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Durability of Long-Lasting Insecticidal Nets (Yorkool) under Operational Conditions, Anseba Zone, Eritrea

By Mensur Yenus, Amanuel Mhreteab, Henos Kiflom, Amanuel Kflemariam & Awet Mebrahtu

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Mensur Yenus [α], Amanuel Mhreteab [σ], Henos Kiflom [ρ], Amanuel Kflemariam [Ѡ] & Awet Mebrahtu [¥]

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Method: A community-based, prospective longitudinal study was conducted in the Asmat, Habero, Hagaz, and Elabered sub-zones to evaluate the survivorship, physical integrity, and insecticidal activity of newly distributed Yorkool-type LLINs. A total of 270 nets were included in the study.

Result: After 12 months of use, the study found a survivorship rate of 95.05% for nets reported as used and 97.9% for stored nets. Over 95% of the LLINs found in households were reportedly used for sleeping every night, with 82% used throughout the year. However, 19% of the nets were used outside the primary residence, such as in gardens, farmland, or other locations. While 20% of the nets had holes, they were all deemed repairable, and none required replacement.

Conclusion: The newly distributed Yorkool LLINs are expected to have a lifespan of approximately 3 years, maintaining their physical integrity, survivorship, attrition resistance, and bio-efficacy. However, the present study identified holes in nearly 20% of the nets after only 12 months of use. Fortunately, none required immediate replacement. Encouragingly, over 95% of the nets in the study remained intact despite the insecticide not meeting WHO's bio-efficacy criteria for knock-down or mortality rates. Further evaluation of net durability is recommended to determine the ongoing protective effect these nets provide to the community.

Keywords: LLINs, durability, attrition or survivorship, physical integrity, and bio-efficacy.

Author α: Entomologist at ministry of Health Anseba Region.
e-mail: mensuryenus@gmail.com
Author σ: Entomologist at ministry of health Gash-Barka Region.
Author ρ Ѡ: Public health officer at ministry of Health Anseba Region.
Author ¥: Public health officer at ministry of health Gash-Barka Region.

I. Introduction

Malaria is one of the world's most deadly diseases, and it is perilous for pregnant women and children under 5 years of age. In 2018, 67% of all the mortality due to malaria was attributed to pregnant mothers and children <5 years (WHO, 2020). Africa is greatly affected by malaria more than the other continents that more than 93% of morbidity and 94% of mortality were from Africa (WHO, 2020). Apart from the consequences in mortality and the subsequent reduction in life expectancy, malaria affects people's physical conditions, making them more vulnerable to other diseases (Blanco, 2018). Anemia, malnutrition, and other health problems can significantly increase one's vulnerability to malaria. This option emphasizes that these factors directly contribute to being more susceptible to malaria.

Malaria-endemic countries are heavily impacted by the economic burden of the disease, primarily due to: -1- Reduced productivity: Malaria affects the workforce by causing absenteeism and decreased work performance due to illness. -2-). Reduces students' attendance at school, affecting their education and productivity in the long run: -3-) Large of money spent for its prevention and treatment that could otherwise be used for investment in productive activities (Blanco, 2018).

Investment in malaria control has greatly reduced transmission. An estimated 663 million cases have been averted worldwide between 2000 and 2015, with 68% of them attributed to insecticide-treated nets (Bhatt, *et al.*, 2015). Long-lasting insecticidal nets (LLINs) protect against malaria by acting as a physical barrier between mosquitos and humans, and by the insecticide repelling or killing susceptible mosquitoes (Darriet *et al*., 1984; Lengeler, 2004 and Davies *et al*., 2007). Insecticide enhances public health by reducing mosquito density and helping maintain the net's effectiveness after holes develop (Derriet *et al.,* 1984)).

In Eritrea, found in Sub-Saharan Africa (SSA), malaria is still endemic in four of the six zones (regions) despite the rate of endemicity is different among these regions. However, malaria is greatly reduced in Eritrea over the past two decades (Mihreteab *et al*, 2020).

During the last years, prevention in Eritrea has been based on two main methods of intervention: LLINs mass distribution and indoor residual spraying (IRS) in selective epidemic-prone areas with other supporting strategies like larval source management (LSM) and larviciding using temephos.

According to WHO Global Malaria Program (a system to improve value for money in LLIN procurement through market competition based on cons per year of adequate coverage), the annual cost of LLINs for malaria control is more than 500 million US dollars; it is the largest commodity category in the malaria control budget, so do in Eritrea mainly in Anseba Zone uses only LLINs with other supporting activity in malaria prevention nowadays every individual is provided with the net with high cost.

The same study was conducted in Benin, West Africa, to assess the physical integrity and survivorship of LLINs distributed to households in a community with similar socio-cultural characteristics. The study found that only 1.73% of the LLINs exhibited visible integrity loss after six months (Gnanguenon *et al*. 2014). After a year, the damaged nets were increased by 10.41%. This study revealed that the survival rate of the nets in households was lower than expected. However, the nets surprisingly met the WHO standard for physical integrity for a period of one year (Ahogni *et al.* 2020). Different studies from the same country found almost the same result in 12 months of utilization, that more than 70% of the nets survived (Azondekon *et al,* 2014 and Gnanguenon *et al*, 2014).

Ahogni's study found that, out of 1,134 bed nets, only 1.41% needed replacement, while 3.44% required repairs. In contrast, another study from Uganda reported a significantly higher rate of net damage, with over 33% of the nets having one or more holes (Kilian *et al*, 2011).

LLINs are expected to remain effective for at least three years under typical use conditions (WHO, 2011; Kilian *et al*. 2011). This recommendation from the WHO informs the practice of mass distribution campaigns every three years. However, numerous studies (Ahogni *et al*. 2020; Massue *et al.* 2016; Tan *et al.* 2016; Randriamaherijaona, 2017) have shown that various factors can compromise net lifespan, preventing them from reaching the expected three years.

Universal coverage campaigns often lack strategies to address net survivorship (resistance to damage and loss), attrition (nets falling out of use), and physical integrity (tears and holes). While the WHO emphasizes the importance of monitoring national coverage and durability (WHO, 2017), a more comprehensive approach is needed. Studies evaluating LLIN durability typically assess survivorship and attrition, physical integrity, and bio-efficacy (insecticide effectiveness).

In Eritrea, LLINs combined with IRS and larviciding remain the primary tools for vector control (Mihreteab et al., 2020). However, despite increased coverage of IRS and LLINs in recent years, malaria cases and deaths haven't shown a consistent decline (Mihreteab et al., 2020). Notably, LLINs have been the mainstay of malaria prevention for many years, distributed freely throughout the country. While the Eritrean government's commitment to tackling communicable diseases and providing free bed nets is commendable, a critical gap exists – a lack of recent studies on net survivorship, fabric integrity, and insecticidal activity (bio-efficacy).

II. Methodology

a) Study design

This study employed a community-based, prospective longitudinal design in the Asmat, Habero, Hagaz, and Elabered sub-zones (January 2021 - December 2020) – a period with an error. During net distribution, researchers identified participants and followed them for six months. The study focused on the durability of Yorkool-type LLINs, distributed one year prior, where each household member received a net (100% coverage). A total of 101 households were selected, enrolling 405 Yorkool nets (263 reported as used and 142 stored). The nets marked for use were assessed for durability every six months over three consecutive years.

Separately, 40 Yorkool LLINs were tested for bio-efficacy at baseline (day zero) and distributed to families in four sentinel sites. After one year, the tagged nets were collected and transported to the Elabered malaria entomology laboratory for further biological testing. Importantly, these families did not receive new nets during the study, as they were considered additional to the standard one-to-one distribution.

b) Study area

The study was conducted at 4-sentinel sites of Anseba region*:* Asneda (Asmat Sub-zone), Filfle (Habero Sub-zone), Adi Berbere (Elabered Sub-zone) and Hagaz town (Hagaz-Sub zone).

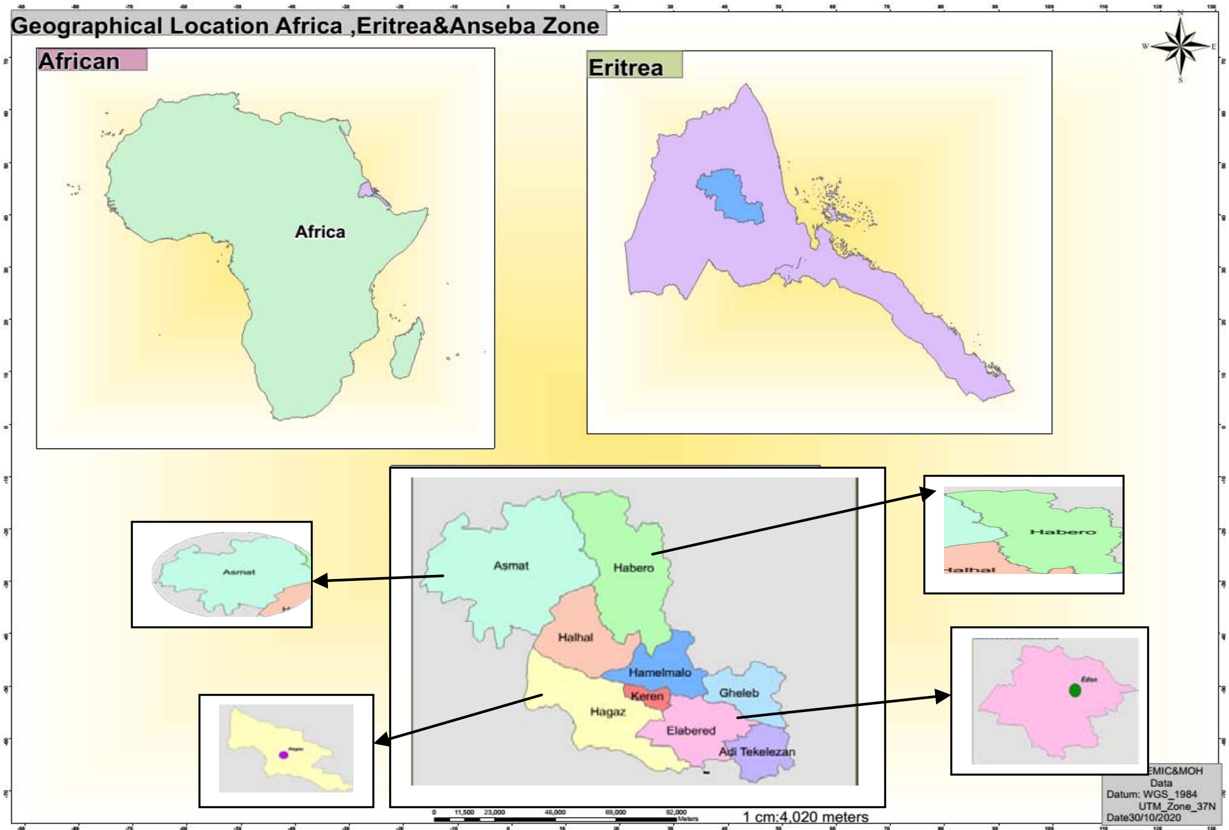

Fig. (2.2): Study area: Africa, Eritrea, Anseba zone, study sites, Hagaz, Asmat, Elabered & Habero sub zones.

c) Study Population

The study population consisted of Yorkool type long-lasting insecticidal nets (LLINs). These nets had been tested for insecticidal activity at day zero and were impregnated with deltamethrin. Nets that were given away for others to use, stolen, destroyed, used for other purposes, or were torn (with a proportionate hole index between 65-642 mm) were excluded from the study. Furthermore marked nets in which the study HH was moved from the village for different purposes.

d) Sampling size determination

According to different studies, a sample size of 250 nets per product was used to detect a 9%-point difference in LLIN attrition rate if the best-performing product has an attrition rate of 10%. An 8% buffer was added to the required sample size to prevent any negative impact of the mid-course withdrawal of some study participants. So, a sample size of 270 LLIN (yorkool) were retained for the study.

e) Sampling Techniques

In this community-based study, villages were selected using convenience sampling, while households (HHs) were chosen through simple random sampling. Villages within each sentinel site were chosen based on malaria incidence and the presence of active breeding sites. Household selection, however, employed simple random sampling. First, a complete census of all HHs in the chosen village was conducted prior to the distribution of nets. Then, from this list, ten households were randomly selected based solely on the head of household's name and provided with marked LLINs, each tested for bio-efficacy at day zero. The remaining 60 HHs per village were selected using the same method, yielding a total of 70 HHs per village to monitor attrition and fabric integrity of the nets.

f) Data Collection

Data was collected at the end of the malaria transmission season, just one year after mass distribution in November 2021. A standard questionnaire was used to collect data from an adult member of each household (HH) at the follow-up. Data collectors, who included public health officers, an entomologist, and insect collectors, were trained before conducting the survey to ensure understanding of the questionnaire. A pilot study was conducted by randomly selecting 10% of the sample size from a non-selected administrative area. Information collected included the status, patterns of use, and handling of each study LLIN distributed to the HH. Additionally, data on fabric integrity and the overall condition of the LLINs were collected.

g) Data Management and Analysis

Data were analyzed using SPSS version 23, and separately it was analyzed on the three factors attributed to durability: The number of nets in the sample, the proportion of the indicator and 95% confidence interval was reported.

h) Measurement of variables

Measurement of survivorship and attrition

The analysis included data on all nets recorded during the exercise at each time interval.

Survivorship:

- Numerator: Total number of LLIN product present in surveyed HHs (and available for sleeping under) x 100
- Denominator: Total number of LLIN product distributed to surveyed HHs

A. Attrition rate-1: for nets that have been destroyed or disposed of:

- Numerator: Total number of LLIN product reported as lost due to wear and tear (poor condition) in surveyed HHs x 100
- Denominator: Total number of LLIN product distributed to surveyed HHs

B. Attrition rate-2 for nets not available for sleeping under:

- Numerator: Total number of LLIN product reported as lost for reasons other than poor fabric integrity (given away, stolen, sold or used in another location) in surveyed households x 100
- Denominator: Total number of LLIN product distributed to surveyed HHs

C. Attrition rate-3 for nets used for other purposes:

- Numerator: Total number of LLIN product reported as being used for another purpose in surveyed HHs x 100
- Denominator: Total number of LLIN product distributed to surveyed HHs For each LLIN product, the survivorship rate plus attrition rate-1, attrition rate-2 and attrition rate-3 will add up to 100%.

Measurement of Fabric integrity

Fabric integrity was analyzed for all the LLINs found in the HHs (and used for sleeping under), and all the LLINs assessed for holes at each monitoring round. Two indicators were calculated at each survey time: the proportion of LLINs with holes and a hole index.

Proportion of LLINs with any holes (with 95% confidence interval):

- Numerator: Total number of LLINs product with at least one hole of size 1–4
- Denominator: Total number of LLINs product found and assessed in surveyed HHs

The hole index was calculated by weighting each hole by size and summing for each net. If the weight of hole sizes 1, 2, 3 and 4 was A, B, C and D, respectively, the hole index was calculated as:

Hole index = (A x no. of size-1 holes) + (B x no. of size-2 holes) + (C x no. of size-3 holes) + (D x no. size-4 holes).

Measurement WHO cone bioassay:

Standard WHO bioassays use standard susceptible 3–5 day old, non-blood fed *Anopheles* females exposed to netting under WHO cones for 5 minutes. Cones will be gently fitted on the net. Five female mosquitoes were introduced in each cone with 5 replicates per net sample (i.e. 25 mosquitoes per net).

After a 5-minute exposure time in each cone, the mosquitoes were held for 24 hours with access to a sugar solution. Knockdown was measured 60 minutes after exposure, and mortality was measured after 24 hours. A negative control, using an untreated net, was included in each round of cone bioassay testing.

If the mortality in the control was between 5% and 20%, the data was adjusted with Abbott's formula. If the mortality in the control is > 20%, all the tests were discarded for that day. Bioassays were carried out at 27 ± 2 °C and 80 ± 10% relative humidity.

Abbott's formula:

$$\text{Corrected mortality} = \frac{(\%\ \text{observed mortality} - \%\ \text{control mortality})}{(100 - \%\ \text{control mortality})} \times 100$$

i) Ethical Clearance

First and foremost, clearance to conduct the study was obtained from the Ethical Approval Committee at the Ministry of Health, Eritrea. Upon entering a selected community, the assistance of opinion leaders was sought to obtain permission to use their communities as study sites and to inform the communities about the study objectives and methods. Informed consent was then obtained from all participants in the study who received the nets. Confidentiality was ensured by not sharing any respondent information with anyone.

III. Result

a) Characteristics of Respondents and Housing Condition

Table 3.1 shows that the majority of respondents who completed the questionnaire were heads of households and parents/guardians. Among the interviewees, 57% had no formal education or only a primary level education. The housing conditions where the nets were placed revealed that 60% of the homes had concrete walls, while the rest were constructed with mud bricks or a combination of mud and wood framing.

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Additionally, 74% of the floors were made of soil or sand.

b) LLINs Utilization and Maintenance

Table 3.2 shows that 92% of participants reported using their long-lasting insecticidal nets (LLINs) the night before the survey. Reasons for not using the nets included no reported malaria or mosquito presence. Over 95% of the LLINs found in households were reportedly used every night for sleeping, with 82% being used year-round. However, 19% of the nets were used outside the main house, such as in gardens or on farmland (Figure 3.2).

Washing frequency, materials, and drying location can impact insecticidal activity. As shown in Table 3.4, only 48% of the nets were washed one year after distribution. The primary cleaning material was local bar soap, though over 80% reported using soap or detergent powder for washing. In more than half of the cases, washed LLINs were dried in sunlight.

Table 1: Percentage distribution of characteristics of respondents, and housing conditions (N=101), regularity of sleeping under, LLINs displacement and maintenance

Characteristics		Hagaz	Elabered	Asmat	Haboro	Total
Interviewee	Head Of HH	48	50	40	19	39
	Guardian/Parent	35	3	4	78	39
	Other Adult	17	12	56	4	22
Educational Level	No Former Education	9	15	4	33	15
	Primary School	52	3	32	44	42
	Junior School	17	19	12	19	17
	High School	17	23	36	4	20
	Higher Level	4	4	16	0	6
Roof of the wall(Where the nets are found)	Mud Brick	45	0	0	7	13
	Mud With Wood Frame	0	4	4	70	20
	Concrete	55	9	76	19	61
	Wood	0	0	4	0	1
	Straw	0	0	0	0	0
	No Wall	0	0	0	0	0
	Other	0	0	0	0	0
Type of flooring in the Room	Soil Or Sand	69	63	95	67	74
	Wood	0	0	0	15	4
	Cement	31	37	5	18	23
	Carpet	0	0	0	0	0
How often the being used is the net being used in the last week	Every night	100	92	96	96	96
	Most nights	0	0	0	4	1
	Some nights	0	8	0	0	2
	Not used at all	0	0	4	0	1
During which period is the net used	All year round	59	85	96	89	82.3
	During transmission season	41	15	0	11	16.7
	During dry season	0	0	0	0	0
Displacement of the net from the main house	Taken to farm land	23	0	0	26	12.3
	Taken to garden	0	4	0	4	1
	Other	0	4	8	7	4.8
	Not used away	77	92	92	63	81.9
LLINs maintenance						
Ever washed Nets	Yes	50	36	47	61	48
	No	50	64	53	39	52
Washing method	washed with cold water	57	8	18	0	20
	washed with a bleach/ soap	43	92	82	100	80
Those Nets Washed With Bleach / Soap	local bar soap	17	0	22	6	9
	detergent powder	50	92	78	94	84
	mix of bar and detergent	33	8	0	0	7
Drying Method	exposed to sun light	29	46	73	59	51
	dried in shaded place	36	54	27	41	40
	dried in indoor	36	0	0	0	9

c) Survivorship and attrition

During follow-up visits at 12 months, a total of 250 LLINs marked as used and 139 marked as stored were found to be available at the households (HHs). While the text mentions a survival rate of 95.05% for used LLINs and 97.89% for stored LLINs, these percentages seem to be incorrect based on the provided data.

d) Physical Integrity

At 12 months of use, the percentage of nets with hole was found to be 20%. As depicted in table 4.7, it was 18.57%, 28.12%, 19.69% and 14.28% in Hagaz, Elabered, Asmat, and Haboro respectively. The average proportional hole index (pHI) of Yorkool®LN mosquito nets after 12 month of distribution was 14.31, 10.75, 3.36, 1.59 in Hagaz, Elabered, Asmat and Haboro respectively. The average of LLINs with a hole but in a good condition was 17.49%. However, the present study found that all damaged e nets could be repaired and be used further; besides, none of the nets was categorized under "to be replaced".

Table 3.2: Survivorship

	Nets in the master list under use	yes use	Survivorship of nets in use	Nets in the master list under store	yes store	Survivorship of nets in store
Hagaz	70	64	91.43%	23.00	22	95.65%
Elabered	66	62	93.94%	39.00	37	94.87%
Asmat	64	64	100.00%	31.00	31	100.00%
Haboro	63	60	95.24%	49.00	49	100.00%
Total	263	250	95.05%	142.00	139	97.88%

Table 3.4: Attrition

	Nets in the master list under use	Attrition rate 1	Attrition rate 2	Attrition rate 3
Hagaz	70	(0/70)*100= 0%	(6/70)*100=8.57%	(0/70)*100=0
Elabered	66	(1/66)*100=1.52%	(3/66)*100=4.55%	(0/66)*100=0%
Asmat	64	(0/64)*100=0%	(0/64)*100=0%	(0/64)*100=0%
Haboro	63	(0/63)*100=0%	(3/63)*100=4.76%	(0/63)*100=0%
Total	263	(1/263)*100=0.38%	(12/263)*100=4.56%	(0/263)*100=0%

Table 3.5: Physical integrity

Sub zone	Nets in the master list under use	Nets with holes	Proportion of the net with holes
Hagaz	70	13.00	0.19
Elabered	66	13.00	0.20
Asmat	64	18.00	0.28
Haboro	63	9.00	0.14
Total	263	53.00	0.20

Table 3.6: PHI Value

	Total nets assessed	Nets with no Holes	Nets with at least one hole		
			Good condition (PHI< 64)	To be repaired (65<= PHI <= 642)	To be replaced (PHI > 624)
Hagaz	70	57(81.43%)	10(14.28%)	3(4.28%)	0(0%)
Elabered	66	53(80.30%)	10(15.15%)	3(4.54%)	0(0%)
Asmat	64	46(71.88%)	17(26.56%)	1(1.56%)	0(0%)
Haboro	63	54(85.71%)	9(14.28%)	0(0%)	0(0%)
Total	263	217(82.51%)	46(17.49%)	7(2.66%)	0(0%)

e) Bio-Efficacy

Table 4.7 shows that 40 nets (10 nets from each sub zone) were enrolled for WHO bio-assay test. So the mean knockdown down rate was 80. 5% and the mean mortality rate after 24 h was 71% with 95% CI of 52.3 – 81.5

Table 3.8: Mean KD and Mean mortality rate of the LLINs after 12 month with WHO Cone Test

	Sub-Zone			
	Hagaz	Elabered	Haboro	Asmat
Total Yorkool LLINs	10	10	10	10
Total Mosquito Inserted (tested)	500	500	500	500
Mean Knockdown Rate	89 %	85%	77%	71%
Mean Mortality Rate After 24 Hrs.	72%	79%	68%	65%
95% CI of percent's	56 - 82	60 - 86	51 – 79	42- 75

IV. Discussion

This study revealed that the washing frequency in the past year was less than half of what was expected for the total number of distributed nets. While washing frequency didn't seem to impact the overall survival rate of the nets, it did affect their physical integrity. This finding aligns with a study from Benin by Gnanguenon et al. (2014), which also observed a negative impact of frequent washing on the physical condition of LLINs. However, another study from Benin by Ahogni et al. (2020) found that even with holes, LLINs generally maintained a mortality rate above 50%. This highlights a crucial point: even if physically damaged, LLINs can still offer significant protection against mosquito bites, making their continued use essential.

The study results showed that, of the total observed LLINs, more than 96% was in serviceable condition after an average use of 12 months. The result also showed that almost none of the nets badly torn and removed from utilization. A study from Chad revealed, among the observed LLINs less than 30% were found to be serviceable after 14 months of utilization and nearly 40% of the total were badly torn and considered unserviceable (Allan *et al.,* 2012). As the study revealed sleeping without mattress was one of the reasons which reduced the serviceable life of the LLINs (Allan *et al.,* 2012). On the contrary a study from Benin on similar type of bed net revealed after eighteen months of use, more than two-third were found functionally survived (Ahogni *et al.,* 2020).

Our study observed a low attrition rate of only 5% after 12 months of monitoring, significantly lower than findings from Benin and Mozambique (Ahogni et al., 2020; Juliette et al., 2015). This lower rate can be attributed to the nets being primarily given away to others, unlike the other studies where misuse was reported. Interestingly, a study from Nepal (mention reference) found LLIN loss due to displacement for seasonal fieldwork, alongside instances of misuse (Ahogni *et al.,* 2020).

Nearly 80% of the study LLINs remained in good physical condition, without holes, after 12 months of use. Similar results were observed in Benin and Madagascar (Ahogni et al., 2020; Tan et al., 2016), while a higher proportion of torn nets was reported in Zambia (Kilian et al., 2011). Furthermore, the present study found that 82.5% of the Yorkool LLINs were in good working condition after 12 months of distribution. This finding is slightly lower than that reported by Ahogni et al. Additionally, the present study did not observe as high a proportion of torn nets as was observed in the study from Zambia (Craig et al., 2015). A high proportion of holes (pHI) compromises the physical protection offered by LLINs. This allows mosquitoes to feed on humans, thereby perpetuating human-vector contact and malaria transmission (Ochomo et al., 2013; Haji et al., 2013). Supporting this, another study demonstrated a direct link between the physical integrity of LLINs and human-vector contact. They found that damaged nets increased the average number of mosquito bites per person per night from zero to five (Gnanguenon et al., 2014).

The study measured a knock-down (KD) rate of 80.5% at 60 minutes and a 71% mortality rate after 24 hours of exposure. These findings fall short of the World Health Organization (WHO) standards. According to the WHO Pesticide Evaluation Scheme (WHOPES), an effective LLIN should retain biological efficacy for at least 3 years. This is defined as at least 80% of nets achieving either 95% knock-down or 80% mortality (WHO, 2012). Ideally, LLINs should maintain their insecticidal activity for this timeframe (Albert, 2012).

A study conducted in Madagascar on Yorkool LLINs reported similar results to the present study, with over 75% of the nets failing to meet the WHO threshold (Tan et al., 2016; Gnanguenon et al., 2014). However, Ahogni et al. (20XX) found that 58% of their study nets met the WHO quality standard for both knock-down at 60 minutes and mortality after 24 hours.

The durability and lifetime of LLINs are critical factors for program planners to determine the most cost-effective timing and distribution strategies for net replacements. However, the most crucial aspect remains the biological efficacy of LLINs. They must meet the WHO's minimum requirements for knock-down (KD) and mortality rates after 60 minutes and 24 hours, respectively.

V. Conclusion

The newly distributed Yorkool LLINs are expected to have a lifespan of approximately 3 years, maintaining their physical integrity, survivorship, attrition resistance, and bio-efficacy. However, the present study identified holes in nearly 20% of the nets after only 12 months of use. Fortunately, none required immediate replacement.

Encouragingly, over 95% of the nets in the study remained intact despite the insecticide not meeting WHO's bio-efficacy criteria for knock-down or mortality rates. Further evaluation of net durability is recommended to determine the ongoing protective effect these nets provide to the community.

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