Physical integrity of three Long-Lasting Insecticidal Net products 30 months after a mass-distribution campaign in Benin

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Abstract

Abstract Background The effectiveness of long-lasting insecticidal nets (LLINs) mainly relies on their physical integrity, an important indicator of the LLINs durability in households. The present study aims to assess this physical integrity for three widely used LLIN products: DawaPlus®2.0, PermaNet®2.0 (polyester) and DuraNet® (polyethylene), distributed in Benin during the mass campaign of 2014. Methods The study was conducted from October 2014 to June 2017 in three districts of Benin: Tori-Bossito, Toffo, and Ouesse. Nine hundred LLINs (a cohort of 300 LLINs per product) in use and found hanging on sleeping materials were selected and tagged. Every six months, the LLIN attrition and their physical condition was monitored. The holes were counted by category allowed to calculate the proportionate hole index (pHI) and classify the LLINs into "good ", "serviceable" or "torn" categories. Factors associated with loss of integrity have also been identified following World Health Organization Guidelines. Results After 30 months of use, 55.9% (n= 503; 95% CI: 52.6-59.2) of the LLINs were lost. Attritions due to physical damage were similar between the LLIN products and were respectively 28.3% for PermaNet® 2.0, 29.7% for DawaPlus® 2.0, and 31% for DuraNet® (p⍰0.05). The mean pHI was significantly higher for DuraNet® LLINs (pHI= 1431) than DawaPlus® 2.0 (pHI =366) and PermaNet® 2.0 (pHI =321) (<0.001). A significant difference was also observed between the proportion of LLINs in “torn” condition and included 8.7% of PermaNet® 2.0, 14.3% of DawaPlus® 2.0, and 34.1% of DuraNet® (p <0.001). The use of LLINs every night, the frequency of washing and other factors were significantly associated with the physical damage of the LLINs (p <0.001). Conclusion These results suggest that the physical barrier conferred by the LLIN can be significantly affected during the normal course of its use depending on the type of product distributed. National malaria programs must, therefore, consider the physical integrity performance in local conditions in the choice of LLIN product to be distributed. Keywords: LLINs, physical integrity, pHI, malaria, Benin.

Background

In sub-Saharan Africa, the proportion of people with access to long-lasting insecticidal nets (LLINs) has increased from less than 2% in 2000 to 67% in 2015 [1]. To improve this performance observed in many countries in Africa and achieve the universal coverage goal, more than 4 million Olyset®Net LLIN were freely distributed to the population in 2011 in Benin during the national mass-distribution campaign [2]. The LLINs distributed act on adult mosquito vectors and aim to reduce or limit human-vector contact to prevent malaria [3]. After 2 years, 56% of them were removed from their initial households, for different reasons [4]. In addition, rapid physical deterioration of the LLINs was observed 24 months after the distribution, with 90% found with holes [4, 5].

The level of rapid damage of these LLINs is a concern. A similar finding was observed In Uganda with 45-78% of the LLINs damaged after one year of use under operational conditions [6]. About 40% of LLINs were also damaged after 2 to 3 years of use in another study in Laos [7]. Although extrinsic factors related to human practices (washing of nets, type of bedding) and the immediate environment are responsible for the rapid deterioration observed on LLINs, the quality of their physical barrier could also be incriminated [8, 9].

The Olyset®Net polyethylene LLINs distributed in 2011 were replaced in 2014 by three other types of polyester (DawaPlus®2.0, PermaNet®2.0) and polyethylene (DuraNet®) [10] LLINs. This offers an exceptional opportunity to simultaneously compare, for the first time in Benin, the performance of these LLINs in large-scale household use condition. The LLINs distributed are industrially pretreated using specific processes that allow them to be effective after at least 20 washes and to maintain their bioefficacy for 3 to 5 years in normal use [11].

The performance of the LLINs distributed is mainly based on three indicators: the attrition representing the proportion of LLINs lost; the physical integrity, an estimate of the number and size of holes the LLINs; and the bio-efficacy, a measurement of the insecticidal effect [9]. The term "hole" is used to describe all types of damage: rips burn holes, rodent damage, torn corners and stitching defects on LLINs [12]. The attrition and physical integrity of the LLINs, which represent the target indicators of this study, are critical indicators since they represent the major limiting factor in LLIN durability and could lead to a poor protection of the sleeper [4].

Although the distributed LLINs (DawaPlus® 2.0, PermaNet® 2.0 and DuraNet®) are approved by the World Health Organization's Pesticide Evaluation Program (WHOPES) [13], the opportunity to compare them simultaneously after a mass distribution campaign is are given the predominance of a single type of LLIN in mass distribution campaigns [14,15]. Several malaria control programs are therefore working with the assumption that the physical integrity of the LLIN varies little between the types of products offered and thus opts for the choice of the lowest bidder [15].

This longitudinal study undertaken by the Center for Entomological Research in Cotonou (CREC) reports the comparative results of the physical integrity of three types of LLINs under community use conditions. It aims to strengthen the capacity of Malaria Programs to select LLINs to be distributed based on their local performance.

Methods

Study sites

Following the LLINs distribution, a monitoring study on their physical integrity was initiated in three districts, Tori-Bossito, Toffo and Ouesse (Table 1). These three districts were randomly selected from a list of districts coded according to the type of LLINs received. This selection was made online using the Random Number Generator [16]. Two of the three districts selected are located in the Atlantic Department: Tori-Bossito in the South and Toffo in the North. The third district (Ouesse) is located in the department of Collines (Figure 1). In each of the three districts, two locations (one rural and one urban) were selected from their location list by applying the same procedure (list of districts, numeric code, random number generator) for the selection of the districts previously mentioned (Table 1).

Study design

The study consists of longitudinal monitoring of the LLINs every 6 months and was conducted from October 2014 to June 2017. It was an observational and descriptive study which compares the physical integrity of three different types of LLINs distributed in 2014 in Benin, West Africa. The three LLINs products are conventional mosquito nets treated only with pyrethroids. DawaPlus®2.0 (Dawa 2.0) is a polyester LLIN treated with deltamethrin at a concentration of 88 mg/m². PermaNet®2.0 (PN 2.0) is also a polyester LLIN treated with deltamethrin at a concentration of 55mg/m². DuraNet® (Dura) is a polyethylene LLIN treated with alphacypermethrin at 261mg/m².

Household selection and tagging the LLINs (T0)

A total of 900 LLINs were randomly selected and marked on the basis of a cohort of 300 LLINs per net brand according to WHO guidelines [17] just after the mass-distribution campaign of October 2014. The consent to participate in the monitoring surveys was obtained from the head of each household or his spouse. Only one LLIN was selected per consenting household to be sure capture how variation in household practices and environment could affect the LLINs durability. The selection of households at each site took into account the household list of all villages to ensure representative sampling [9]. The assessment teams identified a LLIN distributed in 2014 in each selected household and verified whether the LLIN was hanged-up and its physical integrity was not yet compromised. Each selected LLIN has been tagged with a unique identification number to ensure proper identification during subsequent visits. During the monitoring of the integrity of the selected LLINs, the teams entered the homes where the LLINs were installed in accordance with World Health Organization (WHO) recommendations [18].

Monitoring survey and questionnaire

A model questionnaire developed by WHO [18] has been reviewed and adapted to the needs of the study. This questionnaire was used to identify household characteristics, sleeping material, level of education, etc. The questionnaire has been programmed on Samsung Galaxy 10.1 tablets with ODK Collect 1.2.2. Tablets were directly connected to the internet via a SIM card. They were used for the interviews of the head of households or his spouse but also for collecting data on the integrity of

the LLINs (hole size and number of holes). These data were directly sent to a cloud server used to store the data which were retrieved later for data cleaning and analysis.

LLIN attrition

LLIN attrition represent the proportion of LLINs initially enrolled in the study and which have been lost due to different reasons. Attrition has been categorized by the main reasons why a LLIN is no longer used (attrition 1: destroyed, so torn and worn; attrition 2: stolen, given away, moved; and attrition 3: used for other purposes) [18].

Evaluation of the physical integrity of the LLINs

LLINs were examined visually, without being removed from where they were hung in the targeted houses. The total number of holes observed was counted and classified according to four general size categories:

-Size 1: hole smaller than one inch (0.5-2.0 cm),

-Size 2: hole larger than the thumb but smaller than the fist (2-10 cm),

-Size 3: hole larger than the fist but smaller than the head (10-25 cm),

-Size 4: hole larger than the head (> 25cm).

The proportional hole index (pHI) for each LLIN [9] was determined as follows: pHI = 1 × # T1 + 23 × # T2 + 196 × # T3 + 576 × # T4 (# T = number of holes in the size).

Descriptive statistics were used to compare pHI values at each assessment site. Based on the pHI value, LLINs were assigned to one of three categories [19]:

pHI≤ 64 - good

pHI ≤ 642 - serviceable

pHI> 642– torn

Statistical analysis

Data processing is done with R version 3.5.1 software (R Core Team, Vienna, Austria 2018) and Excel. The calculation of the proportions of the type of holes as well as their comparison between two locations were carried out using the chi^2 test. The binomial test was used to estimate the proportions and their confidence intervals. The Shapiro-Wilk test was used to assess the normality of the data. The Kruskal-Wallis test was used to compare the median pHI but also the performance of the LLIN products by category (good, usable, to replace and lost) for each period (6, 12, 18, 24 and 30 months). The test of equality of proportions was used to determine the existence of equality or not between the proportions of the different locations. The threshold of significance of the tests was 5%.

Results

LLIN attrition

After 30 months of use, an average loss of 55.9% (n=503, 95% CI: 52.6-59.2) out of 900 LLINs initially enrolled was observed. The LLIN attrition was similar between the LLIN between the LLIN products with a loss of 56.7% (95% CI: 47.8-59.4) of Dawa 2.0, 52% (95% CI: 46.2-57.8) of PN 2.0 and 62% (95% CI: 56.2-67.5) of Dura. The most frequently cited cause for loss of LLINs was physical deterioration: 29.7% (95% CI: 26.7-32.8) (Table 2).

LLINs fabric integrity

Assessment of holes

At the 6th month assessment visit, the LLINs with holes represented 29% (95% CI: 23.6-35.1) for Dawa 2.0, 36% (95% CI: 29.3-42.2) for PN2.0 and 36% (95% CI: 29.3-42.2) for Dura (Figure 2). After 18 months of use, more than 50% of each type of LLINs have already holes (Dawa 2.0: 56%, Dura: 64%, and PN 2.0: 73%) (Figure 2). After the 24th and 30th month follow-up, the observed physical deterioration increased with hole proportions ranging from 70 to 89% of the LLINs found (all types). Overall, Dura was the most damaged LLIN (Figure 2). The Figure 3 showed, from T6 to T30, an increase in the proportions of size 1 holes for the three types of LLIN. This increase was much more remarkable between T18 and T30.

For Dawa 2.0 and PN 2.0 LLINs, no significant increase in the proportions of Size 2, Size 3 and Size 4 holes was observed from T6 to T30. For Dura, the proportions of the Size 2, Size 3 and Size 4 holes observed at T24 were significantly different from those observed during the other monitoring visits.

In both rural and urban settings, there was no significant difference between the different hole sizes for the three types of LLINs after 6, 18 and 24 months of use. However, a significant difference was observed for the size 3 holes for the PN 2.0 LLINs at 24 months and the size 4 holes for the Dura LLINs at 30 months. However, the hole proportions per size category varied from one location to another, among LLIN products, and over time (Table 3).

Variation of proportionate hole index(pHI) of the LLINs over time

Table 4 showed that the pHI gradually increased from one period to another for the three types of LLINs and were: from 39.8 (at 6 months) to 366 (at 30 months) for Dawa 2.0, 63.6 (at 6 months) to 321 (at 30 months) for PN 2.0, and 176 (at 6 months) to 1431 (at 30 months) for Dura (Figure 4). No significant difference in the pHI was observed from the 6 to 18 months for the three LLINs. A significant difference was noted from at the 24 and 30 months ($p < 0.001$) when the highest pHI was noted.

Comparison of the proportionate hole index between LLIN products

The data showed that the means pHI of Dawa 2.0, Dura and PN 2.0 during the 12 and 18 months were similar ($p > 0.05$) (Table 5). However, at T6, T24 and T30 respectively, the mean pHI of Dura was significantly higher (176, 893 and 1431) than those of Dawa 2.0 (39.8, 345 and 366) and PN 2.0 (63.6, 167 and 321) ($p < 0.001$). However, no significance difference was noted between Dawa 2.0 and PN 2.0 LLINs.

Variation of the physical conditions of the LLINs

After 6 months of use, the proportions of the 3 types of LLINs in "good ", "seviceable" or "torn" categories were respectively 85.5% (95% CI: 82.5-88.1), 11.6% (95% CI: 9.3 -14.3) and 2.9% (95% CI: 1.8-4.5) (Table 6). After 18 months of use, 66.8% (95% CI: 61.7-71.5) of the LLINs were in "good", 26% (95% CI: 21.6-30.8) were "serviceable", and 7.2% (95% CI: 4.8-10.4) in "torn" condition (Table 6). After 30 months, only 29.5% (95% CI: 23-36.7) of the LLINs still present in the households were in "good" condition, 28.4% (95% CI: 22-35.5) were "serviceable" and 16.9% (95% CI: 11.8-23.2) were "torn" (Table 6).

At LLIN brand level, 39.1% (95% CI: 27.6-51.6) of PN 2.0 were "in good" condition, 26.1% (95% CI: 16.3-38.1) were "serviceable" and 8.7% (95% CI: 3.3-17.9) were in "torn" after 30 months of follow-up. In the same period 28.6% (95% CI: 18.4-40.6), 27.1% (95% CI: 17.2-39.1) and 14.3% (95% CI: 7.1-24.7) of the Dawa 2.0 were respectively in "good" condition, "serviceable" and "torn" conditions. For the Dura LLINs, the proportions of the LLINs in "good" condition, "serviceable" and "torn" conditions were respectively 15.9% (95% CI: 6.6-30.1), 34.1% (95% CI: 20.5-49.9) and 34.1% (95% CI: 20.5-49.9) (Table 6).

Factors associated with the loss of LLINs physical integrity

Table 7 shows that most of the recorded factors were significantly associate to the physical damages of the LLINs ($p < 0.05$). LLINs often used are more holed than those used every night for DawaPlus 2.0 without statistical difference ($p > 0.05$) unlike Dura and PN 2.0 ($p < 0.05$). Households where the sleeping beds are cut bamboo or palm branch, with poor maintenance of the LLINs (dirty), having the kitchen indoor close to the LLINs and which have a washing frequency more than 6 times have their

LLIN with more holes than households where the mats were used as sleeping material, where the LLINs are well maintained (clean) and where the kitchen were outside with a washing frequency less than 6 times. There was a correlation between these factors and loss of the physical integrity of the LLINs ($p < 0.001$).

Discussion

The key LLIN component preventing man-vector contact is the physical integrity [5]. Therefore, the loss of physical integrity represents a major threat for the sleeper and need strong attention. In this study, the loss of integrity observed after the mass distribution campaign in 2014 in Benin was so large that it could have compromised the effectiveness of the LLINs in preventing malaria. The proportionate hole index (pHI) [19] provides a standardized approach to describe changes in the tissue integrity. Our results showed that during the 30 months follow-ups, there was a significance difference among the three LLIN products assessed in term of pHI which exponentially increase over time. After 30 months of use, the pHI of Dura (polyethylene) (pHI= 807.21) were higher than those of Dawa 2.0 (pHI= 185.75) and PN 2.0 (polyester) (pHI= 183.15) suggesting that Dura LLINs were more likely to lose their physical integrity.

The categorization of these pHI according to the WHO standards [20] as being in "good condition", "damaged but usable" or "to replace" showed us that after 30 months of use, 29.5 % of the LLINs (all brands) were in good condition. This result was higher than those observed in Madagascar in 2012 [21] where the proportion of LLINs to be replaced after 30 months was 16.9%. Dura polyethylene LLINs have had the highest proportion of LLINs in “to be replace" category (34.1%) after 30 months of follow-up in our study. This level of loss of physical integrity of the LLIN was likely moderate in comparison of the levels of 30 and 33% of the Olyset LLINs (polyethylene) in "torn" category reported by Gnanguenon et al, [5] after only 24 months. The rapid appearance of the Dura holes compared to the Dawa 2.0 and PN 2.0 LLINs confirms the beliefs that polyethylene LLINs lose their physical integrity faster than polyester LLINs. This information may be relevant to the Beninese National Malaria Control Program (NMCP) regarding the choice of LLINs for the future distribution of LLINs through campaigns.

The results of this longitudinal prospective evaluation of the LLINs distributed during the mass campaign in Benin showed that around half of LLINs enrolled were lost after 30 months of follow-up. This loss rate is higher compared to what was observed in Mozambique where there was a 25% loss after 3 years for the Olyset and PN 2.0 LLINs [22]. Different levels of physical damage were observed over time. The physical damage, represented by holes in our study, was already remarkable 6 months after the campaign and varied significantly among the three LLIN products. High retention of the LLINs were also observed in rural areas despite of the damages of the physical barrier.

Thirty months after the LLINs distribution campaign, a larger proportion of polyethylene-based (Dura) LLINs had holes (70-95.8%) compared to the polyester-based LLINs, Dawa 2.0 and PN 2.0 LLINs (64.0-79.5%). For example, when we consider the different hole sizes, we found that Dura LLINs had higher hole proportions than Dawa 2.0 and PN 2.0 LLINs. This finding confirms the results observed in Mozambique (1-year follow-up) [22] but was not consistent with the other findings which reported a low physical damage rate of a polythelene-based LLIN (Olyset net) after 7 years of use [23] suggesting that the loss of physical integrity may vary depending of the local conditions.

The frequency of LLIN use (often or every night), the type of sleeping material (mat or bed), the appearance of the LLIN (clean or dirty), the location of the kitchen (indoor or outdoor) and the frequency washing were correlated with loss of tissue integrity. These different practices in the use and maintenance of LLINs vary from one community to another and probably affect the status of different types of LLINs [24, 25, 26, 27, 28, 29]. It is therefore important to strengthen the awareness of the best practices for the maintenance of LLINs. In Kenya, a recent study found that people washed their LLINs more often than recommended and that this practice was associated with poor physical integrity of the LLINs [9]. It was also revealed that light-colored mosquito nets were more likely to be washed than dark-colored mosquito nets. The polyethylene (Dura) based LLINs in this evaluation were light blue. The majority of LLINs with high pHI values were dirty and often used. Thus, it is possible that these factors also contributed to the observed high frequency of washing that resulted in relatively high pHI of the LLINs washed more than 6 times and that significantly affected the physical integrity ($p < 0.001$).

Limitations

Our findings are limited to the three brands of LLINs, Dawa 2.0, PN 2.0 and Dura, distributed during the 2014 mass campaign; other brands of LLINs may have different performance under the same or different conditions.

WHO recommends that LLINs should be monitored from 6 months [30] after distribution to understand the reasons for attrition and wear in the first year of use. Although this was the case, the study was not able to compare how the extrinsic factors affect the physical integrity of each LLIN product and represents an important limit for the study.

The prospective and longitudinal nature of this study may have led participants to retain LLINs longer than expected if they were not enrolled and monitored. As a result, attrition rates due to LLIN disposal would have been higher and the loss of physical integrity observed may be worse than that normally tolerated before net disposal. A large number of LLINs were no longer available for follow-up for many reasons and could have skewed the results. The LLINs that were monitored were in three different regions. The differences observed between the types of LLINs, such as use and maintenance practices, probably reflect the differences in circumstances and regional customs. The results regarding LLIN repair were not taken consider as the LLINs in this study were poorly repaired as previously reported in many other studies [22, 31]. This study did not also take into account LLIN repair and their effect on physical durability as this practice was not common in the study communities and very few data were recorded. The insecticidal effectiveness of the LLINs and the prevalence of specific damage mechanisms were not also estimate representing an important limit for the study.

Conclusion

The physical integrity of the three LLIN products has been relatively low with a higher damage observed in the polyethylene-base LLINs: DuraNet. LLINs are often used to sleep on beds, often too dirty and washed, but rarely repaired by their owners. Awareness and emphasis on washing frequency, as well as the usefulness of LLINs even with holes, could help prolong malaria prevention. Further research to understand the determinants of LLIN removal and low maintenance is needed to strengthen behavior change communication campaigns and increase the durability of LLINs in communities.

Abbreviations

Dawa 2.0: DawaPlus 2.0

Dura: DuraNet

CI: Confidence Interval

CREC: Center for Research in Entomology of Cotonou

LLIN: Long-Lasting Insecticidal Net

LLINs: Long-Lasting Insecticidal Nets

NMCP: National Malaria Control Program

PN 2.0: PermaNet 2.0

pHI: proportional hole index

WHO: World Health Organization

WHOPES: World Health Organization Pesticide Evaluation Scheme

Declarations

Ethical consideration and consent to participate

The protocol of this study was reviewed and approved by the Institutional Ethics Committee of the Center for Research in Entomology of Cotonou (IECC) which is recorded at the Benin's Ministry of Health (MOH) under the reference number: IORG005696. Before the start of the study, the field team provided more details about the study protocol to the heads of households who gave their written consent to participate.

Authors' contributions

MCA, and VG designed the study. IBA, VG, ASS, RA, JJG, BA, BY, AS, carried out the surveys. IBA and BA analyzed the data. IBA prepared the map. IBA, VG and AS drafted the manuscript. RA, JFD, RHA, FT, UCN, JJG, AAS, GGP and MCA critically revised the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

All data generated or analysed during this study are included in this published article and its additional file.

Consent for publication

Not applicable.

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Tables

Table 1: Study districts and Sub-districts selected for LLINs monitoring

.INs lucts	Code N of districts	N selected	Corresponding district	Code N of the sub-districts	N selected	Corresponding sub-districts	Type of material
a 2.0	1 - 23	7	Tori- Bossito	1-9	6 and 8	Ouèssè, Laminou	Polyester
ıra	24-76	33	Ouèssè	10 -19	10 and 12	Houègbo, Kpomè	Polyethylene
2.0	77	77	Toffo	20-25	20 and 21	Tori-Cada, Tori-Gare	Polyester

Dawa 2.0: DawaPlus® 2.0, Dura : DuraNet®, PN 2.0: PermaNet® 2.0, N:Number

Table 2: LLIN attrition rates

District	LLIN condition physique Periods		Attrition-1 (Physical damage)					Attrition-2 (Removal response)					Attrition-3 (Re-purposed response)					
			T6	T12	T18	T24	T30	T6	T12	T18	T24	T30	T6	T12	T18	T24	T30	Total attrition
Tori-Bossito	Dawa 2.0	N(T0=300)	0	19	56	81	89	12	25	31	39	41	0	6	23	29	31	161
		%	0.0	6.3	18.7	27.0	29.7	4.0	8.3	10.3	13.0	13.7	0.0	2.0	7.7	9.7	10.3	56.7
		CI-95 %	0.0-1.2	3.9-9.7	14.4-23.5	22.1-32.4	24.6-35.2	2.1-6.9	5.5-12.1	7.1-14.3	9.4-17.3	9.9-18.1	0.0-1.2	0.7-4.3	4.911.3	6.6-13.6	7.1-14.3	47.8-59.4
Toffo	PN 2.0	N(T0=300)	5	40	67	76	85	8	27	33	37	42	2	12	25	27	29	156
		%	1.7	13.3	22.3	25.3	28.3	2.7	9.0	11.0	12.3	14.0	0.7	4.0	8.3	9.0	9.7	52
		CI-95 %	0.5-3.8	9.7-17.7	17.7-27.5	20.5-30.7	23.3-33.8	1.2-5.2	6-12.8	7.7-15.1	8.3-16.6	10.3-18.4	0-2.4	2.1-6.9	5.5-12.1	6-12.8	6.6-13.6	46.2-57.8
Ouèssè	Dura	N(T0=300)	5	25	82	89	93	24	30	44	49	52	2	28	32	35	41	186
		%	1.7	8.3	27.3	29.7	31.0	8.0	10.0	14.7	16.3	17.3	0.7	9.3	10.7	11.7	13.7	62
		CI-95 %	0.5-3.8	5.5-12.1	22.4-32.8	24.6-35.2	25.8-36.7	5.2-11.7	6.8-14.0	10.9-19.2	12.3-21	13.2-22.1	0-2.4	6.3-13.2	7.4-14.7	8.3-15.9	9.9-18.1	56.2-67.5
	Total attrition	N(T0=900)	10	84	205	246	267	44	82	108	125	135	4	46	80	91	101	503
		%	1,1	9.3	22.8	27.3	29.7	4.9	9.1	12.0	13.9	15.0	0.4	5.1	8.9	10.1	11.2	55.9
		CI-95 %	0.5-2	7.5-11.4	20.1-25.7	24.4-30.4	26.7-32.8	3.6-6.5	7.3-11.2	9.9-14.3	11.7-16.3	12.7-17.5	0.1-1.1	3.8-6.8	7.1-10.9	8.2-12.3	9.2-13.5	52.6-59.2

Dawa 2.0: DawaPlus® 2.0, Dura : DuraNet®, PN 2.0: PermaNet® 2.0, N: number, CI: Confidence interval, T0: 0 months, T6: 6 months, T12: 12 months, T18: 18 months, T24: 24 months T30: 30 months

Table 3: Proportion of LLINs found with hole by type by area after 30 months use (T30)

Periods	LLINs types	Areas	%Hole size 1	%Hole size 2	%Hole size 3	%Hole size 4
T6	Dawa 2.0	Urban area	63.9a	66.7a	25a	5.6a
		Rural area	68.4a	50a	26.3a	7.9a
	PN 2.0	Urban area	59.5a	62.2a	24.3a	8.1a
		Rural area	76.7a	65.1a	20.9a	9.3a
	Dura	Urban area	63.9a	66.7a	38.9a	36.1a
		Rural area	55.6a	55.6a	44.4a	18.5a
T12	Dawa 2.0	Urban area	79.1a	60.5a	32.6a	13.9a
		Rural area	74.1a	55.6a	48.1a	24.1a
	PN 2.0	Urban area	82.9a	62.9a	14.3a	11.4a
		Rural area	64.6a	77.1a	37.5b	8.3a
	Dura	Urban area	63.4a	58.5a	26.8a	26.8a
		Rural area	65.6a	56.3a	50a	37.5a
T18	Dawa 2.0	Urban area	85.4a	75.6a	36.6a	14.6a
		Rural area	75.6a	85.4a	24.4a	2.4a
	PN 2.0	Urban area	88.2a	64.7a	31.4a	15.7a
		Rural area	87.1a	71a	27.4a	4.8a
	Dura	Urban area	82.1a	53.6a	14.3a	32.1a
		Rural area	83.3a	77.8a	22.2a	27.8a
T24	Dawa 2.0	Urban area	91.9a	62.2a	29.7a	16.2a
		Rural area	77.8a	57.8a	48.9a	15.6a
	PN 2.0	Urban area	93.1a	79.3a	20.7a	3.4a
		Rural area	87a	76.1a	28.3a	4.3a
	Dura	Urban area	82.9a	85.7a	6a	54.3a
		Rural area	100a	81.8a	50a	40.9a
T30	Dawa 2.0	Urban area	91.3a	78.3a	26.1a	4.3a
		Rural area	96.2a	73.1a	50a	23.1a
	PN 2.0	Urban area	81.3a	50a	31.3a	12.5a
		Rural area	91.4a	71.4a	22.9a	5.7a
	Dura	Urban area	85.7a	85.7a	85.7a	14.3b
		Rural area	91.3a	78.3a	60.9a	52.2a

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0, 0.5 ≤ Size 1 ≤ 2 cm ; 2 < Size 2 ≤ 10 cm ; 10 < Size 3 ≤ 25 cm ; Size 4 ≥ 25 cm, Même lettre: p0.05, Différente lettre: p<0.001

Table 4: Variation of pHI over time

Brand	Period	Mean	SE	Median	IQR	P-value
Dawa 2.0	T6	39.8a	161	0	1	<0.001
	T12	150a	374	0	116	
	T18	154a	396	6.5	96	
	T24	345b	806	9	218	
	T30	366b	731	28	356	
Dura	T6	176a	504	0	46	<0.001
	T12	235a	520	1	213	
	T18	258a	566	2	152	
	T24	893b	1494	420	1020	
	T30	1431b	2754	290	1538	
PN 2.0	T6	63.6a	211	0	23	<0.001
	T12	174ab	583	0	49	
	T18	168ab	313	26	196	
	T24	167ab	382	27	171	
	T30	321a	1058	23	138	

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0, pHI: proportionate hole index, SE: Standard Error,

Table 5: Variation of the pHI among the three types of LLINs

Period	Brand	Mean	SE	Median	IQR	P-value
T6	Dawa 2.0	39.8a	161	0	1	0.005
	Dura	176b	504	0	46	
	PN 2.0	63.6a	211	0	23	
T12	Dawa 2.0	150a	374	0	116	0.693
	Dura	235a	520	1	213	
	PN 2.0	174a	583	0	49	
T18	Dawa 2.0	154a	396	6.5	96	0.129
	Dura	258a	566	2	152	
	PN 2.0	168a	313	26	196	
T24	Dawa 2.0	345a	806	9	218	<0.001
	Dura	893b	1494	420	1020	
	PN 2.0	167a	382	27	171	
T30	Dawa 2.0	366a	731	28	356	<0.001
	Dura	1431b	2754	290	1538	
	PN 2.0	321a	1058	23	138	

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0, pHI: proportional hole index, SE: Standard Error, IQR: Interquartil Range, Same letter: p0.05, Different letter: p <0.001

Table 6: Physical condition of the LLIN by districts

District	LLIN		Good category (0 ≤ pHI ≤ 64)					Serviceable category (64 pHI ≤ 642)					Torn category (pHI >642)				
			T6	T12	T18	T24	T30	T6	T12	T18	T24	T30	T6	T12	T18	T24	T30
Tori-Bossito	Dawa 2.0	n	229	141	97	19	20	21	54	40	31	19	5	6	9	41	10
		%	89.8	70.1	66.4	16.0	28.6	8.2	26.9	27.4	26.1	27.1	2.0	3.0	6.2	34.5	14,3
		CI-95 %	85.4-93.2	63.3-76.2	58.2-74	10.0-23.8	18.4-40.6	5.2-12.3	20.9-33.6	20.3-35.4	18.4-35.0	17.2-39.1	0.6-4.5	1.1-6.4	2.9-11.4	26.0-43.7	7.1-24.7
Toffo	PN 2.0	n	193	130	100	23	27	29	29	46	42	18	3	9	9	32	6
		%	85.8	77.4	64.5	23.7	39.1	12.9	17.3	29.7	43.3	26.1	1.3	5.4	5.8	33.0	8.7
		CI-95 %	80.5-90.1	70.3-84.5	56.4-72	15.7-33.4	27.6-51.6	8.8-17.9	11.9-23.8	22.6-37.5	33.3-53.7	16.3-38.1	0.2-3.8	2.5-10.0	2.7-10.7	23.8-43.3	3.3-17.9
Ouèssè	Dura	n	136	100	52	7	7	26	28	11	11	15	11	14	9	42	15
		%	78.6	70.4	72.2	13.4	15.9	15.0	19.7	15.3	16.4	34.1	6.4	9.9	12.5	62.7	34.1
		CI-95 %	71.7-84.5	62.2-77.8	60.4-82.1	6.3-24.0	6.6-30.1	10.1-21.2	13.5-27.2	7.9-25.7	8.5-27-5	20.5-49.9	3.2-11.1	5.5-16.0	5.9-22.4	50.0-74.2	20.5-49.9
Recapitulative of the 3 districts/period		n	558	371	249	49	54	76	111	97	84	52	19	29	27	115	31
		%	85.5	72.6	66.8	17.3	29.5	11.6	21.7	26.0	29.7	28.4	2.9	5.7	7.2	40.6	16.9
		CI-95 %	82.5-88.1	68.5-76.4	61.7-71.5	13.1-22.2	23-36.7	9.3-14.3	18.2-25.6	21.6-30.8	24.4-35.4	22-35.5	1.8-4.5	3.8-8.0	4.8-10.4	34.9-46.6	11.8-23.2

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0, n: number, CI: Confidence interval, pHI: proportional hole index, T0: 0 months, T6: 6 months, T12: 12 months, T18: 18 months, T24: 24 months T30: 30 months

Table 7: Factors Associated with loss of Integrity after 30 Months

	Factors	Modalities	Mean(pHI)	OR adj.	SE	OR (95%CI)	P (Wald's test)	P(LR-test)
0	Frequency of use of LLINs	Often	787	783				
		Every night	448	110	1.02	(0.97-1.07)	0.443	0.443
	Type of sleeping	Mat	296	98				
		Bed	729	230	3	(2.91-3.1)	< 0.001	< 0.001
	Aspect of LLINs	Dirty	557	152				
		Clean	287	138	0.43	(0.42-0.45)	< 0.001	< 0.001
	Location of kitchen	Inside	486	116				
		Outside	24	Na	0.06	(0.04-0.09)	< 0.001	< 0.001
	Washing frequency	1-5times	488	152				
		6 & more	456	178	1.12	(1.08-1.15)	< 0.001	< 0.001
	Frequency of use of LLINs	Often	677	180				
		Every night	828	352	1.26	(1.22-1.3)	< 0.001	< 0.001
	Type of sleeping	Mat	183	133				
		Bed	861	217	5.56	(5.19-5.95)	< 0.001	< 0.001
	Aspect of LLINs	Dirty	886	341				
		Clean	627	193	1.13	(1.1-1.17)	< 0.001	< 0.001
	Location of kitchen	Inside	799	197				
		Outside	37	36	0.07	(0.05-0.09)	< 0.001	< 0.001
	Washing frequency	1-5times	637	166				
		6 & more	1053	549	1.76	(1.7-1.82)	< 0.001	< 0.001
	Frequency of use of LLINs	Often	967	307				
		Every night	234	73	0.33	(0.31-0.34)	< 0.001	< 0.001
	Type of sleeping	Mat	84	27				
		Bed	605	197	4.89	(4.66-5.14)	< 0.001	< 0.001
	Aspect of LLINs	Dirty	480	152				
		Clean	69	22	0.19	(0.18-0.2)	< 0.001	< 0.001
	Location of kitchen	Inside	345	109				
		Outside	122	81	0.44	(0.41-0.48)	< 0.001	< 0.001
	Washing frequency	1 -5times	146	101				
		6 & more	337	124	1.49	(1.42-1.57)	< 0.001	< 0.001

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0, OR: Odds ratio, SE: Standard Error, CI: Confidence interval, p (Wald test); p-Value (test de Walid de significativité des coefficients), p(LR-test):p-Value (Likelihood ratio-test ou test de vraisemblance)

Figures

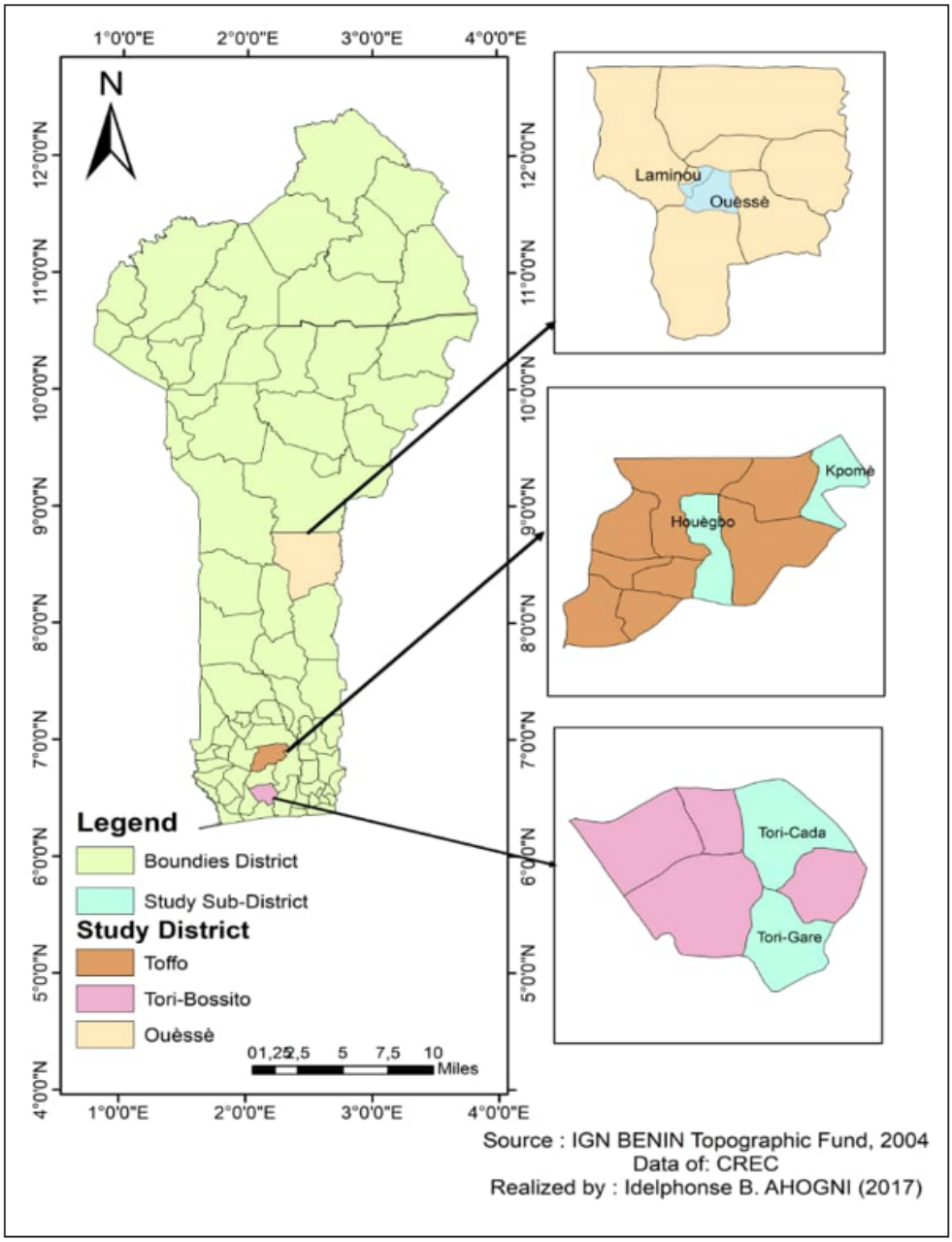


Figure 1

Map of Benin showing the study sites

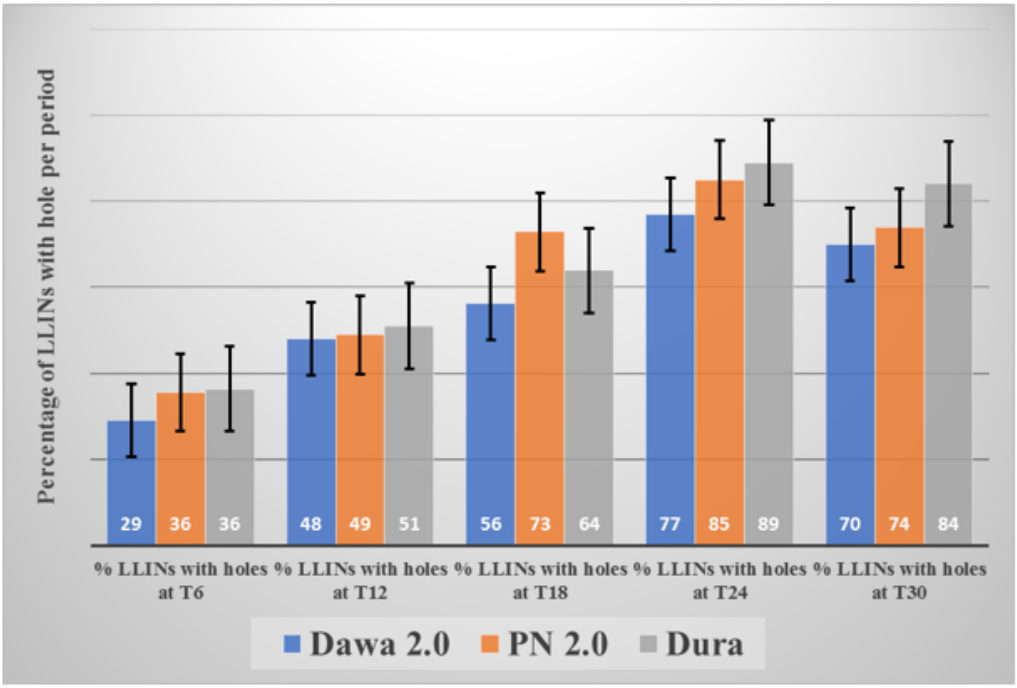
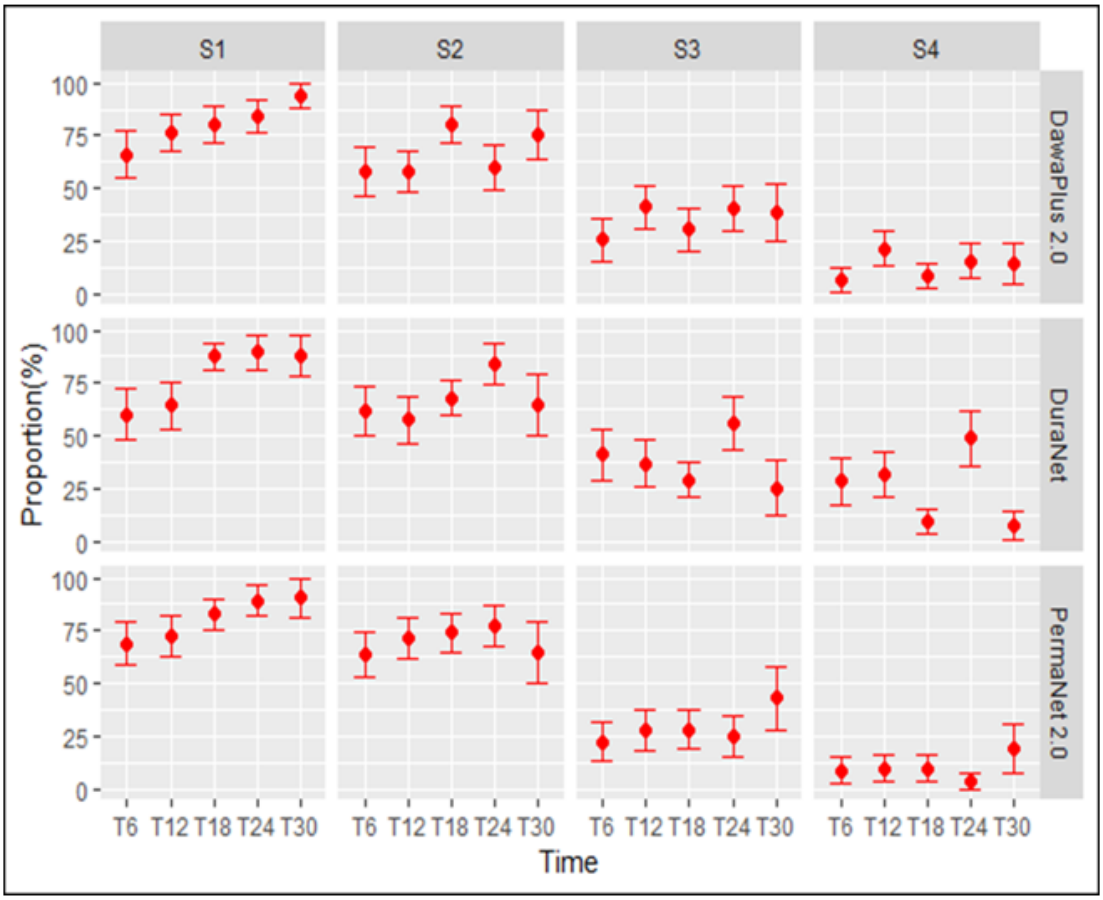


Figure 2

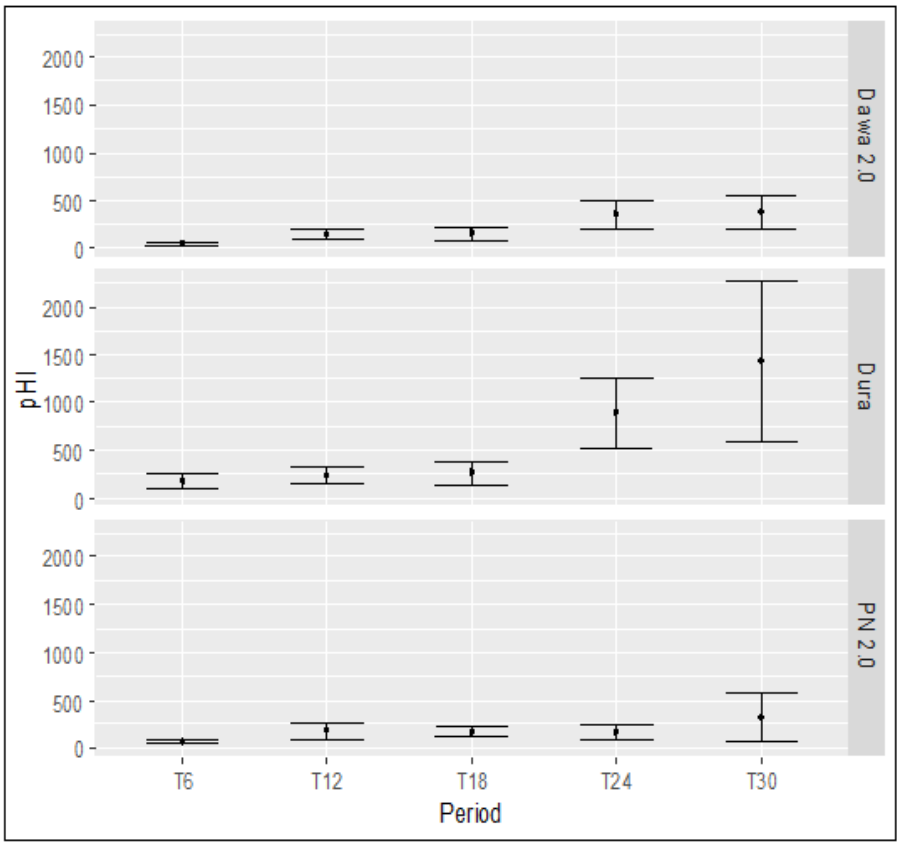
Proportion of LLINs with any type of hole at 6, 12, 18, 24 and 30 months



S: Size of hole, 0.5 ≤ S1 ≤ 2 cm, 2 < S2 ≤ 10 cm, 10 < S3 ≤ 25 cm, S4 ≥ 25 cm, T6: 6 months, T12: 12 months, T18; 18 months, T24: 24 months, T30: 30 months

Figure 3

Proportion of LLINs with size 1, 2, 3 and 4 holes at 6, 18 and 30 months



T6: 6 months, T12: 12 months, T18: 18 months, T24: 24 months; T30: 30 months

Dawa 2.0: DawaPlus® 2.0, Dura: DuraNet®, PN 2.0: PermaNet® 2.0

Figure 4

Variation in pHI of the three types of LLINs over time