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Field evaluation of lambda-cyhalothrin (ICON 10 CS) indoor residual spraying against *Anopheles culicifacies* in India

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ABSTRACT

Background & objectives: Field trials of lambda-cyhalothrin 10 CS (ICON 10 CS) in indoor residual spraying (IRS) with 25 mg a.i./m^2 against *Anopheles culicifacies* was undertaken *vs* malathion IRS (25% WP–2 g a.i./m^2) in Tumkur district, Karnataka; *vs* deltamethrin IRS (2.5% WP–20 mg a.i./m^2) in Dharmapuri district; and *vs* lambda-cyhalothrin (10 WP–25 mg a.i./m^2) in Ramanathapuram district, Tamil Nadu, India.

Methods: Spray operations in the experimental villages were done by the National Institute of Malaria Research (NIMR) and in the control villages by the respective State Health Department staff. Persistence of efficacy of insecticide sprayed in villages was assessed by contact bioassays against vector mosquitoes. Entomological indicators such as per structure density, parity rates of vector mosquitoes and sporozoite rates were measured in all the three study areas using standard procedures. Mass blood surveys and active fever case detections were carried out in experimental and control villages to study the impact of IRS on malaria transmission.

Results: Persistence of effectiveness of ICON 10 CS was observed up to 2–3 months in all the three study areas. ICON 10 CS was found effective at par with or better than the insecticides used in the national programme in reducing the mosquito densities and in interrupting malaria transmission in the study villages. Vector density, parity rates and malaria cases considerably reduced in the ICON 10 CS-sprayed villages.

Conclusion: Field trials at three sites have established that ICON 10 CS formulation was relatively more effective than malathion 25% WP, deltamethrin 2.5% WP and lambda-cyhalothrin 10% WP in some evaluation parameters like indoor resting mosquitoes, parity rates in vector mosquitoes and persistence of effectiveness. It can be used for IRS for malaria vector control with two rounds of spray at an interval of 3 months for curtailing the malaria transmission and an additional round is recommended in perennial malaria transmission areas.

Key words *Anopheles culicifacies;* India; indoor residual spraying; lambda-cyhalothrin (ICON 10 CS); malaria control

INTRODUCTION

Indoor residual spraying (IRS) with insecticides is being used for malaria control in rural areas in India. IRS has been the mainstay in the National Vector Borne Diseases Control Programme (NVBDCP) for the control of insect disease vectors. *Anopheles culicifacies* Giles 1901 (Diptera: Culicidae), is one of the six primary malaria vectors in India[1]. In the national programme, DDT, malathion and synthetic pyrethroids like deltamethrin, cyfluthrin, lambda-cyhalothrin and alpha-cypermethrin are being used for vector control[2]. Due to the development of resistance in malaria vectors to different classes of insecticides in many countries worldwide, public health programmes are facing challenges in vector control[3,4]. Thus, there is a continued need for introduction of new insecticide molecules, formulations and interventions in the armamentarium of residual sprays.

Lambda-cyhalothrin, a synthetic pyrethroid insecticide of the alpha-cyano group was recommended by WHO for indoor residual spraying[5,6]. This has low vapour pressure, volatility and essentially insoluble in water. Its formulation is reported to have a residual efficacy of 12 weeks. The WHO classified this insecticide as class II category in the moderately hazardous group of insecticides[7]. The formulation of lambda-cyhalothrin used for evaluation is a 'capsule suspension'. In this, the active ingredient is concealed in polymer capsules. The water suspension of this formulation after spray releases the insecticide slowly, extending the compound's residual life. This formulation is neither adsorbed nor absorbed by the porous sprayed surfaces and adheres easily to the insects thereby increasing the insect-insecticide contact. In WHOPES supervised trials, this formulation showed equal or better efficacy than the WP formulation and trials carried out elsewhere also reported good efficacy of ICON 10 CS IRS in controlling

mosquito densities[8]. A field trial with lambda-cyhalothrin IRS in Brazil showed higher efficacy in controlling the *Plasmodium* transmitted-malaria[9]. Few other studies also reported effectiveness of lambda-cyhalothrin IRS in the control of sandflies and other insects[10–12].

This paper presents the results of a field trail undertaken in three different ecological settings in India where *An. culicifacies* is the primary malaria vector. The study was conducted in southern part of India in Tumkur district in Karnataka state, and Dharmapuri and Ramanathapuram districts in Tamil Nadu state to assess the efficacy of ICON 10 CS in comparison with routinely used insecticides for vector control.

MATERIAL & METHODS

Study areas

The present evaluation was carried out in three areas and the description of the study areas follows.

Study site #1

Tumkur district in Karnataka state, India, one of the highly malarious districts of Karnataka was selected as one of the study sites. It lies between 11° 47´ and 12° 33´ north latitude and 77° 02´ and 78° 40´ east longitude. The average annual rainfall is 857 mm. The weather is warm with a maximum temperature of 35°C and a minimum of 17°C. The epidemiological data indicate that about 15–20% of malaria cases of the state were contributed by this district. The district population is more than 2.5 million and has 10 talukas (secondary division of a district). The main vector is *An. culicifacies,* which breeds in village ponds and irrigation wells. The area comes under the dry semi-arid zone. In a large portion of the district, local people grow coconut. Besides this, ground nut, sunflower, ragi (a type of millet) and seasonal vegetables are grown. Rice is cultivated in the low-lying areas. The famous Sira granite quarry is situated in one of the study villages. *Anopheles culicifacies* was found to breed in quarries. The villages located adjacent to this quarry were selected for the present study.

Study site #2

Dharmapuri district, Tamil Nadu state was selected as one of the study areas. This district has an area of 4497.77 km^2, which is 3.46% of Tamil Nadu state. According to 2001 census, the total population of the district is 1,295,182. It lies between 11° 47´ and 12° 33´ north latitude and 77° 02´ and 78° 40´ east longitude. The climate is generally warm with a maximum temperature of 38°C and minimum temperature of 18°C. On an average, the district receives an annual rainfall of 895.56 mm. Streams, wells, ponds, irrigation channels, rice-fields, etc. are the main breeding sources of mosquitoes. *An. culicifacies* is the major vector of malaria in this area.

Study site #3

District Ramanathapuram in coastal part of Tamil Nadu was selected as the third area for the trial. The study localities in this district are located in Rameswaram Island in the south-eastern part of the district. Rameswaram lies at 9° 22´ north latitude and 78° 52' east longitude. The islands are spread in an area of 51.8 km^2 with resident population of 750,000 and floating population of 3,000–10,000 per day, being a pilgrimage centre. The climate is generally warm with a maximum temperature of 37°C and minimum temperature of 17°C. Malaria transmission is perennial and is most intense during January to April and June to September. *Anopheles culicifacies* is the vector in this area and breeds profusely in pits meant for irrigation around coconut–casuarina plantations.

Selection of villages in all the three study sites was done in consultation with the respective district/state health programme personnel. Villages with an average annual parasite incidence (API: no. of malaria cases reported in a year per 1000 population) of 2 and above (in the last 3–5 years) and a population of ~3000 (one or cluster of villages) were selected for evaluation. Control village(s) with a similar population size and eco-topography at 5–10 km apart from the experimental village(s) was(were) selected. Preliminary surveys were conducted to assess density of the prevalent disease vectors. Villages with good vector abundance were selected for the study. Assessment of the density of the vector and non-vector species was done prior to the selection of study villages. Allocation of intervention arms was done randomly.

Preparation of spray suspension

Spray suspension was prepared fresh just before the start of the spray operations every day. ICON 10 CS was provided by M/s. BASF India Pvt. Ltd, Mumbai, India. The required quantity of the insecticide was measured (125 ml of ICON 10 CS) and poured into 10 litres of water and stirred vigourously to obtain a uniform suspension and filtered through a muslin cloth to sieve to remove any particulate matter to avoid clogging of the nozzle of the spray pump. Stirrup pumps with flat fan nozzle were used for spray operations. All the spraymen were imparted training before the spray operations. Two persons were involved in the spray operation. One person operated the pump and the other one sprayed the suspension on to the surface.

Spraying was done as per the guidelines mentioned in "Protocols for Uniform Evaluation of Insecticides for use in Vector Control"[13]. The nozzle discharge rate was calibrated on each day of operation to ensure proper dose dispensation. All necessary safety measures were taken during spraying operation to avoid accidental insecticide exposure to both spraymen and inhabitants.

Spraying schedule

Spraying in the experimental and control villages was carried out as per the schedules of spray suggested by the State Health Department. All the dwellings, namely human dwellings, mixed dwellings, cattle sheds, temporary sheds and other structures were sprayed. Spraying was done with the techniques and equipments used in routine vector control programme as per the norms of supervision suggested by NMEP now NVBDCP[14]. Inhabitants were informed to prepare their houses for the spray a day in advance and free informed consent was obtained. Necessary precautions were taken for the protection of spraymen by providing protective clothing, goggles, gloves, etc. Throughout the spray operations, the Medical Officers of the local PHCs were involved. Mopping up of spray activities were undertaken after each round to ensure maximum coverage of spray in the study villages.

Insecticides and doses

In all the experimental villages of three study areas, ICON 10 CS was sprayed with 25 mg a.i./m^2 (two rounds in Tumkur and Dharmapuri districts, and three rounds in Ramanathapuram district).

In the control villages in Tumkur district, Karnataka, malathion 25% WP was sprayed at a dosage of 2 g a.i./m^2 (two rounds); in Dharmapuri district, deltamethrin 2.5% WP was sprayed at a dosage of 20 mg a.i./m^2 (two rounds) and in Ramanthapuram district, lambda-cyhalothrin 10% WP was sprayed at a dosage of 25 mg a.i./m^2 (three rounds).

Insecticide susceptibility tests

Before the spray operations, insecticide susceptibility tests were carried out on *An. culicifacies* collected from the study villages using WHO insecticide impregnated papers of the specified diagnostic doses of insecticides using WHO kits and method[15]. A minimum of four replicates were used for each insecticide. Percent mortality was scored 24 h after specified diagnostic exposure time and the percent corrected mortality was calculated. Abbott's correction was made when the control mortality was ranging between 5 and 20% in control replicates[16].

Persistence of residual efficacy studies

Persistence of residual efficacy of insecticide spray in study villages was assessed using contact bioassays on sprayed surfaces using WHO kit and procedure[15]. These bioassays were carried out once in a month in all the study villages (both control and experimental). Mosquitoes were exposed to prescribed diagnostic time of exposure of 1 h and held for 24 h and mortality was scored. Residual action was determined using cone bioassays on different wall surfaces available in the study villages, viz. cement, mud, thatched and brick surfaces. Four houses with different sprayed surfaces were selected for the cone bioassays in each study village (both control and experimental). On the selected surfaces, areas of 1 ft^2 were marked with pencil at different levels. Bioassays were carried out in the above-marked squares to assess the persistence of efficacy. Inhabitants were advised not to physically alter the marked areas with renewed mud plaster, white wash and paint. *Anopheles culicifacies* mosquitoes collected from insecticide unsprayed villages were exposed to the test surfaces for 30 min and mortality was scored after 24 h holding period. Mortality was corrected using Abbott's formula as per the crietrion[16].

Mosquito collections

Total indoor resting mosquitoes were collected by pyrethrum space spray method in the early morning hours (0600 to 0800 hrs). For this, before spray all the eves, windows, doors and other exit points were closed. White cloth sheet (bed sheet) was spread on the floor. Pyrethrum extract (0.2% in kerosene) was sprayed in the entire space of the room and the room was closed. After 15 min, all the knocked-down insects lying on the cloth sheet were collected carefully with the forceps and placed in petri dishes lined with moist filter paper and brought to the laboratory for further analysis. Later, mosquitoes were identified to species based on morphological characters using standard keys and abdominal condition was recorded. Results are expressed as density per structure. These collections were performed in four houses in each study village fortnightly.

Parity rates

All the unfed collected mosquitoes were dissected for parity to observe ovaries for distended tracheolar skeins as per the procedure described by WHO[17]. Mosquitoes were categorized as nulli-parous and parous and parity rates were calculated.

Vector incrimination

Vector species were dissected for gut and gland infec-

tions. Mid-gut was examined for the presence of oocysts and salivary glands for sporozoites in 0.6% saline using standard procedures[17].

Disease prevalence

During the study period point prevalence studies (mass blood surveys) were carried out both in the experimental and control villages after the spray. Blood smears were collected from all the inhabitants of every fourth house (irrespective of fever symptoms). In addition, active fever surveillance was undertaken in all the study villages fortnightly. Blood smears were collected from all fever cases. Both thick and thin smears were prepared. These smears were stained with Giemsa and examined under microscope for the presence of malaria parasites. Cases found malaria positive were intimated to Primary Health Centres and treated as per the prescribed drug policy of the National Vector Borne Disease Control Programme.

Human safety

To assess the safety of ICON 10 CS on spraymen and inhabitants, blood and urine samples were collected from 20 participants before and after spray at one study site Tumkur district. All the spraymen and few inhabitants were checked by a qualified physician before and after spray. Blood samples were also collected from the spraymen and inhabitants for biochemical and haematological analyses. Kidney function tests, urine analysis, haematocrit, blood analysis were performed using the standard methods with the help of a qualified pathologist using standard laboratory procedures. Perceptions of spraymen and inhabitants during spray were collected using a standard questionnaire.

Adverse effects, acceptability by householders and collateral benefits

Social acceptability and community acceptance was assessed by collecting information from the inhabitants in the experimental villages using a pre-tested questionnaire. Every fourth house was visited and adult member or head of the family was included for administering the questionnaire. Questionnaire was read in local language with the help of local health staff or villagers.

Statistical analysis

All the data were entered in MS Exel and statistically analysed using SPSS v.10.0 (SPSS Inc. Chicago, USA). Student's *t*-test was applied for comparison of mosquito densities in between control and experimental villages. Fisher's exact test and chi-square test were used for comparing the parity rates, mortality of mosquitoes and parasitological observations between the control and experimental villages. P-values were considered significant at 0.05 level of significance.

RESULTS

Study site #1

In District Tumkur, ICON 10 CS was sprayed in four villages (experimental), comprising of a population of 3098, and malathion was sprayed in three villages (control), comprising of 2820 population. In insecticide susceptibility tests, *An. culicifacies* registered 97% mortality to malathion and 93% to lambda-cyhalothrin in the experimental villages (Table 1). Two rounds of ICON 10 CS were sprayed in the experimental villages with percent house coverage of 81.3 and 76.7 in first and second rounds, respectively (Table 2). Two rounds of malathion were sprayed in the control villages with percent house coverage of 46.5 and 62.1% in first and second rounds, respectively. The pre-spray mortalities in cone bioassays on ICON 10 CS sprayed surfaces was >80% (WHO criterion for efficacy) up to three months of post-spray while in the control area on malathion sprayed surfaces it was >80% only in the first month and decreased by second month (Fig. 1). Per structure densities of mosquitoes assessed from total catch also decreased in the post-spray period in comparison to the pre-spray period (Fig. 2). The parity rates during the pre-spray period was 69 and 75% respectively in the experimental and control areas which decreased to 39 and 43%, respectively, during the post-spray period and the difference was statistically significant (p <0.05) indicating superior performance of ICON 10 CS over malathion in reducing the parity rates. Neither sporozoites nor oocysts were detected in dissected vector mosquitoes. In both the experimental and control areas malaria cases reduced after IRS in comparison to pre-spray period. In mass blood surveys carried out after spray

Table 1. Insecticide susceptibility status of *An. culicifacies* in the study areas before spray operations

Insecticide conc & exposure)	Mortality		
	Site #1	Site #2	Site #3
DDT (4% 1h)	–	46.6 (60)	83.3 (180)
Malathion (5% 1h)	97 (60)	100 (45)	100 (180)
Deltamethrin (0.05% 1h)	–	73.3 (60)	100 (180)
Lambda-cyhalothrin (0.05% 1h)	93 (60)	93.3 (60)	100 (180)
Alpha-cypermethrin (0.1% 1h)	–	–	100 (180)

Figures in parentheses indicate number of mosquitoes exposed; Site #1: Tumkur district, Karnataka; Site #2: Dharmapuri district, Tamil Nadu; and Site #3: Ramanthapuram district.

Table 2. Details of spray coverage at three study sites

Parameters	Site #1 (Tumkur district)		Site #2 (Dharmapuri district)		Site #3 (Ramanthapuram district)	
	E	C	E	C	E	C
Insecticide	ICON 10 CS	Malathion	ICON 10 CS	Deltamethrin	ICON 10 CS	ICON 20 WP
dose	25 mg/m^2	2 g/m^2	25 mg/m^2	20 mg/m^2	25 mg/m^2	25 mg/m^2
I Round						
Date of spray	Oct 2005	Sep 2005	Jan-Feb 2006	Mar 2006	Jul 2006	Jul 2006
No. of villages	4	3	2	4	5	1
No. targeted houses	786	497	918	780	792	1340
% house coverage	81.3	46.5	66.3	51.9	98.6	95.5
II Round						
Date of spray	Feb 2006	Feb 2006	Jul 2006	Aug 2006	Nov 2006	Nov 2006
No. of villages	4	3	2	4	5	1
No. targeted houses	760	567	987	780	797	1608
% house coverage	76.7	62.1	72.03	65.7	98.2	90.8
III Round						
Date of spray					28Feb–10 Mar 07	12 Feb–15 Mar 07
No. of villages					5	1
No. targeted houses					794	1608
% house coverage					98.6	81.4

E—Experimental villages; C—Control villages.

in both the experimental and control areas, there was no significant difference in the malaria positive cases between the areas (p >0.05) (Table 3). The active surveillance data indicated a reduction in total malaria cases by over 50%,

Table 3. Results of mass blood surveys (irrespective of fever) carried out in experimental and control villages in three study areas after spray

	E	C	*p*-value
Site # 1: Tumkur district			
No. of blood slides examined	1269	1829	
No. positive for malaria parasites	3	1	χ^2=1.99
No. positive for *P. vivax*	1	1	p>0.05
No. positive for *P. falciparum*	2	0	
Site # 2: Dharmapuri district			
No. of blood slides examined	1019	774	
No. positive for malaria parasites	6	10	χ^2= 2.46
No. positive for *P. vivax*	4	0	p >0.05
No. positive for *P. falciparum*	2	10	
Site # 3: Ramanathapuram district			
No. of blood slides examined	898	705	
No. positive for malaria parasites	8	8	χ^2= 0.23
No. positive for *P. vivax*	7	7	p<0.05
No. positive for *P. falciparum*	1	1	

E—Experimental villages; C—Control villages.

Table 4. Results of active surveillance (fever cases) carried out in experimental and control villages

	E	C	*p*-value
Site #1 Tumkur district			
Pre-spray (Jan to Sep 2005)			
No. of blood slides examined	4956	1164	
No. positive for malaria parasites	928	60	χ^2=128.22
No. positive for *P. vivax*	647	49	p <0.0001
No. positive for *P. falciparum*	281	11	
Post-spray (Oct 2005 to May 2006)			
No. of blood slides examined	2108	467	χ^2=91.8
No. positive for malaria parasites	413	7	p <0.0001
No. positive for *P. vivax*	391	3	
No. positive for *P. falciparum*	22	4	
Site #2: Dharmapuri district			
No. of blood slides examined	1034	1024	χ^2=1.56
No. positive for malaria parasites	36	26	p>0.05
No. positive for *P. vivax*	33	23	
No. positive for *P. falciparum*	3	3	
Site #3: Ramanathapuram district			
No. of blood slides examined	1100	705	χ^2=39.8
No. positive for malaria parasites	29	61	p<0.0001
No. positive for *P. vivax*	18	45	
No. positive for *P. falciparum*	11	16	

E—Experimental villages; C—Control villages.

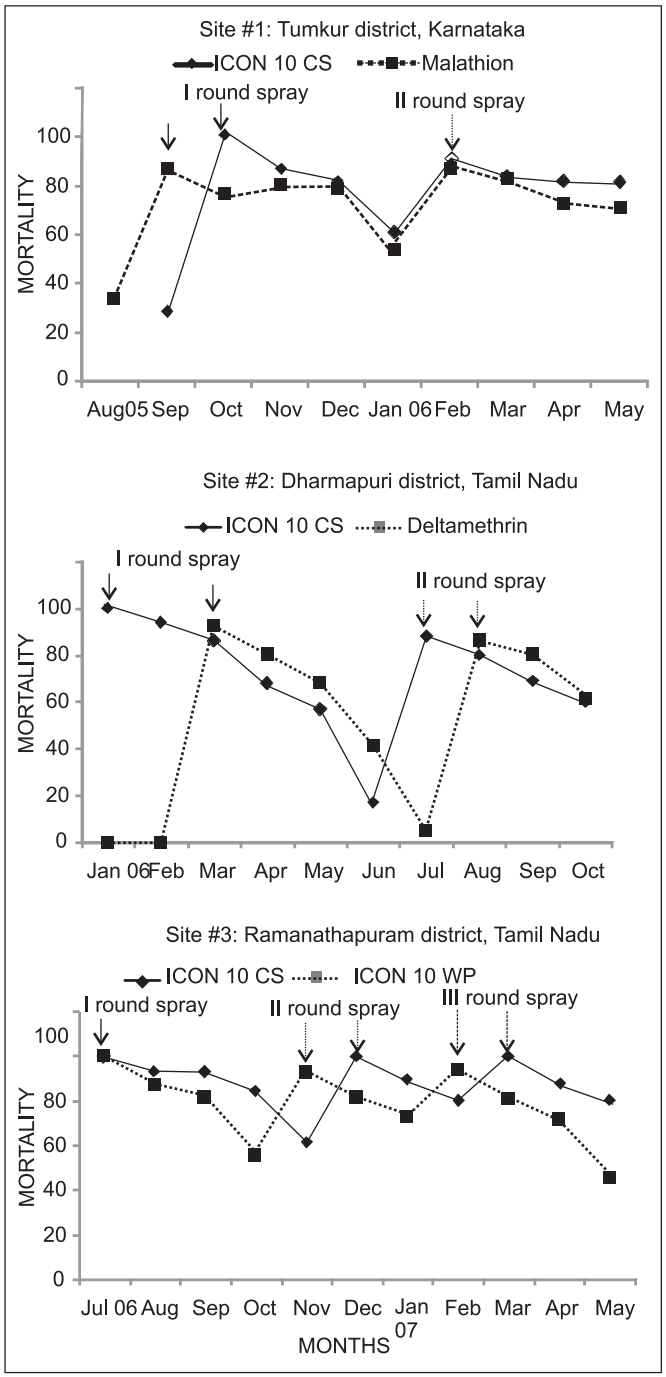

Fig. 1: Residual activity of insecticides sprayed in three study areas

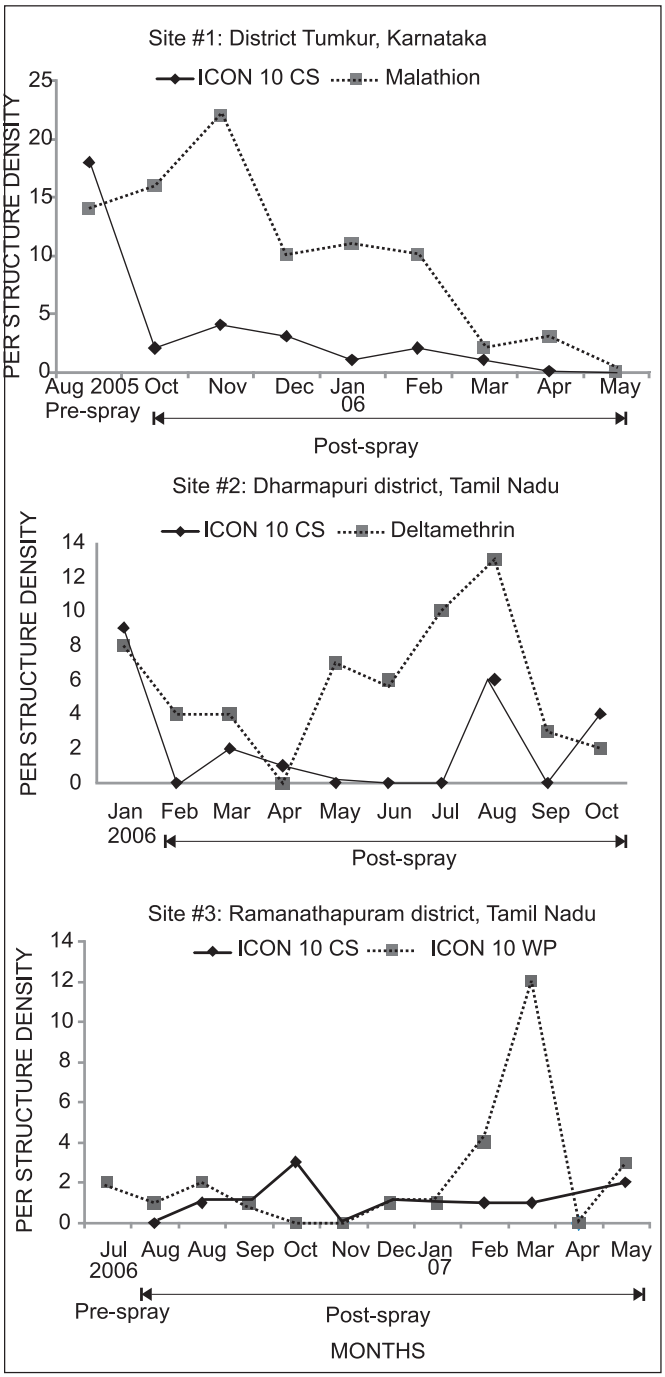

Fig. 2: Per structure density of *An. culicifacies* in experimental and control villages in three study areas

especially the *P. falciparum* cases when compared to the pre-spray data (Table 4). Human safety of ICON 10 CS was evaluated in human volunteers (spraymen and inhabitants) in the experimental villages on general health, biochemical parameters, and routine and biochemical analyses of urine and differential counts of blood. No significant changes were observed in the profiles of inhabitants and spraymen in the pre- and post-spray periods. Inhabitants have expressed satisfaction over the spray operations especially on the reduced mosquito nuisance and reduced densities of other non-target domestic insects/pests. No adverse effects were reported by the interviewees and 99% asserted the use of IRS.

Study site #2

In District Dharampuri, two villages comprising of a population of 2810, were selected for evaluation of ICON 10 CS (experimental). Four villages in PHC Balrampatti

were selected as control villages where deltamethrin 2.5% WP was sprayed as a comparative insecticide. Insecticide susceptibility tests showed that *An. culicifacies* was 93% susceptible to lambda-cyhalothrin and 73.3% to deltamethrin (Table 1). In experimental villages, the house coverage was 66.3 and 72.03% in the first and second rounds respectively, and in the control villages it was 51.9 and 65.7%, respectively (Table 2). Persistence of effectiveness of insecticide (>80% mortality) was observed up to three months after spray in the experimental areas and up to two months in the control areas (Fig.1). Persistence studies indicated relatively higher efficacy of ICON 10 CS formulation than deltamethrin. There was a decrease in the per structure density of mosquitoes after the spray (Fig. 2) and the impact was significant (p <0.05) in the experimental areas indicating higher efficacy of ICON 10 CS probably being a slow release formulation. Further, the susceptibility of *An. culicifacies* was also less to deltamethrin in this area, which might also be one of the the reasons for higher mosquito densities. Parity rates in *An. culicifacies* decreased from 76 in the pre-spray period to 44 in the post-spray period in the experimental area and from 68 to 42 in the control area indicating equal effectiveness on parity rates of the insecticides (p >0.05). Oocysts and sporozoites were not detected in the dissected *An. culicifacies* mosquitoes.

Active and passive malaria surveys indicated prevalence of both *P. vivax* and *P. falciparum* with high prevalence of *P. vivax* in the experimental areas. In mass blood surveys, there was no significant difference between the malaria positive cases in the experimental and control areas (p >0.05), however, more *Pf* cases were reported from the control areas indicating continued transmission (Table 3). The active surveillance data also showed no significant differences in malaria cases between the experimental and control areas (Table 4). It may be stated that the villages in both the areas were receiving pyrethroid spray and being an effective insecticide kept the transmission under control. However, in the present surveys ICON 10 CS has shown a comparable effect during the trial period. Human safety and perceptions survey revealed enthusiastic response from the inhabitants and no adverse effects were reported by the spraymen or inhabitants.

Study site #3

In District Ramanathapuram, five villages, comprising a population of 2827 were experimental villages and one village and few hamlets comprising of a population of 2626 were control villages. Both experimental and control areas received different formulations of lambda-cyhalothrin (ICON 10 CS and ICON 10 WP). In the experimental villages, three rounds of spray were carried out with CS formulation with percent house coverage of 98.6, 98.2 and 98.6%, and in the control villages with WP formulation with a percent house coverage of 95.5, 90.8 and 81.4% in the first, second and third rounds, respectively (Table 2). Persistence of effectiveness of sprayed insecticide was up to two months in both the areas (Fig. 1). Total catch assessment in structures in the post-spray period on indoor densities indicated better impact of ICON 10 CS probably owing to the slow release characteristic of the CS formulation (Fig. 2). A significant decrease in the parity rates was observed ($p < 0.05$). Pre-spray parity rate of vector mosquitoes in the experimental area was 62 and decreased to 22 in the post-spray period. Similarly, in the control area it decreased from 58 to 24. Oocysts and sporozoites were not detected in the dissected *An. culicifacies* mosquitoes. The malaria incidence in the experimental and control villages was very low throughout the study period. Mass blood surveys did not show any difference between the control and experimental villages indicating equal effectiveness of insecticides (Table 3). The number positives parasites in experimental area was 29 (18 *Pv* + 11 *Pf*) while in the control area it was 61 (45 *Pv*+16 *Pf*) indicating an interruption of transmission in the experimental villages (Table 4). Inhabitants and spraymen did not report any adverse effect due to the spray. There was a good response from the inhabitants for the spray.

DISCUSSION

The results of field trials at three sites on ICON 10 CS formulation revealed comparable efficacy at par with the insecticides used for the indoor residual spraying in the national programme. In all the three study sites, lambda-cyhalothrin showed efficacy at par or slightly better than the insecticides sprayed regularly in the programme.

Persistence of effectiveness of ICON 10 CS was up to 2–4 months in the three study sites and the results are in conformity with previous studies[8,11,18–20]. Trials in Tanzania with ICON 10 CS recorded 100% mortality of *An. gambiae* – the main malaria vector up to seven months on sprayed surfaces[18]. In Vietnam, persistence of effectiveness lasted up to four, five and three months, respectively, on wood, bamboo and brick walls in bioassays against *An. dirus*[8]. In a WHOPES supervised trial with CS and WP formulations with 30 mg/m^2 in Benin, persistence of effectiveness was reported up to two months only[8], whereas, WHOPES supervised trials in India reported persistence up to 4–6 months on different surfaces. In the present trials also, the persistence was reported up to 2–4

months on different wall surfaces. In WHOPES supervised trials[8], CS formulation produced comparable or better efficacy than the WP formulation sprayed at a dosage of 30 mg a.i./m^2. In the present study in Ramanathapuram district, IRS of ICON 10 CS also showed promising results over WP formulation.

Curtis *et al*[18] reported reduced vector densities, sporozoite rates and malaria incidence in villages sprayed with ICON 10 CS sprayed at a dosage of 30 mg/m^2 in Tanzania. In Vietnam trial also human landing rates, density of day-time resting mosquitoes and light-trap catches greatly reduced in ICON 10 CS sprayed sites than the unsprayed ones[8]. Few studies also reported reduced sandfly densities after ICON 10 CS with lambda-cyhalothrin[10–12,20]. Mathews *et al*[20] reported reduced mosquito densities in houses with intervention with ICON 10 CS IRS + ITN than the houses with other intervention or no intervention. In the present study also, ICON 10 CS spraying resulted reduction in vector densities and parity rates of vector mosquitoes.

Malaria cases in all the three study sites were reduced considerably in all the three ICON trial sites *vis-à-vis* control ones indicating the effectiveness of the CS formulation in interrupting the malaria transmission. However, in Tumkur district, Karnataka though malaria incidence could not be curtailed completely, there was a considerable decrease in the number of malaria cases after the spray with ICON 10 CS in experimental villages, especially *P. falciparum* cases. In this area, due to the presence of stone quarries there is a congregation of labour population and due to their outdoor sleeping habits, malaria transmission could not be controlled completely with spray. During the pre-spray period (January to September 2005), 928 malaria cases were reported, whereas during the post-spray period (October 2005 to May 2006) the number of cases reduced to 413 cases. The incidence of *P. falciparum* has reduced drastically from 281 in pre-spray to 22 cases in post-spray, indicating the effectiveness of the ICON 10 CS. In the control area also, similar results were reported. In Dhramapuri district, there was no significant difference in malaria incidence between the control and experimental villages ($p > 0.05$) whereas in Ramanathapuram district there was a significant difference in malaria cases between the control and experimental villages ($p < 0.0001$) indicating superior performance of ICON 10 CS over WP formulation. In a study carried out by Bukirwa *et al*[21] in western Uganda, it was reported that lambda-cyhalothrin IRS produced consistent decrease in the proportion of malaria positive cases in the first four months of IRS indicating the effectiveness of lambda-cyhalothrin in reducing the malaria incidence.

In view of the results, the field trials at three sites have established that ICON 10 CS formulation was found comparable or relatively more effective than malathion 25% WP, deltamethrin 2.5% WP and lambda-cyhalothrin 10 WP in some evaluation parameters like indoor resting mosquitoes, parity rates of vector mosquitoes, increased persistence, etc. and in reducing the malaria cases. It can be used for IRS for malaria vector control with two rounds of spray at an interval of 3 months for curtailing the malaria transmission and an additional round is recommended in perennial malaria transmission areas.

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