Review Article

Journal of Biological Research

& Biotechnology

Bio-Research Vol. 21 No.1; pp. 1789-1804 (2023). ISSN (print):1596-7409; eISSN (online):2705-3822

Why the World Health Organization should reconsider long lasting insecticide nets (LLIN) and indoor residual spraying (IRS) in primary mosquito/malaria control in favour of house screening

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Abstract

Mosquitoes spread malaria parasites in closed/open environment when they feed endophagously/ exophagously. Indoor residual spraying (IRS) and long-lasting insecticide nets (LLIN) are control measures adopted by the World Health Organization (WHO) that have not led to malaria elimination. Delay in defeating mosquito/malaria is attributed to WHO's espousal of the last line of intervention that at-risk persons often ignore. Mosquito control methods will have to change if we must make progress in this direction. This paper shows that mosquitoes must survive four barriers before successfully attacking a host in a bed net. Correspondingly, indoor hosts have four levels of defenses where mosquitoes could be challenged albeit with increasing impediments. The first line of defense consists of net-screened windows, doors and eaves which circumscribe houses-outdoor environment. At-risk persons do not resist/refuse net-screening the openings in their houses. The last defensive intervention which most at-risk persons often resist most is sleeping in bed nets. The Achilles heel of IRS and LLIN include but not limited to vector resistance to insecticides, discomfort to beneficiaries, harm to non-target organisms, inequity in supply and distribution of control materials. List of advantages attributable to LLIN use has only 7 items whereas disadvantages have 37 items. House screening has better appeal to control mosquito/malaria indoors. The WHO should replace LLIN and IRS with house screening as the primary control method. Governments in endemic regions must use legislation to drive house screening especially with the s/o channel/grip devices that is accessible, cheap, effective and sustainable.

Keywords: WHO, IRS, LLIN, mosquito control, malaria control, house screening.

Received October 28,2022; **Revised** January 13, 2023; **Accepted** January 18, 2023

https://dx.doi.org/10.4314/br.v21i1.3
Journal Homepage: http://www.bioresearch.com.ng.
Publisher*: Faculty of Biological Sciences, University of Nigeria, Nsukka, Nigeria.*

INTRODUCTION

According to the World Health Organization (WHO) (2021), The WHO African Region had about 228 million cases of malaria in 2020, which was 95% of global figure. Deaths globally then was put at 602 000 out of which 96% was in Sub Sahara Africa (SSA) with Nigeria accounting for 27%. To prevent malaria infections, integrated control methods have been recommended for endemic areas while antimalarial drugs are the choice for non-endemic regions (Shariat-Madar *et al.*, 2018). Unfortunately, mosquito/malaria control is like a recurring decimal in SSA where debility and casualty tolls resulting therefrom keep the region underdeveloped and in poverty (Ugwu, 2021). Every year, affected governments recycle donor dependent mosquito/malaria interventions that they had previously (Abdullahi *et al.*, 2019). The WHO adopts two main tools to deal with malaria vectors. The first is insecticide treated nets (ITN) which consist of the conventional ones and the long-lasting insecticide (LLIN). They are mainly directed at indoor-biting vectors that are responsible for roughly 80% malaria infection (Bhatt *et al.*, 2015; Aïzoun *et al.* 2021). The second insecticide dependent intervention recommended by the WHO is indoor residual spraying (IRS) (Okumu and Moore, 2011).

LLIN and IRS, according to Birkholtz *et al.* (2012), are not sufficient to achieve malaria elimination in Africa and that where agriculture mediated vector resistance prevail, they are ineffective mosquito/malaria control. In fact, Msellemu *et al.* (2017) paradoxically found that malaria infection prevalence in urban Dar es Salaam was higher amongst bed net users than in non-users. LLIN uptake remains poor (Von Seidlein *et al.*, 2012). Trusting *et al.* (2017) noted that living in improved houses is equivalent to use of ITN bed net and that house improvement has the potential to enhance malaria elimination and forestall its recycling while Ugwu (2019) observed that the WHO is consistent in blacking out house screening among control strategies she promotes. In his opinion, delay in defeating mosquito/malaria is attributed to WHO's adoption of the last line of defense that is riddled with most *resistance* (Ugwu, 2019) and inherent biological property of the pathogen. However, the question remains why WHO could not consider other outdoor tools for complementary general use (Aïzoun *et al.* 2021) and looks the other way when permanent and sustainable measures like house screening is offered as alternatives to deal with these intractable problems caused by mosquito/malaria? Containing malaria in SSA will fail if the environmental factors that create opportunities for mosquito breeding are not adequately addressed (Abdullahi *et al.*, 2019). There is overwhelming need to review the current approach to mosquito/malaria control if SSA must attain or push beyond malaria elimination. This paper discusses insecticide treated nets and indoor residual spraying after identifying barriers mosquitoes must break and lines of defense that man currently employs. Some inherent impedance that is responsible for the poor performances of IRS and LLIN are presented to sensitize WHO to the reality of their unsustainability as they are interventions that have the most resistance. The global *primum mobile* is seriously urged to consider leaving LLIN and IRS to affected individuals to handle themselves in favour of shifting their anti-mosquito activities to environmental management particularly by adoption of house screening because of its effectiveness as *first line of defense with the least resistance*.

REVIEW METHODOLOGY

Relevant literature accessed via the internet formed the major source of information in this work. Google Scholar search engine was used to obtain relevant articles by using the following key words: WHO, IRS, LLIN, mosquito control, malaria control, house screening. Searches were limited to recent publications (with few exceptions) not earlier that the year 2010 to sense knowledge gap and to keep abreast with new developments. Only peer reviewed articles from reputable journals were downloaded for study while documents excluded were those that had no relevant in-depth contents. Those downloads were also explored to show how mosquitoes strived to obtain blood meals indoors and the hurdles they face. Vectors engaged in this quest were hence considered to be on the *offensive*. Observed alongside were the responses of man at each barrier level to identify their inherent peculiarities and weak points that make them unsuccessful as sustainable tools for mosquito/malaria control. In this context, host indoors were to be perceived as being on the *defensive*. Further, owing to the fluid nature of open environment of the vectors, it would be assumed to be a homogenous one and that those barriers of biological origin such mosquito predators did not count.

STUDY FINDINGS AND DISCUSSION

Barriers mosquitoes must break if it must assail the host

Mosquitoes as malaria vectors spend their early lives in aquatic environment and later mature as adults in terrestrial milieus. Both immature and mature forms are seen in open environment that constitute their natural or artificial habitats. Pathogenic mosquitoes are mostly in tropical regions and may be found anywhere there is warmth and access to stagnant water, vegetation, physical features that embody such places as mashes, ponds, hoof marks, refuse dumps, stagnant water-logged gutters, old tyres, etc. Thus, any ecology akin to that of SAA will support mosquitoes to flourish. Within the open environment are man-made houses that humans and animals inhabit. Humans emit volatile organic compounds as a result of intrinsic metabolism and from his interactions with microbes around him which undergo chemical changes like ozone-initiated reactions that result in a range of new products that may impact on air quality beyond those discharged from expired air (Beko *et al.*, 2022). Carbon dioxide is a principal component of expired air that is attractive to mosquitoes (Jerry *et al.*, 2017). Mosquitoes use these volatiles to gain entry into houses through external gaps on buildings such as vents, doors, windows, broken walls and eaves which exude into the open environment (Kaindosa *et al.*, 2018). Homes in malarious areas are still traditionally designed to be permissive to mosquito entry (Jawara *et al.*, 2018). To transmit malaria to new host, infective parasites in the mosquitoes are injected to new host when they blood-feed. Human infections occur mainly in children who are prone to malaria more than adults by a ratio of 2:1 (Echodu *et al.*, 2021).

Our hypothetic prospective mosquito must leave the open environment to penetrate huts or houses to obtain blood meal from hosts within. Luckily for female mosquitoes, people still live in traditional houses (Jawara *et al.*, 2018) where eaves are agape, windows are unscreened and gaps on doors/walls abound (Kaindosa *et al.*, 2018) as external house boundary a prospective mosquito must penetrate to exit the open environment (Figure 1).

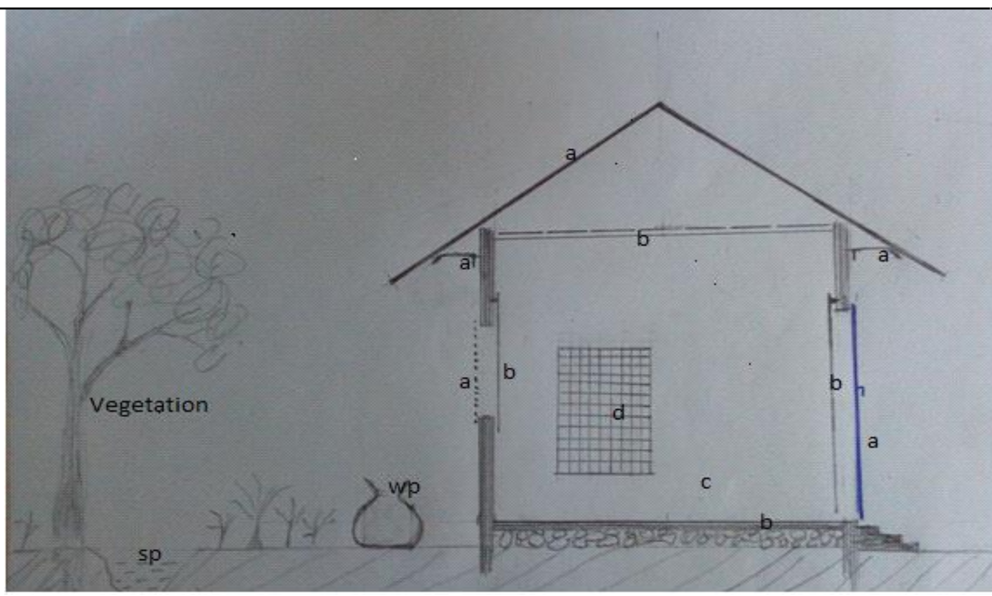

Figure 1: Illustration of open and indoor environments. The barriers that an endophilic/endophagous mosquito would break in an insect proof house are: a – external perimeter and primary barrier of a room consisting of window net, eaves, roof, door; b - internal perimeter and secondary barrier of the room including window curtain, door curtain or uncovered wall; c – is space surrounding the bed space and the tertiary barrier; d – is the bed space, the quaternary barrier and the last obstacle a mosquito must overcome to reach a host within. The environment outside the house shows other potential breeding mosquito habitats: wp - water pot; sp – small pond; vegetation includes trees with hollows, plantain, cocoa yam, grasses. etc.

The space within a room, unlike the open environment, could be sharply delineated into the following – the interior boundary which is composed of the four/circular wall, the floor and the ceiling/inside-roof and the space enclosed. Where another enclosure such as a bed net is created, such a mosquito will still have to contend with additional barrier (Figure 1). So, to reach a person sleeping indoor in a bed net, mosquitoes must break these four barriers – primary, secondary, tertiary and quaternary barriers sequentially. If a host has no protective clothing out-door, there is no barrier at all to the vector as it can just land on the host's skin and commence haemophagy.

It follows that intervention/defensive measures can also be categorized into four. Table 1 shows where intervention measures currently used against haemophagous mosquitoes apply in the four categories. All defensive activities embarked upon in the first category are referred to as environmental management of mosquitoes (EMM) (Table 1). According to WHO (2019) environmental management of water bodies like altering natural and man-made breeding mosquito habitats fall into the following categories: a) habitat modification that involve making a stable change in the environment like filling a water body such as lake and thereby recovering the land; b) habitat manipulation which will be repeated as the occasion demands such as draining stagnant water; c) larviciding, that involve use of insecticides from chemical or biological origin to get rid of immature mosquito forms breeding in water; and d) biological control, that involve the use of natural enemies of mosquitoes such as the nymphs/adult dragon flies.

Table 1: Common anti-mosquito strategies showing defense categories and where they are applied (land filling, drainage, etc. excluded).

Anti-mosquito strategy	Defenses				References
	Out-door	In-door			
	Primary	Secondary	Tertiary	Quaternary	
Larval source management:					
Larvicides	+	-	-	-	Kilma, 2009
Gambusia and Tilapia fish	+	-	-	-	Kilma, 2009
Bacillus thuringiensis spore	+	-	-	-	Kilma, 2009
Adulticides sprays:					
Eaves screen	+	-	-	-	Mmbando *et al.*, 2018
Window net screen*	+[c]	+[b]	-	+[d]	Anaele *et al.*, 2021; Ahorlu *et al.*, 2019.
Door screen/ Curtain	+	-	-	-	Lorono-Pino *et al.*, 2018; Jawara *et al.*, 2018.
IRS	+	+	-	-	Garcia *et al.*, 2022
Spatial	+	-	+		Mmbando *et al.*, 2018; Sayono *et al.*, 2019.
Indoor curtain	+	+	-	-	Lorono-Pino *et al.*, 2018; Jawara *et al.*, 2018
Insecticide-Treated durable wall lining (ITWL)	-	+	-	-	Messenger and Rowland (2017)
Electronic racket		+			Aïzoun *et al.* 2021
Baites	+		+		Jerry *et al.*, 2017

Notes: +, where applied; -, where not applied; * include non insecticide or insecticide treated nets with or without binding agents. [C]: examples include window, eaves door screen. [b]: example include in-door window screen and treated net hung on walls; d example is bed net treated or untreated.

The first line of defense

All the defensive activities of man within the open environment are the focus of primary mosquito control. This is where mosquitoes are nurtured until they are fit to forage or obtain blood for breeding. Contending with mosquitoes at their early stages of development are effective because they are physically unprotected, behaviourally incapacitated, immunologically immature, among other short-comings that make them vulnerable to deleterious strategies applied by man to neutralize them. The perimeter of open environment is delimited by houses and other structures where man and domestic animals stay. Doors, windows, etc. (Fig. 1) are part of this boundary. House entry by mosquitoes could be reduced by up to 77 % with screened doors which do not alter indoor climate of houses (Jawara *et al.*, 2018). Hessian transfuthrin ribbons appear simple to make and use; they are cheap, scalable and can be useful for low-income earners. Partly covered eaves had been reported to reduce indoor/outdoor bites by > 99% (Mmbando *et al.* 2018).

Governments, NGOs, etc. can exert themselves at the primary level exclusively because: firstly, the capital outlay of such projects far exceeds the capacity of private individuals who are already impoverished as a result of the activities of both vector and parasites so cannot afford the machinery and expertise required; secondly, it has become the norm for governments to provide amenities which serve all concerned and which the people indirectly pay for through their taxes. Individuals cannot embark on drainages through a community, for instance, because his neighbours might advance parochial motives and frustrate such projects. The third reason is that donors and NGOs do have accords with governments and can easily procure rights and privileges necessary for such projects (Ugwu, 2021). Fourthly, results of interventions at this level will engender fast, effective, desirable and measurable outcome that will offer immediate and lasting relief to affected persons because of reasons already alluded to. Fifthly, intervention should be envisioned to outlast the present generation: the MacGregor Canal, Lagos is still effective and was built *circa* 1898 (Ugwu, 2021). Lastly, intervention measures at this level are not easily compromised because such measures cannot be hidden and can be easily scrutinized. Any underhand business will likely provoke public outrage. Governments can, in addition, wield her cohesive power using legal instruments that she could enact: beneficial projects can be placed anywhere across private properties without hindrance by a government whereas such control measures are impossible by individuals. That is, there is the tendency of one to refuse, delay and subvert implementation of anti mosquito/malaria programs which is referred to here as *resistance*. Interventions by governments/donors/NGOs at this primary level will be very successful because, overall, there would be little or no resistance to a government program or promulgation because of the dire consequences of doing so. Government could enforce house screening: by exemplary leadership such as ensuring that all government buildings are, *ipso facto*, mosquito-roof; by monitoring private houses – home-owners cannot circumvent this regulation because screened homes are readily verifiable. With the development of novel hoisting channels (Ugwu, 2019) house screening has become simplified, accessible, affordable, effective and sustainable. Where houses are insect proof, blood feeding by mosquitoes can be prevented entirely. Okumu (2020) argued that the use of intact long-lasting untreated nets (LLUN) can provide near 100% prevention of blood feeding from humans lying within. Moreover, all window screening can now be done from the convenience and safety of rooms (Ugwu, 2019). House screening is scalable and it is also easy to isolate screened and unscreened homes. Directing donor and government subventions to house modifications could lessen the problems poor people have in using modern construction materials to build modern houses that can block mosquito entry (Kaindoa *et al.*, 2018). Okumu and Moore, (2011) indicate that where sustainable preventive measures are sustained to cover everyone and maintained at that level for long periods, there will be a shift in malaria control dynamics towards elimination; and if the pressure is maintained further, it could lead to eradication. House screening is eminently qualified to fulfill this aspiration. Other regulations are also possible: government could define dress code to protect predisposed persons who are exposed out-door to exophagous mosquitoes such as farmers just the same way they could insist on use of helmet by cyclists or use of face mask to minimize the spread of Covid-19.

The second line of defense

The second line of defense is the internal perimeter of a house. It is logical that a hungry female mosquito must pause to survey in-house environment: they may also experience dark/light adaptation, so need some time to adjust to the new environment by resting on walls briefly.

Mosquitoes often haemoconcentrate their blood meals by prediuresis before they escape from rooms, accounting for why blood stains are found on walls where mosquitoes had rested. The development of indoor residual spraying (IRS) stems from the resting behavior of vectors. Consequently, it is *apro pos* to target those malaria vectors that utilize inner walls of houses. IRS is the second most popular insecticide based deterrent tool (WHO, 2019; Okumu, 2020; Garci *et al.*, 2022). Dichlorodiphenyl trichloroethane (DDT) was the main insecticide used for IRS (Murray *et al.*, 2018). Yukich *et al.* (2022) say that the incidence rate ratio (IRR) shows that adding IRS with Actellic®300CS (Pirimiphos methyl) to the usual control measure was more protective when compared with the usual one alone and that it can be cost effective in several transmission backgrounds. IRS involve spraying insecticide to kill insect (malaria) vectors with a weak solution of the agent which is applied on the inside walls of rooms such as those built from absorbent materials like mud, mortar or wood (Shariat-Madar *et al.*, 2018), aimed at attaining universal coverage that guarantee community protection (Garcı´a *et al.*, 2022). Also included for spraying indoors are wall linings, curtain, ceilings where blood fed mosquitoes are likely to rest to digest their meals before searching for suitable locations to lay eggs. In general, the suggested range of IRS coverage has been accepted to be between 80% and 85% of homes within a given community (Garcı´a *et al.*, 2022).

The internal perimeter could be further defended with a second window/door net, insecticide impregnated wall, insecticide wall sheeting material among others (Table 1). IRS is influenced by the type of insecticide, the spray teams and the beneficiary of their services. House owners must agree to co-operate with them, accepting to put away their properties from rooms to be treated and not altering walls of the sprayed rooms like posting pictures, painting the rooms and hanging articles that could cover parts of the sprayed areas so as not to diminish insecticide efficacy (Monroe *et al.*, 2021). Resistance to secondary defense would be high because, inhabitants may forget appointment with fumigators, react to chemicals, not like sprays or may be afraid of the consequences of using such chemicals. They could simply lock their houses and travel during IRS campaigns.

The third line of defense

The third line of defense is the space between the walls, floor and ceiling within a room. This space maintains the same temperature and humidity uniformly within a unit space – they would have the same values whether or not bed nets are within (Von Seidlein *et al.* 2012). Such spaces may be protected with smokes, lures with carbon dioxde bottle trap, glues/insecticide hangings, aerosolized insecticides, etc. D-allethrin is used universally to compose mosquito spray and coils (Sayono *et al.*, 2019). CO_2 production from yeast/sugar mixtures as bait for mosquitoes induce catches of more mosquitoes than octenol baited traps at reduced cost and permits sustainable wide use of this technique in large scale surveillance programs (Jerry *et al.*, 2017). Odour baits and source of light are integrated in such devices as CDC lamp to collect mosquitoes from both open and closed environments. Again, the resistance at this level could be higher than the former because the measures will inundate the room space and further encroach on freedom of the indwellers in addition to those listed in the secondary defense. The caveat with aerosolized insecticide insists that occupants must vacate rooms before fumigation thus inconveniencing and forcing them to remain out door at the risk of exophilic mosquitoes.

The fourth line of defense

The last line of defense in this study is the bed net. They consist of fabrics that can be used to surround animal or human hosts such that vectors are prevented from reaching the host because they have small hole sizes that ensure vectors cannot pass through. Bed net efficiency depends on its ability to retain its material integrity when stretched, squeezed or pulled, remaining the same over time and diligently applying it to cover bed when sleeping (Okumu, 2020). In addition, nets may be so treated with insecticides such that when mosquitoes encounter them, they are repelled, hindered or dispatched permanently. Such devices are the so-called insecticide treated nets. Insecticide activity wane with time, so will those incorporated in nets. For bed nets to retain their activities against vectors, the insecticide content must be renewed by re-treatment with appropriate insecticide at intervals. Items used to control mosquitoes at this stage include treated and untreated bed nets. ITN/LLIN use is the dominant vector intervention measure in Africa (Bhatt *et al.* 2015; Okumu, 2020). Bed nets reduce malaria infection through imposition of physical barrier on mosquitoes thereby reducing their survival and population density as well as their vectoral capacity (Msellemu *et al.,* 2017) but they may be perceived unnecessary once IRS was applied (Echodu *et al.,* 2021). LLIN can still be effective even if riddled with holes, implying that the insecticide content is still active and a potent mosquito deterrent (Minta *et al.* 2017). Most holes occur in the lower quarter of LLIN (Vanden Eng *et al.*, 2017). The World Health Organization Pesticide Evaluation Scheme (WHOPES) recommended proportionate hole index (pHI) for judging the physical state of LLIN by counting the number of holes on them and categorizing them according to sizes related to the size of a thumb, fist, head, and larger than a head. The short coming of this method is that it disregards irregular hole shapes and over estimate hole sizes which may lead erroneously to net replacement (Vanden Eng *et al.*, 2017). However, where insecticide sprays had been applied as in the former, it would also protect the spaces within a bed net. This 4th level of defense has the most resistance because of the reasons given above in addition to the following: heat, itching, rashes, death struggles during sleep, restraining intimacy of couples, where to hang, etc (Galvin *et al.*, 2011; Ahorlu *et al.*, 2019; Eleazar *et al.*, 2022). Other issues concerning bed nets are discussed further below (see Table 2).

Indoor insecticide control strategy

It is said that about 80% of malaria transmission occur indoors so it is perceived that more weight should be put in controlling the infection by concentrating intervention within houses. Malaria occurrence is linked to lack of bed nets or lack of use by individuals in a household (Echodu *et al.*, 2021). ITN are therefore adopted principally to deal with endophagic mosquitoes such as *Anopheles gambiae ss* or *A. fenestus* (Galvin *et al.*, 2011; Okumu, 2020). IRS is a less popular indoor intervention tool that is employed to deal with resting mosquitoes. This predicament may be due to rising insecticide costs and limited malaria funds (Bath *et al.*, 2021). It is advised that there is no benefit to a community using both IRS and ITN dependent on the same pyrethroid insecticide (Pryce *et al.*, 2022). Mosquito activities are at peak within the hottest and most humid part of the year (Von Seidlein *et al.* 2012) which corresponds to when most vulnerable people would prefer not to sleep under bed nets. Children and pregnant women are the most vulnerable population to malaria risk because the disease management and prevention related information are lacking in these group (Iyanda *et al.*, 2020). This is probably because they are immunologically compromised as well. So, they are the principal target of insecticide-based control. Interventions responsible for the decline of malaria morbidity and mortality up to 2019 (WHO, 2021) is traced to use of insecticide-based control of the vector delivered through insecticide treated bed nets and indoor residual spraying (Bhart *et al.*, 2015; Nesga *et al.*, 2020; Okumu, 2020; Aïzoun *et al.* 2021 Garci*et al.* 2022) among others interventions such as house screening. Households that do not use IRS or LLIN are said to bear the heaviest burden of malaria and when given a choice between insecticides (IRS) and treated bed nets, 1 in 3 households preferred treated bed nets (Echodu *et al.*, (2021).

Mosquito/malaria control is determined by response of people at various planes: individual, household, professional groups, community, region, etc. (Monroe *et al.*, 2021). The extent of counter measures of affected people depends on their level of knowledge of the vector/pathogen and the nature of their environment and even the knowledge status of the community (Nesga *et al.*, 2020). In Nigeria, encouraging knowledge of malaria preventive measures to all concerned and applying measures to stop malaria spread by mosquitoes are crucial tools of current mosquito/malaria control (Iyanda *et al.*, 2020). Within a country, regional gap in the knowledge of malaria risks and interventions subsist and even within a region, urban women with secondary school education are conversant with malaria risk and are more amenable to use of bed nets when pregnant (Iyanda *et al.*, 2020). Other factors that may impact on insecticide mosquito/malaria control include but not limited to culture, social status, habit, etc. of people in affected communities (Tesfazghi *et al.*, 2016; Kaindoa *et al.* (2018). According to Georganos *et al.* (2020), the swift and uninhibited rural-urban exodus in Sub-Saharan Africa profit mosquitoes and exacerbate malaria because vectors density is raised, people get exposed and they are not able to put in place sustainable control measures thereby worsening malaria burden in urban population.

Table 2: Advantages and disadvantages of bed nets

S/ no.	Advantages	Disadvantages
1	Prevent sleepers from falling out of bed when dreaming	Exclude older children and adults
2	Secure babies and small sized individuals (children)	Disruption of sleep arrangement when more persons share the bed space (Galvin *et al*., 2011; Msellemu *et al.* 2017; Iwashita *et al.* (2010)
3	Easy to apply when hanging posts are available	Burdensome daily hanging and dismantling (Galvin *et al*., 2011; Iwashita *et al.* (2010)
4	Effective in preventing bites (Birkholtz et al., 2012; Msellemu *et al.* 2017; Minta *et al.* 2017).	Alter room aesthetics and setting
5	Bed nets also protect against cold (Galvin et al., 2011)	Restricts routine movements within/outside the net (Msellemu *et al.* 2017)
6	Protect users against non-biting nuisance insects pests like flies, cockroaches (Msellemu *et al.* 2017)	Not suitable during copulation of couples (Galvin *et al*., 2011)
7	Bed net use prevent dust accumulation onto bed coverings	Reduce room space especially if hung permanently (Iwashita *et al*., 2010)
8		Cause parental worries for young children
9		Fear of crumpling and choking of children
10		Parents must keep watch when children are within
11		Danger of children ingesting/poisoning with insecticide in net fabrics (Galvin *et al*., 2011)
12		Danger of children getting entangled when awake and they want to exit (Galvin *et al*., 2011)
13		Risk of fire from candles/open flame (Galvin *et al*., 2011)
14		Restrict air flow (Von Seidlein *et al*., 2012; Ahorlu *et al*., 2019)
15		Difficult to use in low/flat roofed rooms (Galvin *et al*., 2011)
16		Exhausted persons may be too tired to hang net (Eleazar *et al*., 2022)
17		Deployment variable across nights and seasons (Ahorlu *et al*., 2019)
18		Non-compliant-bedfellows: one wants, the other does not want bed net (Msellemu *et al*., 2017)
19		Restricts bed sharing
20		May still not prevent frequent attacks of malaria (Hauser *et al*., 2019)
21		Inconvenient (Galvin *et al*., 2011)
22		Provoke beliefs barriers e.g. that sleepers are corpse
23		Allergic reaction to chemicals (Galvin *et al*., 2011)
24		Use cannot be monitored accurately (Alexander *et al.* 2022)
25		For large room and exclusivity to one man (Galvin *et al*., 2011)
26		Inefficient, limited, inequitable distribution (Bhatt *et al*, 2015)
27		Not suited for some house configuration (Galvin *et al*., 2011)
28		LLINs are expensive (Galvin *et al*., 2011).
29		Unsustainable
30		Rapid deterioration (Bhatt *et al*, 2015)
31		Hole development (Msellemu *et al.* 2017; Minta *et al.* 2017; Vanden Eng *et al.*, 2017)
32		Impose thermal related distress (Galvin *et al*., 2011; Ahorlu *et al*., 2019; Eleazar *et al*., 2022)
33		Provoke nightmares, claustrophobia ((Galvin et al., 2011)
34		Huge international efforts dependent (Tesfazghi *et al*., 2015; Okumu, 2020)
35		Accumulate dust

Some social groups and governments look beyond their shores for help in whatever form to cope with supply of mosquito/malaria control materials. It is therefore not surprising that SSA largely depend on technical and financial help from WHO, GFATM, UNICEF, USAID, International Federation of Red Cross, US President's Malaria Initiative (Tesfazghi *et al.*, 2016; Abdullahi *et al.*, 2019; Okumu, 2020). This dependence makes it impossible for SSA nations to make decision that funders object to. Expectedly, governments of rich nations in Europe and America who have the technology to supply LLIN and IRS favourably respond to this need and had been involved for decades in offering assistance to SSA by providing bed nets, insecticides, spraying equipment and other ancillary products and services. Spearheading the campaign to control mosquito/malaria is WHO which had been active in this regard since inception. In addition, she publishes annual report on malaria which keeps stake holders abreast with current developments. Incidentally, WHO had approved 20 LLINs and 6 insecticide management kits for use in endemic countries (Okumu, 2020).

Achilles heel of ITN and IRS

IRS and LLIN protect against mosquitoes within houses but not useful for outdoor malaria vectors (Mmbando *et al.* 2018). Their promoters may have visioned a quick mosquito defeat with the two entities as if the fight against them was a pitched battle. Unfolding events suggest that it may not be a quick fix as will be shown hereafter. One of the indices used in monitoring disease is data obtained from prevalence studies. The WHO data quoted at the beginning is indicative that all is not well as the declining malaria morbidity and mortality increased between 2019 and 2020. According to WHO (2021), malaria cases rose from 213 million to 228 million in WHO African region. The implication from the foregoing is that we must identify what is wrong with our mosquito control strategies and propose remedies. Following will be devoted to itemizing determinants of insecticide-based intervention currently employed that were supposed to speed up mosquito/malaria control but ended up stalling it.

Cost of insecticides

(IRS) is a significant part of mosquito/malaria control in endemic nations. Its application is difficult because it demands the concurrent commitment of several fieldworkers who must work together in a particular locality (Garci *et al.*, 2022). The cost of IRS is prohibitive (Garci *et al.*, 2022). However, Bath *et al.* (2021) argue that targeted IRS is not an inferior intervention and could be a safe, cheap and cost-effective intervention in regions with low malaria infection. Other associated problem of IRS coverage is that estimate of the fumigator's productivity were ambiguous as well as the problem of underspraying or overspraying (Garci *et al.*, 2022). Yukich *et al.*, (2022) indicate that IRS disadvantages are variations in the incremental costs/cost-effectiveness that come from many causes like: disparity in the size of wall surfaces sprayed, house size to household population ratio and the state of malaria burden in the neighborhood sprayed.

Supply and distribution of insecticides

Sub-Sahara Africa does not have the technical know-how, capacity and political will to take control of supply of ingredients of LLIN and IRS. Clearly, authorities in the region lack resources, knowledge and the power to determine insecticide choices and this may account for why the insecticide market in Africa is the fasted across the globe (Norton and Torto, 2020). As at 2020, only 3 of the 20 approved manufacturers have rudimentary presence in Africa (Okumu, 2020). This means that the region cannot have and apply LLIN and IRS as at when due. They must succumb to the whims and caprices of her superiors in Europe, Asia and America. This incapacity would go down the rungs of the ladder until it is reflected at the level of communities and individuals that ultimately receives these interventions. Communities which receive IRS and ITN may achieve better vector control as two interventions is better than one and may also be better where the vector is resistant to ITN (Pryce *et al.*, 2022). The difficulties encountered in ITN bed net and IRS may be the driving force of the stand still or decline in the quantum of intervention materials available to people in endemic areas (Okumu, 2020; Monroe *et al.*, 2021). Another distribution related problem is that IRS and bed net distribution is fraught with inequality among households (Bath *et al.* (2015),

Insecticide deployment and monitoring

Promoters of insecticide interventions do utilize media campaigns effectively. They also deploy some members of the community to facilitate uptake of insecticide intervention. This band of people is the informed critical mass within families and communities that drive mosquito/malaria control because they are like icons whose behaviours attract others (Monroe *et al.*, 2021). Insecticide deployment may provoke false sense of security from mosquitoes. This is informed by urban area extensions into mosquito territories thereby aggravating mosquito/malaria control (Gaugle *et al.*, 2019). However, free net distribution among the most vulnerable group does not translate to deployment at night (Eleazar *et al.*, 2022). Net ownership is not synonymous with usage when it matters. House types and spaces within determine net usage for children (Iwashita *et al.*, 2010). Relying on "the number of people who slept in bed net the night before" could be very deceptive as many worker quote different values: Onyeneho *et al.* (2014) found that only 3% of pregnant women used bed net. Eleazar *et al.*, (2022) noted that only a very small percentage (8.4%) use them. Okumu (2020) indicated that 50% of Africans sleep under bed net. According to Ahorlu *et al.* (2019), ITN use is non-binary, that is, user against non-user; but ITN use could change during the night, over time and across seasons. Continuing they found that about 32% were regular bed net users, 23% use bed net depending on the season of the year, 43% accounted for being sporadic users while 2% were non-users. Accurately measuring use of bed nets is riddled with biases. Okumu (2020) opined that "selective interpretation" of efficacy reports on ITN was intentioned to retain the patrons of mosquito control product. SmartNet, which a small number of people perceived as favourable like the usual LLIN, is a device that enable users of LLIN to be accurately monitored for use or non-use over a period so that researchers can determine with certainty bed net deployed among users is now being applied (Alexander *et al.* 2022). SmartNnet use has access to individual's privacy that had been defined as "the right to be let alone" or "the right of the individual to decide about himself/herself" (Lukács, 2016). With the current level of technology, its use can easily be compromised by converting it to spying devices. No sane person would accept such maleficent device in his bed room. The advantages and disadvantages of bed net are listed in Table 2.

Consistent record of response to intervention can assist the overall national mosquito/malaria control status. This will intimate donors and other stake holders of progress and determine additional inputs which may be brought to play to enhance control programs (Monroe *et al.*, 2021). Getting feedback on number of nets people truly own and use per country is ardous so they recommended five-point indicator system to situate ITN use. Iwashita *et al.* (2010) noted that net use is determined by availability, facility for hanging, and sleeping arrangement. They also added that, house configuration and space provision hamper efforts to use bed nets particularly for young children. Indoor residual spraying (IRS) is an expensive intervention whose delivery is a challenging endeavour that entails the simultaneous deployment of many fieldworkers within a geographical area who may be under-spraying and over-spraying earmarked houses (Garcı´a *et al.*, 2022). The WHO calls the shots whenever health related issues, particularly use of insecticides, is concerned such that policy makers await her recommendation before any intervention is adopted (Tesfazghi *et al.*, 2016). This waiting time may prolong because WHO will have to wait for reports from researchers to confirm that the desired intervention will be significantly safe. In the same vein, any policy change in this context will also require her imprimatur.

Durability

ITN may have short or long duration of activity; LLIN may be active for up to 3 – 5 years (WHO, 2019; Okumu, 2020). IRS using DDT ought to be re-sprayed after 6 – 12 months while pyrethroid bioactivity is retained for even shorter periods and it must be re-sprayed after 3 – 4 months (Okumu and Moore, 2011). Both IRS and ITN are temporary mosquito/malaria control techniques that cannot compare with some permanent mosquito control measures such as drainages and fillings of breeding sites. LLIN has quick rate of deterioration and coverage remain inadequate despite large number of nets distributed (Bath *et al.* (2015). Bhatt *et al.*, (2015) opined that the processes of delivering and distributing LLIN are inefficient. Since 2017, bed net distribution began to stagnate while the estimate that half of Africans slept under ITN and the population with access was 56% was excessive (Okumu, 2020). Continuing, (Okumu, 2020) posits that about 39% of the nets would be serviceable 2 years after commencement of use. If that assessment was correct in 2017, what will it be today when Europe and America are embroiled in war with Russia in Ukraine and facing severe economic recession?

Vector resistance to insecticide

Echodu *et al.*, (2021) observed that after many years of useyet (a brand of LLIN) use, malaria prevalence of 63% was still recorded. Certainly, this must be that the malaria vector in the study are had acquired resistance to pyrethroid. The WHO's dependence on insecticide in their two choice methods are bedeviled by vector acquisition of resistance (Okumo, 2020; WHO, 2021), time-limited intervention that are prone to financial burden (Jawara *et al.*, 2018) and unstable bed nets deployment throughout the night, across seasons, and over time (Ahorlu *et al.*, 2019). Even in non malaria mosquitoes, Lorono-Pino *et al.* (2018) found that pyrethroid resistance compromised the protective effect of insecticide treated curtains such that "super infected homes" were still found in treated homes. Excess dependence on insecticide for deterrence of malaria vectors have pushed them to alter their genes which enable them resist all classes of insecticides even when the concentration is raised up to 1000 times above the level used in the field; moreover, donors and funding agencies would get exhausted (Okumu and Moore, 2011; Okumu, 2020). IRS with non-pyrethroid insecticide can be applied to augment LLIN to improve mosquito control (Pryce *et al.*, 2022). Syme *et al.* (2021) applied non-pyrethroid IRS (which the vector was sensitive to) to the usual pyrethroid based LLIN (which the vector was resistant to) and obtained a level of control better than when either of them was used separately. It must be remarked that synergistic effect, addition or inhibition are possible depending on the insecticides and vector sensitivities.

Comfort among LLIN insecticide beneficiary

Von Seidlein *et al.* (2012) found that bed net reduce airflow between 27% and 71% and that airflow declined with increasing net mesh size and those with a mesh of 136 holes/square inch reduced airflow by 55% while the same size of net with 200 holes reduced airflow by 59%. It does appear that people who complain about heat in bed net (Ahorlu *et al.*, 2019) may in fact have misplaced sensation because Seidlein *et al.* (2012) did not find any difference in temperature within the bed net and the rest of the room. Other discomforts people encounter is listed in Table 2.

Underminers of interventions

There had been unscrupulous officials who horde/steal control materials and later sell them at exorbitant cost to the same people they were meant for (Ugwu, 2021). Surprisingly those who purchased their bed net, for example, are more likely to use them (Eleazar *et al.*, 2022) although there is also the evidence that high cost of IRS may partly explain its poor performance (Benelli *et al.*, 2016). Even WHO reported IRS diminishing usage (WHO, 2021). Locating IRS activities in certain areas are rare (Ugwu, 2021). Continuing with the two programs in an insecure country like Nigeria (Onwuamanam and Agbaenyi, 2021), the epicenter of mosquito/malaria (WHO, 2021) where corruption is the trending norm (Chinna, 2021), is a recipe for mosquito/mosquito-diseases control failure. Disuse and abuse of bed net is rife as some misuse them for fishing net or as pillow, curtain and for other sundry uses (McLean *et al.*, 2014).

The sharp practices of highly placed persons and their collaborators frustrate bed nets/insecticide distribution. These practices whittle down the tempo required to sustain mosquito/malaria control as larger number of people who ought to be covered would be left out. Of course, these workers recycle their iniquities by covering their tracks and by lying to convince the providers to keep providing more resources that go down the drain. So, the WHO, governments and donors are extorted more than is necessary. These criminals thus undermine both donors and target populations. It is impossible to monitor private homes to ascertain the level of implementation of bed net distribution or insecticide fumigations. It will be reprehensible for anyone to go into people's bedroom to crosscheck if they actually applied the bed net or certify that their rooms had been sprayed.

Insecticide intoxication

Occupational insecticidal poisoning (OIP) is rife among IRS workers so pose grim danger to their wellbeing (Karunamoorthi *et al.*, 2013). According to Murray *et al.*, (2018) DDT and dichlorodiphenyldichloroethylene (DDE), a breakdown product of DDT is associated with the risks of hypertensive disorders of pregnancy in women from South Africa who live where DDT is sprayed. They indicated that DDE are soluble in lipids and do remain in tissues and in our surroundings for long periods and can be a threat to new born because they penetrate the foetus and had been banned in Europe since the 1970s but still used in Africa. Verma *et al.*, (2016) say that acute arsenic poisoning is associated with ingestion of insecticides or pesticides and arsenic exposure (arsenicosis) causes cancer and other conditions that are difficult to diagnose because signs and symptoms are not specific or recognized at early stage. They added that natural inorganic arsenic is present in tobacco and its deleterious activity is increased in lead arsenate insecticides.

Insecticides are organically dynamic materials that destabilize ecological fabric of marine and terrestrial ecosystems (Stehle *et al.*, 2015; Yura *et al.*, 2021). Fresh water pollution from agricultural insecticide use poses intolerable threat to marine biodiversity Yura *et al.*, (2021). Haggerty *et al.*, (2022) noted that pyrethroids can be several times more toxic than organophosphate insecticides and its runoffs can induce lethal toxic levels unto non-target beneficial organisms. In fresh water, insecticides runoffs from fields become toxic to prawns (*Macrobrachium* sp.) that keep transmitters of schistosomiasis in check. Populations of honeybees, edible insects and insectivorous birds are declining (Norton and Torto, 2020). Yura *et al.*, (2021) noted that 50% of detected insecticide concentrations in food surpass recommended levels. Insecticide residues in edible plants are indicative of excess application especially from pyrethroids and had been found in vegetables with up to 6% exceeding their maximum residual limits (Amjad *et al.*, 2010). In the same vein, Norton and Torto (2020) alert that beneficial insects and birds are poisoned and so weaken the ecosystem services in agriculture as a result of farmers' intensive use of insecticides for economic reasons with no regard for long term consequences. They also observed that the rich pollinator diversity including edible insects are threatened by neonics, a water-soluble class of insecticides that lack selectivity and which contain nicotine that interfere with insects' nervous system.

CONCLUSION AND RECOMMENDATIONS

The levels of defenses that man indoor can apply to control mosquito/malaria are four: primary, secondary, tertiary and quaternary. Unfortunately, the reluctance of people in malaria endemic regions to the use of ITN and IRS as insecticide-based vectors control is very strong. Resistance increases as level of defense increases: environmental management which is the primary level of defense attracts little or no resistance; ITN which is applied at the 4th and last line of defense attract the most opposition. Only 7 advantages were listed for bed net use. The disadvantages were up to 35, accounting for why people do not use it and why it is unsustainable as mosquito/malaria control. Governments and donor agencies need to focus control activities in open environments where their activities not only face least resistance but also are easily seen and monitored. Through enactments in public and environmental domains (Birkholtz *et al.*, 2012), governments should dictate the tone of vector control at the open environment level with the following measures: adoption of house screening as primary mosquito control where all public/private buildings must be screened by their owners. The WHO and governments in SSA ought to speed up elimination of malaria by urgently reviewing their stand on LLIN and IRS. House screening is the way to go because it is all inclusive, impossible to evade; and with the innovations of s/o channel/grip devices, this intervention will be the driver for a lasting malaria control because it is perceived as accessible, cheap, effective and sustainable (Ugwu, 2019).

Insecticide use in open environment should be banned because of the long-term consequences on food chain and elimination of non-target organisms while repellents should be used to divert mosquitoes away from vulnerable hosts. Insecticidal use should be made optional to individuals for indoor use only but never to be used in open environment except when supervised by government agents to save beneficial insect species.

Acknowledgements

The author is grateful to God for sustaining him during the austere period of the prolonged 8-month strike that stalled all academic endeavours in Nigerian universities, particularly, the University of Nigeria, Nsukka (UNN). This work resulted from persistent promptings of the Dean, Faculty of Biological Sciences, UNN, Professor Nweze, E. I. and Professor Eze S. O. of the Biochemistry Department, UNN. He benefited also from Professor Nwani C. D. for his counsel and profound prayers. May God reward these eminent professors abundantly. He is indebted to his supportive wife and children who contributed

in no small measure to ensure this work succeeded.

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