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EVALUATION OF THE EFFICACY OF LAMBDA-CYHALOTHRIN APPLIED AS ULTRA-LOW VOLUME AND THERMAL FOG FOR EMERGENCY CONTROL OF *AEDES AEGYPTI* IN HONDURAS[1]

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ABSTRACT. An extended-duration formulation of lambda-cyhalothrin (Demand™ CS) applied as either an ultra-low volume (ULV) or thermal fog spray from a new handheld sprayer (Terrier™) against *Aedes aegypti* was evaluated in Honduras. Spray applications were made at the front door for 1 min or to each room for 15 sec, both for the ULV and thermal fog applications to houses in separate blocks for each treatment. The efficacy and duration of effectiveness of the spray was determined from sentinel caged mosquito mortality and collection of mosquitoes within houses with a backpack power aspirator. Sentinel caged mosquito mortality in both open and sequestered locations was 97–100% for all spray treatments, with control mortality less than 2%. Both ULV applications (front door and each room) provided 4 wk of significant control ($P < 0.01$) based on adult *Ae. aegypti* house collections.

KEY WORDS *Aedes aegypti,* ultra-low volume, thermal fog, emergency control, lambda-cyhalothrin

INTRODUCTION

Dengue and dengue hemorrhagic fever (DHF) are mosquito-borne viral diseases that coincide with the distribution of *Aedes aegypti* (L.), the primary vector throughout the tropical and semitropical world (Halstead and Gomez-Dantes 1992). *Aedes aegypti* is an urban mosquito that has adapted to utilizing man-made containers for breeding, feeds almost exclusively on humans (Christopher 1960), and rests in places inside houses where outdoor traditional insecticide spraying is ineffective.

Sanitation and clean up in which potential mosquito breeding containers are eliminated or made mosquito-proof is the primary method for long-term control of *Ae. aegypti.* However, not all breeding sites can be eliminated or totally made mosquito-proof and not all individuals collaborate in clean-up campaigns. In addition, natural disasters (hurricanes, earthquakes, and floods) and man-made disasters (war and economic decline) create conditions for rapid and massive increase in *Ae. aegypti* populations. All these scenarios can lead to outbreaks of dengue and DHF and require effective emergency suppression of *Ae. aegypti* to break the transmission cycle (PAHO 1994).

Adult *Ae. aegypti* control by means of either ground vehicle–applied or aerially applied insecticide has been found to be at best fair in reducing the *Ae. aegypti* population (Chadee 1985, Hudson 1986, Perich et al. 1990). This primarily is because of the seclusive resting behavior of *Ae. aegypti* within homes (Perich et al. 2000) where traditionally applied insecticide sprays do not penetrate (Perich et al. 1992). This study was designed to evaluate a new extended-duration insecticide formulation (Demand™ CS) applied as 2 spray applications (ultra-low volume [ULV] versus thermal fog) and 2 ways of applying the sprays (through front door versus in each room) against *Ae. aegypti* in Honduras. These evaluations were conducted to determine the efficacy of such methodology for use in emergency suppression of *Ae. aegypti* populations.

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MATERIALS AND METHODS

Study site: Field tests were done from January to April 1998 in a neighborhood in El Progreso, Honduras (16°S, 88°W), a city historically with both dengue cases and high *Ae. aegypti* populations. Five city blocks were selected for the tests. Each block was separated from the others by a minimum of 100 m. Houses typically were 1 story, with 3 or 4 rooms, and made of either stucco-covered cement block or wood. Each house was approximately 250 m^2 and each city block contained approximately 30 houses. Six houses within each block were selected to be sampled and received the same treatment assigned to that block. The most upwind block in relation to the other 4 blocks was designated to be the untreated control block. The other 4 blocks were then designated to receive 1 of the following treatments: ULV at the front door, ULV in each room, thermal fog at the front door, or thermal fog in each room.

Mosquito sampling: Two mosquito sampling criteria were used to determine the efficacies of the treatments: adult mosquito collections within houses and sentinel mosquito mortality. Mosquitoes were collected with backpack power aspirators (Clarke et al. 1994) operated by Honduran Ministry of Health (MOH) personnel aspirating within each house for 15 min. All collected mosquitoes were identified to species, the number was recorded, and then the mosquitoes were released back into the house. Mosquito collections were initiated 2 wk before spraying and then thereafter weekly through 7 wk after treatment. An additional collection was made 24 h after spraying. Before mosquito collections were made, 3 control tests were conducted to determine if the aspiration affected the survival of *Ae. aegypti.* Less than 3% mortality was found after holding the mosquitoes for 24 h. For sentinel cage tests, twenty-five 3- to 5-day-old nonbloodfed female *Ae. aegypti* reared from eggs collected from the test site were placed into 6-cm^3 fine-mesh screened sentinel cages. Sentinel cages were transported to the field in coolers with damp paper towels on top of the cages. Two sentinel cages were placed into 3 houses in each block before spraying at each site (control and 4 treatments). One sentinel cage was placed in an open location on top of a table, and the other sentinel cage was placed in a hidden location beneath a bed. Sentinel cages were retrieved 30 min after spray application, mosquitoes were transferred to clean holding cages, and a water-soaked cotton ball was placed on each cage. Mortality was recorded at 3, 12, and 24 h after treatment.

Spray treatment: Spray applications were made with a new handheld spray generator, the Terrier™ (Vectec Engineering Division, Rogers, MN; now Clarke Mosquito Control Inc., Roselle, IL). The Terrier sprayer can be operated either in the ULV or thermal fog mode by flipping a switch to the desired mode of application. The Terrier was calibrated to disperse insecticide at a flow rate of 100 ml/min and a ULV droplet size of 10–25 μm. For both ULV and thermal fog applications made at the front door, spraying was done for 1 min, and for those designated for room treatment, spraying was done for 15 sec in each room. Spraying was done by Honduran MOH personnel, who wore rubber gloves, protective eye and ear protection, respirators, and protective clothing.

The insecticide applied in this study was lambda-cyhalothrin capsule suspension (CS; Demand CS; Zeneca Public Health, Surrey, United Kingdom), a new microencapsulated formulation that is registered by the Environmental Protection Agency. The Demand CS used in this study contained 25% active ingredients (AI). The final applied concentration was 0.5% AI and was obtained by mixing with water for the ULV applications and with diesel fuel for the thermal fog applications. Before spraying, susceptibility tests were done with lambda-cyhalothrin–impregnated filter papers following the WHO (1981) insecticide resistance testing protocol to determine the level of susceptibility of the *Ae. aegypti* in El Progreso, Honduras, to lambda-cyhalothrin. Mosquitoes used in the susceptibility tests were reared from eggs collected from the test sites.

Statistical analysis: Treatment mortality for the sentinel cage data was corrected with Abbott's (1925) formula. Corrected sentinel mortality is reported in Table 1. The experimental design of this study was a 2 × 2 factor with analysis of variance for repeated measurements (Winer 1991). The factors were sprayed treatment (ULV or thermal fog) and application site (at front door or inside each room). Because each sampling period included data from 6 control houses, Dunnett's multiple comparison procedure was used to compare shifts from pretreatment levels for each treatment combination with corresponding changes in the untreated (control) group (Cytel Software Corp. 1994). Additional comparisons of treatment groups (e.g., front door versus each room and ULV versus fogging) were examined with F tests (Cytel Software Corp. 1994).

Table 1. Mean percent mortality of sentinel caged female *Aedes aegypti* from open and hidden locations from houses in El Progreso, Honduras.[1]

Treatment	Cage location	Postspray time (h) 3	12	24
ULV front door	Open	98	100	100
	Hidden	94	98	100
ULV each room	Open	100	100	100
	Hidden	96	99	100
Thermal fog front door	Open	97	99	100
	Hidden	96	100	100
Thermal fog each room	Open	98	98	100
	Hidden	90	96	100

[1] Mean mortality based on 3 sentinel cages per treatment per location with 25, 3- to 5-day-old, nonbloodfed female *Ae. aegypti* in each cage. ULV, ultra-low volume.

RESULTS

The *Ae. aegypti* population in El Progreso, Honduras, was determined to be 100% susceptible to lambda-cyhalothrin based on the resistance tests conducted before the spray applications in this study. Mixing and application of the lambda-cyhalothrin CS insecticide with the Terrier sprayer was done with no difficulties. Flow rate was maintained for all ULV and thermal fog applications.

Sentinel cage mortality was determined to be highly significant (Table 1; $P < 0.001$) for all 4 spray treatments in both the open and hidden locations compared to the untreated controls. Mortality for the untreated control site cages was always less than 2%. Initial mortality (3 h after spray) was found to be 97–100% for the open sentinel cage

Table 2. Mean number of *Aedes aegypti* collected by backpack aspiration per house treated with ULV spray or fog applications of lambda-cyhalothrin CS in El Progreso, Honduras.[1]

	Mean number of *Ae. aegypti* collected									
	Pretreatment time		Posttreatment time							
Treatment	1 wk	2 wk	24 h	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk
ULV front door	5.0[a]	8.2[a]	0.0[a]	0.3[a]	1.0[a]	0.8[a]	1.0[a]	1.8[a]	1.3[a]	1.8[a]
ULV each room	6.5[a]	6.0[a]	0.0[a]	0.2[a]	0.3[a]	0.8[a]	0.2[b]	2.3[a]	0.7[ab]	1.7[a]
Thermal fog front door	2.8[a]	7.2[a]	0.0[a]	0.3[a]	1.0[a]	2.0[ab]	1.0[a]	1.8[a]	1.7[a]	3.0[a]
Thermal fog each room	12.7[a]	16.2[ab]	4.7[b]	14.0[b]	28.0[b]	12.0[b]	12.0[c]	8.4[ab]	7.2[ac]	18.3[b]
Control untreated	4.7[a]	7.8[a]	8.8[b]	8.0[b]	4.5[ab]	8.0[b]	5.0[ac]	8.0[ab]	7.6[ac]	4.5[a]

[1] Based on collections made by 2 collectors sampling 6 houses for 5 min per house. Means in a column with different superscript letters are significantly different ($P < 0.05$). CS, capsule suspension; ULV, ultra-low volume.

locations and 90–96% for the hidden locations. Within 24 h, mortality was 100% in all the sentinel mosquitoes both from open and hidden locations for all 4 spray application methods (Table 1). This indicates that the insecticide applied by any of the 4 spray application methods done in this study reached both open and secluded potential resting sites of *Ae. aegypti* in houses in lethal amounts.

No significant difference ($P < 0.05$) in the mean number of *Ae. aegypti* collected from houses was found among the 5 test blocks before spray treatment (Table 2). This indicated that the mosquito population was relatively consistent throughout the 5-block test site and would allow for treatment comparison between the blocks. However, 1 house in the block designated to receive the thermal fog in each room always had the highest number of mosquitoes collected from it, ranging from 2.5 to 7.2 times more than any other house before spraying. This house may represent an outlier because of a large number of breeding containers and poor house construction compared to other houses in the area.

Twenty-four hours after spraying, no *Ae. aegypti* were collected in most of the houses that had received either the ULV spray at the front door or in each room, or thermal fogging at the front door (Table 2). The block of houses that had received thermal fog in each room did not have mosquito counts of zero, because of the outlier home from which 28 *Ae. aegypti* were collected. Through 4 wk after treatment, the 3 blocks of houses that had received the ULV spray application at either the door or in each room and the thermal fog application at the door had significantly ($P < 0.05$) fewer *Ae. aegypti* collected inside them compared to the untreated control block houses (Table 2). Starting on the 5th week after treatment, houses from the treatment blocks began to show an increase in the mean number of mosquitoes collected, but still had 2–4 times fewer compared to the number collected from the sample houses in the untreated control block (Table 2).

A significant difference was found between the mean numbers of *Ae. aegypti* collected from the houses that received the ULV at the front door or in each room or thermal fog treatment at the front door compared to the mean number from the untreated control houses for the entire 7 wk of posttreatment sampling ($P < 0.0001$). However, no significant difference was found between those 3 treatments. If the outlier house from the block that received the thermal fog in each room is removed from the data set, this treatment is also significant.

DISCUSSION

The lambda-cyahalothrin CS formulation as applied in our study with the Terrier sprayer significantly affected *Ae. aegypti* within houses in El Progreso, Honduras. Although *Ae. aegypti* are known to rest in sequestered places within a house (PAHO 1994, Perich et al. 2000), and insecticide droplet penetration into such places in lethal amounts is often not obtained (Perich et al. 2000), this was shown not to be the case in this study. This is probably because in our study, the application of the insecticide was done directly into the houses, allowing the insecticide droplets a greater chance to reach the mosquitoes in those secluded resting sites.

Two criteria are required of space spraying of an adulticide for it to be of any potential value in use in emergency dengue vector suppression: an initial kill of adult vectors that are present, and the provision of a significant level of residual control to allow for other implemented suppression interventions (source reduction and larviciding) to take effect. Both of these criteria are shown to have been met when using lambda-cyhalothrin CS applied by the Terrier sprayer under the conditions described in our study. The 100% sentinel cage mosquito mortality found from both the open and hidden locations and the collection of no mosquitoes from houses 24 h after spraying for 3 of the 4 spray and fogging application methods indicates successful completion of the 1st criterion. The 2nd criterion was met in our study as shown by the significant ($P < 0.05$) suppression of adult *Ae. aegypti* within houses, again for 3 of the 4 treatment blocks for 4 wk after treatment. The treatment of thermal fogging with lambda-cyhalothrin in each room is probably as effective as the other 3 spray treatments after disallowing the outlier house from that block in our study. Lambda-cyhalothrin when applied as a residual insecticide to wooden huts in Malaysia was reported to produce 100% knockdown of *Ae. aegypti* through 28 days (Sulaiman et.al 1993). The residual effect found in this study is most likely due to the capsule suspension formulation of the lambda-cyhalothrin CS. This formulation allows for a slow release of the lambda-cyhalothrin, which explains the 4-wk significant effect that was not found with other ULV or thermal fog insecticide applications.

The exact level of vector suppression and for what duration it must be maintained in order to suppress a dengue outbreak is not known. The use of lambda-cyahalothrin CS applied as either a ULV or thermal fog with the handheld Terrier sprayer as described in our study has potential in emergency control of *Ae. aegypti.* We determined that 1 spray operator could treat 75 houses in a day when ULV is applied at the front door. The front door application is the faster and more cost-effective spray application evaluated in this study. Although to treat a large area of several hundreds to thousands of homes would be labor intensive, the ineffectiveness of either vehicle-mounted spray equipment or aerial application of adulticides makes the described methods in our study a true alternative for emergency *Ae. aegypti* suppression.

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