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ASSESSMENT OF THE RESIDUAL EFFICACY OF LAMBDA-CYHALOTHRIN 2. A COMPARISON WITH DDT FOR THE INTRADOMICILIARY CONTROL OF *ANOPHELES ARABIENSIS* IN SOUTH AFRICA

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ABSTRACT. There are several factors that support the need to assess the efficacy of potential alternative insecticides to DDT for malaria vector control. The objectives of this study were to evaluate the persistence and efficacy against *Anopheles arabiensis* of lambda-cyhalothrin used as an intradomiciliary insecticide in daub huts and to compare its efficacy in this regard to DDT. Exit trap catches showed the population of *An. arabiensis* was high during the months of January to March, with a peak in February. During all months, the number caught leaving lambda-cyhalothrin-sprayed huts was markedly less than the number from both control and DDT-sprayed huts. The percentage survival of bloodfed mosquitoes ranged from a low of 55% caught leaving the lambda-cyhalothrin-sprayed huts, to 82% of those caught leaving DDT-sprayed huts. The percentage of bloodfed mosquitoes caught leaving huts was high (>60%). The survival of unfed mosquitoes was low, even from the control huts (43%).

INTRODUCTION

Anopheles arabiensis Patton is the primary vector of malaria in many parts of Africa (White 1974). This member of the *Anopheles gambiae* complex predominates in malaria endemic areas of northern Natal Province and KwaZulu, South Africa, and throughout southern Africa (Shelley 1973, le Sueur and Sharp 1988, Sharp et al. 1990, Sharp and le Sueur 1991). Control of adult malaria vectors was started in the Natal Province of South Africa in 1931, with the use of intradomiciliary pyrethrum spray (Park Ross 1936). Residual house spraying with DDT was first used in 1948 and by 1958 all homesteads in the malarious areas were subject to the annual application of 75% w.w. DDT at 2.5 g/m^2. Currently no evidence exists of DDT resistance by any species of the *An. gambiae* complex in these areas (Sharp et al. 1990).

The efficacy of potential alternative insecticides to DDT for malaria vector control in South Africa should be assessed because of the following factors: 1) It is generally accepted that agricultural pesticide use associated with large scale agricultural irrigation projects exacerbates the development of insecticide resistance in mosquitoes. A project of this nature has been initiated in the malaria area of northern Natal/KwaZulu. 2) Social attitudes against the use of DDT have increased to the degree that certain international research funding agencies will no longer fund research in any way associated with DDT. 3) Research on DDT levels in men and women in the endemic area of northern Natal/KwaZulu showed 20× the adult dietary intake overall in the study and 31× the adult dietary intake in primiparous mothers (Bouwman et al. 1990). 4) Sharp et al. (1990) showed that the hut-leaving behavior of *An. arabiensis* hampered the control of this species by intradomiciliary DDT spraying. 5) The spread of chloroquine- and multi-resistant *Plasmodium falciparum* malaria in southern Africa places an increasing emphasis on the need for more efficient vector control (Freese et al. 1988, 1991; Schapira 1990).

The above factors justify the present assessment of a suitable alternative to DDT should such a need for more efficient vector control arise. Lambda-cyhalothrin, a biodegradable synthetic pyrethroid, recently passed through all phases of the World Health Organization (WHO) Pesticide Evaluation Scheme (WHO 1990a, 1990b, 1991). Both laboratory and field trials have shown that lambda-cyhalothrin as both an ultra-low volume (ULV) spray and a contact insecticide was highly effective in the control of mosquito species (Roberts et al. 1984, Schaefer et al. 1990, Miller et al. 1991, Sulaiman et al. 1991, Weathersbee et al. 1991).

The objectives of this study were to evaluate the persistence and efficacy of lambda-cyhalothrin used as an intradomiciliary insecticide in daub huts against *An. arabiensis* and its efficacy as compared to DDT.

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MATERIALS AND METHODS

The study was carried out at 2 localities, Mamfene (27°23′S, 36°16′E), Ubombo District, and

Ndumo (26°54'S, 32°19'E), Ingwavuma District, from January 1991 to May 1991.

At Ndumo, 24 newly built daub huts were sprayed with lambda-cyhalothrin on January 9, 1991, and 6 newly built daub huts were retained as control huts. At Mamfene, 18 newly built daub huts were sprayed with lambda-cyhalothrin on January 14, 1991, and 4 newly built daub huts were retained as control huts. DDT-sprayed houses were freely available, as all houses in both areas were subjected to DDT spraying with 75% w.w. DDT powder at 2.5 g/m^2 during January 1991. Lambda-cyhalothrin packed in soluble sachets containing 62.5 g AI of Icon® 10% was used in the spraying of huts and applied at a rate of approximately 30 mg AI/m^2. All spraying was performed under field conditions as part of the existing spraying program and application rates were not verified using gas chromatography. Because of the nonstaining nature of lambda-cyhalothrin, spraying did not necessitate the removal of hut contents as is usual during the spraying of DDT. This resulted in variably increased toxic surface areas within lambda-cyhalothrin sprayed huts relative to DDT-sprayed dwellings.

Exit traps of the Muirhead-Thomson (1947) design were fitted to control, DDT-, and lambda-cyhalothrin-sprayed huts for a minimum of 4 nights per month per area and cleared before 0800 h each day. Monthly checks were carried out on the sprayed huts to ensure that homes that had been replastered, thereby covering the insecticide, were not used.

Identification of the *An. gambiae* sibling species was by isoenzyme electrophoresis (Mahon et al. 1976; Miles 1978, 1979). The origin of *An. gambiae s.l.* blood meals was determined using the Ouchterlony double diffusion technique and human and bovine antisera to whole blood.

After capture by an exit trap, the mosquitoes to be used for DDT and lambda-cyhalothrin susceptibility testing were bloodfed (if not already fed), placed in individual breeding tubes, and held in an insulated container for transfer to an insectary (27 ± 1°C, 80 ± 5% RH) where individual family broods were reared. Susceptibility tests (World Health Organization 1975) were performed using 1–4-day-old adult females.

After removal from the exit traps, mosquitoes were stored in collecting cups in an insulated container covered with damp muslin cloth. Mortality counts were done periodically until 12–16 h after collection (0800 h) and the blood meal status of both the surviving and dead mosquitoes was scored.

Contact bioassays (World Health Organization 1975) were done on the walls of both DDT- and lambda-cyhalothrin-sprayed huts and nonsprayed huts (controls) using 2–5-day-old *An. arabiensis* from a colony strain (KANB) that originated from Kanyembe, Zimbabwe (15°40'S, 30°20'E).

The classification of the blood meal status of the mosquitoes as unfed, bloodfed, and gravid was based on abdominal appearance aided by a dissecting microscope.

One-hour contact bioassays (World Health Organization 1975) were carried out in the 2 areas (Mamfene and Ndumo), using 30–70 colonized *An. arabiensis* per determination.

Families raised from 26 individually identified exit trap-caught *An. arabiensis* were tested for DDT and lambda-cyhalothrin susceptibility. These mosquitoes were exposed to 5 standard concentrations of DDT and 2 concentrations of lambda-cyhalothrin, respectively, for 1 h and the 24-h mortality noted.

The chi-square test was used to compare control, DDT-, and lambda-cyhalothrin sprayed huts with relation to the percentage of mosquito activity in the huts (where the expected cell sizes were less than 5 in the 2 × 2 case, Fisher's exact test was used). The measure of mosquito activity was the percentage of huts (control, DDT, lambda-cyhalothrin) that caught mosquitoes. A second analysis was undertaken using only those huts that showed a positive catch. A one-way analysis of variance (ANOVA) was used to compare the number of mosquitoes from control, lambda-cyhalothrin-, and DDT-sprayed huts. A third analysis compared the population index (mean number of mosquitoes per hut per night) from control, DDT-, and lambda-cyhalothrin-sprayed huts in a 2-way ANOVA and using Duncan's multiple range test.

RESULTS

Exit traps fitted to huts in the Ndumo area showed very low catch returns during February and March and captures virtually ceased thereafter. Catch returns were less than one mosquito per hut per night irrespective of hut status (control, DDT-, or lambda-cyhalothrin-sprayed). Based on control hut catches the population of *An. gambiae s.l.* at Mamfene was more than 19 times greater than that at Ndumo during February and March 1991. Because of the small population of *An. gambiae s.l.* in the Ndumo area, the data presented, unless stated otherwise, are from the Mamfene area.

Seven hundred and twenty-two exit trap-caught *An. gambiae s.l.* were identified by isoenzyme electrophoresis from both the Ndumo (n = 55) and the Mamfene (n = 667) areas. Only *An. arabiensis* was identified from Ndumo. In the Mamfene area 98.2% of identified *An. gambiae s.l.*

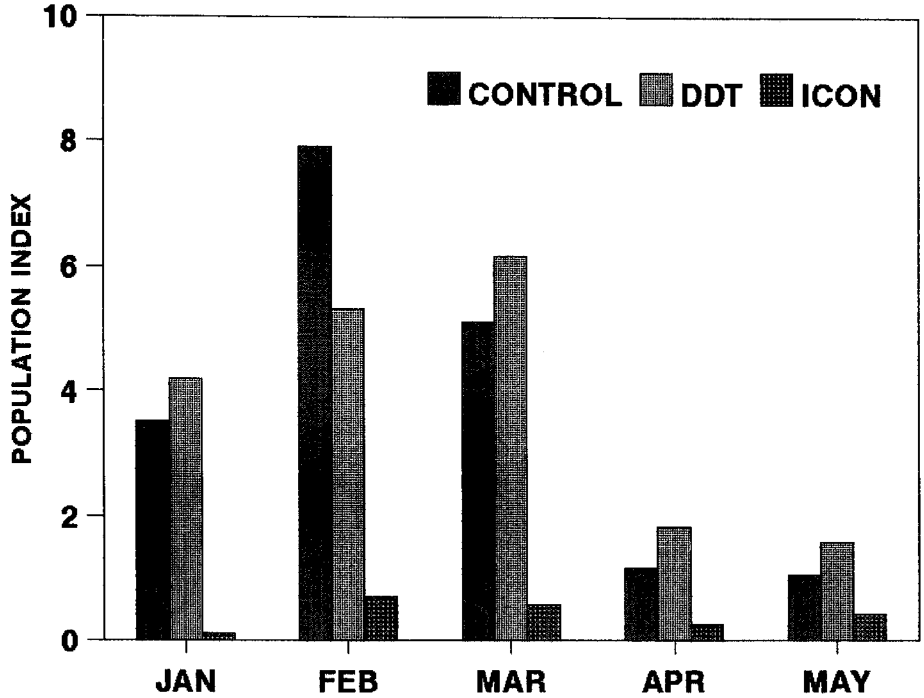

Fig. 1. Monthly population index of *Anopheles gambiae s.l.* caught leaving control, DDT-, and lambda-cyhalothrin (ICON®)-sprayed huts at Mamfene area.

were *An. arabiensis* and <1.8% were *Anopheles quadriannulatus* (Theobald). Species identifications were carried out each month from January to May, and only during January did *An. quadriannulatus* account for more than 0.5% of the *An. gambiae s.l.* identified. Of the 184 *An. arabiensis* blood meals identified from exit trap-caught mosquitoes, 97.8% were human fed.

The mean number of *An. gambiae s.l.* caught per hut per night was calculated for the 4 nights of trapping each month and used as an index of population abundance (Fig. 1). The population of *An. gambiae s.l.* was high during the months of January to March, with a peak in February, followed by a dramatic reduction in numbers during April and May. During 4 of the 5 months more mosquitoes were caught leaving DDT-sprayed huts than control huts. During all months the number caught leaving lambda-cyhalothrin-sprayed huts was markedly less than the number from both control and DDT-sprayed huts. An analysis of the mosquito activity data for all months combined found that mosquitoes were significantly less active in lambda-cyhalothrin-sprayed huts ($P < 0.0001$). For each month separately, no significant differences were found between control and DDT-sprayed huts. In all months significantly less ($P < 0.05$) activity was found in the lambda-cyhalothrin-sprayed huts than in the DDT-sprayed huts.

For the months combined, using the second analysis method, the number of mosquitoes caught leaving lambda-cyhalothrin-sprayed huts was significantly lower than the number from DDT-sprayed and control huts ($P = 0.04$). The third method of analysis found the number of mosquitoes from DDT-sprayed huts to be significantly higher than those from the lambda-cyhalothrin-sprayed huts.

The ratio of the number of *An. gambiae s.l.* caught leaving DDT-sprayed vs. lambda-cyhalothrin-sprayed huts is shown in Fig. 2. During the month of January, >39 times as many *An. gambiae s.l.* were caught leaving the DDT-sprayed as opposed to the lambda-cyhalothrin-sprayed huts. During both February and March the DDT-sprayed huts caught in excess of 10 times more *An. gambiae s.l.* than the lambda-cyhalothrin-sprayed huts. This difference between the DDT- and lambda-cyhalothrin-sprayed huts decreased during April (7.28 fold) and showed the least difference in May (3.67 fold).

Based on bioassay data, lambda-cyhalothrin sprayed in January was found to be effective 5 months later in May, with a 100% effectiveness at Mamfene and 91.7% at Ndumo. The DDT was 100% effective in both areas during May.

The greater percentage of *An. gambiae s.l.* caught leaving huts (Table 1), irrespective of hut status, were bloodfed, followed by unfeds, with the lowest number being gravid. A chi-square test showed no difference in these ratios between huts of different status ($\chi^2 = 8.48$, df = 4, $P = 0.08$).

The survival of *An. gambiae s.l.* caught leaving huts varied depending on blood meal status of the mosquitoes and depending on the insecticide status of the hut (Table 2). The percentage survival of bloodfed mosquitoes ranged from a low of 55% caught leaving the lambda-cyhalothrin-sprayed huts to 82% of those caught leaving DDT-sprayed huts. The percentage of bloodfed mosquitoes caught leaving huts was high (>60%). The survival of unfed mosquitoes was low, even from the control huts (43%). There was no significant difference in the survival of unfed mosquitoes between the huts of different status ($P > 0.05$). In respect to bloodfed mosquitoes, there was a significant difference between the control and the DDT-sprayed huts ($P = 0.006$), and between the DDT- and lambda-cyhalothrin-sprayed huts ($P < 0.001$), but not between the control and lambda-cyhalothrin-sprayed huts ($P > 0.05$). In both the DDT and the control huts there was a significant difference in the survival of bloodfed vs. unfed mosquitoes ($P < 0.002$). Dosage mortality regressions showed no DDT or lambda-cyhalothrin resistance in the population at discriminating dosages of 4.0% DDT and 0.025% lambda-cyhalothrin.

DISCUSSION

Two study sites were chosen, one in the Ndumo area of Ingwavuma District and the second at Mamfene in the Ubombo District, to optimize the chances of obtaining a population of *An. arabiensis* of a suitable size to carry out the study. Only the population at Mamfene was of a suitable size for investigation.

The use of the Miles (1979) key and nonspecific esterases (Mahon et al. 1976) for the electrophoretic identification of *An. arabiensis* from this area has been verified chromosomally (Sharp et al. 1990). Using these isoenzyme systems, 722 *An. gambiae s.l.* were identified from both the Ndumo and the Mamfene areas. All 55 specimens identified from the Ndumo area were *An. arabiensis.*

Both *An. arabiensis* and *An. quadriannulatus* were caught leaving huts at Mamfene. *Anopheles arabiensis* was, however, the dominant species (>98%), as was also found during the 1986–88 period by Sharp et al. (1990). As a consequence, the data presented are considered to reflect the behavior of *An. arabiensis.*

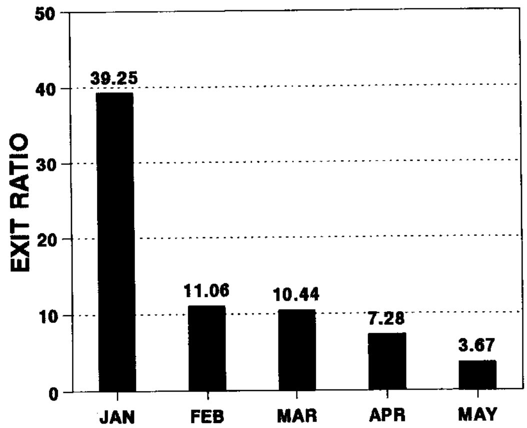

Fig. 2. Monthly ratio (lambda-cyhalothrin [ICON®]: DDT) of *Anopheles gambiae s.l.* caught leaving DDT- and lambda-cyhalothrin-sprayed huts at Mamfene area.

The fed : gravid ratios of the exit trap-caught mosquitoes from lambda-cyhalothrin-sprayed, DDT-sprayed, and control huts (7.4:1, 11.7:1, 22.5:1) were considerably higher than those found previously for *An. arabiensis* resting indoors in control huts (1.4:1–3.9:1) (Shelley 1973, Sharp et al. 1990). These higher ratios of exit trap-caught mosquitoes are in keeping with the exit trap data of Sharp et al. (1990) and are indicative of hut leaving by *An. arabiensis* after feeding. The blood meal statuses of the hut-leaving mosquitoes from control, lambda-cyhalothrin-, and DDT-sprayed huts in the present study were very similar to one another (Table 1), with the highest percentage being bloodfed, followed by unfeds, and a low number of gravids. These data compare well with those found by Sharp et al. (1990) from control huts, but the percentage of bloodfeds from both the lambda-cyhalothrin- and DDT-sprayed huts in this study were higher than that found for DDT-sprayed huts by Sharp et al. (1990). The relatively lower percentage of bloodfed mosquitoes caught leaving DDT-sprayed huts (Sharp et al. 1990) was previously interpreted as an indication of irritancy by the DDT (Muirhead-Thomson 1960), but the high percentages of bloodfeds from both the DDT- and lambda-cy-

Table 1. Number of exit traps fitted, number of *Anopheles gambiae s.l.* caught, and their blood meal status.

	Percentage			Number of *An. gambiae s.l.*	Exit traps fitted
	Bloodfed	Gravid	Unfed		
DDT	67.2	5.7	27.0	1,013	269
Control	63.2	2.8	34.0	250	66
Lambda-cyhalothrin	63.8	8.6	27.5	58	147

Table 2. Percentage survival and percentage bloodfed of *Anopheles gambiae s.l.* caught leaving control, DDT-, and lambda-cyhalothrin-sprayed huts.

Status of hut	Number		Percent bloodfed	Percent survival		
	Huts	Mosquitoes		Bloodfed	Unfed	Overall
Control	24	159	68.5	71	43	63
DDT	139	998	64.0	82	38	68
Lambda-cyhalothrin	36	105	61.0	55	49	52

halothrin-sprayed huts in this study do not substantiate this.

Sharp et al. (1990) found that 72.9% of the bloodfed *An. arabiensis* caught leaving huts were surviving and this constituted 26.2–31.5% of the exiting mosquitoes. The results of this study confirm the high survival of bloodfeds in that 82% of the bloodfed *An. arabiensis* caught leaving DDT-sprayed huts survived (Table 2). The survival of *An. arabiensis* caught leaving lambda-cyhalothrin-sprayed huts was, however, lower at 55%.

The proportion of the mosquitoes that were bloodfed and caught leaving DDT-sprayed huts (64%) was considerable higher than that found previously (26.2–31.5%). The percentage that had fed on humans (human blood index = 97.8%) and caught leaving huts was far higher than that found in a previous study in the area (human blood index = 66.8%) (Sharp and le Sueur 1991). Of 184 blood meals analyzed from *An. arabiensis,* 49.4% were collected from homesteads that had a cattle kraal within 20 m. This is in keeping with the finding of Sharp and le Sueur (1991) that the presence of a cattle kraal close to the homestead did not appear to affect the human blood index of exit trap-caught mosquitoes.

The bioassay results from both DDT- and lambda-cyhalothrin-sprayed huts indicate that indoor resting on the inner surfaces of the huts would not have been possible for the duration of the study period. This conclusion conforms with the findings of Sharp et al. (1990) that indoor resting/survival was not occurring in DDT-sprayed huts.

Dose mortality curves showed no increased vigor tolerance or physiological resistance to DDT or lambda-cyhalothrin in the wild *An. arabiensis* relative to WHO standards, indicating that limited contact had occurred by the exit trap-caught *An. arabiensis* with the residual insecticides.

Control of *An. arabiensis* as measured by the mean number of *An. arabiensis* caught leaving control, DDT-, and lambda-cyhalothrin-sprayed huts was significantly better in the lambda-cyhalothrin-sprayed huts than in the DDT-sprayed huts. Over the 5-month study period (January–May), 9.5 times more *An. arabiensis* were caught leaving DDT-sprayed huts than lambda-cyhalothrin-sprayed huts. Control in lambda-cyhalothrin-sprayed huts exceeded that in DDT-sprayed huts during each of the 5 months of the study (Fig. 1). During January lambda-cyhalothrin showed <39 times better control than DDT. The exit traps were fitted in January 2 wk after spraying with lambda-cyhalothrin and this marked difference may in part have been due to a fumigant effect (Fig. 2) or extreme toxicity of the insecticide resulting in only very limited contact being necessary.

The monthly population relative abundance, determined as the mean number of *An. arabiensis* caught leaving per hut per night, was highest during February and March and showed a dramatic reduction during April and May (Fig. 1). Malaria transmission is seasonal in the endemic malaria area of northern Natal/KwaZulu with more than 70% of reported cases occurring from January to May (Sharp et al. 1988). Bioassays on hut walls showed lambda-cyhalothrin to be effective in killing *An. arabiensis* for the duration of the study period (January–May) in both the Mamfene and the Ndumo area.

A high level of DDT resistance exists in the bedbug *Cimex lectularius* Linn. in northern Natal/KwaZulu allowing infestations to thrive in the DDT-sprayed huts (Newberry and Jansen 1986). These high infestations lead the residents to replaster the walls of the huts to cover bed bug harborages, thereby effectively covering the DDT and reducing vector control (Newberry et al. 1987, Sharp et al. 1990). Laboratory studies on lambda-cyhalothrin have shown this insecticide to be highly effective in killing bedbugs (le Sueur et al. 1994) and its use would reduce the need for replastering.

The laboratory study by le Sueur et al. (1993) showed a markedly reduced residual effect of lambda-cyhalothrin on mud substrates from the Tetepan and Mfekayi areas of KwaZulu. Organophosphates and carbamates also showed reduced effectiveness in the latter area (K. Newberry, personal communication). These data emphasize the need for area-specific investigations when considering alternative insecticides that are less stable than the traditionally used organochlorines.

Ongoing investigations of insecticides alternative to DDT in which the surface area of hut contents is taken into account, indicate that mosquito control in dwellings with many unsprayed surfaces (furnishings) is reduced, probably as a result of alternative nontoxic mosquito resting sites. This creates a stong argument for the use of insecticides that can be sprayed acceptably on furnishings. The marked improvement in vector control achieved by lambda-cyhalothrin in the present paper must be partially attributable to increased sprayed surface area relative to DDT-sprayed huts.

It must be concluded that the intradomiciliary spraying of the synthetic pyrethroid lambda-cyhalothrin was highly effective in the control of *An. arabiensis* at Mamfene and should be further tested in a large-scale control trial in an effort to demonstrate comparative disease reduction relative to DDT. Laboratory trials are currently in progress to optimize dosage rates suitable for mud substrates.

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REFERENCES CITED

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

Freese, J. A., M. B. Markus and J. Golenser. 1991. *In vitro* sensitivity of southern African reference isolates of *Plasmodium falciparum* to chloroquine and pyrimethamine. Bull. W.H.O. 69:707–712.

Freese, J. A., B. L. Sharp, S. M. Ngxongo and M. B. Markus. 1988. *In vitro* confirmation of chloroquine-resistant *Plasmodium falciparum* malaria in KwaZulu. S. Afr. Med. J. 74:576–578.

le Sueur, D. and B. L. Sharp. 1988. The breeding requirements of three members of the *Anopheles gambiae* Giles complex (Diptera: Culicidae) in the endemic malaria area of Natal, South Africa. Bull. Entomol. Res. 78:549–560.

le Sueur, D., B. L. Sharp, C. Fraser and S. Ngxongo. 1993. Assessment of the residual efficacy of lambda-cyhalothrin 1. A laboratory study using *Anopheles arabiensis* and *Cimex lectularius,* on treated daub wall substrates from Natal, South Africa. J. Am. Mosq. Control Assoc. 9:408–413.

Mahon, R. J., C. A. Green and R. H. Hunt. 1976. Diagnostic allozymes for routine identification of adults of the *Anopheles gambiae* complex (Diptera: Culicidae). Bull. Entomol. Res. 66:25–31.

Miles, S. J. 1978. Enzyme variation in the *Anopheles gambiae* Giles group of species (Diptera: Culicidae). Bull. Entomol. Res. 68:85–96.

Miles, S. J. 1979. A biochemical key to adult members of the *Anopheles gambiae* group of species (Diptera: Culicidae). J. Med. Entomol. 15:297–299.

Miller, J. E., S. W. Lindsay and J. R. M. Armstrong. 1991. Experimental hut trials of bednets impregnated with synthetic pyrethroid of organophosphate insecticides for mosquito control in The Gambia. Med. Vet. Entomol. 5:465–476.

Muirhead-Thomson, R. C. 1947. The effects of house spraying with pyrethrum and with DDT on *Anopheles gambiae* and *A. melas* in West Africa. Bull. Entomol. Res. 38:449–464.

Muirhead-Thomson, R. C. 1960. The significance of irritability, behaviouristic avoidance and allied phenomena in malaria eradication. Bull. W.H.O. 22: 721–734.

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

Newberry, K., E. J. Jansen and A. G. Quann. 1987. Bedbug infestation and intradomiciliary spraying of residual insecticides in KwaZulu, South Africa. S. Afr. J. Sci. 80:377.

Park Ross, G. A. 1936. Insecticide as a major measure in the control of malaria, being an account of the methods and organisations put into force in Natal and Zululand during the past six years. Q. Bull. Health League Nations 5:114–133.

Roberts, R. H., P. M. Stark and M. N. Meisch. 1984. Aerosol evaluation of selected adulticides against colonized and field strains of mosquitoes. Mosq. News 44:528–533.

Schaefer, C. H., E. F. Dupras, Jr. and F. S. Mulligan III. 1990. Etoc® and lambdacyhalothrin: new pyrethroid mosquito adulticides. J. Am. Mosq. Control Assoc. 6:621–624.

Schapira, A. 1990. The resistance of falciparum malaria in Africa to 4-aminoquinolines and antifolates. Kaleidoscope Ltd., Copenhagen.

Sharp, B. L. and D. le Sueur. 1991. Behavioural traits of *An. arabiensis* (Diptera: Culicidae) populations in Natal, South Africa. Bull. Entomol. Res. 81:107–110.

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. 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.

Shelley, A. J. 1973. Observations on the behaviour of *Anopheles gambiae* sp. B in Kambole village in the Zambezi Valley, Zambia. Ann. Trop. Med. Parasitol. 67:237–248.

Sulaiman, S., B. Omar, J. Jeffery and V. Busparani. 1991. Evaluation of pyrethroids lambda-cyhalothrin, deltamethrin and permethrin against *Aedes albopictus* in the laboratory. J. Am. Mosq. Control Assoc. 7:322–323.

Weathersbee III, A. A., M. V. Meisch, A. Inman and D. A. Dame. 1991. Activity of lambda-cyhalothrin applied as an ultralow volume ground treatment against *Anopheles quadrimaculatus* adults. J. Am. Mosq. Control Assoc. 7:238–241.

White, G. B. 1974. *Anopheles gambiae* complex and disease transmission in Africa. Trans. R. Soc. Trop. Med. Hyg. 68:278–301.

World Health Organization. 1975. Manual on practical entomology in malaria. World Health Organization, Geneva.

World Health Organization. 1990a. Cyhalothrin. International Programme on Chemical Safety, Environmental Health Criteria 99.

World Health Organization. 1990b. Cyhalothrin and lambda-cyhalothrin. International Programme of Chemical Safety, Health and Safety Guide No. 38.

World Health Organization. 1991. Interim specifications for lambdacyhalothrin: technical, water-dispersible powder and emulsifiable concentrate. VBC/IS/91.23.