Journal of the American Mosquito Control Association, 9(4):408–413, 1993

ASSESSMENT OF THE RESIDUAL EFFICACY OF LAMBDA-CYHALOTHRIN 1. A LABORATORY STUDY USING *ANOPHELES ARABIENSIS* AND *CIMEX LECTULARIUS* (HEMIPTERA: CIMICIDAE) ON TREATED DAUB WALL SUBSTRATES FROM NATAL, SOUTH AFRICA

D. LE SUEUR, B. L. SHARP, C. FRASER AND S. M. NGXONGO[1]

National Malaria Research Programme, Medical Research Council, P. O. Box 17120, Congella 4013, Natal, South Africa

ABSTRACT. Laboratory assessment of the residual efficacy of lambda-cyhalothrin (Icon®) 10% AI against *Anopheles arabiensis* and *Cimex lectularius* was carried out. The insecticide was applied to daub substrates, simulating the wall surface of houses from 3 areas within the endemic malaria area of Natal, South Africa. Variability in residual efficacy was found between different areas and appeared to correlate to organic content of the substrate. Residual efficacy against *An. arabiensis* ranged from as little as 2 wk in some areas to in excess of 14 wk in others. Residual efficacy against *C. lectularius* was 4 wk for all 3 areas, but was 10 wk in only 2 areas.

INTRODUCTION

The first ever trials testing the residual application of insecticide for malaria control were conducted in 1931 in the province of Natal, South Africa (le Sueur et al. 1993). These were conducted by Senior Malaria Inspector S. Hamilton under the direction of G. A. Park Ross, the Assistant Health Officer for the Union of South Africa. By 1932 widespread application was undertaken and was successful in bringing the 1930s epidemics under control. In 1946 pyrethrum was replaced as the insecticide of choice by DDT, which was used for both indoor residual application and larviciding. In 1956 larvicidal measures were discontinued. During the 1970s the control program became increasingly well structured, due to the formation of regional malaria committees. The malaria situation between 1976 and 1985 has recently been documented by Sharp et al. (1988).

However, despite total insecticide coverage of all homesteads with DDT, sporadic epidemics occur when parasite control has been limited by chloroquine resistance (Herbst et al. 1987), and vector population intrinsic rates of increase have been enhanced through the extensive provision of optimal breeding sites as a result of agricultural irrigation spillage. More recently Sharp et al. (1990) have demonstrated that a component of the *Anopheles arabiensis* Patton population in the region is entering dwellings, biting the inhabitants, and exiting without making contact with the residual insecticide applied to the dwelling walls. The above factors have led to changes in the drug of treatment used by control authorities to Fansidar® (sulfadoxine-pyremethamine) and the reintroduction of focal larviciding. The failure of DDT to achieve total control, whether through behavioral avoidance or irritancy effects, motivated the need to assess alternative insecticides for the control of this species. The local *An. arabiensis* population is susceptible to DDT, which has a residual efficacy in excess of 9 months, based on tests (15-min exposure) at a single locality (Sharp et al. 1990). It was decided that a laboratory assessment of lambda-cyhalothrin should precede its field assessment (reported in Part 2) as it would be logistically easier to carry out a study on substrate effect in this manner.

There is a high degree of DDT resistance in the bedbug *Cimex lectularius* Linn. in KwaZulu, which enables infestations to thrive in DDT-sprayed dwellings (Newberry and Jansen 1986). This has led to community objection to the application of DDT in some regions. It was thus considered important that the efficacy of an alternative, candidate insecticide also be tested against the local bedbug population.

MATERIALS AND METHODS

Collection of daub wall substrates: Daub samples were collected in plastic boxes, where the surface of daub approximates to 20.5 × 30.5 cm. The daub (mud mixed with cow dung) was prepared by the local villagers and field staff. The collection sites were listed in Table 1 and shown in Fig. 1.

The blocks were retained in their plastic containers (which had drainage holes) and allowed to dry. This took approximately 2 months. Blocks from 2 localities within each of the 3 areas were

[1] KwaZulu Department of Health and Welfare, Malaria Control Program, Private Bag X002, Josini 3969, Natal, South Africa.

Table 1. Origin of simulated wall daub substrates. The Area, Section, and Homestead numbers reflect those allocated by the malaria control program.

Area	Section	Homestead	Owner	Subsequent treatment
Mamfene	1	92a	Myeni	Control
Tetepan	2	23	—	Control
Mfekayi	1	174	Sibiya	Control
Mamfene 1	2	14	Ndwande	Experiment
Mamfene 2	2	89	Zondo	Experiment
Tetepan 1	5	15	Mkumbuzi	Experiment
Tetepan 2	6	24	Mathomsi	Experiment
Mfekayi 1	1	174	Sibiya	Experiment
Mfekayi 2	1	174	Sibiya	Experiment

made up for the *An. arabiensis* and *C. lectularius* trials. For the bioassays conducted using *C. lectularius* only one daub block from one locality within each region was utilized.

Application of insecticide: An Efekto "Home and Garden Spray" hand pump of 550-ml capacity, operated by a hand lever with delivery rate of 1.06 ml per stroke was used for spraying the insecticide. Rectangles the size of the surface of the daub blocks were chalked onto a wall, and practice runs showed that a nozzle-to-surface distance of 8 cm enabled the block to be covered in 3 swathes of 7–8 cm width, moving the pump quickly lengthwise over the rectangle. There was therefore some overlap between swathes, but very little spray fell outside the target area. Some spray was lost due to bounce off from the surface.

The lambda-cyhalothrin 10% AI wettable powder (wp) was an off-the-shelf formulation and was mixed at the same concentration as would be used for spraying in the field (i.e., 75 g/10 liters of aqueous mixture). The 3 strokes each of 1.06 ml therefore delivered approximately 0.038 g/m^2 of lambda-cyhalothrin onto the daub blocks. This is higher than the target dose of 0.03 g/m^2, but the closest approximation possible using the "field" mixture and the Efekto pump. When mixing the lambda-cyhalothrin, no undissolved lumps were noticed. During mixing and spraying, irritation of the nasal membranes occurred, indicating that field spraymen would have to be adequately protected.

Bioassays of Cimex lectularius*:* Four weeks after the application of lambda-cyhalothrin, bioassays were carried out using adult *C. lectularius* bedbugs from a colony founded using insects caught in homes in northern Natal/KwaZulu.

The colony had been kept unfed at 19°C for 4 wk so the abdomens of the bugs were flat and thus less susceptible to damage during handling. The colony was kept unfed at 25°C and RH of >80% prior to the second trial. Bedbugs can survive starvation at moderate temperatures for many months without harm (Johnson 1941). The insects were introduced through the top of a bioassay cone of the type used for mosquito bioassays (World Health Organization 1960) on to daub block surfaces and exposed at room temperature (26°C) for 5 h. The bioassay cones had foam rubber glued to the bases to ensure contact with the uneven surfaces and were pinned into place.

After exposure, the bugs were transferred by brush or forceps to a holding tube containing cardboard for them to rest on. Ten male and 10 female bugs were used per cone on the 3 test and 3 control blocks of daub. Mortality was scored immediately after exposure, then 24 h thereafter.

Bioassays of Anopheles arabiensis*:* One week after the application of insecticide, bioassays were

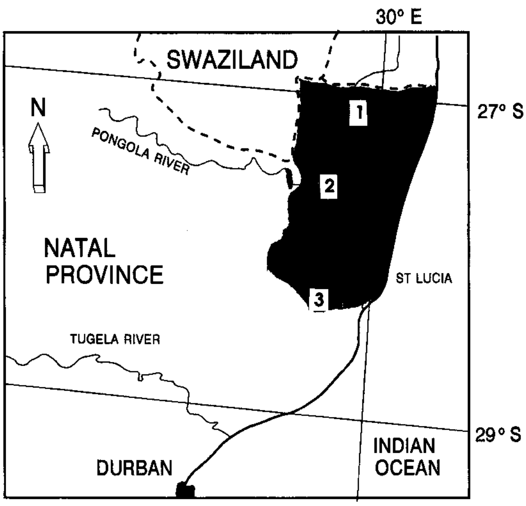

Fig. 1. Map indicating the sites of origin for the 3 daub substrates. The shaded area indicates the high-risk malaria areas for the province of Natal.

Table 2. Percentage mortality of KwaZulu colony *Cimex lectularius* immediately after, and 1 day after, exposure for 5 h to daub blocks sprayed 28 and 70 days previously, at a target dosage rate of 0.038 g/m² lambda-cyhalothrin.

Source of daub blocks	No. and sex of bugs	Treatment	% mortality: End of exposure	% mortality: One day later
		28 days		
Mfekayi	9 males	Experiment	11.1	100.0
	10 females	Experiment	0	90.0
	9 males	Control	0	44.0
	9 females	Control	0	11.1
Mamfene	10 females	Experiment	90.0	90.0
	10 males	Experiment	100.0	100.0
	9 females	Control	0	11.1
	10 males	Control	0	33.3
Tetepan	10 females	Experiment	90.0	90.0
	10 males	Experiment	100.0	100.0
	8 males	Control	0	12.5
	10 females	Control	0	0
		70 days		
Mfekayi	10 males	Experiment	0	0
	10 females	Experiment	0	0
	10 males	Control	0	40.0
	10 females	Control	0	0
Mamfene	10 females	Experiment	70.0	80.0
	10 males	Experiment	30	90.0
	10 females	Control	0	10.0
	10 males	Control	0	10.0
Tetepan	10 females	Experiment	30.0	80.0
	10 males	Experiment	40.0	80.0
	10 males	Control	0	0
	10 females	Control	0	0

carried out using *An. arabiensis* from a colony founded by individuals from Kanyemba, N. Zimbabwe (15°40′S, 30°20′E). Bioassays were carried out at weekly intervals for the first 4 wk and then at monthly intervals thereafter. The last assay was conducted at 14 wk (98 days). Bloodfed female mosquitoes 2 to 4 days old were used.

The insects were introduced through the top of a bioassay cone of the type used for mosquito bioassays (World Health Organization 1960) on to daub block surfaces and exposed at room temperature (23°C) for 1 h. The bioassay cones were kept in the same position (on the daub block) for the duration of the study. Thirty females were used in each assessment. The blocks were positioned 45° from the horizontal plane. After exposure, the females were placed in a container in the insectary and offered a sugar meal (7% solution). Mortalities were assessed after 24 h.

To assess that the spraying of the daub blocks had been uniform, a second bioassay cone was affixed to 3 of the treated daub blocks and parallel bioassays carried out. Three trials were carried out at weekly intervals.

Susceptibility: Three tests were carried out using the standard WHO kit. Thirty individuals were exposed to 0.025% lambda-cyhalothrin for 1 h and then placed in holding containers and offered a sugar meal. Mortalities were assessed at 1 h and at 24 h.

Activity measurements: Individual *An. arabiensis* were placed in bioassay cones against untreated daub surfaces of each type to assess whether any of the various daub materials was irritant to the mosquitoes. The duration each individual spent in contact with the daub substrate over a 10-min period was measured using a stopwatch. Standard *t*-tests were then conducted to assess whether contact time differed between those on which the insecticide had shown good residual activity and those on which it had been poor.

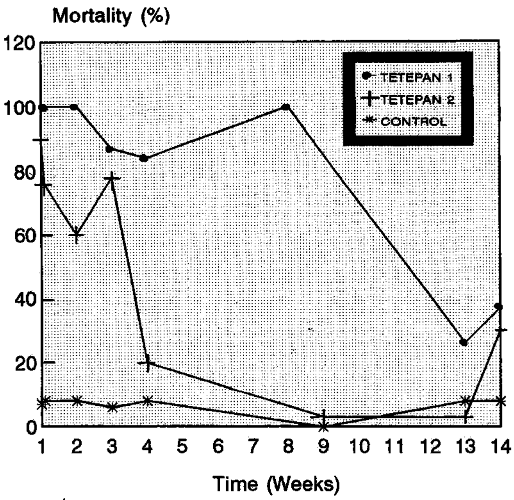

Fig. 2. Residual efficacy of lambda-cyhalothrin at an application rate of 0.038 g/m² against *Anopheles arabiensis* for the Tetepan region.

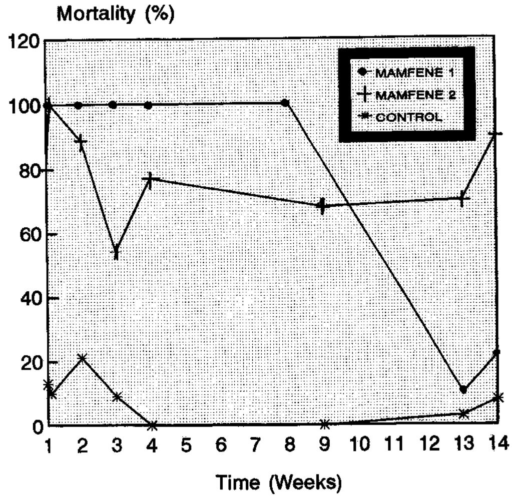

Fig. 4. Residual efficacy of lambda-cyhalothrin at an application rate of 0.038 g/m² against *Anopheles arabiensis* for the Mamfene region.

Physical analysis of daub substrate: Samples of the daub substrate that had shown the greatest difference in residual activity were analyzed for the parameters listed in Table 4.

RESULTS

Table 2 shows the residual efficacy of lambda-cyhalothrin at an application rate of 0.038 g/m² on different substrates against the bedbug *C. lectularius* 28 and 70 days after application.

The results of the bioassays, assessing the residual efficacy of lambda-cyhalothrin against *An. arabiensis* over a 14-wk period are shown in Figs. 2–4. The differences between and within areas (Tetepan 1 and 2) should be noted. The results of the assessment of spraying uniformity are shown in Fig. 5. The colony was sensitive, with 100% mortality after 1 h exposure to 0.025% lambda-cyhalothrin in all 3 trials. Trials conducted using local field *An. arabiensis* also indicated susceptibility at this level; these results are reported in Part 2.

The results of the individual mosquito activity trials on different substrates are shown in Table 3. Activity of the mosquitoes on the different substrates was tested for differences between lo-

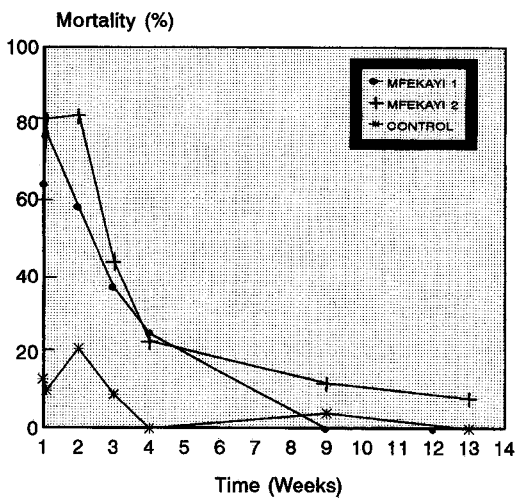

Fig. 3. Residual efficacy of lambda-cyhalothrin at an application rate of 0.038 g/m² against *Anopheles arabiensis* for the Mfekayi region.

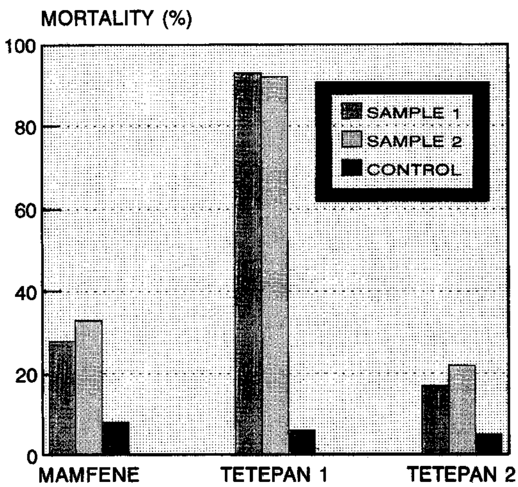

Fig. 5. Histogram showing the assessment of spraying uniformity onto the daub substrates against *Anopheles arabiensis*.

Table 3. Comparison of individual mosquito (*Anopheles arabiensis*) activity on substrates from 5 collection points.

Area	n	Mean resting time ± SD
Mfekayi 2	28	7.3 ± 3.9
Mamfene 1	17	6.4 ± 4.7
Mamfene 2	8	7.7 ± 3.8
Tetepan 1	28	7.2 ± 4.1
Tetepan 2	28	6.5 ± 4.5

calities/regions using the student *t*-test. No significant differences were found. Analytical results of the substrate samples are shown in Table 4.

DISCUSSION

The high mortality of *C. lectularius* immediately after exposure (Table 2) produced by the blocks from Mamfene and Tetepan contrasts with the very low mortality for Mfekayi. This finding ties in with the previous work done on other insecticides (deltamethrin, fenitrothion, and bendiocarb) that had least residual life in the Nkundusi/Mfekayi areas (K. Newberry, personal communication). However, high mortalities were recorded for Mfekayi insecticide bioassays 1 day after exposure (Table 2), with low female mortality in the controls, indicating the insecticide residue was effective against bedbugs in all 3 areas 1 month after spraying. Seventy days after the application of the insecticide to the daub blocks, no mortalities were recorded for Mfekayi, indicating that the residual effect of the insecticide had ended (Table 2). In contrast, mortalities for Mamfene and Tetepan were in excess of 80% 24 h after exposure. The decreasing residual effect is, however, clearly indicated by the reduced mortalities for these regions, directly after exposure, when compared to the trial conducted at 28 days (Table 2).

Judged on the criterion of length of life of insecticide residue on daub surfaces, lambda-cyhalothrin shows promise for bedbug control in daub-walled houses in KwaZulu and Natal.

Figures 2–4 show the percentage mortality with time for the daub substrates from the 3 regions. The pattern of reduced effectivity for the Mfekayi region is consistent with the results obtained for the *C. lectularius* trials. At one stage it was thought that the individuals placed into cones on the Mfekayi daub blocks showed greater activity (i.e., that there was an irritant effect, reducing resting time and thus mosquito insecticide contact). The results from the bedbug trials would, however, indicate otherwise. The possibility that the results may indicate a combination of reduced re-

Table 4. Physical and chemical analysis of different regional daub wall substrates used.

Analytical component	Area			
	Tetepan 1	Tetepan 2	Mamfene 1	Mfekayi 1
Sample density (g/ml)	0.96	1.17	1.13	1.00
Phosphorous (mg/liter)	35	2	95	16
Potassium (mg/liter)	292	332	733	415
Calcium (mg/liter)	2,064	1,385	1,103	1,093
Zinc (mg/liter)	1.4	0.5	3.1	1.2
Magnesium (mg/liter)	571	582	755	536
Acidity, Al + H ($cmol_c$/liter)	0.03	0.02	0.01	0.03
Total cations ($cmol_c$/liter)	15.78	12.57	13.60	10.96
Acid saturation (%)	0.2	0.2	0.1	0.3
Particle analysis (% clay : silt : sand)	26:7:67	21:8:71	32:5:63	26:14:60
Cation exchange capacity values (me/100 g clay, %)	60	51	42	38
Organic carbon (%)	1.93	1.02	1.19	0.89
Estimated organic matter (%)	3.32	1.75	2.05	1.53
pH (soil ground H_2O)	7.3	6.4	8.5	7.6
pH (KCl)	6.6	5.3	8.2	7.3

sidual effect and irritant effect cannot be ruled out. It is known that in the Mfekayi region a large portion of the area consists of exposed marine cretaceous deposits that are saline in nature. When mud from such deposits is incorporated into daub there is a possibility that it may irritate the insects and/or reduce the residual effect of the insecticide. To assess these factors, comparative activity trials were conducted, and samples of the daub blocks were subjected to physical and chemical analysis.

The result of the activity trials showed similar mean resting times (Table 3) over a 10-min assessment period and comparisons of activity between different substrates showed no statistical differences. Thus, it may be concluded that the differences in mortality were not a result of reduced contact with the insecticide-treated substrate due to inherent, irritant properties of the substrate on the test mosquitoes.

The cation exchange capacity values shown in Table 4 show that Tetepan 1 and 2 have a greater percentage of lattice clays than the samples from Mfekayi and Mamfene. It was thought that this greater surface area and therefore more adsorption sites to bind the insecticide may have affected the residual activity of the applied insecticide. From Table 4 and Figs. 2–4 it is, however, clear that this is not the case. Excluding the values for organic content, no other physical or chemical component showed correlation with the residual efficacy. Increasing organic content correlated to increases in the residual efficacy of the insecticide; however, the data set is too small to make any firm conclusions.

CONCLUSIONS

Lambda-cyhalothrin appears to satisfy the prerequisites for it to be effective in the control of bedbugs within the endemic malaria area. The reduced effectiveness on certain daub substrates requires investigation and precludes its widespread application in the endemic area of Natal, South Africa. Unlike DDT, lambda-cyhalothrin may be applied to all the contents of the huts (i.e., furniture, etc.), thus increasing the amount of treated surface within an abode. The persistence on such structures (e.g., wood) is known to be good (100% effective after 24 wk; Tropical Disease Research Institute 1985). There is an increasing number of western style houses in the area (owners object to DDT on the painted walls) and lambda-cyhalothrin is probably suitable for application in these.

Malaria transmission is seasonal within the endemic area, with in excess of 70% of the cases occurring over a 5-month period. Considering this, the results obtained, the reduced control of *An. arabiensis* being obtained with DDT (Sharp et al. 1990), the high levels (18 × Allowable Daily Intake) of DDT reported in breast milk of mothers living in the endemic region (Bouwman et al. 1990), and the bedbug problem associated with DDT application (Newberry and Jansen 1986), we feel that there are specific situations where application of the insecticide lambda-cyhalothrin could be considered. Residual persistence will be good especially in areas in which homes are largely constructed with reeds, wood, and grass. Application would have to be carried out after consultation with the National Malaria Research Programme/KwaZulu Health surface data base. This data base lists regionally the type of surface of every homestead for all areas in the KwaZulu areas of malaria control.

ACKNOWLEDGMENTS

Special thanks are given to Keith Newberry for his input in the planning stages of the study and the spraying of the daub blocks, Barry Bredenkamp for his constructive criticism of the manuscript, and Joseph Shozi for his input in the insectary. This study was supported in part by a grant from Imperial Chemical Industries.

REFERENCES CITED

Bouwman, H., P. J. Becker, R. M. Coopan and A. J. Reinecke. 1990. Levels of DDT and metabolites in breast milk from KwaZulu mothers after application for malaria control. Bull. W.H.O. 68:761–768.

Herbst, J. M., L. A. Taylor and S. M. Joubert. 1987. Chloroquine resistance in *Plasmodium falciparum* in Natal. S. Afr. Med. J. 72:627–629.

Johnson, C. G. 1941. The ecology of the bedbug *Cimex lectularius* in Britain. J. Hyg. 44:345–459.

le Sueur, D., B. L. Sharp and C. C. Appleton. 1993. A historical perspective of the malaria problem in Natal with emphasis on the period 1928–1932. S. Afr. J. Sci. 89:232–239.

Newberry, K. and E. J. Jansen. 1986. The common bedbug *Cimex lectularius* in African huts. Trans R. Soc. Trop. Med. Hyg. 80:653–658.

Sharp, B. L., D. le Sueur and P. Bekker. 1990. Effect of DDT on survival and blood feeding success of *Anopheles arabiensis* in northern KwaZulu, Republic of South Africa. J. Am. Mosq. Control Assoc. 6:197–202.

Sharp, B. L., S. Ngxongo, M. J. Botha, F. C. Ridl and D. le Sueur. 1988. An analysis of 10 years of retrospective malaria data from the KwaZulu areas of Natal. S. Afr. J. Sci. 84:102–106.

Tropical Disease Research Institute. 1985. Evaluation of OMS-3021. Unpublished TDRI/WHOPES Report 84/7.

World Health Organization. 1960. Insect resistance and vector control. 10th Report of the Expert Committee on Insecticides. W.H.O. Tech. Rep. Ser. 191.