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Short-Term Changes in Mosquito Indicators Following an Integrated Control Package in Coastal and Mining Areas of Jambi Province: A Controlled Before-and-After Field Study

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ABSTRACT

Coastal pools and water-filled mining excavations may sustain mosquito breeding and malaria receptivity after local elimination. This study aimed to compare short-term changes in mosquito-catch, larval, and household behavior indicators between nonrandomized intervention and control clusters after implementation of an integrated mosquito-control package in Jambi Province, Indonesia. A controlled before-and-after field study was conducted in four geographical clusters comprising 200 households, with one intervention and one control cluster in each of two ecosystems (coastal and mining). The seven-day package combined community mobilization, habitat management, ultraviolet mosquito traps, and a 3% aqueous duku peel preparation, with seven nights of standardized observation before and immediately after implementation. The primary outcome was adult mosquito catch per valid trap-night; larval indices and household vector-control behavior were secondary outcomes, and household-level model estimates were treated as exploratory. In intervention clusters, the House Index changed from 28.0% to 12.0%, the Container Index from 18.0% to 7.0%, and the Breteau Index from 42 to 17, compared with 27.0% to 25.0%, 17.0% to 16.0%, and 40 to 38 in control clusters. Adult mosquito catch changed from 1.34 to 0.60 per valid trap-night in intervention clusters and from 1.31 to 1.24 in control clusters (model-based incidence rate ratio 0.48), and the behavior score rose from 58.4 to 80.6 versus 59.1 to 61.3. The package was associated with favorable immediate changes in entomological and behavior indicators; however, the nonrandomized four-cluster design, dual use of ultraviolet traps for intervention and measurement, multicomponent package, and brief follow-up preclude attribution to individual components or conclusions about sustained mosquito abundance or malaria transmission.

Keywords: Community mobilization; Duku peel; Entomological surveillance; Integrated vector management; Mosquito trap

INTRODUCTION

Persistent mosquito-breeding habitats present an environmental management challenge in Indonesia's coastal and mining communities, including areas approaching or maintaining malaria elimination. Indonesia reported 418,546 malaria cases in 2023, with an annual parasite incidence of 1.5 per 1,000 population; although 92% of cases occurred in the Papua region, outbreaks were also reported in low-transmission and malaria-free areas (Kementerian Kesehatan Republik Indonesia, 2024). These patterns highlight the importance of addressing both imported infections and ecological conditions that could support local transmission. Supporting this concern, an Indonesian study combining surveillance data from 2021–2023 with entomological observations documented imported malaria cases alongside the presence of potential vectors, including coastal *Anopheles sundaicus* populations, in East Java (Ngadino et al., 2024). Thus, elimination status does not remove the need to monitor potentially receptive environments. Maintaining environmental surveillance alongside case surveillance is consistent with the continuing role of vector control in elimination programmes (Wilson et al., 2020).

This concern is relevant to Jambi Province, where provincial health authorities documented indigenous malaria cases in Batang Hari in 2022, indicating that recent local transmission remained a programmatic challenge (Dinas Kesehatan Provinsi Jambi, 2023). Within the present research project, preparatory mapping identified brackish coastal pools in Tanjung Jabung Barat and persistent water-filled mining excavations in Batang Hari as priority mosquito habitats. These project observations establish the operational rationale for selecting the study environments, although habitat presence alone does not demonstrate malaria-vector competence or ongoing transmission. Evaluating locally feasible mosquito-management activities

in these contrasting environments may therefore inform environmental surveillance and control planning without presuming a corresponding reduction in malaria risk. In another Sumatran mining setting, breeding-site availability was associated with malaria occurrence among workers in Muara Enim, supporting attention to mining-related aquatic habitats without establishing the risk level in the present Jambi clusters (Hasyim et al., 2023).

Recent empirical evidence indicates that community participation and larval source management can improve entomological outcomes, but their additional benefits vary across settings. In rural south-eastern Tanzania, Mapua et al. (2024) trained community volunteers to identify aquatic habitats and apply *Bacillus thuringiensis israelensis*. Their small-scale field evaluation reported reductions of 46.3% in indoor adult *An. funestus* abundance and 74% in late-instar larvae. Conversely, an 18-cluster randomized trial in Malawi found no detectable additional reduction in entomological inoculation rate, mosquito density, or parasite prevalence from community-based house improvement, larval source management, or their combination when added to existing interventions and intensive community engagement (McCann et al., 2021). These contrasting findings indicate that operational feasibility and favorable larval responses do not necessarily translate into additional population-level or epidemiological benefits. A related community-participation study in Malawi documented reduced anopheline larval densities after larviciding while highlighting the importance of implementation and participation (Gowelo et al., 2023).

Field studies also demonstrate opportunities and limitations in integrating adult mosquito trapping with community action. In residential Valencia, Spain, the NESCOTIGER intervention combined resident-operated traps, treatment of public breeding sites, and educational activities; findings supported the potential of integrated community-based management of *Aedes albopictus*, although associations between trap deployment and mosquito outcomes differed among trapping approaches (López-de-Felipe et al., 2025). However, these results concern residential *Aedes* control and cannot establish the performance of ultraviolet traps in malaria-relevant coastal or mining environments. In Bangkok, Pimnon et al. (2022) collected 6,929 mosquitoes during 72 collection nights and found that fluorescent light traps outperformed the tested ultraviolet light-emitting diode traps. Collections were predominantly *Culex*, with relatively few *Anopheles*. Consequently, trap catch depends on device characteristics and mosquito composition and should not be interpreted directly as ambient mosquito density or infectious exposure.

Botanical preparations provide another experimental component, but evidence must be interpreted in relation to formulation, concentration, and target species. Yunus and Rosanty (2024) tested *Lansium domesticum* preparations against *Ae. aegypti*, using concentrations of 10%–50% for repellency and 20%–100% for larvicidal assessment. Repellency exceeded 50% across the tested concentrations, whereas the highest tested concentration produced the greatest larval mortality. These experimental findings provide a rationale for further investigation, but they do not validate a 3% aqueous duku peel preparation under household field conditions or establish activity against local malaria vectors. The preparation evaluated here therefore represents an operationally selected complementary component whose independent efficacy remains undetermined. A published community-engagement project in Muara Kumpeh, Jambi, also described using duku peel waste in mosquito-repellent candles, but did not establish the efficacy of an aqueous preparation in mosquito-control field trials (Chandra et al., 2023).

The studies reviewed address community-led habitat management, integrated residential *Aedes* control, ultraviolet trap performance, and botanical activity under different ecological and experimental conditions. They do not directly establish how a package combining community mobilization, habitat management, ultraviolet mosquito traps, and an aqueous duku peel preparation performs across both coastal and mining environments. The specific gap concerns the short-term operational performance of this combination, rather than the absence of research on its individual components. This study contributes an exploratory controlled before-and-after evaluation in four nonrandomized geographical clusters, with one intervention–control pair per ecosystem. Its contribution is limited to observed entomological and household behavioral changes; the design cannot isolate component effects, establish sustained mosquito suppression, or demonstrate malaria prevention.

This study aimed to compare before-and-after changes in adult mosquito catch per valid trap-night as the primary outcome, and house, container, and Breteau indices and household vector-control behavior as secondary outcomes, between clusters receiving community mobilization, habitat management, ultraviolet mosquito traps, and a 3% aqueous duku peel preparation and contemporaneous control clusters in coastal Tanjung Jabung Barat and mining-area Batang Hari, Jambi Province.

METHODS

Study Design

A controlled before-and-after field study with repeated household measurements was conducted in four geographical clusters: one intervention and one control cluster within each ecosystem. The geographical cluster was the treatment-assignment and effective experimental unit; households and their peridomestic environments were repeated measurement units nested within clusters. Allocation was nonrandomized and based on operational feasibility and geographical separation. Consequently, the design cannot reliably distinguish the package-associated change from unmeasured cluster-specific ecological or social characteristics. Reporting was guided by the TREND principles for nonrandomized public-health interventions (Des Jarlais et al., 2004).

Study Setting and Period

The broader research project was conducted from March to August 2026 in coastal villages of Tanjung Jabung Barat Regency and villages surrounding mining excavations in Batang Hari Regency, Jambi Province. Preparatory activities included habitat mapping, intervention development, and field planning. The field intervention was implemented for seven days and was preceded and followed by seven nights of standardized entomological observation. Sites were selected based on prior mapping that identified persistent larval habitats.

Population and Sample

The target population comprised households located in coastal and mining ecosystems with potential mosquito-breeding habitats. The study included 200 households: 100 intervention households and 100 control households, with 50 households per study arm in each regency. Respondents were adult household members responsible for environmental management.

Sampling and Group Allocation

Villages were selected purposively after project mapping identified persistent larval habitats and operationally feasible surveillance areas. Within each regency, candidate clusters were reviewed for ecosystem type, settlement pattern, accessibility, routine malaria-control activities, presence of standing-water habitats, and feasibility of placing traps. One intervention and one control cluster were then selected and assigned nonrandomly on operational grounds; the control cluster was located at least one kilometer from the intervention cluster to reduce direct contamination. Households were selected systematically from primary health-center or village lists. Household-level baseline characteristics and baseline mosquito-catch rates were similar descriptively, but environmental equivalence was not established statistically and cannot be assumed. With only one intervention and one control cluster in each ecosystem, any ecosystem-specific treatment contrast is inseparable from the characteristics of the particular clusters selected.

Intervention

The intervention clusters received a seven-day integrated mosquito-control package comprising community mobilization, identification and management of potential mosquito-breeding habitats, filling or draining manageable standing-water sites, clearance of obstructed drains and excessive vegetation, and operation of one ultraviolet mosquito trap per participating household. Each trap was operated from 18:00 to 06:00 for seven consecutive nights. Field workers visited participating households daily to inspect trap operation, reservoir condition, household adherence, habitat-management activities, and any adverse events or complaints.

The liquid duku peel preparation was produced by adapting the method reported by Januariana et al. (2018). The 3% concentration was defined on a weight-to-volume basis as 30 g of dried duku peel powder per 1,000 mL of clean water. This concentration corresponded to the 30 g/L treatment evaluated in the previous experimental study. In that study, concentrations of 25, 30, and 35 g/L were evaluated in mechanical mosquito traps, with mosquito mortality increasing with concentration and exposure duration. The 30 g/L concentration was selected for the present field intervention as an intermediate concentration intended to provide operational feasibility while limiting the amount of botanical material introduced into household environments (Januariana et al., 2018).

Ripe duku fruit peels (*Lansium domesticum* Corrêa) were collected from locally available duku fruit in Jambi Province. The peels were separated from the remaining fruit material and inspected to remove visibly decomposed or contaminated material. They were then dried under direct sunlight until their moisture content had visibly decreased and the peels had become firm and stiff. The partially dried peels were cut into smaller pieces using a clean stainless-steel knife and subsequently sun-dried again until completely dry. The dried material was ground using a clean electric blender to produce a relatively homogeneous powder.

For each batch, 30 g of dried duku peel powder was weighed using a calibrated digital scale and mixed with 1,000 mL of clean water, producing a nominal concentration of 3% w/v. The mixture was stirred until the powder was evenly dispersed and was allowed to soak before use. Because this procedure involved aqueous soaking without solvent extraction, evaporation, or concentration, the material is more accurately described as a 3% aqueous duku peel preparation rather than a purified duku peel extract. No ethanol, methanol, n-hexane, emulsifier, preservative, or other organic solvent was added.

The preparation was made in clean, covered containers and was protected from direct sunlight and environmental contamination before distribution. The prepared liquid was used during the designated field-application period and was not retained beyond the prespecified daily replacement schedule. Before application, the mixture was stirred again to redistribute suspended plant material. The same preparation procedure, weighing equipment, water source, mixing container, and distribution procedure were used throughout the intervention period to reduce variation between batches.

A standardized volume of the 3% aqueous preparation, as specified in the field protocol, was placed in the reservoir of each ultraviolet mosquito trap. The reservoir preparation was replaced once daily during field-worker visits or earlier when the liquid had spilled, become visibly contaminated, developed an abnormal odor or appearance, or declined below the operational reservoir level. The remaining liquid and collected mosquito material were removed by trained field workers and disposed of away from drinking-water sources, food-preparation areas, drainage channels leading directly to surface water, and locations accessible to children or domestic animals.

Application outside the trap reservoirs was restricted to selected, non-potable standing-water habitats that could not be immediately drained, filled, covered, or removed.

The preparation was not applied to drinking-water containers, cooking or food-storage areas, bathing-water sources, wells, aquaculture ponds, animal drinking vessels, or habitats readily accessible to children. Environmental management remained the preferred response for manageable standing-water habitats; the botanical preparation was used only as a complementary component of the integrated package.

Personnel involved in preparation and application used gloves and followed hand-hygiene procedures. Daily monitoring included checks for spills, skin irritation, respiratory complaints, accidental ingestion, unpleasant odors, damage to trap components, and household refusal or discontinuation. Any preparation showing visible fungal growth, marked discoloration, putrefactive odor, or other signs of deterioration was discarded and replaced. No adverse effects were attributed to the preparation during the seven-day intervention period.

The control clusters continued routine malaria-program activities and underwent the same scheduled entomological observations but did not receive the integrated study package during the seven-day intervention period. Additional mosquito-control activities received or independently undertaken by households in either study arm were recorded as potential co-interventions.

All intervention components were implemented concurrently. Consequently, the study evaluated the short-term association of the integrated package with mosquito-trap yield, larval indices, and household behavior. It was not designed to determine the independent effect of the 3% duku peel preparation, ultraviolet traps, environmental management, or community mobilization. Furthermore, the selected concentration should not be interpreted as an optimal concentration because the present field study did not directly compare different duku peel concentrations.

Outcomes and Variables

The primary outcome was adult mosquito catch per valid trap-night, defined as the number of mosquitoes recovered from an operational trap divided by the number of nights on which that trap met the prespecified operating-time requirement. It is described as trap yield rather than ambient mosquito density because ultraviolet light, reservoir condition, and duku peel preparation could affect attraction, entry, retention, or survival within the trap. Secondary outcomes were HI, CI, BI, genus-level mosquito composition, a household vector-control behavior score standardized to 0–100, the proportion of scheduled nights on which traps operated, habitat-management actions, acceptability, and complaints. HI was the percentage of inspected houses with at least one larva-positive water-holding habitat; CI was the percentage of inspected water-holding containers positive for larvae; and BI was the number of positive containers per 100 inspected houses. Malaria infection, entomological inoculation rate, human-biting exposure, and clinical incidence were not measured.

Research Instruments and Field Procedures

Data were collected using a household characteristics form, larval surveillance form, standard mosquito dipper, pipettes, labeled specimen containers, ultraviolet mosquito traps, aspirator, stereomicroscope, morphological identification keys, trap-night operation log, household vector-control behavior questionnaire, intervention adherence checklist, and complaint form. Each specimen was labeled with the household code, cluster, ecosystem, collection date, habitat or trap source, and developmental stage. Trained entomology personnel counted and morphologically identified larvae and adult mosquitoes to the genus level. Specimen collection, handling, and identification followed established principles of field entomological surveillance (Silver, 2008; World Health Organization, 2013).

Before data collection, all enumerators and entomology personnel completed standardized training covering informed-consent procedures, household interviews, inspection of water-holding habitats, collection of larvae and adult mosquitoes, trap placement and operation, specimen labeling, questionnaire administration, and data-completeness checks. Field supervisors reviewed all forms and specimen labels daily to ensure data completeness, accuracy, and consistency.

Baseline and final assessments were conducted in the same households. At each visit, field personnel inspected all accessible water-holding containers and peridomestic habitats. The number of containers inspected during each assessment served as the denominator for calculating the Container Index, whereas the number of houses inspected served as the denominator for calculating the House Index and Breteau Index. This approach ensured that each index reflected the entomological conditions present at the time of assessment.

Each household completed seven trap-nights at baseline and seven trap-nights at the final assessment. Ultraviolet traps were positioned approximately 1.0–1.5 m above the floor or ground in sheltered locations away from other strong light sources. The traps were operated from 18:00 to 06:00. Field personnel recorded operating time, reservoir condition, rainfall, power interruptions, and equipment functionality each day. A trap-night was considered valid when the trap operated for at least six hours during the scheduled observation period.

Household vector-control behavior was measured using a structured 10-item questionnaire. The instrument was developed based on household- and community-based vector-management practices recommended in the WHO integrated vector management guidelines (World Health Organization, 2012, 2013). The questionnaire assessed the routine elimination of standing water, cleaning and covering of water-storage containers, disposal of items capable of holding water, clearance of drains and vegetation, inspection of habitats around the home, use and maintenance of household mosquito-control measures, participation in environmental-cleaning activities, and reporting of potential mosquito-breeding sites.

Each item had four response options (never, sometimes, often, and always), scored 0, 1, 2, and 3, respectively. All items were positively worded and therefore required no reverse scoring. The total raw score ranged from 0 to 30 and was linearly converted to a standardized scale ranging from 0 to 100. Higher scores indicated more consistent engagement in mosquito-prevention practices. The behavior score was analyzed as a continuous variable to preserve the precision and variability of information across households. The instrument was prepared in Bahasa Indonesia and reviewed to ensure its clarity, relevance, and alignment with the intervention components.

The adherence checklist was used to document the number of valid trap-nights, trap-operating duration, reservoir-fluid replacement, household participation, and completion of habitat-management activities. The complaint form recorded odor-related complaints, skin or respiratory symptoms, accidental exposure, equipment-related problems, and intervention discontinuation. Field supervisors reviewed all implementation data daily to ensure consistent intervention delivery and accurate documentation.

Rainfall, trap condition, and operational disruptions were recorded daily as environmental and technical factors that could affect mosquito catches. This standardized documentation supported the interpretation of entomological findings in relation to the actual field conditions during the study period.

Bias Control and Data Quality

Systematic household selection, geographical separation, standardized trap placement, identical observation durations, field-worker training, labeled specimens, daily log checks, and use of valid trap-nights as exposure time were used to reduce avoidable bias. Missing or invalid trap-nights were excluded from exposure time and were not coded as zero catch; the number of valid nights was retained in rate denominators. Where feasible, personnel counting and identifying mosquitoes were not informed of household behavioral responses, although complete masking to cluster allocation could not be guaranteed. Potential contamination remained possible through movement of residents, information, or vector-control practices between villages. The principal residual threats were cluster-level confounding, ecological change over time, trap-related measurement effects, differential implementation, Hawthorne effects, social desirability, and short-term regression or seasonal variation.

Statistical Analysis

Household characteristics and outcomes were summarized using n (%), mean ± SD, median (IQR), rates per valid trap-night, and baseline-to-final changes, as appropriate. Standardized mean differences were used only to describe household-level balance and were not interpreted as evidence that clusters were exchangeable. The prespecified household-level exploratory models comprised negative-binomial GEE for adult mosquito and positive-container counts, logistic GEE for household larval positivity, and a linear mixed-effects model with a household random intercept for behavior scores. Count models used valid trap-nights or the relevant inspected denominator as an offset. Model terms included group, time, group-by-time interaction, and ecosystem. Overdispersion was assessed by comparing count variance with the mean and by model fit diagnostics; the negative-binomial specification was used because a Poisson equidispersion assumption was not considered tenable. Records with invalid trap-nights contributed no exposure for that night; paired household analyses used the available baseline and final records, and no outcome values were imputed.

Because treatment was assigned at the geographical-cluster level and only four clusters were included, household observations do not provide 200 independent treatment assignments. Conventional sandwich standard errors from GEE and asymptotic mixed-model confidence intervals can be anti-conservative with so few clusters, while reliable cluster-level variance estimation or small-sample correction is not possible with only one intervention and one control cluster per ecosystem. Accordingly, the primary analysis emphasizes descriptive cluster-arm changes and difference-in-change patterns. Model-based effect estimates are retained only as secondary exploratory summaries; their conventional confidence intervals and p values must not be interpreted as confirmatory tests of a package effect. Correlations between implementation adherence and household outcome changes were also exploratory, unadjusted for nonrandom adherence, and not evidence of the independent effectiveness of a component. Simulation evidence confirms that standard-error estimation for between-cluster associations can be unreliable in small samples; it does not resolve the lack of treatment-assignment replication in this study (Bie et al., 2021).

RESULTS AND DISCUSSION

Table 1. Baseline Characteristics of Respondents and Households

Characteristic	Intervention (n = 100)	Control (n = 100)	SMD
Respondent age, years, mean ± SD	43.6 ± 12.4	44.1 ± 12.1	0.04
Female, n (%)	62 (62.0)	60 (60.0)	0.04
Education ≤ junior high school, n (%)	48 (48.0)	46 (46.0)	0.04
Coastal Tanjung Jabung Barat, n (%)	50 (50.0)	50 (50.0)	0.00
Batang Hari mining area, n (%)	50 (50.0)	50 (50.0)	0.00
Household residents, mean ± SD	4.5 ± 1.6	4.4 ± 1.5	0.06
Used a bed net the previous night, n (%)	57 (57.0)	55 (55.0)	0.04
Household with peridomestic standing water, n (%)	44 (44.0)	47 (47.0)	0.06
Behavioral score, 0–100, mean ± SD	58.4 ± 10.7	59.1 ± 10.4	0.07

Note: SMD = standardized mean difference; values below 0.20 indicate small household-level imbalance.

The study included 200 households with paired baseline and final observations: 100 in intervention clusters

and 100 in control clusters. Of 2,800 scheduled trap-nights, 2,757 were valid (98.5%). Household-level demographic characteristics and overall baseline trap-yield rates were descriptively similar. Nevertheless, baseline comparability at the household level does not remove confounding by unmeasured cluster attributes such as salinity, water permanence, vegetation, local vector-control activity, temperature, humidity, or human and mosquito movement.

Table 3. Adult Mosquito Catch Rate by Site and Study Group

Site/group	Baseline mosquitoes	Final mosquitoes	Valid trap-nights (baseline/final)	Catch rate baseline	Catch rate final	Change
Tanjung Jabung Barat—intervention	486	219	343/347	1.42	0.63	−55.6%
Batang Hari—intervention	432	201	342/349	1.26	0.58	−54.0%
Total intervention	**918**	**420**	**685/696**	**1.34**	**0.60**	**−55.2%**
Tanjung Jabung Barat—control	472	451	344/346	1.37	1.30	−5.1%
Batang Hari—control	425	407	341/345	1.25	1.18	−5.6%
Total control	**897**	**858**	**685/691**	**1.31**	**1.24**	**−5.3%**

Note: Catch rate = mosquitoes per valid trap-night; change is the relative change from baseline to final.

Table 2. Changes in Larval Indices by Study Group

Indicator	Intervention		Control		Relative change[a]
	Baseline	Final	Baseline	Final	
House Index, %	28.0	12.0	27.0	25.0	−57.1%
Container Index, %	18.0	7.0	17.0	16.0	−61.1%
Breteau Index	42	17	40	38	−59.5%

Note: House Index and Container Index are percentages; the Breteau Index is the number of positive containers per 100 inspected houses. [a]Relative change from baseline to final in the intervention group.

The intervention clusters showed immediate reductions in all three larval indices: HI changed from 28.0% to 12.0%, CI from 18.0% to 7.0%, and BI from 42 to 17. Control-cluster changes were smaller. The same households were revisited, but the set and number of water-holding containers could change between surveys; indices therefore used the containers and habitats observed at each assessment rather than assuming an unchanged container denominator.

Adult mosquito catch in the intervention group decreased from 918 mosquitoes over 685 valid trap-nights at baseline (1.34 per trap-night) to 420 over 696 valid trap-nights at final assessment (0.60 per trap-night), corresponding to a 55.2% reduction. In the control group, catch decreased from 897 over 685 valid trap-nights (1.31 per trap-night) to 858 over 691 valid trap-nights (1.24 per trap-night), a 5.3% reduction.

Table 4. Exploratory Household-Level Model Estimates (Secondary, Nonconfirmatory)

Outcome	Adjusted effect estimate	95% CI	*p* value
House Index	aOR 0.43	0.23–0.82	0.010
Container Index	aOR 0.38	0.24–0.61	<0.001
Breteau Index	aIRR 0.43	0.31–0.59	<0.001
Adult mosquito catch rate	aIRR 0.48	0.42–0.55	<0.001
Anopheles spp. catch rate	Not estimable from available summary data	—	—
Behavioral score	β 20.0 points	17.4–22.6	<0.001

Note: aOR = adjusted odds ratio; aIRR = adjusted incidence rate ratio; β = adjusted difference in score. Models included group, time, group-by-time interaction, and ecosystem. Conventional confidence intervals and *p* values are reported for transparency only and are not cluster-confirmatory.

Exploratory household-level models produced group-by-time estimates in the direction of larger reductions in intervention clusters. For adult mosquito trap yield, the model-based incidence rate ratio was 0.48. The conventional interval and p value shown in Table 4 derive from asymptotic household-level modeling and are likely to overstate precision because only four clusters were treatment-assigned. They are reported for transparency but are not interpreted as confirmatory statistical evidence. Species-specific *Anopheles* effects were not estimable from the available data.

Table 5. Behavior, Implementation, Acceptability, and Safety

Indicator	Intervention	Control	Effect/*p* value
Baseline behavioral score, mean ± SD	58.4 ± 10.7	59.1 ± 10.4	—
Final behavioral score, mean ± SD	80.6 ± 9.2	61.3 ± 10.1	β = 20.0; p < 0.001
Trap operational for ≥6 nights, n (%)	92 (92.0)	Not applicable	—
Household completed ≥2 habitat-management actions, n (%)	84 (84.0)	23 (23.0)	Risk difference 61.0 percentage points (95% CI 50.1–71.9)
Satisfied/very satisfied with the package, n (%)	88 (88.0)	Not assessed	—
Mild transient odor complaint, n (%)	3 (3.0)	Not applicable	—
Serious adverse events	0	0	—

The intervention group showed a larger improvement in vector-control behavior. Ninety-two percent of intervention traps operated for at least six nights, and 84.0% of intervention households completed at least two habitat-management actions. Satisfaction with the package was reported by 88.0% of intervention respondents. Three respondents reported a mild transient odor complaint, and no serious adverse events were recorded.

Table 6. Exploratory Correlations Between Implementation and Outcome Changes

Variable pair	*r*	95% CI	*p* value
Proportion of active trap-nights vs change in household mosquito catch rate	−0.46	−0.60 to −0.29	<0.001
Number of habitat-management actions vs change in positive-container count per household	−0.39	−0.54 to −0.20	<0.001
Change in behavioral score vs change in household mosquito catch rate	−0.34	−0.50 to −0.15	0.001

Higher implementation activity was associated with larger reductions in mosquito catch and positive-container measures. These associations are exploratory and do not establish the independent causal contribution of any individual component of the integrated package.

This controlled before-and-after field study observed larger immediate changes in mosquito-catch, larval, and reported household behavior indicators in clusters receiving the integrated package than in control clusters. HI, CI, and BI in the intervention arm declined by 57.1%, 61.1%, and 59.5%, respectively, and adult mosquito trap yield declined by 55.2%; the behavioral score increased from 58.4 to 80.6. These findings answer the exploratory research question at the level of the observed clusters, but they do not establish a causal package effect because the four clusters were selected and allocated nonrandomly and each ecosystem contained only one intervention-control pair.

The direction of the larval-index changes is compatible with the rationale of larval-source management, particularly where breeding habitats are identifiable and manageable. Recent reviews indicate that integrated and community-based mosquito-control programs can improve entomological and behavioral outcomes, while also emphasizing heterogeneity in ecological context, intervention intensity, acceptance, and sustainability (Otolorin et al., 2025; Yulfi et al., 2025). In this study, community mobilization and habitat management may have contributed to the observed pattern, but this is a plausible explanation rather than a component-specific estimate. The integrated package did not include a factorial comparison capable of separating community mobilization, habitat management, trapping, and botanical preparation. For comparison, an Indonesian field evaluation combined sterile male releases with chemical control and breeding-source reduction, illustrating a different integrated strategy whose results cannot be transferred directly to the present package (Sasmita et al., 2025).

Adult mosquito trap yield declined substantially in intervention clusters, but this observation is intrinsically difficult to interpret because the ultraviolet trap was simultaneously an intervention component and the primary measurement device. Changes in catch may reflect altered mosquito abundance, trap attraction, entry, retention, reservoir effects, competing environmental light, mosquito behavior, or species composition. The result therefore cannot be translated directly into an equivalent reduction in ambient mosquito density. Independent surveillance using traps or human-exposure measures not modified by the intervention would be required to distinguish population change from altered capture efficiency. Comparative field sampling in the Republic of Korea also found differences in collection efficiency and species representation between trap types (Lee et al., 2024). In a separate six-month field evaluation, In2Care traps showed clearer differences from routine integrated vector management for eggs and larvae than for adult catches, and required greater servicing effort (Buckner et al., 2021).

Reported household behavior improved during implementation, consistent with evidence that community participation can increase engagement with environmental vector-control actions (Yulfi et al., 2025). However, respondents knew that an intervention was being evaluated and were assessed immediately after a visible seven-day program. Hawthorne effects, interviewer effects, recall, and social desirability may therefore explain part of the score increase. Until the questionnaire specifications and psychometric results are documented, the score should be interpreted as a study-specific reported-behavior measure rather than a fully validated behavioral construct.

Duku peel was included as a locally adapted botanical component, and *Lansium domesticum* contains phytochemical groups with potential insecticidal or repellent activity. Nevertheless, botanical performance depends on extraction, formulation, concentration, stability, exposure, and target species (Abdallah et al., 2022; Isman, 2020). The present study did not compare the integrated package with an otherwise identical package lacking duku peel. Consequently, neither the mosquito-catch change nor the larval-index change can be attributed specifically to the 3% preparation, and no statement of component effectiveness is warranted.

The ecological contrast between coastal and mining environments strengthens the operational relevance but also increases confounding. Coastal pools may vary with salinity, tides, vegetation, and transient rainfall, whereas mining excavations may retain deeper and more persistent water. Rainfall was recorded, but complete time-varying temperature, humidity, salinity, vegetation, water chemistry, and habitat-persistence measurements were unavailable for adjustment. With one intervention and one control cluster per ecosystem, an apparent ecosystem-specific pattern could reflect unique village conditions rather than intervention modification. Field surveys across ecological zones in Ghana found habitat- and season-related variation in larval occurrence and productivity, reinforcing the need for local habitat characterization (Hinne et al., 2021). Indonesian surveillance in Buton Utara likewise demonstrated the value of combining habitat surveys, alternative adult-collection methods, and molecular identification rather than inferring vector status from genus-level counts alone (Lempang et al., 2023).

The study has several strengths. It was conducted under real field conditions in two ecologically distinct malaria-receptive settings, used repeated entomological

observation before and after intervention, included a concurrent control condition, assessed both entomological and behavioral outcomes, and recorded implementation and acceptability indicators. The high proportion of valid trap-nights also indicates good operational completion of the planned surveillance period.

Several limitations materially constrain interpretation. First, only four nonrandomized geographical clusters were studied; the cluster, not the household, was the treatment-assignment unit, and cluster-level confounding cannot be removed by the number of household observations. Conventional GEE and mixed-model uncertainty estimates may therefore be anti-conservative. Second, the multicomponent package prevents attribution to any individual element, including duku peel. Third, ultraviolet traps served as both intervention and measurement devices. Fourth, the seven-day implementation and immediate seven-day observation period capture only short-term change and cannot establish persistence across seasons. Fifth, residents or practices may have moved between clusters despite geographical separation. Sixth, environmental covariates were incompletely characterized. Seventh, genus-level identification, absence of independent human-biting or sporozoite measures, and absence of malaria incidence data preclude conclusions about vector species, infectious exposure, transmission, or disease. Eighth, immediate self-reported behavior is vulnerable to Hawthorne and social-desirability bias, and complete questionnaire validation must be documented. Finally, exploratory adherence correlations are confounded by household motivation and environmental conditions and do not identify effective components.

The observed patterns justify a larger confirmatory study rather than a claim of established effectiveness. Future evaluations should randomize or otherwise replicate substantially more clusters, prespecify small-sample cluster inference, extend observation across seasons, measure environmental covariates, use independent surveillance devices, conduct species-level or molecular identification, standardize and chemically characterize the botanical formulation, validate behavioral measures, and include human-biting, infection, and epidemiological outcomes. Recent field evidence also shows why entomological improvements should not be treated as surrogates for disease reduction without direct epidemiological measurement (Dean et al., 2025).

CONCLUSION

In the four observed geographical clusters, implementation of the integrated package was followed by favorable immediate changes in mosquito trap yield, larval indices, and reported household vector-control behavior relative to contemporaneous control clusters. These findings constitute exploratory field evidence only. Nonrandomized allocation, one intervention-control cluster pair per ecosystem, the multicomponent package, use of ultraviolet traps for both intervention and measurement, and the brief observation period prevent causal attribution, identification of an effective component, or conclusions about sustained mosquito abundance, human exposure, malaria transmission, or malaria incidence. A larger cluster-replicated study with independent entomological and epidemiological surveillance is required.

DECLARATIONS AND ETHICAL STATEMENTS

Ethical Approval and Consent to Participate

The project received approval from the Health Research Ethics Committee of the Jambi Health Polytechnic, Ministry of Health (approval No. LB.02.06/2/0049/2026, dated February 22, 2026). Written informed consent was obtained from respondents. Household identifiers were coded and access to study records was restricted. The preparation was not applied to drinking water, food, aquaculture ponds, or locations readily accessible to children. Complaints were documented and exposure was discontinued if a clinically meaningful reaction occurred. Participation did not affect access to malaria services.

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Conflict of Interest Disclosures

The authors declare that they have no conflicts of interest related to this study or the preparation of this manuscript.

Author Contributions

Emilia Chandra: Conceptualization, Methodology, Investigation, Project administration, Funding acquisition, Writing – original draft. **Sukmal Fahri:** Methodology, Formal analysis, Data curation, Validation, Writing – review & editing. Both authors read and approved the final manuscript.

Artificial Intelligence (AI) Usage Statement

Generative AI tools were used only for language editing and proofreading during the preparation and copyediting of this manuscript. They were not used to generate, analyze, or interpret data or to formulate scientific conclusions. The authors reviewed all edits and take full responsibility for the content of this article.

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