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FIELD EFFICACY OF COMMERCIAL ANTIMOSQUITO PRODUCTS IN ILLINOIS

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ABSTRACT. We evaluated the efficacy of commercial antimosquito products in field trials in Illinois in June 1998 by comparing mosquito landing rates. Products tested were a sonic mosquito repeller, an insect killing grid using ultraviolet light and 1-octen-3-ol as lures, mosquito smoke coils containing a pyrethroid, citronella candles, the mosquito plant *Pelargonium citrosum,* and a *N,N*-diethyl-3-methylbenzamide (deet)-impregnated wrist band. The sonic mosquito repeller, insect killing grid, and mosquito smoke coils were evaluated in 16 trials over 5 days; the citronella candles and mosquito plants in 11 trials over 4 days; and the wrist bands in 4 trials on 1 day. In all 3 studies, we compared landing rates with the antimosquito products to both positive (topical application of a deet formulation) and negative (no treatment) controls. The deet topical repellent had a consistently lower landing rate than all the nontopically applied products tested. However, the mosquito coils and the deet-impregnated wrist bands did significantly reduce mosquito landing rates relative to untreated controls.

KEY WORDS antimosquito products, field efficacy, mosquito repellents

INTRODUCTION

The public's demand for convenient, safe, and effective antimosquito products has led to the mass marketing of many types of products that are advertised to keep the user mosquito-free. Although some of these products seem to be based on known aspects of mosquito behavior, many often do not have scientific data to substantiate their claims. For example, light-based devices and traps baited with chemical attractants are often used to collect a variety of mosquitoes (Bidlingmayer 1980, Service 1993); however, there is no indication that these devices effectively compete with human stimuli to reduce the biting pressure on humans. When consumers are misled into purchasing ineffective antimosquito products, the result can be an unintentional exposure to biting mosquitoes. The consequences range from annoyance or discomfort from mosquito bites to an increased risk of infection with mosquito-borne disease pathogens.

Herein we report the results of studies evaluating the effectiveness of 6 commercial antimosquito products under typical wooded conditions in Illinois. This type of study site was selected because the flora and mosquito fauna are typical of recreation areas in the midwestern United States, sites where campers and outdoor enthusiasts are potentially exposed to biting mosquitoes. Products tested were a sonic mosquito repeller, an insect-killing grid using an ultraviolet (UV) light and 1-octen-3-ol as lures, mosquito smoke coils containing a pyrethroid, candles containing citronella oil, the mosquito plant *Pelargonium citrosum,* and a *N,N*-diethyl-3-methylbenzamide (deet)-impregnated wrist band. The efficacies of these products were compared to negative controls (untreated volunteers) and positive controls (volunteers with a topical application of deet). Deet is a mosquito repellent that provides protection against a wide range of mosquito species when applied properly (Fradin 1998). The results of this study are compared to previous studies.

MATERIALS AND METHODS

The efficacy of 6 antimosquito products was determined in 3 studies conducted in Trelease Woods, a University of Illinois protected woodlot in Champaign County, in east central Illinois. Preliminary landing–biting counts were conducted at sunset in Trelease Woods the evening before each study began. The mosquitoes coming to the legs of untreated volunteers included *Aedes triseriatus* (Say), *Aedes vexans* (Meigen), *Aedes trivitattus* (Coquillett), and *Psorophora ferox* (Humboldt). Vegetation in Trelease Woods consists primarily of mature maple, hickory, and oak trees with the woodlot bordered by preserved prairie to the south and corn and soybean fields on the east, north, and west.

The 1st study evaluated the efficacy of the Flowtron® Insect Killer Model BK-15D with Flowtron® Octenol Mosquito Attractant (Flowtron Outdoor Products, 2 Main Street, Melrose, MA 02176), Mosquito Contro™ Portable Mosquito Repeller (Lentek International Inc., 16 Prime Court, Suite 800, Orlando, FL 32809), and Off® Mosquito Coils (S. C. Johnson and Sons, Inc., Racine, WI 53403). A 2nd study evaluated the efficacy of Skeeter Beeter™ 3% Citronella Candles (American Candle Co., Inc., Haskell, NJ 07420) and the mosquito-repellent plant *P. citrosum* var. 'van Leeni.' A 3rd study evaluated the efficacy of Repello™ Insect Repelling Wristbands (Repello Products Inc., Mineola, NY 11501).

The Flowtron Insect Killer Model BK-15D with Flowtron Octenol Mosquito Attractant is a mosquito removal device that lures mosquitoes to a UV light source and a time-release packet of 1-octen-

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Table 1. Rank-adjusted scores for mosquito landing rates associated with the Flowtron Insect Killer, Mosquito Contro Portable Mosquito Repeller, mosquito coils, *N,N*-diethyl-3-methylbenzamide (deet) repellent, and an untreated control in a field test conducted in Trelease Woods outside Champaign, IL, June 15–19, 1998.

Treatment	Mean score[1]	Standard error
Insect killer	4.1a	0.28
Mosquito coils	2.7b	0.24
Ultrasonic repeller	3.4a	0.27
Untreated	3.7a	0.25
Deet repellent	1.1c	0.06

[1] $n = 16$; scores followed by the same letter are not significantly different at the 95% confidence level.

3-ol. Theoretically, this combination of stimuli attracts host-seeking mosquitoes in an area that are killed when they contact an electric killing grid surrounding the UV light. Packaging with the Mosquito Contro Portable Mosquito Repeller claims that the sound frequencies produced by this battery-operated device repel female mosquitoes. Both the Off Mosquito Coils and Skeeter Beeter 3% Citronella Candles release compounds during combustion, D/L-allethrolone D-*trans*-chrysanthemate and citronella oil, respectively, which supposedly reduce the number of host-seeking mosquitoes in the vicinity of the source. The mosquito-repellent plant *P. citrosum* is said to repel host-seeking mosquitoes from areas near the plant because of its citronella-like scent. The Repello Insect Repelling Wristbands consist of plastic bands that can be attached to the wrist or ankle and contain 9.5% deet as an active ingredient. This product claims to provide protection of deet to the wearer while eliminating the need to treat clothes or skin. All tested products were locally purchased at retail outlets in Champaign, IL, during late May and June 1998.

The positive control for the 3 studies was a common formulation for the topical application of deet: Unscented Backwoods Cutter® Insect Repellent with 21.85% deet, 1.15% other isomers, and 77% inert ingredients (Miles Inc., Consumer Household Products, Chicago, IL 60638). The insect repellent and all other products were used according to the instructions accompanying the product. The only exception was the mosquito-repellent plant, which did not come with instructions.

For the 1st 2 studies, sampling stations were spaced about 50 m apart and 2–4 mosquito collection periods were made at each station daily under crepuscular light conditions. The collection periods occurred between 30 min before to 30 min after sunset (2015–2115 h). The number of collections varied because thunderstorms caused sampling to be terminated prematurely on 3 evenings. The treatments were rotated to new stations each day.

To evaluate the efficacy of the insect-repelling wrist bands, 4 15-min collection periods were made on a single day, 1 each at 4 sampling stations 25 m apart in Trelease Woods. Collections were made in early morning (0800–0900 h) and the species collected were *Ae. triseriatus* and *Ae. vexans.*

Landing rates for the 1st 2 studies were based on the number of mosquitoes landing on the exposed legs of a volunteer collector during each sampling period. For the 3rd study, we collected mosquitoes from the arm with the deet-impregnated wristband. For all studies, mosquitoes were collected using a mechanical aspirator.

Changing weather conditions and increasing host-seeking mosquito populations caused the number of landing mosquitoes to change over time, with substantial variation in the number collected in each period. To overcome the problem of unequal variance between days, we rank transformed the data for the 1st 2 studies. For each collecting period, collections from each site were assigned a rank of 1 through 4 or 5 based on the number of mosquitoes collected with each treatment (including controls). The treatment with the greatest number of mosquitoes was assigned the highest score (4 or 5 depending on the number of treatments) and that with lowest number of mosquitoes, the lowest score (1). Rank transformation equalized variances and allowed the data from each collection to be weighed equally during statistical analysis.

For all 3 studies, the statistical design was a Latin-square with days as replicates (Cochran and Cox 1957). Initially, treatments and positive and negative controls were randomly assigned to each sampling station. The treatments were moved to new stations each evening until all treatments had been evaluated at each station at least once. The study sites were separated by 25–50 m to prevent interactions between treatments. The hypothesis that rank-transformed mosquito landing rates differed significantly by treatment and/or site was tested using analyses of covariance and variance using the procedure ONEWAY (Minitab 1991). Pairwise comparisons of all treatments were made using Fisher's least significant difference method. For all tests, differences were considered significant at the 95% confidence level.

In the 1st study, conducted June 15–19, 1998, a portable 110-V generator was used to provide electricity via an extension cord for the Flowtron Insect Killer. The generator was placed 30 m from the device, so as not to interfere with its operation. All products were used according to labeled instructions. The Flowtron Insect Killer and the Mosquito Contro Portable Mosquito Repeller were switched on and the mosquito coils and candles were ignited 15 min before sampling commenced. Three mosquito coils or candles were placed in an equilateral triangle, 3 m apart, with the sampling station in the center, about 1.5 m from each coil or candle. The 2nd study was conducted June 22–25, 1998, with all treatments set out 15 min before the study commenced.

Table 2. Rank-adjusted scores for mosquito landing rates associated with citronella candles, mosquito-repellent plants, topical application of *N,N*-diethyl-3-methylbenzamide (deet) repellent, and untreated control in a field test conducted in Trelease Woods near Champaign, IL, from June 20 to 23, 1998.

Treatment	Mean scores[1]	Standard error
Citronella candles	3.1a,b	0.21
Mosquito plant	3.4b	0.24
Untreated	2.6a	0.24
Deet repellent	1.0c	0.00

[1] $n = 11$; scores followed by the same letter are not significantly different at the 95% confidence level.

The 3rd study evaluating the wrist bands was conducted on July 14, 1998. Four volunteers participated in the study; 2 used a single Repello Brand wrist band (on their right wrist), 1 used the insect repellent (Unscented Backwoods Cutter Insect Repellent), and the 4th served as the untreated negative control. The products were used as per the instructions; bands were attached to the wrists of the volunteers 30 min before beginning the study and were worn for 15 min indoors before driving to the study area. The topical insect repellent was applied as directed on the label to the right arm of the volunteer serving as the positive control 30 min before the study began. After each 15-min collection interval, the volunteers rotated positions until each person had occupied each station.

RESULTS

A total of 639 mosquitoes was collected during June 15–19, 1998, in the comparisons of the ultrasonic mosquito repeller, insect killer, and the mosquito coils with our positive and negative controls. Test scores for this study are presented in Table 1. Treatment, but not site, had a highly significant effect on landing rate rank score ($F = 25.21$; df 4,75; $P < 0.00001$). The deet repellent had a significantly lower rank adjusted score than all other treatments, indicating that it was the most effective treatment for preventing mosquitoes from landing on the volunteers. Of the remaining nontopical treatments, only the mosquito smoke coils had a mean rank-adjusted score that was significantly lower than the negative control. Although the collector was surrounded by 3 coils, the collector's legs were only enveloped by the smoke during part of each collecting period because of wind currents.

A total of 1,593 mosquitoes was collected during the study comparing the efficacy of the citronella candles, the citrosa plant, and our positive and negative controls on June 22–25, 1998. The mean landing rate rank scores are presented in Table 2. Treatment, but not site, had a significant effect on the rank score ($F = 27$; df 3,40; $P < 0.00001$). In pairwise comparisons, deet repellent had a significantly lower mean landing rate rank score than all other treatments. No differences were found between the citronella candles and the untreated controls. Surprisingly, the score for the citrosa plant was significantly higher than our negative (untreated) control, indicating a greater landing rate on volunteers in the vicinity of the plant.

The results for the deet-impregnated wrist bands are presented in Table 3. Treatment, but not site or time, had a significant effect on mosquito landing rates (df 3,12; $F = 12.487$; $P < 0.005$). In pairwise comparisons, all of the treatments had significantly fewer mosquitoes landing than the untreated volunteer at the 95% confidence interval. The topical insect repellent also had significantly less mosquitoes than both wrist band treatments. No differences were detectable in landing rates for the 2 collectors using wrist bands.

DISCUSSION

The results of our study indicate that none of the nontopically applied products were as effective in repelling mosquitoes as a topical application of deet. However, at least 2 products significantly reduced mosquito landing rates relative to untreated controls under our field conditions and 1 treatment was associated with a significant increase in landing rates. The mosquito smoke coils and wrist bands had rates below those observed for untreated controls. The remaining products, citronella candles, Flowtron Insect Killer Model BK-15D with Flowtron Octenol Mosquito Attractant, Mosquito Contro Portable Mosquito Repeller, and the mosquito-repellent plant *P. citrosum* var. 'van Leeni' were ineffective in protecting against host-seeking mosquitoes under field conditions in Illinois. Volunteers surrounded by mosquito-repellent plants actually had greater landing rates than controls.

Table 3. Numbers of mosquitoes landing on the exposed arms of collectors per 15-min period in Trelease Woods near Champaign, IL, when comparing *N,N*-diethyl-3-methylbenzamide (deet)-impregnated wristbands, a topical application of 21% deet insect repellent, and an untreated control.

Treatment	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Mean ± SE[1]
Topical repellent	0	0	1	0	0.3a ± 0.5
Wrist band 1	7	8	2	3	5.3b ± 3.3
Wrist band 2	8	4	5	10	6.8b ± 2.8
Untreated	10	8	11	13	10.5c ± 2.1

[1] $n = 4$; rates followed by the same letters are not significantly different at the 95% confidence level.

Our results for the mosquito smoke coils are similar to those of Hewitt et al. (1996), who reported a moderate decrease in mosquito blood-feeding rates when pyrethroid coils were burned inside huts. Pyrethroids such as D/L-allethrone D-*trans*-chrysanthemate are insecticidal and mosquitoes tend to avoid these compounds. The inability of the smoke coils to provide protection comparable to that of deet repellent likely stemmed from the inability of the smoke plumes to completely envelop the collector. In our study, mosquito landing activity was lower when the collector was enveloped in smoke and higher when air movement caused the smoke plume to drift away from the collector. However, it is not recommended that an individual be completely enveloped in smoke from the coils as the packaging for this product states "avoid prolonged inhalation of smoke."

The manufacturer of the Insect Killer claims that the combination of UV light and 1-octen-3-ol draws host-seeking mosquitoes away from humans to the device, but our results suggest that it is a poor competitor to humans in wooded conditions. Nasci et al. (1983) reported that only 3% of insects killed in a similar device were mosquitoes and that the device did not reduce mosquito biting rates. The Insect Killer killed 24 mosquitoes when operated overnight in a suburban backyard in Savoy, IL, where mosquito landing rates ranged between 120 and 180 per hour at sunset (T. Jensen, unpublished). The 1-octen-3-ol is believed to increase the effectiveness of the Insect Killer up to 5-fold based on the package insert. Although 1-octen-3-ol is an effective lure for a limited number of mosquito species when used alone, it is highly effective when used in synergy with carbon dioxide (Kline et al. 1991, Kline 1994). Synergism with UV light was not evident in Illinois with our our primary nuisance species, *Ae. vexans* and *Ae. triseriatus* (T. Jensen, unpublished).

The inability of the sonic device to protect the user from biting mosquitoes likely stems from the absence of repellency. The manufacturer's claim that female mosquitoes are repelled by the sounds produced by male mosquitoes is implausible considering that insemination and fertilization are required for mosquito reproduction. Male mosquitoes are attracted to the sounds produced by female mosquitoes (Clements 1992), but no evidence of male repellency to females has been reported. Our results are consistent with the results of previous studies that also found that sonic mosquito repelling devices are ineffective (Kutz 1974, Schreck et al. 1977, Snow 1977, Soltavatta and Singleton 1977, Belton 1981, Lewis et al. 1982, Foster and Lukes 1985, Schreiber et al. 1991).

The absence of a reduced landing rate with citronella candles is in contrast with the results of Lindsay et al. (1996), who reported a 42% reduction in mosquito biting rates using the same type of product. Results may differ because of the experimental habitat or differences in mosquito fauna between the 2 studies. Citronella oil is a moderately effective topical mosquito repellent, but the inability of citronella candles to protect against landing mosquitoes suggests that the quantity or concentration of citronella oil released by the melted wax is too low to effectively repel mosquitoes in open-air conditions. Citronella candles may provide protection if used in an area that traps the vapors of the citronella oil.

The significantly higher rank scores for the citrosa plant than controls differ from the results of previous studies. In the field and laboratory, respectively, Matsuda et al. (1996) and Cilek and Schreiber (1994), found no differences in landing rates on humans between the plants and untreated controls. Our results, coupled with field observations of mosquitoes swarming around and alighting on the citrosa plants, suggest that the plant may provide a preferred resting site due to chemical or physical characteristics. Cilek and Scheiber (1994) previously observed colony *Aedes albopictus* Skuse and *Culex quinquefasciatus* Say alighting on citrosa plants.

The wrist bands impregnated with deet did reduce mosquito landing rates compared to untreated controls, although they were much less effective than a topical application of deet. The collectors in this study were frequently bitten on the exposed head and neck, suggesting that the repellent effect is limited to areas close to the treated band, just as topical application of deet on one area of exposed skin generally does not provide protection for untreated areas. It is important to evaluate antimosquito products under a wide range of field and laboratory conditions, comparing their effectiveness to both negative and positive controls.

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