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Review Article

Role of Pyrethroid-elicited Mosquito Behaviour in Control Programmes

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I N F O

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A B S T R A C T

This review study envisages the role of insecticide-elicited mosquito behaviour for disease eradication programmes. Changes in behaviour due to insecticides may, at times, be of more practical importance than the actual lethal effect of the insecticide, especially if these changes help to disrupt the contact between man and mosquito. Two important aspects of mosquito behaviour, either repellency or irritability and biting patterns in response to insecticide exposure have been taken into consideration. This paper throws light on the significance of two synthetic pyrethroids, permethrin and deltamethrin, when impregnated into mosquito nets for self-protection and vector control. The determination of any changes with respect to behaviour of mosquitoes, before and after the introduction of bed nets is reflected in the potential of the mosquitoes to transmit diseases and can be of great epidemiological significance in mosquito abatement programmes.

Keywords: Behaviour, Repellency, Irritability, Biting, Insecticide-treated nets(ITNs), Pyrethroids, Mosquito Control

Introduction

Mosquitoes transmit an ever-lengthening list of human diseases resulting in a major crisis in public health management. Past experiences have convincingly demonstrated that mosquitoes have the ability to elude the chemical weapon as they have developed resistance to most of the synthetic insecticides. A survey conducted in 1985 showed that a total of 113 vector species of mosquitoes are known to resist insecticides belonging to the three major groups of insecticides.[1] In the present scenario with an almost depleted pesticide armoury, the fourth group of insecticides called pyrethroids still have the biological potency to be considered as promising alternative insecticides in combating mosquito menace, though reports of the development of pyrethroid resistance are not unknown. Besides the development of resistance, the selection pressures exerted by insecticide use also lead to a change in the behaviour of mosquitoes, albeit slowly.[2] Though there have been extensive studies pertaining to insecticide resistance in mosquitoes, the evolution of mosquito behaviour is little known.[3]

Pyrethroid insecticides are the synthetic analogues of naturally occurring pyrethrins, which are extracted from the flowers of *Chrysanthemum* species. They are considered to be successful insecticides due to factors such as i) they have unprecedented levels of pest control, ii) their rates of use are low, iii) they are extremely cost competitive,

iv) they present very low hazards to users as compared to other pesticides and v) they do not cause major adverse environmental impact.[4] Many synthetic pyrethroids are being considered as candidate chemicals in mosquito abatement programmes all over the world. Among these,

deltamethrin & permethrin are considered to be the most effective insecticides as they are shown to have superior insecticidal potency to many organochlorine, organophosphate & carbamate insecticides coupled with their low toxicity to mammals & are thus being used in malaria control programmes.

Behavioural changes due to Pyrethroids

Many species of mosquitoes are secondary vectors of diseases. Their exact vectorial potential is unknown because of the lack of information concerning their behaviour. Mattingly, in as early as 1962, highlighted the significance of behaviour in combating mosquito-borne diseases.[5] Behaviour has also been useful in controlling many agricultural pests.[6]

Repellence & Irritibility

The control of vectors by insecticides depends on the mosquitoes entering houses and resting on treated surfaces. Two kinds of behaviour may be observed a) refractory types of natural behaviour (exophily, exophagy), or (b) refractory behaviour due to the presence of insecticides (avoidance) which can be due to repellency (when the insecticide can be perceived from a distance) or irritability (when the insecticide can be perceived on touch).[7] Irritability/ Irritancy is a phenomenon when mosquitoes fly off from insecticide treated surfaces when coming in physical contact with them, while repellency is when mosquitoes fly off from the environment even before coming in contact with the insecticide treated surface.[8]

Pyrethroids are also known to affect the behaviour of mosquitoes apparently by causing either repellency or irritability which induces flight and enables them to escape from the toxic residue. This behavioural attribute is of great significance during pyrethroid use in mosquito abatement programmes. The beginning of this response prior to the consumption of a lethal dose would impact the advantage of an insecticide along with delay in the development of physiological resistance due to less or no contact with the insecticide. The development of behavioural resistance occurs when the frequency of insecticide avoidance behaviour in a population is increased as a result of insecticide serving as a selective agent.[9] Since the last few decades, behavioural avoidance responses have been documented in both laboratory and field populations of mosquitoes. In general, pronounced contact irritancy rather than spatial repellency to pyrethroids is noticed in mosquitoes. It has been shown by Hougard et al that resistant strains of *Anopheles gambiae* and *Culex quinquefasciatus* demonstrate different levels of irritability to pyrethroids.[10] Cooseman and Sales have shown that in Upper Volta, deltamethrin applied@25mg a.i.m^{-2} caused irritation in *An.gambiae & An.funestes*, resulting in exophily, thus reducing man-mosquito contact and also reducing the number of mosquitoes entering the houses.[11] Deltamethrin was also reported to cause exodus of mosquitoes from treated houses in Nigeria and when applied @ 50 mg a.i.m^{-2}, it satisfactorily reduced the indoor resting and biting densities of *An.gambiae and An.funestus* and eliminated infective mosquitoes.[12,13]Also, deltamethrin EC and suspension concentrate applied @ 15 mg a.i.m^{-2} as deposits on interior surfaces of houses in a village in Kenya to control *An.gambiae* and *An.funestus* reduced the number of adults resting in the houses as effectively as fenitrothion applied @2000 mg a.i.$^{m-2}$.[14] However, Vatandoost and Borhani reported that out of the different insecticides tested, permethrin had the maximum irritant effect on *An.stephensi and An.dthali* with 0.42 -+0.08 take offs /min/ adult.[15] Recent studies done by Dhiman et al., demonstrated strong excite-repellency response elicited by three major vectors of mosquitoes *Aedes aegypti, Anopheles stephensi* and *Culex quinquefasciatus* to synthetic pyrethroid and organophosphorus based slow release insecticidal formulation.[16]

Biting Behaviour

Haddow has emphasised the fact that the biting cycle is another factor governing the behaviour of mosquitoes. These biting periodicities are governed by an endogenous "circadian clock".[17] Understanding the biting rhythms of mosquitoes is important to determine the time period of dissemination of mosquito-borne diseases as well as to program the sampling of the female mosquitoes with the aid of baits. These rhythms seen in the field are quite difficult to elucidate because of various abiotic factors of the environment influencing them as shown by Seaton and Lumsden[18] Lumsden[19] and Parker.[20,21] Studies concerning biting habit has been done in the laboratory in different species of mosquitoes. Suleman et al., had attempted to study the biting behaviour of *Culex quinquefasciatus* under controlled laboratory conditions.[22] However , a lot of recent studies have now been done in the field as well by Cooke et al.,[23] Milali et al.[24] and Sherrard-Smith et al.,[25] on *Anopheles* in reference to control of malaria.

It is clear that different species exhibit variation in the time of biting the host, either during the day or night and conform to around the same routine. In *Ae.aegypti*, a peak in biting behaviour has been observed in the morning during dry season and in the afternoon at the end of the rainy season by Atmosoedjono et al.[26] However, the biting cycle of *Cx.quinquefasciatus* is nocturnally periodic and preferably endophilic in character. Sucharit et al. and Suleman et al., found a trimodal biting cycle in *Cx.quinquefasciatus*, with a peak at midnight and two crepuscular peaks.[27,22] The biting rhythm of this species of mosquito is periodic (i.e. from 18.00 hrs to 06.00 hrs) in Pondicherry and it is believed that

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this periodicity is of "Harmonic wave type".[28] Reisen and Aslam Khan reported that usually *An.stephensi* exhibited unimodal biting rhythm with maximum biting taking place in the evening in winters and at night during summers.[29]

Vector Control by Pyrethroid treated Nets

Though pyrethroids are effective insecticides as such, it appears more economic to target them by applying them to fabrics such as bednets, wearable clothes, screens and curtains which the mosquitoes are likely to contact.[30] Vector control methods through the use of bednets have received considerable attention since they are being recommended by WHO.[31] They offer a simple and effective means of preventing bites from infective and non-infective mosquitoes, even when torn and can be used to complement a control programme by helping to reduce disease transmission.[32] The vector population have a tendency to feed on humans (anthrophagy), inside houses (endophagy) and resting indoors (endophily) after feeding; these behavioural characteristics are utilised during bed net protection from mosquitoes.[33] The protective effect of mosquito nets can be further enhanced and hence the "time to first bite" may be prolonged by treatment with a repellent or with a killing insecticide. For quite sometime now, interest has arisen to control the diseases transmitted by mosquitoes by using pyrethroid-impregnated bed nets in order to prevent man-mosquito contact. The efficacy of these mosquito nets, called Insecticide Treated Nets (ITNs)/ Long lasting Insecticidal nets (LLINs) has thus improved significantly with the advent of quick-acting synthetic pyrethroids. Use of such bed nets have added advantage in minimising selection pressure for physiological resistance to pyrethroids.[9] Photostable pyrethroids developed as analogues of natural pyrethrum have proved to be highly successful in laboratory tests of impregnating of bednetting.[34] The two pyrethroids which are most commonly used for bed net impregnation are permethrin and deltamethrin.[35,36,37,38] They are classified by WHO as moderately hazardous, have rapid insecticidal effect and low volatility with consequent long persistence on netting and lack of odour.[39] The EC formulations are preferred for mosquito net treatments because it provides better adhesion to the net fibre and does not leave a powdery residue.[40] Following successful application of tsetse fly traps impregnated with deltamethrin, Darriet et al studied the effect of mosquito nets impregnated with permethrin on mosquitoes entering experimental huts.[41] In Mali, Ranque et al., were the first to carry out a village scale trial using impregnated nets.[42] Other research workers followed suit in China,[43] Malaysia,[44,45] United Republic of Tanzania,[46] Papua New Guinea,[47] The Solomon Islands[48] and Suriname.[49] A higher rate of exophily of *An.gambiae* was noted in rooms containing permethrin-treated nets in The Gambia.[50] A report by WHO showed that bednets impregnated with permethrin at 0.5 g/m^2 & deltamethrin at 25 mg/ m^2 were effective for at least 6 months.[51] In a field trial done in Sundargarh district of Orissa, treatment of a 10 m^2 mosquito net with deltamethrin deposit of 25 mg/m^2 showed 100% mortality of *An.fluviatilis* even after 7 months, whereas *An.culicifacies* showed a decline from 100% to 71% mortality over this period after which the nets were re-treated. Insecticide-treated nets are being continuously used in sub-Saharan Africa since the year 2000 for malaria control.[53] Moiroux and his coworkers found evidence that two ITNs advocated by WHO are effective against *An.gambiae* s.l. even after washing them multiple times. [54] Darriet et al., reported that bednets treated with permethrin and deltamethrin remained effective even in areas where *An.gambiae* s.s. was resistant to these insecticides leading to behavioural changes like reduced repellency.[55] Similarly, Kawada et al found significant increase in the frequency of take offs from a pyrethroid treated surface in pyrethroid susceptible *An.gambiae* s.s.in comparison to its wild , resistant counterpart.[56] Recent studies conducted by Zhou et al., indicate that pyrethroid resistant and susceptible *An.gambiae* behaved very differently when they encountered LLINs vs. untreated nets. Overall, pyrethroid-resistant mosquitoes showed less activities compared to the susceptible mosquitoes in the presence of treated nets.[57] Thus, irritancy/ repelling property of pyrethroids and the biting behaviour of mosquitoes are some of the important factors influencing the extent to which an impregnated mosquito net is successful in protecting against mosquito bites or in reducing disease incidence or morbidity.

Mbogo et al., reported that usage of LLINs in Kenya resulted in biting rate of *An.gambiae* decreasing from 95 to 34 bites/ night while the proportion of these mosquitoes feeding outside increased from 1.2% to 30.3%.[58] Thus continued use of LLINs by a large population, often leads to " Mass Community effect" in which there is drastic thinning of vector population.[59] However, following the introduction of impregnated bednets into a village in coastal New Guinea, the biting activity of some members of the genus Anopheles shifted to the earlier part of the night from the middle of the night.[47] It has also been seen that in those areas where ITNs or indoor residual spraying (IRS) is routinely followed, selection may favour change in biting time of mosquitoes to early evening or late morning; these are times when bed net protection to the host is missing.[60] Such behavioural shift from night to evening biting has been observed in *An.farauti* on The Solomon Islands[61] and Papua New Guinea,[62] *An.funestes* in Tanzania[63] and both *An.funestes* & *An arabiensis* in Kenya.[64] Thus behavioural changes, following continued usage of nets may involve a change in feeding time along with a switch towards

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exophagy.

Conclusion

The epidemiological importance of avoidance behaviour in controlling the disease vectors can be ascertained by using insecticides in sub lethal doses which besides eliciting a behavioural response, also helps to prevent or delay the resistance in insect population.[65] Behavioural changes involving exophily and exophagy is likely to reduce exposure of mosquitoes to insecticides inside the houses, thereby decreasing the selection pressure for physiological resistance.[66] Thus both physiological and behavioural adaptations of mosquitoes to insecticides need to be considered for determining the feasibility of indoor-based treatments.[67] However, interventions targeting outdoor resting and feeding mosquitoes also becomes necessary in the light of behavioural avoidance involving enhanced exophily being observed in mosquitoes.[68] Therefore, importance of monitoring the behavioural changes, both indoors and outdoors, must be stressed upon for effective implementation of the vector control programme.

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