

Original Article

The Effectiveness of the Torn Bed Nets in People's Protection from Mosquito Bites in the Prevention of Malaria Transmission in the Republic of Bénin, West Africa

Lègba Nazaire Aïzoun^{1*}, Goué Géorcelin Alowanou^{1,2}, Alda Aude Sèna Yémadjè^{1,3}, Mindégnisèa Habib Tamègnon¹, Chèpo Daniel Chougourou⁴

¹Laboratory of Pluridisciplinary Research of Technical Teaching (LaRPET), Normal High School of Technical Teaching (ENSET) of Lokossa, National University of Sciences, Technologies, Engineering and Mathematics (UNSTIM) of Abomey, P.O. Box 133, Lokossa, Cotonou, Bénin

²Laboratory of Ethnopharmacology and Animal Health (LESA), Faculty of Agronomic Sciences, University of Abomey-Calavi (UAC), Cotonou, Bénin

³Laboratory of Research in Biochemistry and Environmental Toxicology, Faculty of Sciences and Techniques (FAST), University of Abomey-Calavi (UAC), Abomey-Calavi, Bénin

⁴Department of Environment Genius, Polytechnic School of Abomey-Calavi (EPAC), University of Abomey-Calavi (UAC), Cotonou, Bénin

* Corresponding Author : aizoun.nazaire@yahoo.fr

Received: 05 April 2026

Revised: 10 May 2026

Accepted: 27 May 2026

Published: 12 June 2026

Abstract - Malaria is a public health problem. The use of long-lasting Insecticide-Treated Bed Nets (LLINs) is the most prominent malaria preventive measure for large-scale deployment in highly endemic areas. The current study was aimed at investigating the protection conferred by torn bed nets to people in the prevention of malaria transmission. Four bedrooms corresponding to four houses were selected for adult mosquito collection in the morning in May 2025 during the great rainy season in each of two locations surveyed, which were Minontin and Sahouèkomey in the Lokossa district in Mono department. Mosquitoes inside the nets were collected by an electronic racket from 6 a.m. to 7 a.m in both locations. The survey was done simultaneously for fourteen consecutive nights (two weeks). All collected mosquitoes were put in netted plastic cups and transferred to the Laboratory of Pluridisciplinary Research of Technical Teaching (LaRPET) in Normal High School of Technical Teaching (ENSET) of Lokossa for identification of *Anopheles gambiae* mosquitoes. Then, the physiological status of the abdomen of *Anopheles gambiae* mosquitoes was determined. The results showed that the mosquitoes collected in bedrooms where impregnated mosquito nets were torn were higher than those collected in bedrooms where impregnated mosquito nets were not torn. No gravid mosquitoes were found in the collected mosquito fauna. The physical barrier of Long Lasting Insecticidal Nets (LLINs), which are frequently distributed free by Beninese National Malaria Control Program throughout the entire country to increase coverage of LLINs, is still important. It is important to sleep under impregnated mosquito bed nets that are not torn at night.

Keywords - *Anopheles Gambiae*, Bed, Malaria Prevention, Republic Of Bénin, Torn Net.

1. Introduction

Globally in 2024, there were an estimated 282 million malaria cases in 80 malaria-endemic countries, an increase of about 9 million cases (3%) compared with 2023.[1]

Between 2000 and 2015, although the trend in case numbers fluctuated, there was a slight decrease overall of about 3.8%, from 239 million to 230 million cases, across the 108 countries that were malaria endemic in 2000. Since 2015, malaria cases have increased by 22.6%. Of the regions that showed an increase, most of this increase was observed in the WHO African Region (88%) and the WHO Eastern Mediterranean Region (12%). [1]

Globally in 2024, there were an estimated 610,000 malaria deaths, an increase of 12,000 compared with 2023. Between 2015 and 2024, deaths increased by 5.5%, with more than one-third of the increase occurring between 2023 and 2024. The mortality rate remained unchanged in 2024 compared with 2023, at 13.8 per 100,000 population at risk. [1]

In malaria-endemic countries, resistance to pyrethroids remains widespread, with resistance confirmed in 55 of the 64 countries where it was monitored between 2018 and 2023. Resistance to neonicotinoids has also been reported in five of the 16 countries where it was monitored. Countries are encouraged to continue to test the susceptibility of mosquitoes to the insecticides used in



their vector control interventions and to adopt pyrethroid-PBO or dual active ingredient ITNs to improve the effectiveness of ITNs against mosquitoes resistant to pyrethroids. [2]

The use of LLINs provides a physical barrier that reduces human-mosquito contact; furthermore, the insecticidal and repellent activity of the insecticide incorporated into the LLIN fiber protects the users as well as non-users by providing community protection through spatial effects. [3] LLINs used at the community-wide level can exhibit cumulative effects on vector density, survival, and longevity over a large area and may force *Anopheles* mosquitoes to find alternative animal hosts and ultimately reduce human malaria transmission. [4] Many studies across the world have revealed that LLINs were able to reduce the malaria burden and significantly reduce the uncomplicated malarial episodes in areas of both stable and unstable malaria transmission. [5-7]

The bed net is the most widely used as a malaria control measure all over the world and in Africa, particularly. In addition, it is important that after the distribution of Long-Lasting Insecticidal Nets (LLINs) by the National Malaria Control Programs (NMCPs) in countries at risk of malaria, many evaluations or assays are conducted on these tools of prevention in order to evaluate their effectiveness. So, in addition to the evaluations of the effectiveness of LLINs used by the people by the NMCP of Bénin, many assays or tests must be conducted on these LLINs by local researchers for this purpose.

Very few studies were published on the people's practice or behavior using bed nets in the prevention of malaria transmission in Bénin. Therefore, there is a need to carry out new research for this purpose. The goal of this study was to investigate the protection confers by torn bed nets to people in the prevention of malaria transmission in the Republic of Bénin, West Africa.

2. Review of Literature

The loss of household protection from the use of insecticide-treated nets against Pyrethroid-Resistant Mosquitoes was shown in the Republic of Bénin. In this study, the authors investigated whether nets in use were still protective. For that, they conducted household trials in northern and southern Bénin, where *Anopheles Gambiae* mosquitoes are susceptible and resistant, respectively, to pyrethroids. Rooms were fitted with window traps and monitored for mosquito biting and survival rates before and after the nets were treated with pyrethroid. Sleeping under an ITN in the location with resistant mosquitoes was no more protective than sleeping under an untreated net, regardless of its physical condition. By contrast, sleeping under an ITN in the location with susceptible mosquitoes decreased the odds of biting by 66%. ITNs provide little or no protection once the mosquitoes become resistant and the netting acquires holes. These authors concluded that resistance seriously threatens malaria control strategies based on ITN. [8] In addition, it was shown in laboratory

conditions that torn nets treated with pyrethroids, cyfluthrin, deltamethrin, and Permethrin were effective against *Anopheles Stephensi* with a high protection rate. [9] Insecticide-Treated Nets (ITNs) and Long-Lasting Insecticidal Nets (LLINs) are the primary interventions for preventing malaria in sub-Saharan Africa. [10] Nets accumulate holes through wear and tear during the course of everyday use, but the pyrethroid treatment continues to provide personal protection and to reduce vector capacity through excito-repellency and the killing of mosquitoes that contact the net. [8]

3. Materials and Methods

3.1. Study Area

The study area is located in the Republic of Bénin (West Africa) and includes the department of Mono. The Mono department is located in the south-western Bénin, and the study was carried out more precisely in the Lokossa district (Figure 1). The southern borders of the Lokossa district are Athiémé and Houéyogbé districts. The northern border is the Dogbo district. The eastern border is the Bopa district, and the western border is the Togo Republic. The Lokossa district covered 260 km². The choice of the study site took into account the economic activities of populations, their usual protection practices against mosquito bites, and peasant practices to control farming pests. We took these factors into account to investigate the protection confers by torn bed nets to people in the prevention of malaria transmission in the Republic of Bénin. Mono has a climate with four seasons, two rainy seasons (March to July and August to November) and two dry seasons (November to March and July to August). The temperature ranges from 25 to 30°C, with the annual mean rainfall between 900 and 1100 mm.



Fig. 1 Map of the Republic of Bénin showing the Lokossa district surveyed



Fig. 2 Electronic rackets used during the mosquito collection in the field

3.2. Field Mosquito Collection

Four bedrooms corresponding to four houses were selected for adult mosquito collection in the morning in May 2025 during the great rainy season in each of two locations surveyed, which were Minontin and Sahouèkomey in the Lokossa district in Mono department. Mosquitoes inside the nets were collected by an electronic racket (Figure 2) from 6 a.m. to 7 a.m. in both locations. The survey was done simultaneously for fourteen consecutive nights (two weeks). All collected mosquitoes were put in netted plastic cups and transferred to the Laboratory of Pluridisciplinary Research of Technical Teaching (LaRPET) in Normal High School of Technical Teaching (ENSET) of Lokossa for identification of *Anopheles Gambiae* mosquitoes. Then, the physiological status of the abdomen of *Anopheles Gambiae* mosquitoes was determined.

3.3. Collected Mosquito Identification

Adult collected mosquitoes were identified to species based on morphological characters using identification keys.[11]

3.4. Statistical Analysis

A chi-square test for proportion comparison was performed to compare the proportions of mosquito species related to each bedroom.

4. Results and Discussion

The analysis of Table 1 showed that some mosquito species were found in bedroom 1 and bedroom 3 in the Sahouèkomey location, despite the bed nets in these bedrooms not being torn. However, there was no mosquito species collected under impregnated bed nets that were not torn in Minontin.

The analysis of Table 2 showed that the mosquitoes collected in bedrooms where impregnated mosquito nets were torn were higher than those collected in bedrooms where impregnated mosquito nets were not torn.

The analysis of Table 3 showed that no gravid mosquitoes were found in the collected mosquito fauna. Only unfed and blood-fed mosquitoes were found.

Figure 3 showed a bedroom where an impregnated mosquito net was not torn in the study area, whereas Figure 4 showed a bedroom where an impregnated mosquito net was torn. Regarding Figure 5, it showed the blood of killed *Anopheles Gambiae* fed mosquitoes under a bedroom where an impregnated mosquito net was torn in the study area.



Fig. 3 A bedroom where an impregnated mosquito net was not torn



Fig. 4 A bedroom where an impregnated mosquito net was torn



Fig. 5 The blood of killed *Anopheles Gambiae* fed mosquitoes in the study area

In the current study, some mosquito species were found in bedroom 1 and bedroom 3 in the Sahouèkomey location, although the impregnated bed nets in these bedrooms were not torn. However, there was no mosquito species collected under impregnated bed nets that were not torn in Minontin. These results showed that the bed nets in bedroom 1 and bedroom 3 in the Sahouèkomey location were not well-appointed by their users before sleeping inside them. In the current study, the number of mosquitoes collected in bedrooms where impregnated mosquito bed nets were torn was higher than that collected in bedrooms where impregnated mosquito nets were not torn. These results showed that torn bed nets were not effective in protecting people against mosquito bites. The necessity of communicating the importance of the use of bed nets, which are not torn, is emphasized by the National Malaria Control Program (NMCP) of Bénin. Although mass distribution campaigns frequently occur, the NMCP must engage with communities more frequently to remind them why and how to use, maintain, repair, wash, and ultimately dispose of bed nets. These results obtained in the current study, corroborated with the evidence of man-vector contact in torn long-lasting insecticide-treated nets. This study was carried out in three geo-locations in Bénin. Two types of LLINs (polyester and polyethylene) with 'standardized' physical damage were compared with similarly damaged, but non-insecticidal (control) nets. The proportionate Holes Index (pHI) of each net was 276. Mosquitoes were captured inside the nets, identified taxonomically, and subjected to molecular analysis to estimate *knockdown resistance* (*Kdr*) frequency. Their results showed that the most commonly observed species was *Anopheles Gambiae*, accounting for approximately 70% (1,076/1,550) of the total mosquitoes collected both in LLINs and non-insecticidal nets.

When compared with controls, the number of vectors captured in torn LLINs was significantly reduced. Nonetheless, in a night, an average of 5 *An. Gambiae s.l* could enter the damaged LLINs to bite. Similar numbers of resistant mosquitoes were collected in both LLINs and non-insecticidal (control) nets. These authors concluded that at a pHI of 276, man-vector contact was observed in torn LLINs. The insecticide on the surface of LLINs could only reduce the number of vectors. Resistant mosquitoes have the opportunity to enter both non-insecticidal (control) nets and LLINs to bite. [12] Another study had shown the effectiveness of older Insecticide-Treated Bed Nets (ITNs) to prevent malaria infection in an area of moderate pyrethroid resistance: results from a cohort study in Malawi. In this study, one year following a baseline cross-sectional malaria parasitaemia prevalence survey and universal distribution of deltamethrin ITNs (May 2012), a fixed cohort of 1223 children aged 6-59 months was enrolled (April 2013). Children were tested for parasitaemia at monthly scheduled visits and at unscheduled sick visits from May to December 2013 using rapid diagnostic tests. ITN use the prior night, and the condition of ITNs (based on the presence of holes) was assessed by caregiver self-report. The incidence Rate Ratio

(RR) comparing malaria infection among users and non-users of ITNs was modelled using generalized estimating equations, adjusting for potential confounders and accounting for repeated measures on each child. The Protective Efficacy (PE) of ITN use was calculated as 1-RR. The results showed that in this cohort, self-reported ITN use remained consistently high (>95%) over the study period. Although users of ITNs were slightly more protected compared to non-users of ITNs, the difference in incidence of infection was not statistically significant (RR 0.83, 95% confidence interval [CI] 0.54–1.27). Among ITN users, malaria incidence was significantly lower in users of ITNs with no holes (of any size) compared to users of ITNs with ≥ 1 hole (RR 0.82, 95% CI 0.69–0.98). There was no significant PE of using 1-2 year-old ITNs on the incidence of malaria in children in an area of moderate pyrethroid resistance, but among ITN users, the authors found increased protection by ITNs with no holes compared to ITNs with holes. The authors concluded that, given the moderate levels of pyrethroid resistance in the primary malaria vector and recent evidence of added benefits of ITNs with synergists or non-pyrethroid insecticides, next-generation ITNs may be a useful strategy to address pyrethroid resistance and should be further explored in Malawi. [13]

In the current study, no gravid mosquitoes were found in the collected mosquito fauna. Only unfed and blood-fed mosquitoes were found. That is good news, as *Anopheles gambiae* gravid mosquitoes will take blood meals later for the maturation of their eggs.

Mosquito nets offer physical and chemical barriers against mosquitoes that cannot enter them. When nets are torn, mosquitoes can enter them and take their blood meals. That exposes the sleepers to the risk of suffering from malaria. The physical barrier is due to the type of tissues (nets are made of polyester, cotton, nylon, and so on...) used to make the nets, whereas the chemical barrier is due to the insecticides used to impregnate the mosquito nets. Two kinds of mosquito nets were often used by the people for their protection. There were: Permanet 2.0 and Olyset net. These mosquito nets were often received from the different free distributions of Long-Lasting Insecticidal Nets (LLINs) by the National Malaria Control Program (NMCP) of Bénin. Some of these mosquito nets used were bought by the people themselves or received as a donation by them. Permanet 2.0 and Olyset are impregnated with pyrethroids. Pyrethroids have unique modes of action, such as fast knockdown and excito-repellent effects.[14]

5. Novelty of the Study

Compared to the previous studies, the originality of the current study lies in the method used in mosquito collection. In fact, in the previous studies, they used mouth aspirators to collect mosquitoes under bed nets. However, the current study is the first to use the electronic racket in mosquito collection under torn bed nets in the evaluation of the effectiveness of LLINs.

6. Study Limitations

The current study needs more information about net damage classification, sampling, ethical procedures, inter-rater reliability, demographics, and public health implications. For that, further studies will be carried out in the future in more locations of the country by taking these factors or parameters into account.

7. Conclusion

The physical barrier of Long Lasting Insecticidal Nets (LLINs), which are frequently distributed free by Beninese National Malaria Control Program throughout the entire country to increase coverage of LLINs, is still important. It is important to sleep under impregnated mosquito bed nets that are not torn at night.

Recommendations

It would be pertinent to add to the different free distributions of Long-Lasting Insecticidal Nets (LLINs), the Indoor Residual Spraying (IRS) as tools for people's protection from mosquito bites in each department of the

country, for the protection of the people. In fact, the Indoor Residual Spraying (IRS) is expensive for different National Malaria Control Programs of Africa. For this reason, NMCPs make more frequent free distributions of Long-Lasting Insecticidal Nets (LLINs) to their people than they do IRS throughout the continent.

Conflicts of Interest

There are no conflicts of interest in regard to the publication of this paper.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgment

The authors would like to thank the people from the Lokossa district surveyed who helped us in mosquito collection.

References

- [1] World Health Organization, World Malaria Report, World Health Organization, 2025. [Online]. Available: <https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2025>
- [2] World Health Organization, World Malaria Report, World Health Organization, 2024. [Online]. Available: <https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2024>
- [3] Delenasaw Yewhalaw et al., "Bio-Efficacy of Selected Long-Lasting Insecticidal Nets Against Pyrethroid Resistant Anopheles Arabiensis from South-Western Ethiopia," *Parasites and Vectors*, vol. 5, no. 1, pp. 1-9, 2012. [CrossRef] [Google Scholar] [Publisher Link]
- [4] C.A. Maxwell et al., "Effect of Community-Wide use of Insecticide-Treated Nets for 3-4 Years on Malarial Morbidity in Tanzania," *Tropical Medicine and International Health*, vol. 7, no. 12, pp. 1003-1008, 2002. [CrossRef] [Google Scholar] [Publisher Link]
- [5] Christian Lengeler, "Insecticide-Treated Bed Nets and Curtains for Preventing Malaria," *Cochrane Database of Systematic Reviews*, no. 2, pp. 1-55, 2004. [CrossRef] [Google Scholar] [Publisher Link]
- [6] Alexander K. Rowe et al., "The Burden of Malaria Mortality Among African Children in the Year 2000," *International Journal of Epidemiology*, vol. 35, no. 3, pp. 691-704, 2006. [CrossRef] [Google Scholar] [Publisher Link]
- [7] Sibylle Gerstl et al., "Long-Lasting Insecticide-Treated Net Usage in Eastern Sierra Leone – The Success of Free Distribution," *Tropical Medicine and International Health*, vol. 15, no. 4, pp. 480-488, 2010. [CrossRef] [Google Scholar] [Publisher Link]
- [8] Alex Asidi et al., "Loss of Household Protection from use of Insecticide-Treated Nets Against Pyrethroid-Resistant Mosquitoes, Benin," *Emerging Infectious Diseases*, vol. 18, no. 7, pp. 1101-1106, 2012. [CrossRef] [Google Scholar] [Publisher Link]
- [9] H. Vatandoost et al., "Laboratory Efficacy of Protection Rate of Torn Nets Treated with Pyrethroids, Cyfluthrin, Deltamethrin and Permethrin Against Anopheles Stephensi (Diptera: Culicidae)," *Journal of Biological Sciences*, vol. 6, no. 2, pp. 331-336, 2006. [CrossRef] [Google Scholar] [Publisher Link]
- [10] Hmwe Hmwe Kyu et al., "Evaluation of the Association Between Long-Lasting Insecticidal Nets Mass Distribution Campaigns and Child Malaria in Nigeria," *Malaria Journal*, vol. 12, no. 1, pp. 1-8, 2013. [CrossRef] [Google Scholar] [Publisher Link]
- [11] M. Coluzzi, "Morphological Divergences in the *Anopheles Gambiae* Complex," pp. 197-232, 1964. [Google Scholar]
- [12] Virgile Gnanguenon et al., "Evidence of Man-Vector Contact in Torn Long-Lasting Insecticide-Treated Nets," *BMC Public Health*, vol. 13, no. 751, pp. 1-11, 2013. [CrossRef] [Google Scholar] [Publisher Link]
- [13] Monica P. Shah et al., "The Effectiveness of Older Insecticide-Treated Bed Nets (ITNs) to Prevent Malaria Infection in an Area of Moderate Pyrethroid Resistance: Results from a Cohort Study in Malawi," *Malaria Journal*, vol. 19, no. 1, pp. 1-12, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [14] M. Zaim, A. Aitio, and N. Nakashima, "Safety of Pyrethroid-Treated Mosquito Nets," *Medical and Veterinary Entomology*, vol. 14, no. 1, pp. 1-5, 2000. [CrossRef] [Google Scholar] [Publisher Link]

Table 1. Mosquito species collected in bedrooms where impregnated mosquito nets were not torn

Mosquito species	Minontin		Sahouekomey				Number of mosquitoes caught in bedroom 3	Number of mosquitoes caught in bedroom 4	Total
	Number of mosquitoes caught in	Number of mosquitoes caught in	Number of mosquitoes caught in	Number of mosquitoes caught in	Number of mosquitoes caught in	Number of mosquitoes caught in			
	bedroom 1	bedroom 2	bedroom 3	bedroom 4	bedroom 1	bedroom 2			
<i>Anopheles gambiae</i>	0	0	0	0	1	0	0	0	01 ^a
<i>Culex quinquefasciatus</i>	0	0	0	0	5	0	3	0	08 ^b
<i>Aedes aegypti</i>	0	0	0	0	2	0	0	0	02 ^a
Other mosquito species	0	0	0	0	7	0	8	0	15 ^c
Total	0	0	0	0	15	0	11	0	26

Noted: Means followed by the same letter do not differ significantly ($p < 0.05$ chi-square test).

Table 2. Mosquito species collected in bedrooms where impregnated mosquito nets were torn

Mosquito species	Minontin				Sahouekomey				Total
	Number of mosquitoes caught in bedroom 1	Number of mosquitoes caught in bedroom 2	Number of mosquitoes caught in bedroom 3	Number of mosquitoes caught in bedroom 4	Number of mosquitoes caught in bedroom 1	Number of mosquitoes caught in bedroom 2	Number of mosquitoes caught in bedroom 3	Number of mosquitoes caught in bedroom 4	
<i>Anopheles Gambiae</i>	8	12	10	4	13	16	7	15	85 ^a
<i>Culex Quinquefasciatus</i>	29	38	34	67	33	43	39	47	330 ^b
<i>Aedes Aegypti</i>	11	14	16	19	16	18	21	28	143 ^c
Other Mosquito Species	53	61	49	21	57	88	71	36	436 ^d
Total	101	125	109	111	119	165	138	126	994

Noted: Means followed by the same letter do not differ significantly ($p < 0.05$ chi-square test).

Table 3. Physiological status of the abdomen of the collected *Anopheles Gambiae* Mosquitoes

Mosquito specie	Minontin								Sahouekomey								Total
	Number of mosquitoes caught in bedroom 1		Number of mosquitoes caught in bedroom 2		Number of mosquitoes caught in bedroom 3		Number of mosquitoes caught in bedroom 4		Number of mosquitoes caught in bedroom 1		Number of mosquitoes caught in bedroom 2		Number of mosquitoes caught in bedroom 3		Number of mosquitoes caught in bedroom 4		
	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	Unfed	Blood fed	
<i>Anopheles gambiae</i>	7	1	8	4	7	3	3	1	11	2	13	3	5	2	7	8	85