A New Strategy for *Aedes aegypti* (Diptera: Culicidae) Control With Community Participation Using a New Fumigant Formulation

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**ABSTRACT** Dengue and dengue hemorrhagic fever are mosquito-borne viral diseases that coincide with the distribution of *Aedes aegypti* (L.), the primary vector in the tropical and semitropical world. With no available vaccine, controlling the dengue vector is essential to avoid epidemics. This study evaluates the efficacy of a new smoke-generating formulation containing pyriproxyfen and permethrin in Puerto Libertad, Misiones, Argentina. A fumigant tablet (FT) was applied inside the houses by the community members and compared with a professional application. A treatment combining the application of fumigant tablets indoors and ultralow volume fumigation outdoors was also assessed. The community perceptions and practices about dengue disease and the acceptance of this new nonprofessional FT were evaluated through surveys. Results show >90% adult emergence inhibition and 100% adult mortality with these treatments. More than 80% of the residents applied the FT and preferred participating in a vector control program by using a nonprofessional mosquito control tool, instead of attending meetings and workshops promoting cultural changes.

**KEY WORDS** community participation, *Aedes aegypti*, fumigant tablet, vector control.

Dengue and dengue hemorrhagic fever is a mosquito-borne viral disease that coincides with the distribution of *Aedes aegypti* (L.), the primary vector in the tropical and semitropical world (Halstead and Gomez-Dantes 1992).

*Ae. aegypti* is an urban mosquito adapted to using artificial containers for breeding (Perich et al. 2001). In the absence of a vaccine, controlling the dengue vector is essential to avoid epidemics. The application of larvicides in containers that cannot be eliminated is still a priority during control programs. However, this activity is both labor intensive and time consuming, and not all containers are treated, particularly those inside dwellings as a result of the increasing distrust residents have to allow pest control operators enter their homes. However, given the acquired resistance to temephos, the main larvicide used, new larvicides are increasingly necessary (Macoris et al. 2003, Braga et al. 2004, Seccacini et al. 2008).

The World Health Organization recommends using the insect growth regulator pyriproxyfen for treating drinking water, among other products (WHO 2003).

The main treatment for adult control is ground application of space sprays delivering a minimum volume of insecticide formulation per unit area, called ultralow volume (ULV) (PAHO 1994). Nevertheless, this space treatment shows low larvicide efficacy inside and outside dwellings and has been repeatedly inefficient for controlling adult *Ae. aegypti* populations (Perich et al. 1990). One reason for this reduced effectiveness is the resting behavior of this mosquito species: they are found in wardrobes, under beds, behind furniture, and in closed rooms where it is difficult for ULV aerosol droplets to reach (Pant and Yasuno 1970, Perich et al. 2000). Another challenge is that homeowners will not open the doors and windows to allow the ULV droplets to enter the home. Furthermore, in countries like Vietnam, in urban areas with very high number of inhabitants per house, most water-holding containers are located indoors (Ataru et al. 2009).

There is an increasing need to develop effective vector control programs to prevent the transmission of dengue (Ballenger-Browning and Elder 2009). Innovation in the area of insecticidal tools is required to strengthen weak aspects of the current chemical control efforts, and thus progress toward reducing mosquito populations using environmentally friendly insecticides. The development of a novel insecticidal formulation containing pyriproxyfen as a larvicide and...
permethrin as an adulticide that is effective against both adult and immature aquatic forms of mosquitoes significantly increased *Ae. aegypti* control in recent field trials carried out in Argentina (Masuh 2008; Lucia et al. 2009). A new smoke-generating formulation also containing pyriproxyfen and permethrin was evaluated under laboratory conditions against *Ae. aegypti* with the idea of finding an alternative to conventional tools for indoor treatments (Harburguer et al. 2009).

However, dengue vector control programs require effective community participation through educational campaigns, prevention methods, and control activities. In the last few decades, efforts to promote community-oriented activities for dengue control have increased. A community-based dengue control intervention was defined as any intervention in which at least one component targeted the community (educational meetings, involvement of local leaders, elimination of useless water containers, and covering useful ones) (Heintze et al. 2007). However, there are no references on active community participation using nonprofessional mosquito control tools except some recent experiences using window curtains and water container covers treated with insecticides in Mexico and Venezuela (Kroeger et al. 2006). Bednets are currently used with community participation in malaria control programs (Nahlen et al. 2003), as well as in some trials for Chagas disease (Kroeger et al. 2003) and other illnesses. Likewise, there is certain experience in the use of an insecticidal fumigant canister (Zerba 1995; Masuh et al. 2003) with community participation for controlling *Triatoma infestans* and *Ae. aegypti*.

The objective of this study is to evaluate the efficacy against *Ae. aegypti* in the field, of an experimental nonprofessional fumigant formulation developed by our laboratory, and the resident’s acceptance of this tool together with its role in community participation for indoor control activities. As most experts agree that the best strategy for dengue control is to maintain a proactive participation of community (Espinoza-Gomez et al. 2002), the use of this new smoke-generating formulation by the community will also be discussed.

### Materials and Methods

**Chemicals.** A 50-g fumigant tablet containing 10% permethrin (3-phenoxypyphenyl) methyl-3-(2,2-dichloroethenyl)-2,2-(dimethyl cyclopropane carboxylate), cis:trans relationship (45:55), and 2% pyriproxyfen (2-[1-methyl-2-(4-phenoxyphenoxy) ethoxy] pyridine) was prepared according to Harburguer et al. 2009 by Chemotecénica S.A. (Carlos Spezazzini, Argentina).

For the ULV treatment, we used a formulation containing 10% permethrin plus 2% pyriproxyfen as an emulsifiable concentrate, formulated by Chemotecénica S.A. Polyethylene glycol 1000 was used as an antievaporant.

**Study Site.** Field tests were performed in Puerto Libertad (25°55′S, 54°35′W), a small subtropical city with historical cases of dengue and high *Ae. aegypti* populations. This city has 6,000 residents in an area of 2.62 km², and is located 40 km south of Puerto Iguazú in the Province of Misiones (Argentina). Almost all the houses in Puerto Libertad are based on two types of construction: wooden walls and sheet metal roofs or brick walls and tiled roofs. A typical one floor house has two or three bedrooms, a living room, and a kitchen.

**Biological Material.** A susceptible strain of *Ae. aegypti* (CIPEIN) originated from the Rockefeller strain in Venezuela was used. It has been reared in the laboratory since 1996, at 25 ± 2°C under a photoperiod of 12:12 h, as previously reported by our laboratory (Seccacini et al. 2006).

**Fumigant Treatments.** The city of Puerto Libertad was divided into four areas with 200 houses each; the houses were the same size and evenly spaced and distributed within each area. One of four possible treatments was assigned at random to each area. Two areas were assigned for the fumigant tablet treatments, as follows: one was to be treated by the community itself (area A), and the other by the local workers of the National Vector Control Program of Argentina (area B or professional application). Two tablets were applied in each house, one in the dining room/kitchen and the other near the bedrooms/bathroom, keeping all room and closet doors open. After releasing the formulation fumes, the dwellings were kept closed for 1 h and then ventilated. Residents had to keep out of their dwellings during the 1-h fumigant tablet. In area A, left for community application, the residents of each house were provided with two fumigant tablets and the corresponding safety and lighting instructions, and were asked to use them during the same week the tablets were applied in area B, application by professional pest control staff.

In the third area (area C), the fumigant tablet was also applied indoors by local workers of the National Program of Vector Control of Argentina and the dwellings were kept closed for 1 h. After this, windows and doors were opened and a ULV professional treatment was performed outdoors using a vehicle-mounted cold fog generator, FOG XXI Minor Plus. The flow was regulated to release 380 cm³ of mixture every 36 s, the time taken to spray 1 ha; thus, the area was sprayed with 10 g of permethrin + 2 g of pyriproxyfen/ha. This application was carried out during the peak of mosquito flight activity (either before dawn or after sunset), on 31 March 2009. A fourth area (area D), with similar characteristics to the previous three, remained untreated as a control area.

**Fumigation Effectiveness.** Field bioassays were performed according to World Health Organization protocols (Reiter and Nathan 2003) with minor modifications. Cylindrical screened sentinel cages, built with 18-mesh nylon, 15 cm long × 3 cm diameter, were used. A few hours before treatment, 10 adults (50% of each sex), 1–3 d old and fed on raisins, were transferred to each cage. Ten cages were randomly hung inside 10 dwellings (one per house) in area B, another
10 cages were hung inside 10 houses in area C, and 10 more cages were placed in the control area (area D). In addition, 250-ml plastic jars (7.5 cm in diameter) containing 15 late third or early fourth instar *Ae. aegypti* larvae in 200 ml of tap water were placed inside the dwellings. Ten plastic jars were placed in area B, 10 in the area with the combined treatments (area C), and 10 more in the control area (area D).

Both screened cages and plastic jars were placed between 4 and 5 m from the fumigant tablet and taken back to the laboratory after treatment ended and kept at room temperature. Cages were provided hydration, and adult mortality was assessed after 24 h. The 250-ml plastic jars were inspected daily until death or adult emergence of all the individuals to determine the inhibition of adult emergence (EI%). EI% was calculated as shown below and adjusted for larval or pupal mortalities in the corresponding controls according to Mulla et al. (1974).

\[ EI(\%) = 100 - 100 \times \left( \frac{T}{C} \right) \]

where \( T \) is the percentage of emergence in treated containers and \( C \) is the percentage of emergence in control containers.

Because of the fact that the residents were given 1 wk to complete the application of the fumigant tablet in area A, we were unable to determine fumigant effectiveness in this area using sentinel cages with adults and plastic cups with larvae.

**Entomological Evaluation.** Population levels of *Ae. aegypti* larvae were determined using larval sampling according to PAHO (PAHO 1994) and expressed as Breteau index (BI; defined as the number of positive containers per 100 inspected houses) and adult index (mean number of *Ae. aegypti* adults per house during 10 min of inspection by one person). Adults were captured with a manual aspirator (Philips FC 6092 12V), placed in drinking cups covered with netting, and taken to the laboratory for identification. As adult capture with manual aspirators depends on the skills of the collectors, the same collector was assigned to an area for the entire study period. To control for collection bias, we compared captures in the 2 wk before the treatments, and if there were no significant differences between areas we determined that there were no differences in the efficiency of adult capture between the collectors.

BI and adult index were determined weekly, starting 2 wk before treatment and ending once the mosquito population levels returned to pretreatment values. To assess larvae and adult infestation, 25 houses in each area were randomly selected each week. Entomological studies were carried out for 13 wk, from 20 March to 5 June 2009.

**Community Participation.** To evaluate the resident’s acceptance of this new nonprofessional fumigant tablet, we used an integrated strategy developed in three stages. In the first stage, the planning stage, informal interviews were made to 45 randomly selected households in area A. From these interviews, we collected data on the perceptions and practices of the community regarding dengue disease and vector control strategies, and these data allowed us to design the second stage, a training workshop with the community.

This second stage, or communicational stage, consisted of a training workshop with the community on dengue disease, *Ae. aegypti* control, and the corresponding safety and lighting instructions for applying the fumigant tablet. It was widely announced by radio, and people were invited to attend house by house. It was held in public conference hall and consisted of two presentations by members of our group and a demonstration of how to light the fumigant tablet. We also provided a leaflet containing the safety and lighting instructions of the tablet that was distributed with the product 1 wk after the workshop to 100% of the houses of area A.

In the third stage, or evaluation stage, we designed a survey to obtain quantitative information on the perceptions and practices of the community after the training workshop and application of the fumigant tablet. This questionnaire was administered in 111 of the 200 houses treated with the fumigant tablet by the residents. The households were selected at random and the respondents were household heads.

The questionnaire was administered only in area A because this was where the community applied the fumigant tablet, and one of the objectives of the study was to determine the applicability and community perceptions about use of the tablet. All surveys and interviews were conducted with the written consent of the respondents.

**Statistical Analysis.** Adult mortality and EI% were corrected with Abbott’s formula (Abbott 1925) and subjected to an arcsine square-root transformation before the analyses. Data were compared using one-way analysis of variance. The accepted level of significance for all comparisons was \( P < 0.05 \) (Statistica for Windows V7.0, StatSoft, Tulsa, OK).

Adult index values were compared using one-way analysis of variance for each date; differences between means were compared using Duncan’s multiple range test. Data from 3 April, 17 April, and 22 May were square root transformed before analyses. The accepted level of significance was \( P < 0.05 \) (Statistica for Windows V7.0, StatSoft).

**Results**

**Fumigation Effectiveness.** Table 1 shows adult mortality 24 h after treatment. More than 95% mortality was observed in adult *Ae. aegypti* after 1 h of exposure to the smoke of two fumigant tablets per house (area B), or this fumigant treatment plus ULV application (area C). No significant differences were found between these two treatments \( (F = 0.81, df = 17, P > 0.05) \).

Table 1 also shows that EI% was ~90% in both treatments; again, no significant differences were found between both treatments \( (F = 1.12, df = 17, P > 0.05) \).
Table 1. %EI and adult mortality 24 h after treatment with the fumigant tablet or a combination of the fumigant tablet and ULV outdoor application

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adult mortality (% ± SD)×</th>
<th>%EI (% ± SD)×</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fumigant tablet (area B)</td>
<td>100 ± 0.001a</td>
<td>89.5 ± 2.4b</td>
</tr>
<tr>
<td>Fumigant tablet + ULV (outdoors, area C)</td>
<td>95.5 ± 4.7a</td>
<td>92.6 ± 1.8b</td>
</tr>
</tbody>
</table>

× Results are the mean of 10 independent determinations ± SD. Percentages followed by the same letter within the same column are not significantly different (one-way ANOVA, P < 0.05).

Entomological Evaluation. Entomological surveillance showed that in the four areas assayed, larval and adult index values were very high before the treatment, which is characteristic of this area of Argentina (Masuh et al. 2003). Pretreatment adult index values (Fig. 1) were between three and four Ae. aegypti adults per house during 10 min of search. No significant differences were observed between the four areas (F = 2.38, df = 96, P > 0.05; F = 0.66, df = 96, P > 0.05), indicating that the mosquito population was relatively consistent throughout the region, facilitating the comparison of treatments and ensuring that there were no differences in the efficiency of adult capture between the collectors.

Immediately after treatment, the adult index fell almost to zero in all treated areas, including area A, where the residents applied the fumigant tablet themselves. There were no significant differences between treatments (P > 0.05), and all values were significantly lower than the control area (F = 100.4, df = 96, P < 0.05). After 8 wk posttreatment, the adult index in areas A and B was not significantly different from the control area (P > 0.05). However, the adult index remained significantly lower (P < 0.05) in area C, where the fumigant tablet was combined with the ULV treatment. Nine weeks after treatment (≈63 d), adult index values in all treated areas were not significantly different from the control area, area D (F = 1.62, df = 96, P > 0.05).

Fig. 2 shows the results of the BI. As can be observed, the pretreatment values were between 120 and 160 for all four areas. BI started to fall almost 2 wk after treatment in area C, showing a minimal value of 96 at 4 wk after application. Although this value continued to be very high, it represented a decrease of ≈30–40 compared with pretreatment and control values coinciding with previous results of our laboratory (Lucia et al. 2009). Values similar to the control area were regained almost 8 wk after application. Instead, for areas A and B, the BI shows a slight decrease from 140 to 120, only lasting for 2 wk after which the values in these areas became similar to those in the control area.

Community Participation. Only 16% of the people living in area A attended to the training workshop organized during the second stage or communicational stage. Despite this low attendance, when people were asked regarding “how they felt about dengue disease,” on a scale from 1 to 10 in which 1 is not worried at all and 10 is highly concerned, 88% of the people responded by giving a value of 10. Among those who did not attend the workshop, 57% did not do it for personal impediments (did not have time, work, disease, etc.), 26% did not hear about the workshop, and 16% did not show interest in it.

However, 81% of the people applied the fumigant tablet. Among those who did not apply the fumigant tablet, 47% did not do it because they could not organize it (did not have time, could not leave the house, etc.), 39% did not want to, and 14% did not receive the tablet. When people who applied the fumigant tablet were asked how difficult it was to apply, on a scale from 1 to 10 in which 1 is very difficult and 10 very easy, 82% of the people responded by giving a value of 10 (mean = 9.43).
When people were asked about the results obtained after applying the fumigant tablet, on a scale from 1 to 10 in which 1 is bad and 10 is excellent, the mean of all answers was 7.08. Eighty percent of residents who applied the fumigant tablet did it during the same week in which the professional application was performed. Only 50% of the people waited between 1 and 3 h before entering the house after the application, whereas the rest returned to their homes >3 h later in spite of asking them to keep the house closed only for 1 h.

When we asked about the preference of residents regarding who should apply the fumigant tablet, 80% of the respondents preferred applying it themselves, 11% preferred others to do it, such as the local workers of the National Program of Vector Control, and 9% did not have a preference.

Discussion

The results of this study evidence the high penetration and mosquito adulticidal and larvicidal properties of the fumes delivered by the fumigant tablet, which could be a novel alternative for indoor control of dengue vectors. When the fumigant tablet was used alone, the adult index fell to almost zero immediately after application and remained lower than the control values for 8 wk. However, when this fumigant tablet was applied in combination with the ULV formulation, the effect lasted an additional week. Furthermore, the BI with this combined treatment decreased ≈30–40 compared with pretreatment values and only regained values similar to those of the control area almost 8 wk after application; however, in the areas where the fumigant tablet was applied alone, BI showed only a slight decrease that lasted for just 2 wk.

These results show that a strategy based on the combined application of fumigant tablets indoors and the mixed ULV formulation outdoors could be a new successful alternative for controlling dengue vector populations during outbreaks. As we treated only a reduced area and not the whole city, reinfestation with adults indoors was similar between the areas with and without ULV application. To evaluate the performance of this strategy at a real scale, it is necessary to perform a new field trial applying it to an entire city in the case of an outbreak.

Sustainable effective mosquito control programs require community participation. As stated in several works (Espinoza-Gomez et al. 2002, Lardeux et al. 2002), community participation strategies in urban areas can be complicated because community organization often lacks coherence and effectiveness in mosquito control efforts. Educational campaigns showed different results in the reduction of larval indexes; whereas some studies demonstrate that educational campaigns have limited effects (Lloyd et al. 1992, Rosenbaum et al. 1995), others found a decrease in these indexes (Espinoza-Gomez et al. 2002).

It is necessary for social scientists to contribute in the planning and implementation of control programs to create sustainable mechanisms for community involvement. In this study, we not only assessed the entomological efficiency of the fumigant tablet, but also the resident’s acceptance of this new nonprofessional tool to be used in an integrated control strategy. The results showed that 88% of residents of Puerto Libertad were very concerned about dengue disease. Nevertheless, it is evident they did not consider the training workshop as part of a community participation program because only 16% of the residents attended. However, the fumigant tablet was widely accepted: 81% of the people applied it, and entomological surveillance showed that it had the same effect when applied by the community as when applied by professionals. It is noteworthy that the residents who did not apply the product (19%) did not attend to the workshop either.
Although most residents preferred to apply the fu-

migant tablet themselves, the majority stated that pre-

vious training is essential even though this is contra-

dictory with the fact that only a few people attended

to the corresponding training session. However,

early nearly all the people considered that the fumigant

tablet was easy to apply, which corresponded with the

entomological results.

This study showed that the community is capable of

participating in a mosquito control program through

the use of nonprofessional control tools like the fu-

migant tablet, and that it does not consider a training

workshop part of community participation. Therefore,

in a city like Puerto Libertad, a control strategy that

gives people a chemical control tool is preferable to a

strategy based solely on communication programs

promoting cultural changes.

Both the larvicide and adulticide mixed formul-

ations presented in this work are a potential new

alternative for *Ae. aegypti* control strategies, espe-

cially in epidemic outbreaks, that include active

participation, as well as personnel from the local Ministry of

Health office for attendance.

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