially developed neighborhoods that were exposed to heavy *Ps. columbiae* populations (R.-D.X., personal observation).

The use of mosquito repellents is the first line of defense in personal protection to reduce nuisance and vector mosquito bites (Freedman 2008). The active ingredient ([AI] *N,N*-diethyl-*m*-toluamide or *N,N*-diethyl-3-methyl-benzamide, also called DEET) has proven to be the most effective mosquito repellent against biting mosquitoes (Yap et al. 1998, Thavara et al. 2001). However, this compound has been reported to

have many problems, including an unpleasant odor and possible central nervous system depression (Kim et al. 2004). Although the Centers for Disease Control and Prevention (CDC) still recommends the use of DEET, these problems have resulted in a need to identify DEET-alternative insect repellents (Fradin and day 2002, Barnard and Xue 2004).

In 2008 the CDC updated its recommendations for personal repellent use in the face of continued West Nile virus transmission throughout North America (<http://www.cdc.gov/ncidod/dvbid/westnile/repellentupdates.htm>). Four AIs in repellents are currently recommended for use by the CDC: DEET, picaridin [KBR 3023, 2-(2-hydroxyethyl)-1-piperidine-carboxylic acid 1-methylpropyl ester], oil of lemon eucalyptus (para-menthane-3,8-diol [PMD]), and IR3535 (3-[*N*-butyl-*N*-acetyl]-aminopropionic acid, ethyl ester). Oil of lemon eucalyptus is an effective mosquito repellent (Barnard and Xue 2004). The CDC recommendation of an insect repellent with a plant-based essential oil as the active ingredient (oil of lemon eucalyptus essential oil) has increased the number of commercially available plant-based essential oil repellents.

However, many of these essential plant-based products are locally produced, locally distributed, appear on the market for only a brief period and are informally promoted as alternatives to DEET without appropriate evaluation of their effectiveness against nuisance and vector mosquitoes (Isman 2006, Maguranyi et al. 2009). There is a need to identify repellents available for consumer purchase that provide adequate mosquito protec-

This is a report on a research study only and does not mean that AMCD endorses any products.

¹ Corresponding author, e-mail: quallsamcd@bellsouth.net.

tion to the user. Field studies using local mosquito populations provide an accurate evaluation of repellent protection times against known mosquito pests and disease vectors. The results of these evaluations are important when making repellent use recommendations to the public. Thus, field research results designed to evaluate new repellents that provide acceptable protection times against aggressive biting mosquitoes, such as *Ps. columbiae*, and the standard of mosquito repellents, DEET, are reported here.

Materials and Methods

Three plant-based repellents were selected to be evaluated against DEET (OFF! Family Care Insect Repellent, S.C. Johnson and Son, Inc. Racine, WI). The three repellents selected were as follows: REPEL LEMON Eucalyptus Insect Repellent Lotion (WPC Brands, Inc., Jackson, WI), Bite Blocker Xtreme Sportsman Organic Insect Repellent (HOMS, LLC, Clayton, OH), and Bite Blocker BioUD Insect Repellent (HOMS, LLC). The AI in REPEL was 30% oil of lemon eucalyptus. Bite Blocker Xtreme Sportsman included a combination of AIs: soybean oil (3%), geranium oil (6%), and castor oil (8%). The AI in Bite Blocker BioUD was 7.75% 2-undecanone originally derived from wild tomato (*Lycopersicon hirsutum* Dunal f. *galabratum* C. H. Mull) plants. The AI for OFF! consisted of 15% DEET.

A field site in SJC (29.860830°S–81.461290°W) was selected as the test site because of an abundant *Ps. columbiae* population. The field tests were conducted on a 242-ha undeveloped residential site that was leased for sod cultivation. The surrounding areas consisted of artificial ditches and hardwood, low-lying areas that periodically flood during the rainy season (June–October). Based on a previous study (Qualls and Xue 2009), this site had large populations of *Psorophora ferox* (von Humboldt), *Psorophora ciliata* (F.), *Ps. columbiae*, *Aedes mitchelliae* Dyar & Knab, and *Aedes atlanticus* Dyar & Knab from early June through October in 2008 and 2009. During the study reported here, *Ps. columbiae* comprised 92% (29,770/32,385) of the adult mosquitoes collected in CDC light traps baited with dry ice. These collections took place a day before each repellent evaluation.

The first field trial was conducted on 26 August 2009. The trial began at 1900 hours and ended at 2300 hours. Seven human volunteers, who had read and signed an informed consent form, two females and five males; aged 28–60 participated in the first trial.

Each arm of the volunteer was treated with 1.0 ml of repellent that was applied from the elbow down to the wrist, an area of ≈ 550 cm². The other arm of the volunteer was treated with 1.0 ml of a second test repellent or served as an untreated control. The volunteers sat 6.0 m apart. Timed repellent failure was determined after a second mosquito landed and probed for >3 s on the treated area of the volunteer's arm. Two volunteers' arms were used as the untreated control and used to assess the biting pressure at the field site during the duration of the study. The biting pressure of the mosquito population at the field site was determined by conducting landing rate

counts (LRCs) for 5 min every 30 min until the trial was over. The number of mosquitoes landing on the untreated arms was recorded. After each 5-min LRC, the untreated volunteer's arm was concealed with a long-sleeved shirt.

Due to the persistence of REPEL during the first trial (>4 h of complete protection), a second trial with this repellent was conducted on 2 September 2009 from 1900 hours to 2230 hours. Three human volunteers from the first field trial, one female and two males, aged 28–55 yr, participated in the second trial. One arm of each volunteer was treated with 1.0 ml of REPEL LEMON Eucalyptus Insect Repellent Lotion from the elbow to the wrist, an area of ≈ 550 cm², at 1550 hours, 3.5 h before the start of the field test. The other arm of each volunteer was treated with alcohol and served as the control for biting pressure. The volunteers sat 6.0 m apart. Repellent failure was determined after a second mosquito landed and probed for >3 s on the treated arm. Again, the biting pressure of the mosquito population at the test site was determined by conducting LRC for 5 min every 30 min until the end of the field trial. During this second evaluation, three untreated arms were used as the control. The numbers of mosquitoes landing on the untreated arms were recorded. Long-sleeved shirts were used to conceal the untreated arm when LRC were not conducted.

The time between application of the test products and two consecutive mosquito bites was recorded and used to calculate the mean protection times (MPTs) as the average for the four repellents. Statistical differences between the MPTs were analyzed using analysis of variance (ANOVA), and Tukey–Kramer test ($P \leq 0.05$). The biting pressure for each trial was calculated by determining the mean number of mosquitoes landing on the control arms. A Student's *t*-test was used to determine whether there were any differences in the biting pressure during the two field trials.

Results and Discussion

All three plant-based repellents provided a longer MPT than the DEET repellent. There was a significant difference in MPT among the repellents ($F = 39.2$, $df = 3$, $P = 0.01$) with REPEL LEMON Eucalyptus providing a significantly longer MPT (330 ± 15 min) compared with the other repellents (Fig. 1). Bite Blocker Xtreme, Bite Blocker BioUD, and OFF! provided just under 180 min of MPT (163 ± 18 , 140 ± 20 , and 130 ± 25 min, respectively). There were no significant differences in biting pressure observed during the two trials ($t = 1.3$, $df = 2$, $P = 0.2943$). The number of mosquitoes landing on the untreated arms averaged 45 ± 6.4 and 39 ± 5.3 , for the two field evaluations, respectively.

Although MPT for REPEL LEMON Eucalyptus was determined during a second field trial, the authors consider the second trial to be a continuation of the first trial based on the biting pressure and mosquito populations present during the two test dates. Mosquito populations at the test site were monitored using CDC light traps baited with one pound of dry ice. Collections were brought back to the laboratory and

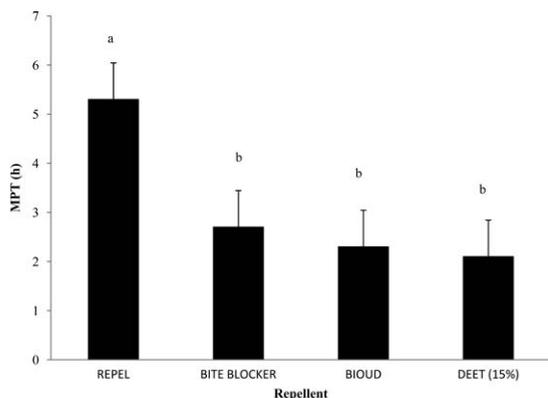


Fig. 1. Mean protection times of the three plant-based products compared to the DEET control. Differences in the MPT to second bite are significant $P < 0.05$ (Tukey-Kramer test).

identified to species (Darsie and Ward 2004). The first collection took place on 25 August 2009, with *Ps. columbiana* representing 93% (16,080/17,135) of the collection. The second collection took place on 1 September 2009, with *Ps. columbiana* representing 89% (13,690/15,250) of the collection.

Witting-Bissinger et al. (2008) reported two field studies evaluating 7.75% 2-undecanone (Bite Blocker BioUD) against 30% DEET (Deep Woods OFF!). The first field study conducted in North Carolina found BioUD provided the same repellency as 30% DEET against field populations of *Ps. ferox*. The second field study conducted in Canada found BioUD provided significantly greater repellency than both 30% DEET and Bite Blocker Extreme against field populations of *Aedes vexans* (Meigen) and *Aedes euedes* Howard, Dyar & Knab. Both of these trials resulted in 90% reduction in mosquito landing rates for up to 6 h. Although we evaluated the MPT of the insect repellents, our observations suggest that all three plant-based products could be substituted for DEET to prevent or reduce mosquito bites.

An important aspect of this study is the field evaluation of lemon eucalyptus oil. The CDC recommendation of lemon eucalyptus oil is based on laboratory evaluations (Barnard and Xue 2004). Our evaluation provides the first report of the efficacy of oil of eucalyptus against field populations of *Ps. columbiana*. REPEL LEMON Eucalyptus was very effective at providing protection from biting *Ps. columbiana* (MPT of 5.5 h).

The continued land development in rural areas of SJC, FL, increases the likelihood of human exposure to flood-water mosquito species. The increase of human exposure to biting mosquitoes and the popular use of plant-based repellents for personal protection against mosquitoes

further illustrate the need to critically evaluate new repellent formulations against mosquitoes in the field.

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