Insecticide-treated combinations of window screens and eave baffles may help control physiologically and behaviorally resistant malaria vector mosquitoes

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Abstract

Netting window screens and eave baffles (WSEBs), allowing mosquitoes to enter but not exit from houses, were assessed as an alternative to indoor residual spraying (IRS) for malaria vector control. WSEBs treated with water, the pyrethroid lambda-cyhalothrin (LC), or the organophosphate pirimiphos-methyl (PM), with and without a binding agent (BA) for increasing insecticide persistence on netting, were compared with IRS in experimental huts. Compared with IRS using the same insecticide, WSEBs killed similar proportions of *Anopheles funestus* which were resistant to pyrethroids, carbamates and organochlorines, and greater proportions of pyrethroid-resistant, early-exiting *An. arabiensis*. WSEBs with PM killed greater proportions of both vectors than with LC or LC plus PM, and were equally efficacious when combined with BA. WSEBs required far less insecticide than IRS and BAs may enhance durability. WSEBs may enable affordable deployment of insecticide combinations to mitigate against physiological insecticide resistance, and improve impact upon behaviorally-resistant, early-exiting vectors.

Summary

Here we show how insecticide-treated netting window screens and eave baffles may be an efficacious alternative to indoor residual spraying for malaria vector control, to reduce insecticide consumption and enable affordable deployment of insecticide cocktails against physiologically and behaviorally resistant mosquitoes.

Running title

Insecticidal window screens and eave baffles

Keywords

Malaria, *Plasmodium*, vector control, indoor residual spraying, insecticide resistance, residual transmission, behavior, mosquito, *Anopheles*

Background

Vector control with long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) interventions account for 78% of the 663 million malaria cases, and most of the four million deaths, averted globally over recent years (1, 2). LLINs and IRS can dramatically reduce malaria transmission by killing sufficient numbers of vector mosquitoes when they attack sleeping humans and/or rest indoors (3-5). However, as these approaches have been scaled up, *physiological* resistance to their insecticidal active ingredients has become increasingly common, threatening a "looming public health catastrophe" (6). Physiological resistance to pyrethroids, the only class of insecticides suitable for use on LLINs, is now widespread and undermining the impact of vector control all across Africa (7).

Only four directly lethal insecticide classes are currently recommended for control of adult malaria vectors with LLINs or IRS: Pyrethroids (eg permethrin, deltamethrin, lambda-cyhalothrin), organochlorines (eg DDT), carbamates (eg bendiocarb, propoxur) and organophosphates (eg. malathion, fenitrothrion, pirimiphos methyl) (8). Mechanisms of cross-

resistance against both organochlorines and pyrethroids limit their utility for combined use in rotations, mosaics or combinations (7, 8). Organochlorines (DDT in particular) and carbamates have a long history of use in both agriculture and public health and resistance to both these classes is already emerging following only a few brief years of use in IRS at programmatic scales (7). Neither these classes, nor the organophosphates, can be safely applied to LLINs at operationally effective doses (8), and they are all prohibitively expensive for routine IRS applications (9-11).

For example, year-round protection of all 40 million (M) people at risk in Tanzania, with IRS using the ideal recommended dose of the new capsule suspension (CS) formulation of organophosphate pirimiphos-methyl (PM), would cost $157M annually for insecticide procurement alone, exceeding the entire national malaria control budget of $114. PM procurement alone for continuous IRS coverage of all at-risk populations would cost $3.3 Billion (B) annually across Africa and $12.5B worldwide, dwarfing the total global malaria control budget of only $2.5B (10). As such expensive insecticides have become increasingly necessary due to pyrethroid resistance, IRS coverage has inevitably declined (9-11) and now stands at only 3.4% globally (12). While new insecticides are being developed for malaria vector control (6, 7, 13), these may well be similarly expensive. Also, unless these new active ingredients are astutely delivered through rotations, mosaics or combinations, they may not necessarily be any less prone to the emergence of physiological resistance (6-8).

Beyond physiological resistance, the impacts of LLINs and IRS are also attenuated by the tendency of vectors to enter but then rapidly exit again from houses, without resting on treated surfaces for long enough to accumulate a lethal doses of insecticide (14-16). Repeatedly entering and then rapidly exiting from several houses, until an unprotected human victim can be attacked,

allows mosquitoes to mediate persistent residual malaria transmission, by maximizing their feeding opportunities while minimizing their risks of exposure to LLINs and IRS when foraging indoors (17, 18). New insecticide delivery methods will therefore be required to tackle such evasive early-exiting vectors (14, 16), which may be described as behaviorally resilient (pre-existing traits, typically with considerable phenotypic plasticity) or even resistant (increasing frequency of selected heritable traits) (17, 19). In fact, life history simulation analyses suggest such repeated visits to houses represent a vulnerability that can be exploited to great effect with improved methods for killing mosquitoes inside houses (17, 18). Even for early-exiting vectors which often feed outdoors instead, most mosquitoes old enough to transmit malaria have previously entered at least one house, where they could be targeted with lethal insecticides or traps (18).

The personal protection provided by LLINs and IRS can be superseded and improved upon by physically mosquito-proofing houses with screened windows, ceilings and closed eaves (20). However, most of the impact of LLINs and IRS upon malaria transmission is achieved by killing off mosquito populations *en masse* to protect entire communities, with the more obvious contributions of personal or household protection being far less equitable and important (4). Household protection measures like spatial repellents or physical mosquito-proofing, which merely deter mosquitoes from entering houses and force them to seek blood elsewhere, may therefore have far less overall impact than those which kill them outright (21). In many settings with highly efficient vectors, elimination of malaria transmission will probably require lethal measures that suppress (3-5), or even eliminate (22), entire mosquito populations, rather than merely deter them from entering houses (21). New insecticide delivery methods are therefore

urgently needed, to enable affordable deployment of multiple active ingredients, and more effective targeting of early-exiting mosquitoes (6, 8, 13).

Here we describe a simple housing modification with widely-available netting materials, which traps mosquitoes inside houses after they enter, and forces them into lethal contact with insecticides when they attempt to exit again (Figure 1). Eave baffles have been used for decades (23) in standardized experimental hut designs for assessing LLINs and IRS (24, 25). Eave baffles consist of netting panels slanting inwards and upwards from the upper end of the wall towards the roof, but leaving a small gap so that mosquitoes can freely enter the hut but cannot leave by the same route (Figure 1A). Eave baffles have been successfully used to target house-entering mosquitoes with fungal entomopathogens (26), so here they were combined with netting window screens, and evaluated as a targeted delivery format for "off-the-shelf" formulations of commonly-used chemical insecticides (Figure 1B). Even though treated window screens and eave baffles (WSEBs) required far less insecticide than IRS, they achieved equivalent control of physiologically-resistant *Anopheles funestus* and improved control of early-exiting *An. arabiensis*. All these experiments were conducted in rural Tanzania with commercially-available IRS formulations of pyrethroids and organophosphates, which were combined with existing binding agent (BA) products for extending insecticide durability on LLINs.

Methods

These experiments were conducted in Lupiro village in the Kilombero Valley of southern Tanzania, where intense malaria transmission is mediated by two of the most important malaria vectors in Africa: (1) Local *Anopheles funestus* mediate *rebounding* (14) malaria transmission because they are physiologically resistant to pyrethroids, carbamates and organochlorines (27),

and (2) Local *An. arabiensis* mediate resilient *residual* transmission (14) because they are physiologically resistant to pyrethroids (27) and also exhibit early-exiting behaviors that render them remarkably robust to indoor control with LLINs and IRS (18, 28, 29). All procedures were approved by the Institutional Review Board of the Ifakara Health Institute (IHI/IRB/34-2014) and the Medical Research Coordination Committee of the National Institute for Medical Research (NIMR/HQ/R.8a/Vol IX/1903).

Thirteen experimental huts of the Ifakara design (24, 29, 30) were used to assess the impact of LLINs, IRS and insecticide-treated WSEBs, using standard methodology (31). Four of these huts were randomly selected and their inner wall and roof surfaces were sprayed with 2 $g \cdot m^{-2}$ of a CS formulation of PM (Actellic 300CS®), using standard programmatic application procedures (32). Another four randomly-selected huts were sprayed with 30 $mg \cdot m^{-2}$ of the pyrethroid lambda-cyhalothrin (LC), also in a CS formulation (Icon 10CS®). The remaining five huts were sprayed only with water to act as negative controls. Both of these long-lasting micro-encapsulated insecticide formulations are manufactured by Syngenta Crop Protection AG, Basel Switzerland for IRS applications, and are well characterized (33-35). After spraying, two mattresses and fully intact Permanet™ LLINs (100 denier polyester multifilament mesh with 156 $holes \cdot inch^{-2}$, surface-treated with 45 to 55 $mg \cdot m^{-2}$ of deltamethrin in a resin foundation) were installed in each hut.

Eave baffles are incorporated into experimental hut designs, to ensure mosquitoes can enter through approximately half of the eave gaps between the wall and the roof, but are then all either retained in the hut itself or forced into interception traps fitted to the remaining exit points (24, 25). In a conventional experimental hut study, those remaining exit points are the windows and the remaining un-baffled half of the eave gaps (24, 25). However, the purpose of this study was

to evaluate WSEBs as an insecticide delivery format in their own right. All the WSEB treatments, except for the full negative control, therefore included eave baffles fitted to *all* eave gaps, with and without exit traps, and identically-treated screens fitted over *all* windows (Table 1, Figure 1). Treated WSEBs were fitted in front of the exit traps, which were fitted immediately outside the hut (24), so that any mosquito attempting to exit through any eave gap or window would be forced into contact with these insecticidal netting barriers (Figure 1).

The only treatment without screens over the windows, or eave baffles over the half of the eave gaps with exit traps immediately outside, was therefore the full negative control (Table 1). These full negative controls had untreated eave baffles fitted only to the half of the eave spaces lacking exit traps, thus allowing mosquitoes to both enter and exit. The two partial negative controls had screens fitted over the windows and baffles fitted to all eave gaps, regardless of whether they acted as entry or exit points for mosquitoes, but were not treated with any insecticides (Table 1). One of the partial negative controls was treated with the non-insecticidal binding agent (BA) that Syngenta include along with LC (the same Icon 10CS formulation we used for IRS) in their Icon Maxx® product, to extend its active life on polyester netting (36). Note that although the manufacturer-recommended dose of LC on netting treated with the Icon Maxx® product (55 $mg \cdot m^{-2}$) is somewhat higher that used for IRS (30 $mg \cdot m^{-2}$), it is similar to that for deltamethrin on the Permanet® LLINs used in this study (45 to 55 $mg \cdot m^{-2}$).

The first insecticidal WSEB treatment, listed fourth in Table 1, was this same long-lasting Icon Maxx® product, this time including both the BA and the LC active ingredient (36). Also, WSEBs treated with PM were assessed at three different dosages that were comparable with typical IRS application rates per square meter treated (Table 1). These three PM doses were also assessed as a co-treatment with BA to potentially extend insecticide life, both with and without

LC as a complementary second insecticide from a different chemical class (Table 1). LC was chosen, despite coming from the pyrethroid class to which both vector species in the study area are resistant (27), to assess the potential of such cocktails to select for restored pyrethroid susceptibility by selectively reducing mortality of insects that are both susceptible to its lethal mode of action and responsive to its irritant/repellent effects on mosquito behaviour (37). The mathematical modeling study which motivated assessment of this combination assumed that these two pyrethroid susceptibility and responsiveness phenotypes, and presumably their underlying genotypes, are closely associated and therefore co-selected (37).

While all exit traps on eaves and windows were made of Teflon-coated fibreglass mesh (24), all eave baffles and window screens were instead made of 100-denier polyester netting (A to Z Textile Mills, Arusha, Tanzania) of the kind typically used for bed nets. All WSEB were treated by soaking in aqueous suspensions of the insecticides and/or BA and then drying in the shade.

To execute the full experimental design of this study, duplicate sets of the 13 detachable, movable WSEB treatments (Table 1), were rotated nightly through the 13 huts over two full 26-day rounds of experimental replication (Additional file 1), between the 5th of December 2015 and the 1st of February 2016. Each night, two adult male volunteers slept under the two LLINs inside each hut from 19:00 to 07:00 hr. The volunteers then collected all mosquitoes inside the hut with a Prokopak aspirator (John W. Hock) (38), and then those inside the exit traps with a mouth aspirator (24). Dead mosquitoes were then sorted taxonomically, classified by sex and abdominal status, and counted. Specimens collected alive were maintained in a field insectary for 24 hours before separating live and dead specimens for sorting, classification and counting. A random sample of 242 specimens from the *An. gambiae* complex were identified to sibling species by polymerase chain reaction (39).

Each pair of volunteers remained assigned to a fixed experimental hut throughout the study, so that variability associated with these individuals and the huts themselves could be analyzed as a single, consistent source of variance. Following mosquito collection each morning, each pair of volunteers was only responsible for installing the set of WSEBs assigned to their hut that evening, and for removing it from the hut it had been fitted to the previous night. All volunteers used a fresh pair of gloves each morning and were not allowed to handle any WSEBs other than those to be used in their hut that night. All WSEB sets were individually labelled, and stored in labelled buckets during transfer between huts and the 13 day storage period of each 26 day replication cycle (Additional file 1).

All field data were collected on hard copies of the ED1 and SS3 forms, recently described for informatically-robust collection of entomological data (40). To ensure rigid compliance with the experimental design, all attributes defined by it were prefilled into the forms (Additional file 1). All statistical analysis was accomplished using generalized linear mixed models (GLMMs) with a binomial distribution and logit link function for the binary mosquito mortality outcome, fitted using R version 3.2.1. The IRS and WSEB treatments were included as categorical independent variables, while hut and night were included as random effects.

Results

A total of 1318 specimens from the *An. funestus* group and 5842 from the *An. gambiae* complex were captured. Molecular identification in the laboratory confirmed the continued absence of nominate *Anopheles gambiae* from the study area (22), with all (100%; 176/176) successfully amplified (73%; 176/242) specimens from this complex identified as *An. arabiensis*. All

WESBs, other than the full negative control, clearly retained mosquitoes within the huts, because this is where the vast majority (>90%) were collected, rather than in the exit traps.

Comparing the impact of WSEBs and IRS upon An. funestus mortality

When used alone, most of the WSEB treatments that included insecticides (8/10) killed similarly high proportions of *An. funestus* to IRS alone using the same insecticide formulations (Figure 2A). For example, mortality for LC plus BA-treated WSEBs alone was indistinguishable from LC IRS alone (P=0.363). The only exceptions amongst the 10 WSEB treatments were those two with the highest PM dose plus BA and the intermediate PM dose plus LC and BA: Both of these WSEB treatments alone killed somewhat lower proportions of *An. funestus* than IRS with LC alone, and a similar but non-significant pattern was observed for comparisons of the same WSEB treatments alone with PM IRS alone (Figure 2A, Additional file 2). Nonetheless, mortality rates achieved by PM-treated WSEBs alone were consistently high (Figure 2A), regardless of treatment dosage ($P \geq 0.156$), and were statistically indistinguishable from PM IRS alone ($P \geq 0.713$), even though the lowest WSEB dose per unit area treated was only half that for IRS. While all the combinations of PM-treated WSEBs with PM IRS resulted in higher mortality than PM-IRS alone or PM-treated WSEBs alone, none of these contrasts were significant ($P \geq 0.080$) because too few mosquitoes survived either the treated WSEBs alone or IRS alone.

Comparing the impact of WSEBs and IRS upon An. arabiensis mortality

Overall, insecticide-treated WSEBs either matched or proved superior to IRS when deployed against *An. arabiensis* (Figure 2B, Additional file 2). WSEBs alone treated with LC plus BA achieved similar mortality to IRS alone with the same LC formulation (P=0.345). WSEBs alone treated with the lowest dose of PM achieved similar *An. arabiensis* mortality to IRS alone using twice as much PM per square meter treated (P=0.419). However, increasing the PM treatment

dosage from 1 to 2 or 4 $g \cdot m^{-2}$ increased the mortality achieved by WSEBs alone (OR [95%CI] =2.10 [1.16, 3.79], P = 0.0139 and 2.34 [1.28, 4.26], P = 0.0055, respectively), although there was no difference between the intermediate and high dosages (P=0.758). WSEBs alone with either the intermediate or high PM dosage killed more *An. arabiensis* (Odds ratio (OR) [95% Confidence Interval (CI)] = 5.9 [1.4, 24.3], P=0.0145 and 10.8 [1.6, 74.8], P=0.0157, respectively) than IRS alone, even though the intermediate PM dosage was the same as IRS per square meter treated. Supplementing PM-treated WSEBs with PM IRS did increase *An. arabiensis* mortality for the lowest WSEB dose (OR [95% CI] = 4.8 [1.5, 15.5], P=0.0081), which was half that of IRS per unit area treated. However, supplementary PM IRS did not increase mortality when WSEBs were treated with the same dosage as IRS (P=0.748), or with twice that dosage (P=0.429).

Combining PM with BA and LC as WSEB co-treatments

Adding BA had no effect on the mortality rates achieved by PM-treated WSEBs alone, for either *An. funestus* (P = 0.393) or *An. arabiensis* (P = 0.424). Supplementing the organophosphate PM plus BA treatment with the irritant pyrethroid LC as a second active ingredient, reduced *An. funestus* mortality rates achieved by WSEBs alone (OR [95% CI] = 0.64 [0.46, 0.89], P = 0.0076), presumably because the irritant properties of LC reduce mosquito contact times with co-treated WSEBS, and therefore exposure to both insecticides. A similar but less dramatic and non-significant trend was observed for *An. arabiensis* (OR [95% CI] = 0.88 [0.73, 1.06], P = 0.174).

Discussion

While WSEBs exhibited higher efficacy than IRS against early-exiting *An. arabiensis*, the two delivery formats had similar efficacy against *An. funestus*. The most striking advantage of WSEBs is therefore that it reduced the surface area treated per hut by more than 5-fold. Furthermore, the possibility of co-application with existing BAs that already extend durability of pyrethroids on LLINs (36) for up to 3 years (41), suggests new opportunities for also reducing reapplication frequency by up to six-fold, relative to IRS.

Of course these WSEBs are merely an experimental prototype, which were evaluated in the necessarily homogenous and controlled environment of experimental huts. This short term efficacy study cannot address key issues regarding the potential effectiveness and cost-effectiveness of WSEBs under programmatic operational conditions. It is encouraging that a full set of these WSEBs for these experimental huts, specifically designed to match the dimensions of local houses (24), required only 11 m^2 of netting to manufacture, similar to a typical LLIN. However, they had to be carefully hand-tailored with hooks and Velcro™ to enable easy daily removal and reinstallation in experimental huts, at a manufacturing labor cost of $47 per set. More practical and affordable formats for operational use in a diversity of house designs clearly to be developed and rigorously evaluated before WSEBs could be considered for routine, programmatic deployment by national programs.

Nevertheless, the potential of this approach merits consideration, even if only speculatively at his early stage. For example, it takes almost an entire 833ml bottle of the 0.3 $g \cdot ml^{-1}$ PM formulation used here, costing almost $24, to protect just one typical rural Tanzanian house against perennial transmission for one year, through two IRS treatments of its internal surfaces (60 m^2 (24)) at the ideal recommended dose of 2 $g \cdot m^{-2}$. By comparison, a house of equivalent size with WSEBs

installed could be treated with the same insecticide at the same dosage per square meter of treated netting for only $2.15. While greater quantities of BA may be required than applied here (42), if it were to extend the life of PM on netting to the same extent as LC, and the physical structure of WSEBs themselves were also to last that long in real houses under normal operational conditions, they could potentially provide up to 3 years of protection for only $0.72 per annum in recurrent insecticide procurement costs. Scale up nationally in Tanzania would cost only $4.8M for insecticide procurement, so even a combination of three similarly expensive complementary insecticides would be affordable to the national program at <$15M annually. Corresponding global costs would be <$1.2B annually for such a triple cocktail.

While these insecticide cost estimates are entirely speculative, assume that BA will be equally efficacious for extending the longevity of PM, and do not consider costs of netting installation or maintenance, they do illustrate the potential economic benefits that could be accrued by optimizing WSEB deployment formats, netting materials and treatment formulations. More importantly, such reduced insecticide requirements might make rational resistance management (8) both feasible and affordable with existing budgets and off-the-shelf insecticide products.

Also, the observation that supplementing PM-treated WSEBs with the irritant pyrethroid LC reduced mortality rates of *An. funestus*, which were strongly resistant to pyrethroids but not organophosphates (27), suggests WSEBs could be used as an affordable format with which to field-test the theory that such combinations might select for restored pyrethroid susceptibility (37). The underlying assumption of this hypothesis is that physiological susceptibility and behavioral responsiveness to pyrethroids are genetically linked, so that insecticide combinations like the LC-PM mixture used here would selectively kill insects that are both resistant and non-responsive to pyrethroids. The case for assuming physiological susceptibility and behavioral

responsiveness are at least phenotypically associated has recently been strengthened by laboratory studies of *Culex quinquefasciatus*, demonstrating that four different pyrethroid-resistant field populations were all less responsive to the irritant properties of permethrin than a fully-susceptible laboratory colony (43). These empirical studies (43) also suggest grounds for optimism regarding the recent theory that combining recently-developed low-technology emanators for airborne pyrethroid vapor (44, 45) with complementary non-pyrethroid indoor control measures like IRS, WSEBs or alternative technologies such as eave tubes (46-48) and entry traps (49), could also co-select for physiological susceptibility and behavioral responsiveness to pyrethroids generally (50). Nevertheless, genetic linkage between physiological susceptibility and behavioural responsiveness to pyrethroids remains to be demonstrated. Also, both of the mathematical models predicting restoration of these preferred traits (37, 50), by definition, merely illustrate the plausibility of these hypotheses in mathematically explicit terms. Alternatively, it is also possible that selection for physiological resistance to both insecticides may be exacerbated by reducing contact exposure to sub-lethal levels. So while the potential benefits and risks of combining irritant pyrethroids with non-irritant insecticides from complementary classes remain to be satisfactorily assessed, the results presented here suggest that WSEBs may be a potentially scalable delivery format with which to test these hypotheses empirically through large-scale field studies.

Changing deployment format for existing IRS formulations could also eliminate the need to apply them in potentially hazardous aerosol form. While handling insecticides is always associated with some risks, so protective clothing, eyewear and breathing apparatus might be required, WSEBs may be impregnated by simply dipping in an aqueous suspension, similarly to

bed nets. WSEB deployment formats might therefore allow national programs to develop and manage their vector control platforms more flexibly than IRS.

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Biographical Sketch

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Additional file 1. The 26-day schedule applied to complete one full replicate of evaluation for duplicates of the 13 treatments of window screens and eave baffles (WSEBs), by rotating them through all of the 13 pre-sprayed experimental huts.

Additional file 2. Detailed tables describing the estimated mortality rates of both malaria vector species in houses with each of the 39 combinations of treatments for indoor residual spraying (IRS) and window screens plus eave baffles (WSEB), as well as the odds ratios, 95% confidence intervals and significance levels for contrasts between each of these WSEB treatments alone and each other and either of the IRS treatments alone.

Table 1. A summary of the thirteen different window screening and eave baffle (WSEB) treatments which were rotated through experimental huts with three different indoor residual spray (IRS) treatments. IRS treatments of the experimental huts comprized either lambda-cyhalothin (LC: 30 $mg \cdot m^{-2}$ in 4 huts), pirimiphos-methyl (PM: 2 $g \cdot m^{-2}$ in 4 huts), or the negative control (Water diluent only: 5 huts), applied to all inner surfaces of the walls and ceilings. Note that all dosages described herein are per square meter of treated netting (WSEBs) or wall and ceiling surface (IRS), so that these can be directly compared in terms of lethality and cost per unit area treated. The 26-day schedule applied to complete one full replicate of evaluation for duplicates of these 13 treatments, by rotating them through all 13 IRS-treated experimental huts, is detailed in additional file 1.

Number	Description	Eaves baffled		Windows screened	Treatment of window screen and eave baffle (WSEB) netting		
		Entrances	Exits		Lambda-cyhalothrin (LC: $mg \cdot m^{-2}$)	Pirimiphos-methyl (PM: $g \cdot m^{-2}$)	Binding Agent (BA)
1	Full negative control: No trapping or insecticide	Yes	No	No	0	0	No
2	Partial negative control: Trapping without insecticide	Yes	Yes	Yes	0	0	No
3	Partial negative control: Trapping without insecticide	Yes	Yes	Yes	0	0	Yes
4	Trapping plus long-lasting LC+BA treatment	Yes	Yes	Yes	55	0	Yes
5	Trapping plus varying dose PM treatments	Yes	Yes	Yes	0	1	No
6		Yes	Yes	Yes	0	2	No
7		Yes	Yes	Yes	0	4	No
8	Trapping plus varying dose PM treatments with BA	Yes	Yes	Yes	0	1	Yes
9		Yes	Yes	Yes	0	2	Yes
10		Yes	Yes	Yes	0	4	Yes
11	Trapping plus varying dose PM treatments with BA+LC	Yes	Yes	Yes	55	1	Yes
12		Yes	Yes	Yes	55	2	Yes
13		Yes	Yes	Yes	55	4	Yes

Figure legends

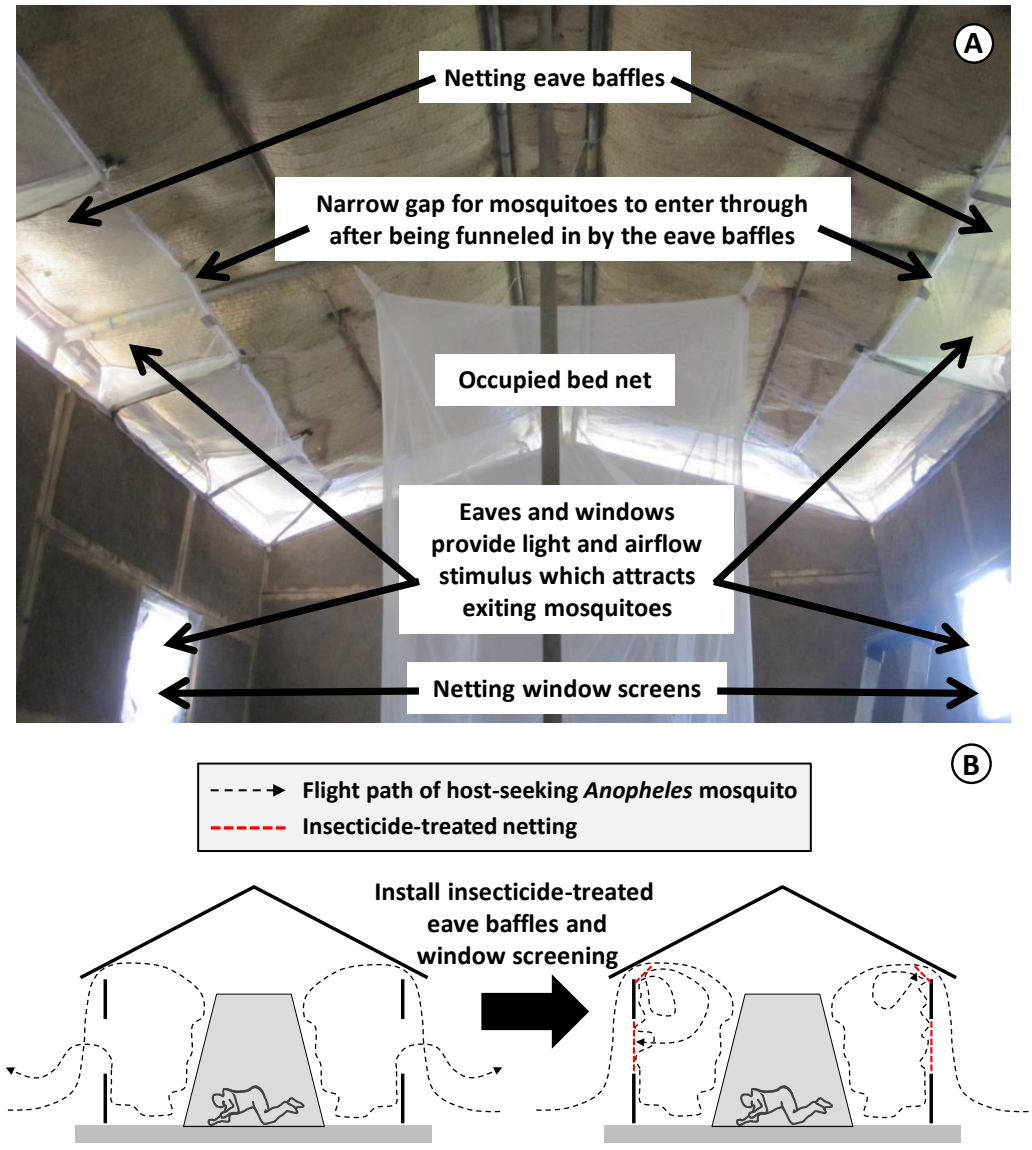

Figure 1. Design (**A**) and mechanism of action (**B**) of insecticide-treated window screens and eave baffles (WSEBs).

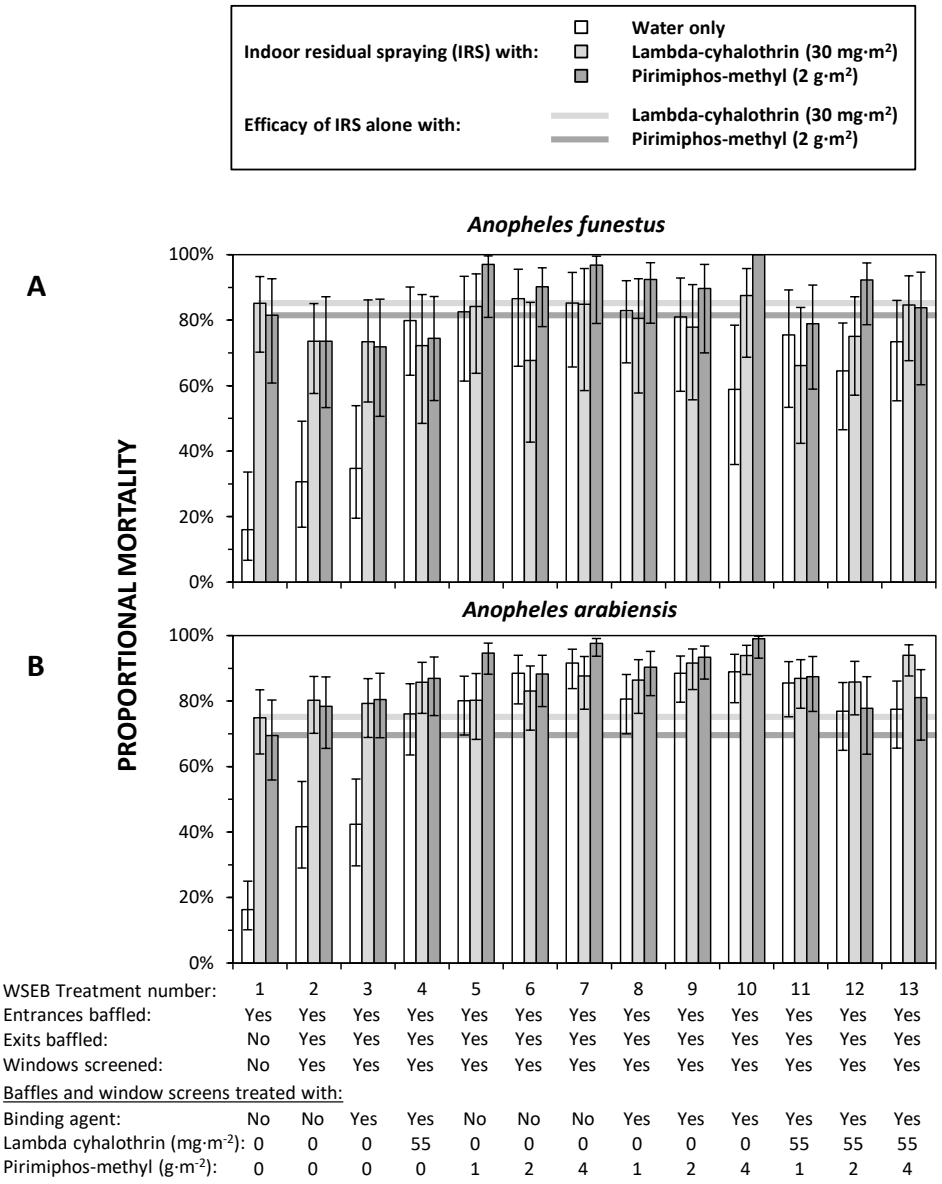

Figure 2. Impact of window screens and eave baffles (WSEBs) treated with various combinations of insecticides and binding agents (Table 1) upon malaria vector mortality inside experimental huts, which were previously sprayed with one of three alternative indoor residual spraying (IRS) regimens (Additional file 1), and occupied by two volunteers sleeping under pyrethroid-treated long-lasting insecticidal nets (LLINs). Each of these estimated mean mortality rates and confidence intervals, as well as the statistical contrasts between the most relevant treatment pairs, are presented in explicit numerical format in Additional file 2.