Indian J Med Res 140, October 2014, pp 538-545

# Effect of house spraying with lambdacyhalothrin 10 per cent capsule suspension (CS) formulation in comparison with 10 per cent wettable powder (WP) against malaria vector in Malkangiri district, Odisha, India

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Received April 24, 2013

***Background & objectives*: Selection of an insecticide and its appropriate formulation is a prerequisite of formulating any chemical control strategy against vectors. A hut scale field trial was carried out to study the effectiveness of house spraying with capsule suspension (CS) formulation of lambdacyhalothrin in comparison with its wettable powder (WP) formulation on mortality, density and behaviour of malaria vector in Malkangiri district, Odisha, India.**

***Methods*: The two formulations were tested at 20 and 30 mg (a.i.)/m$^2$ for their effectiveness in terms of deterrence, excito-repellency, blood-feeding success, mortality and residual activity against *Anopheles fluviatilis*, the major malaria vector, in experimental huts in Malkangiri district, Odisha State, India.**

***Results*: Both CS and WP formulations prevented the entry of *An. fluviatilis* in to the sprayed huts by >90 per cent for >6 months, the entire peak malaria transmission season in the area. The exit rate increased (90-99%) with different treatments and the feeding rate was reduced (91-97%). There was no significant difference between WP 30, CS 20 and CS 30 mg/m$^2$ in these respects. However, WP 20 mg/m$^2$ caused a lesser effect than the other three groups. The formulations or the dosages differed only in causing vector mortalities. Overall, the total mortality rate of *An. fluviatilis* was higher in the huts sprayed with CS 30 (58%) than the huts sprayed with CS 20 (48%), WP 20 (37%) and WP 30 mg/m$^2$ (47%).**

***Interpretation & conclusions*: Considering the duration of residual action and the effect on entry, exit, feeding and mortality of *An. fluviatilis*, the dosage 20 mg/m$^2$ of CS formulation of lambdacyhalothrin could be considered for further use.**

**Key words** *Anopheles fluviatilis* - capsule suspension - India - lambdacyhalothrin - malaria - mortality - vector - water dispersible powder

In many tropical and subtropical countries of the world, malaria is a major public health problem causing human morbidity and mortality. In India, indoor residual spraying still remains one of the major choices for control of malaria vectors[1]. Vector resistance to DDT, hexachlorocyclohexane (HCH) and malathion has necessitated the use of other groups of insecticides in the country[2]. The synthetic

pyrethroids are increasingly being used in malaria control programme[3]. Lambdacyhalothrin, available as 10 per cent wettable powder formulation (WP), is used at a dosage of 20-30 mg (a.i.)/$m^2$ for indoor residual spraying in the control programme in India. However, among the newer insecticides/formulations developed recently, lambdacyhalothrin CS (capsule suspension) formulation has not been studied for its effectiveness under Indian settings. Selection of an insecticide and its appropriate formulation is a prerequisite for formulating any chemical control strategy against vectors. Small-scale field trials are necessary to select such insecticide/formulation suiting to local conditions. As lambdacyhalothrin CS formulation was made available by World Health Organization Pesticide Evaluation Scheme (WHOPES) for Phase II study, a hut scale field trial was carried out to study and compare the effectiveness of house spraying with the two formulations of lambdacyhalothrin (CS and WP) at two dosages in terms of causing immediate and delayed mortality of the vectors and on the density and behaviour of the vectors of malaria in Malkangiri district of Odisha, State in India, which is a falciparum malaria endemic district[4].

## Material & Methods

*Study area*: The trial was carried out in Malkangiri district of Odisha State, India, from May 2004 to April 2005 including a preparatory period of three and half months for construction of experimental huts. The district has an area of 3201sq km, 933 revenue villages with about 1200 hamlets and inhabited by about 0.52 million population (65% tribal). The district has a hilly and forested terrain with many streams criss-crossing (Altitude: 152 to 200 m above mean sea level). Climate of the area is characterized by hot summer (March-June), rainy (July-September) and cold seasons (October-February). Monthly mean maximum temperature varied between 33.1°C and 37.5°C (May) and the mean minimum temperature ranged from 19.0 to 21.5°C (December) during 2000 to 2004. The area received an average annual rainfall of about 1418 mm (range: 967 mm to 1852 mm) during the years due to South-West monsoon (July to October).

*Structure of local houses*: Majority of the houses in the village (>90%) were made up of mud wall and thatched roof (bamboo and straw). A few were with cemented brick walls and tiled roofs. The houses generally had two rooms, one with false ceiling for storing grains and other household articles and the other for cooking (kitchen). The kitchen was also used for sleeping during cold and rainy season. Invariably, every house had a veranda, which was the most frequently used place by the inhabitants, including for sleeping during summer. All houses had one door system. There were no windows in the huts and there was a gap of 15-30 cm between wall and roof (eaves) for ventilation and light.

*Malaria situation and vectors*: The villages in the district are highly endemic for malaria[4]. The annual parasite incidence (API) per 1000 population ranged from 25.0 to 37.7 during 2000 to 2004. There were 54 malaria deaths in the district in 2004. More than 97 per cent of the malaria cases were caused by *Plasmodium falciparum*[1]. Malaria transmission occurs throughout the year. The incidence is low during summer, increases during rainy months and peaks in winter (Nov-Dec)[5]. *Anopheles fluviatilis* is the main vector supplemented by *An. culicifacies* as a secondary vector[1,4]. DDT indoor residual spraying has been the major vector control measure undertaken in the district. *An. fluviatilis* developed resistance to (HCH) but remains susceptible to DDT and *An. culicifacies* was resistant to both DDT and HCH[6]. Both the vectors were susceptible to synthetic pyrethroids[7].

*Study design*: The study was conducted in two randomly selected foothill villages namely, Hatiamba and Balalguda situated, respectively in Kudumulugumma and Korkunda Primary Health Centres of the district. Both the villages had comparable vector densities and malaria prevalence. Since 20 experimental huts were required for the trial and the space for construction of all the 20 huts in one village was not sufficient, two comparable villages were selected. A total of 15 huts (12 sprayed and 3 control) in Hatiamba and five (4 sprayed and 1 control) in Ballalguda were constructed. The huts constructed for each experiment were made up of mud wall and thatched roof (bamboo and straw), resembling those of the local tribes by design and dimensions. The experimental hut consisted of a single room with four windows with entry slots, two on the front door sides and one on each side of the hut and a screened verandah at the backside. An ant trap (gutter filled with water) surrounded each hut. The sprayable surface area in each hut was about 35 $m^2$. The huts were at least 10 meter apart from each other.

After construction, to attract mosquitoes into the experimental huts (acclimatization) two volunteers from the same village were recruited to sleep overnight in each of the huts under an ordinary mosquito net from 2000 to 0600 h for a period of 15 days. Informed

consent was obtained from each volunteer for his participation in the study. Peripheral blood smears were collected from the volunteers and checked for the presence of malaria parasites and ensured that all of them were free of malaria parasites. Clearance from the Ethical Committee of the Vector Control Research Centre, Puducherry was obtained for carrying out the study.

Following the acclimatization, the huts were left unsprayed for one month (September 2004) and during this period the volunteers slept inside the huts without mosquito net. Mosquito catches were initiated in all the huts twice a week. After four weeks, the huts were categorized into five groups of four huts each with comparable density of *An. fluviatilis* and one group was randomly allocated to each dosage of the two formulations and one group to serve as control. Trained spray-men were provided with protective clothing and employed for insecticide spraying. The huts, as allotted, were sprayed with the two formulations (WP and CS) at two application dosages, 20 mg (a.i.)/$m^2$ (WP20 and CS20) and 30 mg (a.i.)/$m^2$ (WP30 and CS30). A hand compression sprayer, fitted with pressure gauze was used after calibrating the discharge rate. Accuracy of the dosages was confirmed by calculating the sprayable surface areas of the huts and the total amount of insecticide used. The control huts were left unsprayed. All necessary precautions were followed during insecticide spraying. The volunteers were asked not to smear or mud plaster or mutilate the sprayed surfaces of the experimental huts and also not to put on fire inside the huts during colder months. After the spraying, the volunteers used to sleep in the huts without net and mosquito collections were continued (from October 2004 to April 2005).

To avoid personal differences in attractiveness to mosquitoes, the volunteers were interchanged between the huts on each collection day. They were administered with chloroquine 300 mg every week (standard prophylactic regimen recommended by the National Programme) as a prophylactic dose throughout the study period.

*Chemical residue analysis*: To monitor the quality of spraying, four Whatman filter papers (surface area of each paper = 122.7$cm^2$) leveled properly were struck on the walls (one on each wall of the hut) of each experimental hut, before spraying, and removed at 24 h after spraying. The papers were wrapped in aluminum foils and sent to WHOPES, Geneva, for analysis of lambdacyhalothrin content.

*Mosquito collections*: In the evening, the room and the verandah were cleaned and white cloths were spread on the floor of the hut including verandah. The verandah trap was furnished with cotton pads soaked in 5 per cent glucose solution to reduce the risk that unfed female mosquitoes exiting in the night would die of starvation. The next morning, the mosquitoes found dead on the floor sheet were picked up using forceps and placed in cups provided with moist cotton wool, and then the white cloths were removed from the floor. The resting alive mosquitoes indoors were collected from all parts of the room including roof, using aspirators and flashlights. Searches were made in verandah traps and live and dead mosquitoes were collected. All mosquito specimens collected from each part of the hut were kept separately, brought to the laboratory of Vector Control Research Centre, Field Station, Malkangiri, identified to species and classified according to their gonotrophic conditions. The live-caught females were kept on observation for 24 h to record delayed mortality, if any. Mosquitoes were collected in the huts, twice a week after spraying for a period until the density of the vector mosquitoes declined to a minimum level (based on the density of vectors in the control huts) due to seasonal effect.

*Contact bioassays*: To determine the persistence of biological efficacy of the insecticide[3] formulations on the sprayed surfaces of the huts, contact bioassays were done concurrently. Wild caught *An. fluviatilis* were exposed to the sprayed walls and roof using standard cones. Into each cone 9-13 blood-fed mosquitoes, obtained from daytime resting collections in human dwellings of the same village, were released and kept for 30 min and then removed using an aspirator. Controls were exposed to an unsprayed surface. Each test batch of mosquitoes was held in a paper cup covered with netting and provided with a cotton pad of glucose solution. The number knocked down at 1 h post exposure and mortality after 24 h holding under ambient temperature were recorded. The results of the tests, when the controls showed more than 20 per cent mortality, were rejected. The frequency of bioassay was on day 1, 2, 4, 8, 12, 16, 20 and thereafter weekly.

The spray-man was interviewed on the spray day after spraying and up to seven days daily to know the perceived side effects, if any. Similarly, the volunteers who were sleeping in the huts were also interviewed using a semi-structured questionnaire developed by authors on the next day of spraying and up to seven days daily.

*Data analysis*: Results from the sprayed huts were compared with the unsprayed (control) huts with respect to the following: *(i)* deterrent effect (reduction of entry): comparison of total number of mosquitoes caught in the sprayed huts with those caught in the unsprayed huts, *(ii)* excito-repellency: proportion of mosquitoes caught in verandah trap to the total entry in to a hut, *(iii)* feeding rate: percentage of blood-fed mosquitoes to the total found inside a hut and in verandah trap, and *(iv)* total (immediate and delayed) mortality: percentage of mosquitoes found dead in a hut (room) and in verandah trap at the time of collection plus those died after 24 h to the total number of mosquitoes entered into the hut. For analysis, data of *An. fluviatilis* were only considered as density of *An. culicifacies* was very low during the study period due to seasonal effect.

From the total mosquitoes entered the hut, the proportion that exited and the proportion that successfully fed were calculated. Besides, comparing with the level prior to treatment in the sprayed as well as in the unsprayed huts, the relative reduction in entry, increase in exit and failure in feeding in sprayed huts were calculated (in percentage) using Mulla's formula[8]. Since the number of collections was not uniform before and after spraying, for calculating per cent reduction or per cent increase using the Mulla's formula, density was calculated as the ratio of number collected to number of collections and used. The percentage reduction or increase was compared between the four sprayed groups using one-way ANOVA after arcsine transformation followed by a multiple comparison test based on the least significant difference between means (LSD). Percentage immediate, delayed and total mortality of mosquitoes were calculated from the total number of mosquitoes entered the hut prior to and after spraying for both sprayed and unsprayed groups. Since, the mortality prior to spraying in both sprayed and unsprayed groups and the post spraying mortality in the unsprayed huts were very negligible, Mulla's formula could not be used to calculate percentage increase of mortality for the different treatment groups during post-spraying period. Therefore, the mortality was compared between the four treatment groups using heterogeneity $\chi^2$ test.

For cross-checking, further analysis was carried out relating all the above parameters for each hut with the data on the actual dosages received by the corresponding huts (as determined by the chemical or residue analysis). The probit of the exit, feeding and mortality rates recorded for each hut was related to logarithmic values of the corresponding actual insecticide concentration received by the hut (average of four filter paper samples from each hut) to determine the dosage mortality relationship. Using the relationship, if any, the concentrations required for different levels of exit, feeding and mortality rates were estimated.

The weekly data on percentage corrected mortalities obtained from contact bioassay for different treatment groups were compared using one way ANOVA after arcsine transformation to see the difference in the residual effect between the dosages and formulations.

## Results

*Species composition*: A total of 67 mosquito collections were carried out in each of the 20 experimental huts, eight prior to spraying and 59 after spraying. From the experimental huts, 17 *Anopheles* species were collected and among them *An. fluviatilis* was the predominant one forming 65.1 per cent of the total collection (n=6109). *An. culicifacies,* the secondary vector constituted 16.6 per cent.

The entry, exit, feeding and mortality (immediate and delayed) rates of *An. fluviatilis* in unsprayed and sprayed huts before and after spraying with two dosages of lambdacyhalothrin 10 per cent WP and 10 per cent CS are given in Table I.

*Entry*: After the spraying, entry of *An. fluviatilis* into different groups of sprayed huts was reduced by 88.7 to 96.7 per cent (Table I). The reduction was observed throughout the study period of seven months (Figure A). Among the four groups of sprayed huts, the entry reduction was significantly higher in the huts sprayed with WP 30, CS 20 and CS 30 mg/m$^2$ ($P$<0.05, One way ANOVA) than in the huts sprayed with WP 20 mg/m$^2$ (88.7%); the former three groups did not differ significantly.

*Excito-repellency*: Prior to spraying, the exit rate of *An. fluviatilis* in unsprayed huts was 1.7 per cent and in sprayed huts it ranged from 6.8 to 14.2 per cent (Table I). After spraying, there was an increase in the exit rate in the sprayed groups (from 6.8 to 86.3% in WP 20, 14.2 to 82.0% in WP 30, 7.5 to 80.4% in CS 20 and 10.3 to 78.0% in CS 30) (Figure B), although the exit rate showed a marginal increase (1.7 to 25.2%) in the unsprayed huts. Among the four sprayed groups, the exit rate in WP20 mg/m$^2$ increased by 90.2 per cent, and this increase was significantly lower in comparison to the huts sprayed with WP 30, CS 20 and CS 30 mg/m$^2$

**Table I.** Percentage reduction of entry, percentage exit, feeding, immediate and delayed mortality of *An. fluviatilis* females in the untreated and experimental huts treated with WP & CS formulations of lambdacyhalothrin

| Formulation | Entry | | % Exit (% increase*) | % Fed (% reduction*) | Immediate mortality (%) | Delayed mortality (%) | Total mortality (%) |
|---|---|---|---|---|---|---|---|
| | Number | % reduction* | | | | | |
| Pre-treatment | | | | | | | |
| Untreated | 117 | - | 1.7 | 100.0 | 0.0 | 0.9 | 0.9 |
| WP 20mg/m$^2$ | 148 | - | 6.8 | 99.3 | 0.0 | 0.7 | 0.7 |
| WP 30mg/m$^2$ | 127 | - | 14.2 | 100.0 | 0.0 | 2.4 | 2.4 |
| CS 20mg/m$^2$ | 186 | - | 7.5 | 98.4 | 0.0 | 0.0 | 0.0 |
| CS 30mg/m$^2$ | 126 | - | 10.3 | 100.0 | 0.0 | 0.0 | 0.0 |
| Post-treatment | | | | | | | |
| Untreated | 2502 | | 25.2 | 96.3 | 0.0 | 0.2 | 0.2 |
| WP 20mg/m$^2$ | 357 | 88.7 | 86.3 (90.2) | 73.1 (91.4) | 4.5 | 33.1 | 37.5 |
| WP 30mg/m$^2$ | 89 | 96.7 | 82.0 (98.7) | 77.5 (97.4) | 3.4 | 43.8 | 47.2 |
| CS 20mg/m$^2$ | 158 | 96.0 | 80.4 (97.1) | 75.3 (96.8) | 10.1 | 38.0 | 48.1 |
| CS 30mg/m$^2$ | 164 | 93.9 | 78.0 (96.9) | 70.7 (95.5) | 17.7 | 40.9 | 58.5 |

*Based on density calculated as the ratio of number collected to number of collections

($P$<0.05, One way ANOVA). Further, the multiple comparison test showed that there was no significant difference between the exit rates of WP 30, CS 20 and CS 30 mg/m$^2$.

*Feeding*: Before spraying, the proportion of fed females of *An. fluviatilis* ranged from 98.4 to 100 per cent in the sprayed and unsprayed huts (Table I, Figure C). After spraying, in all the four groups of sprayed huts, the blood fed proportion reduced to70.7-77.5 per cent, while in the unsprayed huts it was 96.3 per cent. Among the sprayed huts, the huts sprayed with WP30, CS20 and CS30 mg/m$^2$ recorded significantly higher reduction of feeding rate (no significant difference between the three groups) compared to the huts sprayed with WP20 ($P$<0.05, One way ANOVA).

*Mortality*: In the four treatment groups, before spraying, the immediate mortality rate of *An. fluviatilis* was 0 and the delayed mortality was 0-2.4 per cent (Table I). After spraying, the total mortality of *An. fluviatilis* was 58 per cent in the huts sprayed with CS 30 and in the other three groups it was comparatively lower, 48 per cent in CS20, 37 per cent in WP20 and 47 per cent in WP30 mg/m$^2$. The immediate and delayed mortalities were significantly higher in the sprayed huts than in the unsprayed huts ($P$<0.01). The immediate mortality was significantly higher in the huts sprayed with CS20 and CS30 mg/m$^2$ than in the huts of WP groups (heterogeneity $\chi^2$ test, $P$<0.05, for all comparisons). While WP20 and WP30 produced similar level of immediate mortality, CS 30 produced higher mortality than CS20. With respect to delayed mortality, there was no significant difference between the two dosages of the two formulations. Immediate mortality was there only for the first three months post-spraying. Delayed and total mortality were also relatively higher during the first three months post-spraying and then declined before it increased again (Figure D, E, F).

*Residual effect (cone bioassay)*: Up to 1$^{st}$ week post-spraying, mortality of *An. fluviatilis* was 100 per cent in all the four sprayed groups and during the 2$^{nd}$ week the mortality was between 80 and 100 per cent. From 3$^{rd}$ to 11$^{th}$ week, the mortality ranged from 61 to 89 per cent, and from 12$^{th}$ to 30$^{th}$ week the mortality was 80 to 90 per cent. The decline in per cent mortality between 3$^{rd}$ and 11$^{th}$ week could be due to the unusual heavy rain during this period making the walls wet that became unsuitable for mosquito contact. Over the study period, the per cent mortality did not vary significantly between the sprayed groups, indicating a similar residual effect of the two formulations at the two dosages.

*Perceived side effects*: The spray-man perceived no side effects except complaining a slight headache that lasted for about 30 min. There was no complaint of any sort from the volunteers who slept in the experimental huts, either spontaneously or on probing. They observed that

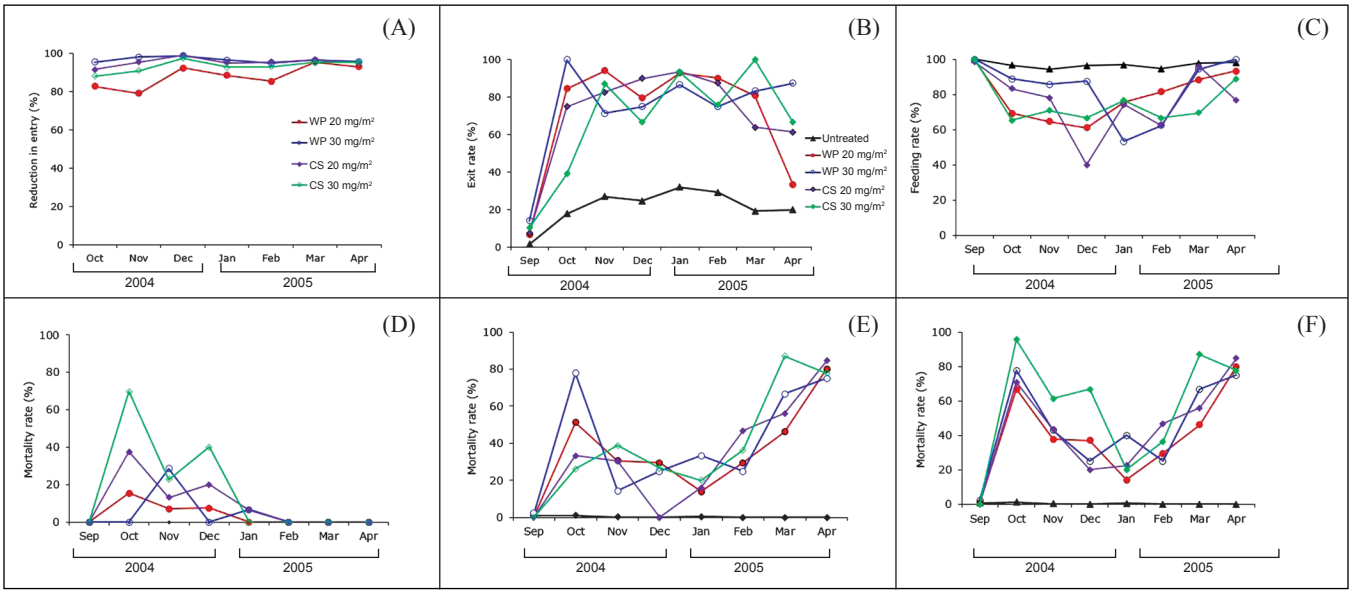


**Fig.** Monthly reduction of entry of *An. fluviatilis* (A) and their exit (B), feeding (C) and mortality (D-F) rates in the untreated and experimental huts.

lambdacyhalothrin formulations had no odour or did not stain the surfaces. They also perceived the benefit of reduced mosquito nuisance in the sprayed huts.

*Residue analysis for lambdacyhalothrin content*: The analysis results for lambdacyhalothrin content in filter paper samples taken from the experimental huts are given in Table II. A total of 63 samples were analyzed, three replicates from one hut (one was damaged) and four each from the remaining 15 huts. The results showed that the insecticide content of the filter paper samples collected from the huts sprayed with WP formulations was lower than the respective experimental dosage, 8.3 mg/m$^2$-11.4 mg (a.i.)/m$^2$ as against 20 mg (a.i.)/m$^2$ and 11.9-15.9 mg (a.i.)/m$^2$ against 30 mg (a.i.)/m$^2$.

Among the four huts, which were sprayed with CS20, the insecticide content in the filter paper samples from the three huts was almost the same as the experimental dosage of 20 mg (a.i.)/m$^2$ (17.8 mg (a.i.)/m$^2$, 19.2 mg (a.i.)/m$^2$ and 19.9 mg (a.i.)/m$^2$ and in the fourth one, the content (42.8 mg (a.i.)/m$^2$) was higher than the experimental dosage. In the case of huts sprayed with CS30, while the insecticide content of the filter papers in two huts was more or less equal to that of the experimental dosage of 30 mg (a.i.)/m$^2$ (28.9 and 35.0 mg (a.i.)/m$^2$), in the other two huts, the filter papers contained over-dosages, 45.2 mg (a.i.)/m$^2$ and 57.1 mg (a.i.)/m$^2$.

*Efficacy in relation to the actual insecticide content available on sprayed surface*: The entry, exit, feeding and mortality rates of *An. fluviatilis* in relation to the insecticide content received by four huts for each dosage are given in Table II. The results of probit

**Table II.** Number of *An. fluviatilis* females entered into the experimental huts and their exit, feeding and mortality in relation to chemical residue analysis results (the range of values obtained from four huts for each dosage)

| Formulation/ Dosage | Entry | | Exit (%) | Fed (%) | Immediate mortality (%) | Delayed mortality (%) | Total mortality (%) | Insecticide content (mg/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| | Number | % reduction | | | | | | |
| WP 20mg/m$^2$ | 37-140 | 82.3-95.3 | 83.6-89.2 | 70.0-77.0 | 1.7-8.1 | 27.0-44.3 | 34.3-47.5 | 8.3-11.4 |
| WP 30mg/m$^2$ | 4-54 | 92.0-99.4 | 75.0-85.2 | 68.5-100 | 0-6.3 | 25.0-50.0 | 25.0-56.3 | 11.9-15.9 |
| CS 20mg/m$^2$ | 28-62 | 93.8-97.2 | 72.4-85.7 | 60.7-89.7 | 4.8-20.7 | 28.2-50.0 | 33.3-67.9 | 17.8-28.9 |
| CS 30mg/m$^2$ | 8-102 | 84.9-98.8 | 12.5-84.3 | 60.0-100 | 11.8-50.0 | 30.0-45.8 | 54.9-87.5 | 35.0-57.0 |

regression analysis showed that with both CS and WP formulations, exit and feeding rates were independent of the actual dosage received by the huts (slopes b) and did not differ significantly from zero for all comparisons, CS: Exit: b=-0.63, SE=0.59; Feeding: b=0.50, SE=0.52; WP, Exit: b=-0.002, SE=1.09; Feeding: b=-0.001, SE=0.99).

In the huts sprayed with WP formulation, both immediate (b= 1.88, SE= 1.65) and delayed mortality rates (b= -0.59, SE= 0.92) were independent of dosages whereas, with CS formulation, immediate mortality was dose dependent (b=2.09, SE = 0.61, $P<0.05$), the maximum mortality was about 30 per cent at the estimated dosage of 30 mg/m$^2$, and delayed mortality was independent of dosage (b=0.18, SE=0.49).

Overall, total mortality was at similar level with both the formulations. The slope of the regression line (b=-0.15, SE=0.91) for total mortality obtained with WP formulation was not significantly different from zero indicating that % mortality was independent of the concentration sprayed, whereas the slope of the regression line (b=1.36, SE=0.49, $P<0.05$) for CS formulation was significantly different from zero indicating that % mortality was dose dependent. Using the relationship, the concentration along with 95% CI required for various levels of mortality were estimated. The estimated lethal concentrations for 45 and 55 per cent mortality was 18.8 (CI: 7.3-24.1) and 28.8 mg/m$^2$ (21.9-43.6), respectively.

## Discussion

Two formulations of lambdacyhalothrin, WP and CS, at the application dosages of 20 and 30 mg (a.i.)/ m$^2$, were tested for their residual efficacy and excito-repellency, and for their effect on vector density, blood feeding success and mortality of the malaria vector, *An. fluviatilis* in experimental huts. The WP30 and CS20 and 30 mg/m$^2$ of lambdacyhalothrin prevented or reduced the entry of *An. fluviatilis* into the sprayed huts by >90 per cent for more than 6 months, the entire peak transmission season of malaria in the area[9]. Further, WP30 and two dosages of CS formulation had similar deterrent effect on mosquito entry. *An. fluviatilis* was predominantly endophilic in the study area[10]. Since one round of spraying with lambdacyhalothrin formulations (WP30 or CS20 or CS30) in the experimental huts made a significant impact on the density of endophilic vector, use of this insecticide formulations at village scale would lead to further reduction of vector densities, thereby resulting in interruption of malaria transmission in the area.

The exit rate of the vector increased with the spraying and there was a reduction of feeding rate after spraying. With reference to these two biological activities, WP30 and the two dosages of CS formulation did not differ significantly indicating their similar action. The WP20 caused lesser impact on exit and feeding rate than the other three groups. It has been accepted that a low excito-repellent action of an insecticide used for indoor spraying is likely to produce a better mass killing effect on mosquito population[2]. However, in the present study, the exit rate of the malaria vector remained >90 per cent in the sprayed huts suggesting that lambdacyhalothrin did not cause mass-killing of vectors.

The formulations or the dosages differed only by causing vector mortalities. The apparent higher mortality obtained with CS30 mg/m$^2$ might be due to the higher concentration of the insecticide that some of the huts actually received than the targeted. The decline in mortality rate of *An. fluviatilis* during November 2004 to January 2005 might be partly because of the higher exit rate observed during that period leading to a higher proportion of mosquitoes avoided the sprayed surface and partly because of the wet condition of the sprayed walls due to unusual rain during the last week of October 2004. Overall, in the present study, the mortality rate was lower in all the four sprayed groups of huts, which could be due to the fact that the vector mosquito, in large numbers, avoided picking up the lethal dosage of the insecticide from the sprayed surfaces because of the increased exit rate (>90% in all the groups) after spraying.

The chemical analysis of filter paper samples showed that there were variations in the content of lambdacyhalothrin on the sprayed surfaces of experimental huts. Since, the required quantity of the insecticide for each dosage was mixed with the required amount of water and sprayed to the huts, each hut would have received the actual quantity of insecticide, but the variations found in the results of chemical analysis might be due to the limitation of human spraying in maintaining the actual dosage uniformly throughout the sprayable surfaces of the hut. Therefore, the chemical analysis results were unlikely to affect the comparison of impact of the insecticide spraying on the biological activities of *An. fluviatilis* observed in different huts sprayed with two dosages of the two formulations of lambdacyhalothrin.

Since both the formulations, at the application rate of 20 mg a.i./m$^2$ caused around 90 per cent mortality

of *An. fluviatilis* for more than seven months, which would be adequate to cover the peak transmission season in the area, this dosage may be selected as the optimum field application dosage. Further, if one would consider the duration of persistent insecticide action on the sprayed surfaces and impact on entry, exit, feeding and in causing mortality of *An. fluviatilis*, the dosage 20 mg a.i./$m^2$ of CS formulation could be a better option for field use. Recently, when bifenthrin (10% WP) was evaluated at four dosages (25, 50, 100 and 200 mg a.i./$m^2$) through house scale trial for controlling *An. culicifacies*, a malaria vector in India, the lowest dosage, 25 mg a.i./$m^2$ was found to be the most effective one[2].

In Malkangiri district, the malaria vectors are endophilic[10]. Indoor residual spraying has been the major vector control measure in the district and two rounds of DDT indoor residual spraying are being carried out every year[11]. The national anti-malaria programme has already started using lambdacyhalothrin WP formulation elsewhere for indoor spraying and CS formulation of this insecticide is now available in India. The house scale trial showed that the 20 mg a.i./$m^2$ of CS formulation was more effective than the corresponding dosage of WP formulation of lambdacyhalothrin in terms of residual effect, limiting entry, increasing exit and inhibiting feeding of the vector mosquito. Further, since there was no difference in effectiveness between the two dosages of CS formulation, it would be preferable to select the lower dosage to be used for a village scale trial.

## Acknowledgment

The authors thank to Dr P. K. Das, former Director, Vector Control Research Centre, Puducherry, for his encouragement and for the facilities provided. The assistance rendered by the technical staff of VCRC field station, Malkangiri, is acknowledged. Authors thank the WHOPES for supplying lambdacyhalothrin formulations and for the financial support.

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