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Effectiveness of a transfluthrin emanator and insecticide-treated barrier screen in reducing *Anopheles* biting in a temporary shelter in Sumatra, Indonesia

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Abstract

Background The World Health Organization-approved *Anopheles* interventions target indoor biting and resting behaviour, but are impractical or inapplicable in some settings. In Jambi Province, Sumatra, Indonesia, local indigenous populations sleep under temporary tarpaulin-roofed shelters, complicating the use of bed nets and preventing the application of indoor residual spraying. Two pyrethroid-based interventions were tested alongside a no-intervention control in the field using a Latin-square design. A volatile pyrethroid spatial emanator (SE) offers an easily deployable, simple to use intervention utilizing transfluthrin, while deltamethrin-impregnated barrier screens represents a more permanent intervention.

Methods Human landing collection was used for mosquito collections throughout the study. Collections occurred near Bukit Duabelas National Park in central Sumatra, Indonesia, an area characterized by secondary forest undergoing widespread conversion to palm and rubber plantations. Collections occurred in three sites located roughly 150 m from each other, with a Latin-square rotational design to account for location and collector effects between experimental replicates. Three complete rotations were achieved over 27 collection nights (a total of 81 trap-nights). Results were analysed with a series of generalized linear models to analyse overall efficacy and the influence of location and device age.

Results *Anopheles* host-seeking activity was reduced in the presence of the SE (RR: 0.30 [0.21–0.43], $p < 0.001$) and barrier screen (RR: 0.39 [0.28–0.54], $p < 0.001$) interventions compared to control shelters over the course of the study. Similar efficacy was observed among non-*Anopheles* species. Hourly differences in behaviour were observed, and device age and location were both significant predictors of efficacy in univariate analyses, with efficacy appearing to decrease with device age. However, it was not possible to differentiate between the device age and location effects, since they were correlated due to an error in the rotational design.

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Conclusions Both interventions appeared to reduce *Anopheles* and non-*Anopheles* mosquito host-seeking behaviour, highlighting the potential of these forms of outdoor mosquito control. Considerable variation was observed between collection locations, highlighting a difficulty in study design and entomological forecasting. Due to the rotational design where the device age correlated with location, it was difficult to disentangle the relative contributions of these factors. Passive SEs and insecticide-impregnated barrier screens represent interventions that may reduce exposure and hence transmission outdoors.

Keywords *Anopheles*, Malaria, Transfluthrin, Spatial repellent, Pyrethroid, Volatile, SE, Barrier screen

Background

As *Anopheles* mosquito populations adapt and shift in response to World Health Organization (WHO) malaria interventions which target indoor transmission, outdoor transmission has become increasingly relevant and prioritized [1–8]. Outdoor transmission occurs from exposure to infective bites—and mosquito bites on infected individuals—outside domestic structures. This exposure is usually outside the protection of interventions such as long-lasting insecticidal net (LLINs) and indoor residual spraying (IRS) that specifically target indoor biting and resting behaviours. Shifts towards outdoor biting vector behaviours and minor shifts in biting patterns from late at night to earlier in the evenings and/or later in the morning are difficult to address, since no currently recommended interventions are optimized to protect people in these times and spaces [9, 10]. These gaps in protection, where new malaria infections occur, can be barriers to local malaria elimination as well as enhance the potential for rebounding transmission as mosquito behaviour and species compositions continue to adapt, or if the original intervention pressure is lightened [5, 11]. Innovative interventions are required to address mosquito behaviours which avoid existing prevention measures and sustain reductions in malaria transmission, enabling vector management efforts with tools to address relevant local behaviours.

The study area, located in the Jambi region of Sumatra, Indonesia, is a heavily forested area with high biological diversity that includes *Anopheles* species [12–15]. Many areas of the forest are in a period of transition from secondary forest to palm and rubber plantations, a trait which may increase the risk of exposure to vectors of zoonotic malaria [16]. The area is inhabited by local indigenous peoples known as the Orang Rimba. These communities are highly mobile, residing in semi-permanent forest camps in addition to frequently spending multiple nights in the forest on excursions to hunt or work [17]. Shelters in these semi-permanent camps are commonly a tarpaulin (roof) suspended between four poles with no walls. These shelters, without walls, were considered outdoor environments that offer very little physical protection from the forest environment and host-seeking mosquitoes. Despite some practical difficulties in deploying them within the shelters and transporting the nets when camps are moved, LLINs are generally deployed to this population and more than 80% of adults reported using them in a field trial (Syafruddin, Pers. Comm.). *Anopheles* in the area tend to be active throughout the night, including times when people may not be under their net [12]. Success of malaria elimination efforts in the province are mixed, with a low reported overall annual incidence rate of 0.01 per 1000 people, and only 63.6% of districts reported elimination in 2021 [18]. The contribution of outdoor biting to this transmission rate is unknown, but the combination of human lifestyles and local vector behaviours create an environment where traditional interventions are difficult to deploy and most exposure is outdoors (due to the lack of an "indoor" roofed and walled environment).

This study seeks to evaluate two alternative interventions with potential to interrupt *Anopheles* host-seeking behaviour in these open and outdoor forest shelters. A volatile pyrethroid spatial emanator (SE) product was investigated which could provide protection to the typical structures in the study area. This product is designed to passively emanate the active ingredient from a stationary location, lasting up to at least a month. The product is a proprietary design by Widder Bros Inc., using a transfluthrin active ingredient which has been demonstrated in previous studies to be effective in reducing survival and landing rates in laboratory, semi-field, and field conditions with laboratory-reared and wild *Anopheles* and other biting invertebrates [19–21] [Syafruddin Pers. Comm., Widder Pers. Comm.]. This design may offer direct protection via a repellency mode of action and a community effect via mortality and reduced fitness of exposed mosquitoes [20, 22–24]. The transfluthrin active ingredient in the SE has displayed efficacy in previous studies against *Anopheles* mosquitoes, including mosquitoes resistant to other pyrethroids [25–31]. This tested SE product and other spatial repellents utilizing transfluthrin have shown promise in reducing the host-seeking activity of malaria and non-malaria vectors, although limited evidence has been generated in Southeast Asia [14, 32]. SEs do not rely on a specific mosquito behaviour such as indoor, late-night biting, instead providing localized protection which is expected to peak closest to the device and gradually decrease as the concentration of the active ingredient diminishes with distance. In addition to general usage as an entomological intervention, SEs appeals to various use-cases, such as for military deployment, acute epidemic responses, or recreational purposes.

This SE product was directly compared to a no-intervention control and a second product, which utilizes a pyrethroid treated screening material (formerly called ZeroFly, Vestergaard Frandsen) to create an insecticide-treated physical barrier around the entire shelter (i.e., by creating barrier screen walls for the structure). Insect impregnated barriers (using Zerofly) were evaluated in the Solomon Islands (Lobo, unpublished) where an impact on *Anopheles* and flies was observed in a community-based trial. Several studies have documented the impact of vertical mesh barriers on vectors [33–36]. The inclusion of an intervention arm with this product is to provide a comparison of the SE to a product providing direct personal protection via a physical barrier in addition to the chemical barrier [37–40].

The direct protection offered by these two interventions was investigated by comparing the host-seeking rate—as measured by overnight human landing collection (HLC)—associated with each intervention compared to a no-intervention control [41]. A 3×3 Latin-square design enabled direct comparison between the two tested interventions and an untreated control structure. Latin-square designs are frequently used in trap comparison studies to account for location and collector/attractant effects (if applicable) [15].

Methods

Ethics approval

This study was approved by the Ethics Committee for Medical Research, Faculty of Medicine, University of Hasanuddin, Makassar, Indonesia, and the University of Notre Dame Institutional review board (Protocol #: 18-05-4675).

Study location

The study was conducted in Jambi Province in central Sumatra, Indonesia. The study site contained 11–14 structures occupied by local Orang Rimba people. The local environment was a mixture of secondary forest and palm plantation with multiple potential mosquito larval sites identified near the collection sites. A map of the area is shown in Fig. 2. The study site was located at an elevation of 50–100 m above sea level, in an area of palm and rubber plantations in the interior of Sumatra. This type of habitat is generally typical of the broader region, which is characterized by secondary forest in various stages of conversion to palm or rubber plantations. The study location was chosen after data from an immediately preceding field trial—where this location served as a control site—revealed consistent mosquito activity.

Structures and rotational design

Three shelters that mimic the open-walled households in the area were constructed for use in the study (Fig. 1). Each was constructed using four structural poles, a tarpaulin roof, and rope guy lines. They measured roughly 3 m by 3 m, with the roof tied at a height of 2 m along the centre peak. To minimize residual active contamination effects between treatments, each structure was assigned a single treatment for the duration of the study. A Latin-square rotational design was employed between the three structures to minimize the collector and location effects in determining device efficacies. Between every collection night, collectors would rotate between structures, completing a rotation after three collection nights. After every third collection night (one complete rotation of collectors, with the collectors spending one collection night in each location), the structures and their attached intervention were rotated between locations and the collector rotation was completed again over the ensuing three collection nights. Thus, over the course of nine collection nights, each combination of trap location and collector was achieved once (one primary rotation). This rotation strategy was repeated a total of three times for a total of three complete rotations over twenty-seven trap nights. A fresh SE device was used for each primary rotation.

Fig. 1 Picture of structure used for study mosquito collections, deployed with screening material. For this photograph, the screen has been pulled up slightly to allow entry and exit between trial replicates

Fig. 2 Map of the study area displaying collection locations (L1–L3), breeding sites, and local occupied structures

Mosquito collections

Mosquito collections took place every other night between May 24 and July 15, 2021. Human landing collection (HLC) was used for all mosquito collections, between 18:00 and 06:00 on designated collection nights. On these nights, a collector sat inside each shelter and captured mosquitoes that landed on their legs, depositing captured mosquitoes into labeled cups by hour. Every hour, captured mosquitoes were transferred to the field station, counted, identified to genus, and preserved in Eppendorf tubes with desiccant beads for future investigations.

SE product description and placement

The SE product is a volatile pyrethroid spatial repellent product designed to be used in both indoor and outdoor settings. The design is proprietary, and was a prototype version of the PIC® BITEBARRIER® product, which has a recommended lifetime of 21 days. Each product consisted of 1.5 g of transfluthrin active ingredient in two thin 30×30 cm sheets hung via twine, with one device deployed to each structure. The devices were placed along the central peak of the tarpaulin roof, 1.5 m above the ground, with each sheet placed on different sides along the centre of the shelter, each roughly 15 cm from the two open sides at opposite ends of the peak centerline.

Barrier screen

The barrier screen is a now discontinued deltamethrin-impregnated fine synthetic netting material manufactured by Vestergaard Frandsen. It is a polyethylene mesh fabric with Deltamethrin insecticide incorporated (4 g active ingredient/kg textile) into the fibre polymer, with a 2-year shelf life. It is designed for long-lasting efficacy, providing a product lifespan of at least a year, depending on environmental conditions. For installation in the shelters, the barrier screen was fitted to the wooden supports of the shelter itself to ensure complete coverage. Small (<10 cm) gaps may have been present between the bottom of the screen and the ground due to vegetation and uneven ground.

Data analysis

The outcome for all model analysis was the human landing rate as measured by HLC. Generalized linear models were generated for nightly biting rates and mixed effect GLMs were employed for hourly biting rates. Nightly models included a logarithmic link function with a negative binomial underlying distribution following confirmation of overdispersion in a Poisson-distributed model. Hourly biting rates were modeled using the Poisson distribution since overdispersion was not observed. All models were assessed for the inclusion of random and fixed effects by likelihood ratio testing, with collection date included as a random effect and location, device age, collector, hour/period of the night (in hourly models) and weather variables as fixed effects. Interactions between location and device age with treatment status were investigated in separate models. All data cleanup and analyses were performed in R version 4.2.2. Data cleanup and validation was performed with the 'dplyr' and 'tidyr' packages and visualized using the 'ggplot2' package. Models were fitted using the 'lme4' and 'arm' packages and assessed using tools within the 'DHARMa' and 'blmeco' packages.

Results

Site weather conditions

The average temperature was 25.0 °C (SD: 1.8) throughout nightly collections; linear models indicated a very slight (0.02 °C per night, $p < 0.001$) seasonal decline (Fig. S1). Relative humidity increased throughout the study (0.27% per night, $p < 0.001$), with an average value of 76.4% (SD: 5.3). Neither temperature nor humidity were significantly correlated with *Anopheles* host-seeking activity.

Anopheles mosquito host-seeking activity

A total of 204 *Anopheles* mosquitoes were captured across 27 collection nights in three structures (81 total trap nights). Of these, 121 (59.3%) were captured in the control structure, an average of 4.5 per night (Table 1). The majority (76.5%, $n = 156$) of *Anopheles* were morphologically identified as *Anopheles letifer*, and a total of 87.3% ($n = 178$) of all *Anopheles* were members of Group Umbrosus, with the remaining identified as members of Group Hyrcanus ($n = 7$) or unable to be identified ($n = 19$) (Table 2). Most mosquito host-seeking activity occurred before midnight, with 36% of total captures occurring between 18:00 and 21:00 and an additional 44% occurring between 21:00 and midnight (Fig. 3). This nightly temporal effect was best captured in models using a binary predictor variable of first half versus second half of the night. These models predicted an hourly mosquito host-seeking activity rate of 0.54 [0.35–0.82] ($p = 0.004$) in the first half of the night; hourly host-seeking activity was reduced in the second half of the night (Relative Rate: 0.16 [0.09–0.31], $p < 0.001$). The host-seeking activity after midnight was slightly higher in the SE structures (38.9%) compared to controls (16.5%) and screened structures (14.9%).

Table 1 Total counts of *Anopheles* mosquitoes captured during Latin-square collections

# *Anopheles* captured		Location			Collector			Quarter of night			
Treatment	Total	L1	L2	L3	C1	C2	C3	Q1	Q2	Q3	Q4
Control	121	46	44	31	28	41	52	42	59	15	5
Screen	47	11	16	20	17	23	7	18	22	6	1
SE	36	30	4	2	16	16	4	13	9	12	2
Total	204	87	64	53	61	80	63	73	90	33	8

Overall totals are displayed to the left, with location, collector, and nightly behavioural trends displayed from left to right in subsections

Table 2 Morphological identification of collected *Anopheles* mosquitoes

Anopheles species	Total	Treatment			Location			Quarter of night			
		SE	Screen	Con	L1	L2	L3	Q1	Q2	Q3	Q4
An. nitidus/sinensis	1	–	–	1	–	–	1	–	–	–	1
An. sinensis	1	–	1	–	–	–	1	1	–	–	–
Hyrcanus Grp	5	1	1	3	–	2	3	3	1	–	1
An. letifer	156	32	30	94	73	47	36	58	70	24	4
An. umbrosus	17	2	8	7	6	7	4	4	7	5	1
Umbrosus Grp	5	–	2	3	3	–	2	3	2	–	–
Unidentified	19	1	5	13	5	8	6	4	10	4	1
Total	204	36	47	121	87	64	53	73	90	33	8

Group Hyrcanus mosquitoes are displayed at the top, with Group Umbrosus mosquitoes below. Species compositions are displayed by treatment, location, and nightly quarter

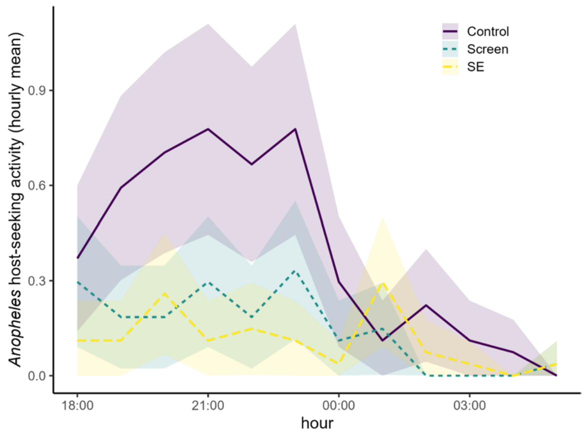

Fig. 3 Hourly host-seeking activity of *Anopheles* mosquitoes. Lines denote hourly means, with ribbons representing upper and lower 95% confidence intervals. Lines and ribbons are colored by intervention, and lower bounds of confidence intervals are truncated at 0

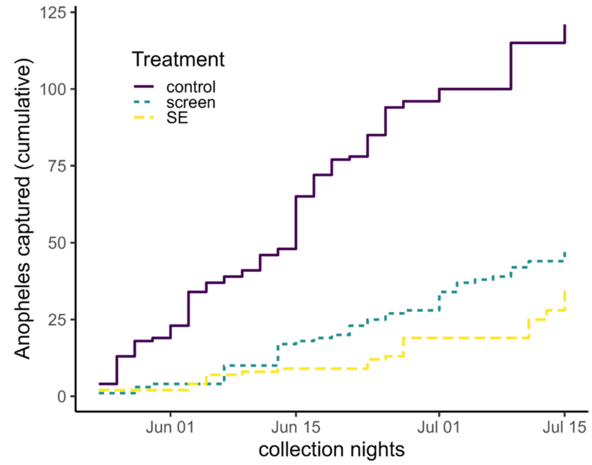

Fig. 4 Cumulative nightly *Anopheles* captures during Latin-square follow-up by treatment. Lines represent the total cumulative number of mosquitoes encountered in each type of structure throughout the course of experimental nights. Each line represents a control or treatment structure

Host-seeking activity was consistent throughout the study and the collection date was not a significant fixed effect in any model. Adding the collection date as a random effect significantly improved the model of hourly mosquito host-seeking activity but resulted in singular fits when modeling nightly host-seeking activity. Temperature and relative humidity did not significantly influence *Anopheles* host-seeking activity in any model.

Intervention efficacy

Fewer overall numbers of *Anopheles* were captured in structures protected by the barrier screens ($n = 47$) and SE ($n = 36$) interventions (Fig. 4). Both represent significant reductions in nightly mosquito landing activity compared to the 121 *Anopheles* captured in control structures (Screen RR:0.39 [0.28–0.54], $p < 0.001$; SE RR: 0.30 [0.21–0.43], $p < 0.001$). These predicted nightly effects are nearly identical in models of hourly mosquito landing rates; full exponentiated model coefficients for nightly and hourly mosquito host-seeking activity are displayed in Table 3. Location and collector were not significant predictors in univariate analysis of these factors by night or hour (Figs S2–S3). There was no significant difference between the efficacy of the two interventions overnight ($p = 0.402$) or by hour ($p = 0.183$).

Models are constructed for nightly (A) and hourly (B) *Anopheles* mosquito host-seeking activity based on SE and screening treatment status. Coefficients have been exponentiated for ease of interpretation, with the intercept relating to the predicted number of control mosquito captures over each period and the coefficients representing rate ratios associated with the treatment. Each rate ratio is in comparison to the control, with an additional coefficient in hourly models comparing behaviour in the second half of the night to behaviour in the first half. Degrees of freedom and AIC are presented for the fitted model with the corresponding null model value presented in parentheses.

Interaction models

Additional models were generated to investigate interactions between treatment status and other predictor variables. There was no significant difference in the efficacy of the barrier screens by location, while the SE displayed significantly higher efficacy in locations 2 and

Table 3 Model outputs for base models fitting *Anopheles* mosquito host-seeking activity

Modelled endpoint	(a) Nightly host-seeking		(b) Hourly host-seeking	
Underlying distribution	Negative binomial		Poisson	
Fixed effects				
(Intercept)	4.48 [3.00–6.96]	<0.001	0.51 [0.37–0.69]	<0.001
Treatment (screen)	0.39 [0.21–0.73]	<0.001	0.39 [0.28–0.54]	<0.001
Treatment (SE)	0.30 [0.15–0.57]	<0.001	0.30 [0.21–0.43]	<0.001
Second half of night	–		0.25 [0.18–0.35]	<0.001
Random effects				
Collection date	–		1.80	
Degrees freedom	78 (80)		967 (971)	
AIC	330 (341)		1042 (1200)	

3 (Table S1). A similar interaction is observed between treatment and device age, with SE devices predicted to have very high efficacy when first opened (RR: 0.05 [0.01–0.17], $p<0.001$) that depletes significantly per day (daily RR: 1.22 [1.07–1.41], $p=0.005$; Table S2). The barrier screen age has no significant effect on efficacy (daily RR: 1.03 [0.94–1.12], $p=0.530$; S2 Table). Treatment efficacy did not significantly interact with collector, overall study visit, or weather variables.

Effects on non-*Anopheles* species

A total of 3257 non-*Anopheles* mosquitoes were captured during the study period, constituting 94.1% of the total collection (Table 4). The efficacy was comparable to the efficacy observed towards *Anopheles* species for both the SE (RR: 0.30 [0.17–0.54], $p<0.001$) and barrier screening (RR: 0.45 [0.25–0.80], $p<0.001$) interventions (Table S3). Location effects were observed with these species, with a different pattern of interaction between the two variables than observed in with *Anopheles* species (Table S4). SE device age had a similar effect on non-*Anopheles* as on *Anopheles,* while the screening material decreased in efficacy over time for non-*Anopheles* captures only (Table S5).

Discussion

The efficacy model serves as the primary analysis for this study, attributing both the volatile pyrethroid spatial emanator (SE) and physical barrier screen with ~60 to 70% reduction in *Anopheles* host-seeking activity overall compared to no treatment controls. While the SE treatment resulted in the fewest number of overall captured *Anopheles,* the difference between the SE and the barrier screen intervention was not significant on a per-night or per-hour basis. These results align with those of other studies of this SE device in Zambia and elsewhere, with this study following a clustered field trial conducted in the same location which displayed a similar overall estimate of SE efficacy [21]. Interaction models offer additional insights into the data, but due to errors in the rotational study design, the factors in the models (location and device age) correlate with each other. These factors should be considered secondary analysis since they were outside the original scope of the study design. They are included as the two best possible explanations for variation in the data as determined by model fit but, due to their correlation, neither was included in the final efficacy estimates.

The *Anopheles* species in the study were predominantly *An. letifer* of Group Umbrosus, a recently incriminated vector of zoonotic *Plasmodium* parasites [42]. The remaining species have not been directly implicated in malaria transmission, but were identified as members of Group Hyrcanus and Group Umbrosus, both of which include species implicated in malaria transmission in southeast Asia [43, 44]. Efficacy was not calculated specifically for each species, but fewer of each were found in SE structures compared to the control. In all locations, raw numbers of *Anopheles* and non-*Anopheles* mosquitoes were lower in treatment structures compared to control. The location interaction models indicated a significant effect of the SE on *Anopheles* host-seeking in two of three locations. It is not clear why this location effect was observed, with no apparent differences between study sites hypothesized to impact SE efficacy. Proximity to preferred larval or resting sites, or wind direction may have influenced the number of *Anopheles* in the specific location. These devices had a significant impact on non-*Anopheles* host-seeking regardless of location and displayed unique patterns of location-device interaction compared to *Anopheles* mosquitoes, suggesting that there might be an influence of location on species-specific mosquito behaviours. The efficacy of the barrier screen did not significantly vary by location for *Anopheles*, but there were significant location differences for non-*Anopheles* species. This interaction model highlights the possibility of location-specific effects and variability in mosquito behaviour during this study on a small scale but is limited and could be better captured by increasing the number of rotations or by adding an additional control structure as a 4×4 rotation, both options which require a considerable number of additional collection nights. Understanding this variation in mosquito host-seeking activity and device efficacy between locations

Table 4 Total counts of non-*Anopheles* mosquitoes captured during Latin-square collections

# Non-*Anopheles*		Location			Collector			Quarter of night			
Treatment	**Total**	**L1**	**L2**	**L3**	**C1**	**C2**	**C3**	**Q1**	**Q1**	**Q1**	**Q1**
Control	1861	1109	316	436	459	728	674	876	515	312	158
Screen	833	292	243	298	405	316	112	346	239	166	82
SE	563	455	55	53	216	206	141	229	153	125	56
Total	3257	1856	614	787	1080	1250	927	1447	904	600	296

Overall totals are displayed to the left, with location, collector, and nightly behavioural trends displayed from left to right in subsections on a small scale is important to projecting intervention impacts. It is also important to understand localized risk factors related to *Anopheles* behaviour for individuals, and the interaction of interventions with the environment (e.g., wind direction, local flora).

Mosquito host-seeking activity was steady throughout the study period, and followed slight overall trends related to temperature and humidity. However, these weather variables were not significant in any model containing an additional parameter (such as treatment status). The per-hour host-seeking activity was also considered to clarify overall patterns of behaviour at the study site. The hour was included as a random intercept term to account for hourly variation. Hour was also investigated as a fixed effect, with the model indicating that hourly host-seeking activity would decline per hour throughout the night. The half of the night proved to be a slightly better predictor of *Anopheles* host-seeking activity than the hour, since mosquito host-seeking activity was not linear and 80% of all *Anopheles* host-seeking activity occurred in the first 6 h of the night. This nightly behavioural decline was more linear among non-*Anopheles* and was modeled as a per-hour predictor for these mosquitoes.

The final secondary analysis describes the relationship of treatment with the age of the treatment devices. The SE was replaced during each rotation, with a maximum tested age of 16 days, while the barrier screen treatment was kept in place across treatments and was tested up to a maximum of 51 days after first use. A strong negative correlation was observed between the age and efficacy of SE devices, with models predicting no effect of SE devices by their oldest collection timepoint. However, this age parameter for the SE devices correlates with the location, presenting difficulty in choosing one model over the other. The dramatic reduction in efficacy over a two-week testing period does not align with results of previous studies of this SE device which show less or no significant age-related decline over longer testing periods up to five weeks. This includes a field trial involving this and other locations which showed no significant decline in SE efficacy throughout the replacement interval [21].

The overall estimate of efficacy attributed to the SE device aligns with results observed in other recent studies of the device and other results from recent studies of other transfluthrin-based interventions [19, 27, 32, 32]. Most of the previous studies of transfluthrin based spatial repellents have been conducted in African countries, with few studies taking place in southeast Asia amid distinct and highly diverse vector populations [14, 20, 27, 32]. A limitation of this study is the lack of data directly measuring the efficacy of the active ingredient in the SE devices over time. Measuring the concentration, or measuring mortality of susceptible laboratory mosquitoes, before and after the study would provide valuable insight into the duration of effect. Additionally, the insecticide resistance status of the local mosquito population was not determined. This was excluded because no resistance has been reported from this area (Syafruddin, pers. comm.) and previous reports that resistant mosquitoes are impacted by volatile transfluthrin [45]. Though endpoints that result in community effects were not measured in this study, semi-field studies with the same product have demonstrated impacts such as disarming (temporary inhibition of host-seeking/feeding behaviour), feeding inhibition and mortality, pointing to community protection [24]. Later biting times in SE structures may be an indication of deterred biting which could result in diversion to unprotected structures in a field setting—this effect was not measured in this study. Previous laboratory, semi-field, and field studies of transfluthrin and the SE devices have indicated that mosquito mortality is increased after exposure, an important contributor to community protection through overall reduction in population fitness and age structures. This could be measured in intensive entomological field trials by measuring survival rates of captured mosquitoes in addition to employing other sampling methods to further understand vector behaviour to these interventions. For example, barrier screen trapping can be employed to identify repellency action and determine the survivability of mosquitoes which resist the intervention to feed and are returning to their resting habitats [46, 47]. These measurements would improve understanding of personal efficacy and greatly contribute to an estimate of community effect provided by these interventions.

Conclusions

The results of this study indicate that the SE provides protection from zoonotic malaria transmitting mosquitoes among local inhabitants in a forested setting in Jambi, Indonesia. The efficacy of the SE was comparable to an outdoor, physical insecticide-treated barrier, with both interventions associated with lower *Anopheles* and non-*Anopheles* host-seeking behaviour across the two-month study period. The landing reduction associated with both interventions extends to non-*Anopheles* species and could be useful in preventing arboviral transmission and nuisance biting. The SE should continue to be investigated in challenging conditions to further understand the longevity of effect, but these results add to the evidence that the devices provide significant protection to host-seeking *Anopheles* and non-*Anopheles* mosquitoes.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12936-025-05285-x.

Additional file 1.

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Author contributions

T.A.B. wrote the main manuscript text, prepared all manuscript materials, and performed statistical analysis. L.S., D.H.P., I.E.R., R.R., S.Z., S.Z., M.M.M., R.E., M.K. collected, validated, and analyzed data. P.B.S.A., D.S., N.F.L. conceived the study and secured funding. All authors were involved in study design and planning, and all authors reviewed the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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