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Original Article

Field evaluation of Yorkool ®, a long-lasting insecticidal net after 12 months of use in Seme, Kisumu County, Kenya

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Integrity, Efficacy, Bioassay, Washing, Drying, Knockdown.

ABSTRACT

Background: Physical integrity and insecticidal efficacy of long-lasting insecticide-treated nets (LLINs) is influenced by the handling practices during use. This was an evaluation of Yorkool® pyrethroid-based LLINs after 12 months of use to determine the washing and drying practices, physical conditions and bio-efficacy. **Methods:** This was a cross-sectional household survey in an area where rectangular Yorkool® a pyrethroid LLINs were distributed during national mass net distribution campaign in 2021. Questionnaires were used for data collection and bioassay tests were done from thirty randomly selected nets. **Results:** 262 household heads were interviewed with their mean age being 46.9 years (SD 17.4 years) and level of education was mainly primary (70.2%). Most households (71.8%) had 1 to 2 sleeping spaces. The households had a total 468 LLINs with 95.1% having been washed at least once. About three-quarters (74.4%) of the LLINs had been washed using local bar soap, with 99.6 % having not been scrubbed on hard surface during washing and 72.1% were dried under a shade. Those evaluated for physical integrity and had at least one hole made up 77.8% of the nets and 57.2% were too torn and requiring replacement. Bio-efficacy test recorded a mean KD of 92% after 1 hour, and mean mortality of 86% after 24 hours. The nets that passed the WHO efficacy cut off for mortality (≥80%) after 24 hours were 83.3% and 70% passed the KD (≥95%) cut off after 1 hour. **Conclusions:** While more than a half of the Yorkool® LLINs needed replacement due to poor physical integrity after one year of use in the households, the bio-efficacy of the LLINs was relatively high with the mortality on vectors meeting the WHO threshold.

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INTRODUCTION

Malaria is a major global public health problem, with an estimated 249 million malaria cases and more than 608,000 malaria-related deaths being recorded in 2022 and out of these, the World Health Organization (WHO) African Region accounted for more than 90% of the cases and deaths (World Health Organization, 2023). Use of long-lasting insecticide-treated nets (LLINs) is currently one of the key malaria prevention measures (World Health Organization, 2022). The LLINs has insecticide that has been incorporated into or coated onto the fibre and thus prevents human-mosquito contact by creating both a physical and an insecticidal barrier which remains effective even after repeated washing and extended use (Randriamaherijaona et al., 2017). The extra benefits of LLINs include their dirt repellent capacity and high durability to washing and wide mesh size to provide good airflow (World Health Organization, 2013)

Physical integrity of LLINs and their insecticidal efficacy determines their prevention effectiveness against mosquito bites. Presence and the number of holes on the nets as well as deterioration of the impregnated insecticide compromises their efficacy. Several studies have reported varying results on physical integrity of LLINs depending on the conditions to which the nets are exposed. A study in Guatemala found a high functional survivorship of up to 88-94% after 18 to 32 months of use (Castellanos et al., 2021). Another study in Zambia recorded that 94% of nets had holes after a median of 31 months of use (Craig et al., 2015). The common causes of holes on the nets include direct contact with the bed frame or mattress during tucking-in of the net, fires in single room houses, tin lamps and tearing caused by animals like cats or rodents (Mutuku et al., 2013). Other causes listed in studies include tearing after the net is caught on an object during use and also children (Castellanos et al., 2021).

Most LLINs are currently treated with pyrethroids due to the relative safety of this class of insecticide for humans at low dosage, repellent, rapid knocking down rates and killing effects (World Health Organization, 2011). The physical and insecticidal durability of LLNs is influenced by many factors including the frequency of washing, type of laundry soap, washing and drying techniques, and other wear-and-tear parameters (Castellanos et al., 2021). LLINs are expected to retain effectiveness against susceptible *Anopheles* species vectors for up to 20 standard WHO laboratory washes and 3 years of recommended field usage (World Health Organization, 2013). Nets washed gently with water and a bar soap under controlled conditions retain all formulations showing good resistance with 100% anopheles' mortality observed in the cone bioassay after three washes (González et al., 2002). A study in Kenya reported that nets retained efficacy when hand-rubbed instead of beating on rocks while washing (Atieli et al., 2010). Washing frequency also has an influence on the durability and efficacy of nets demonstrated by increased feeding success and survival rates of mosquitoes with increasing number of washes up to 100% in certain brands of nets (Atieli et al., 2010). Evidence has been published from laboratory-controlled studies showing decline in the bio efficacy of several brands of LLINs after repeated washings. For instance, in Iran, there was a significant increase in the mean values of the median knockdown time (MMKDT) and reduced mortality as a result of more washing of a brand of deltamethrin-impregnated nets which was more evident after 15 and 21 washings (Kayedi et al., 2017).

Similarly, another brand impregnated with deltamethrin was also studied in Kenya and was

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found to have significant drop of mortality from 95% with unwashed nets to 72% after 15 washings (Etang et al., 2016). The net drying practices in the households has also been a concern in relation to maintaining efficacy of the LLINs. However, bioassay tests on deltamethrin-impregnated nets showed no significant difference between the sun- dried and shade-dried bed nets (Kayedi et al., 2017). The current study sought to determine the physical integrity and bio efficacy of Yorkool® pyrethroid-based LLINs and to assess the washing and drying practices at 12 months of use in a community in Western Kenya where the LLINs were distributed under the National Malaria Control Programme mass net distribution.

MATERIALS AND METHODS

Study site

This study was conducted in Seme Subcounty which is situated in the southwestern part of Kisumu County within the Nyanza region of Kenya. The area lies between latitudes 00 20' and 00 50' South and longitudes 300 20' and 350 20'E. The Sub-County's low ridges, seasonal rivers, Lake Victoria, and scalps are some of its most notable geographical characteristics. The mean annual rainfall varies with altitude and proximity to the highlands along the Nandi Escarpment. There are two rainy seasons in the Sub-County, with prolonged showers in April and May. The average annual rainfall during the August and September brief rains is between 450 and 600 mm. This is a malaria-endemic lake region and is classified as a malaria endemic zone (Pmi, 2022). Malaria transmission occurs all year round and peaks following the rainy season in the area. Because of its vulnerability as a malaria endemic zone, the area has received mosquito nets as malaria control interventions over the years. The economic activities engaged by the people of this region include fishing which is the major preoccupation because of the Lake Victoria, small scale farming of maize, millet, sorghum and beans. Lastly, a section of the population also engages in small scale businesses.

Study design

The study was a cross-sectional household survey, targeting households in an area where rectangular Yorkool® a pyrethroid LLINs had been distributed by the Ministry of Health as part of mass net distribution in 2021.The choice of the study design was informed by the fact that this study had the sole objective of evaluating the nets at the household level at a single point in time which was 12 months after distribution.

Characteristics of Yorkool® LLIN

The Yorkool® net, manufactured by Tianjin Yorkool® International Trading Company limited consists of 100% warp knitted polyester, 100 deniers with deltamethrin content of 55mg/m^2 which is non-systemic synthetic pyrethroid. The insecticide in it is incorporated within the 75-100 denier high density polyethylene monofilaments filaments which diffuses to the surface slowly (controlled release of insecticide) and a small amount of insecticide available on the surface (bio-availability) is sufficient enough to kill the mosquitoes (World Health Organization, 2011). Yorkool® LLINs dimensional stability is not more than 5% shrinkage or expansion in both dimensions, its bursting strength is not less than 350kpa and the available shapes are circular, rectangular and hammock (World Health Organization, 2013).

Sampling procedure

Seme subcounty was purposively selected owing to the fact that Yorkool® nets had been distributed earlier. Multistage cluster sampling technique was used to sample households for inclusion in the study. All the four wards in the sub county were selected (Central, North, East and West Seme). A list of all the available villages in the wards, and households that received LLINs in the 2021 mass net distribution was obtained from the sub county malaria coordinator. Four villages from each ward were randomly selected to participate in the study. A list of all households in the selected villages was obtained from the village head and the community health worker. Depending on the number of households across each village, the targeted

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sample size was allocated to the 16 villages using probability proportionate to size. At the village level, the first household was selected from the middle of the village and thereafter, every fourth household was systematically sampled until the allocated households in that village were exhausted. For purposes of evaluating the physical integrity of the nets, a sample 180 nets were randomly selected which translated to approximately 10 nets per village. In addition, 30 nets were destructively retrieved from selected households and taken to laboratory for bioassay tests. Households where the nets were retrieved from were given new nets for replacement.

Data collection procedures

Interviews were conducted at the household level to collect data about utilization of the nets. A structured questionnaire was administered to the household head or an adult available in the household after obtaining informed consent. The questionnaires captured household demographic information, and the information about the LLINs and handling practices. This data collection technique was the most appropriate as the study was quantitative.

Physical integrity of LLINS measured by net hole assessment

Physical integrity of Yorkool® nets was measured through assessment of holes on the nets. The nets were draped on a frame and inspected for presence of any holes on the sides and roof panels. The number of holes including tears and seam openings were counted and categorized into 4 groups: Hole size T1, were holes smaller than one inch (0.5–2.0 cm), Hole size T2 were holes larger than one inch but smaller than a fist (2–10 cm), Hole size T3 were holes between a closed fist but smaller than a head (10–25 cm) and Hole size T4 were holes bigger than a head (> 25 cm). A proportionate hole index (pHI), which characterized the midpoint diameter to an estimated hole size was calculated by making the sum of the holes weighted by size for each net. The weights were as per the WHO recommendations i.e. 1, 23, 196 and 576. To better translate the hole index to an integrity status (net condition) for each sampled net, the pHI was then categorized into "good" (0–64), "damaged but still useful" (65–642), and "too torn" that protection from mosquitoes is judged to be compromised (≥ 643) (World Health Organization, 2013). Serviceable nets constituted all LLINs in the category of good condition and damaged.

LLIN cuttings for bioassay

The netting pieces were cut from the sampled nets from positions 1–9 for bioassays (World Health Organization and WHO Pesticide Evaluation Scheme, 2013). For each LLIN, 30″ × 30″ sub-samples were cut from all the five sides of the net; the roof panel and each of the four sides of the LLINs. These net cuttings were covered in an aluminum foil envelope, labelled, kept individually at 4°C and transported to Kenya Medical Research Institute (KEMRI) for bioassay analysis.

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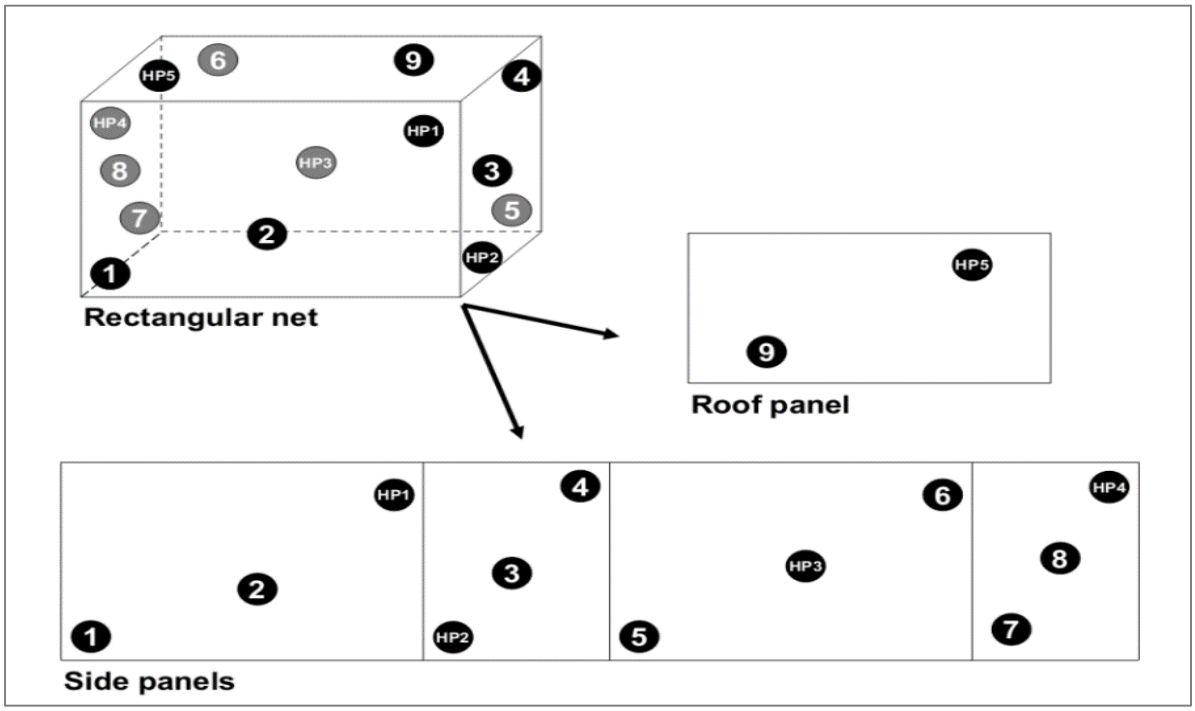
Figure 1: A rectangular net and its individual panels showing positions for cut netting pieces (positions 1–9 for bioassays



(World Health Organization, 2013)**.**

Assessments of LLINs Bio-efficacy (Cone Bioassays Test)

The insecticidal effect of the Yorkool® LLINs was evaluated using cone bioassays at 12 months as per the WHO guidelines (World Health Organization, 2013). On each of the netting pieces cut for bioassays, standard WHO plastic cones were held in place using a plastic manifold and a total of 50 laboratory bred, susceptible Kisumu strain *Anopheles gambiae* (non-blood fed, 2–5 day old) were exposed for 3 min (5 pieces per net × 5 mosquitoes per test × 2 replicates). After the exposure, the mosquitoes were removed gently from the cones and kept in plastic cups provided with cotton-wool moistened with 10% glucose solution. Knockdown (KD) was recorded at 60 min and mortality at 24 h after exposure. The bioassays were carried out at 27 ± 2 °C temperature and 80% ± 10% relative humidity.

Statistical analysis

Data entry was entered in Microsoft Excel spreadsheets and cross-checked for accuracy. Data was exported for analysis in STATA version 15.1 (Stata corporation, college station, TX, USA). Households were described by summarizing the demographic characteristics and net usage information into frequencies and percentages. The presence, location and type of holes on the nets were analysed and presented as percentages. The holes were categorized into sizes and presented as counts with 95% confidence interval by part of the net affected. In addition, fabric integrity was represented using pHI which was categorized into "good", "damaged" and "needs replacement" then presented as percentages. Net washing practices were described based on whether washing was done at least once in past year, duration between washes, detergents used, soaking and scrubbing practices. Drying of nets after washing focused on exposure to the sun. The practices on net washing and drying were analysed and presented as percentages of the of the households where interviews were conducted. The bio-efficacy of Yorkool® LLINs was analysed using mean knock-down and mortality of the mosquitoes and presented as percentages with 95% confidence interval (CI). LLINs passed the WHO efficacy criteria if the mosquito knockdown rate was ≥95% and/or mortality rate ≥80% in cone bioassays.

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RESULTS

A total of 262 households participated in the study, where the household heads were interviewed. The mean age of the household heads was 46.9 years (SD 17.4 years), ranging from 18 to 92 years. Most of the participants were in the 31 to 50 years (36.6%) age bracket. A majority of them had attained primary level education (70.2%), and 42.3% of the households used electricity as the main source of lighting. A majority of the households (71.8%) had 1-2 sleeping spaces. (Table 1).

Table 1: Household demographic characteristics

Variable	Category	Percentage (%)
Age	18-30	63 (24.1)
	31-50	96 (36.6)
	51-70	82 (31.3)
	71-95	21 (8.0)
Education level	No formal education	11 (4.2)
	Primary	184 (70.2)
	Secondary	53 (20.2)
	Tertiary	14 (5.3)
Electricity	Yes	116 (42.3)
	No	146 (55.7)
Sleeping space	1-2	188 (71.8)
	3-4	67 (25.6)
	5-6	5 (1.9)
	7-8	2 (0.7)

Net location

A total of 180 LLINs were physically examined for physical integrity in the households that participated in the study. A majority of these LLINs (98.9%) were located inside the house. The floor type in the houses where the nets were found was mainly soil or sand (49.4%) and cement (48.3%). The walls were mud brick with wood frames (57.9%) or concrete (37.6%) and 99.4% of the houses had corrugated iron roofs (Table 2).

Table 2: Net location and socio-economic parameters

Variable	Category	Total nets=180 n (%)
Location of the net	Inside	178 (98.9)
	Outside	2 (1.1)
Type of floor	Soil or sand	88 (49.4)
	Cement	86 (48.3)
	Cement (incl. vinyl)	2 (1.1)
	Other	2 (1.1)
Walls of the room	Mud brick with wood frames	103 (57.9)
	Concrete	67 (37.6)
	Mud brick	4 (2.3)
	Lime plaster	4 (2.3)
Roof or ceiling of the room	Corrugated iron	177 (99.4)
	Concrete	1 (0.6)

% percentages

Net conditions

Most of the nets examined (77.8%) had at least one hole, with a majority of them (93.6%) having holes in the lower part. Horizontal tears (76.7%) were the most common types of holes observed. The highest number holes were size 1 (n=2015) while size 2 were 1216, size 3 were 995 and size 4 were 314. The lower part of the nets had the highest number of holes of all sizes (Table 3).

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Table 3: Net conditions

Variable	Category	Total nets = 180 n (%)
Nets with holes	Yes	140 (77.8)
	No	40 (22.2)
Specific area of holes	Roof	65 (46.4)
	Upper part	30 (21.4)
	Lower part	131 (93.6)
	Seams	17 (12.1)
Type of holes observed	Horizontal tears at bottom	138 (76.7)
	Holes at hanging points	4 (2.2)
	Open seams	21 (11.7)
	Burn holes	4 (2.2)
	Holes from rodents	0
	Whole section missing	1 (5.6)
Holes observed by size and specific area, # of holes (95% CI)		
Size 1	Roof	212 (89.3-334.7)
	Lower part	1580 (1141.4-2018.6)
	Upper part	220 (79.2-376.7)
	Seams	3 (0-7.3)
	Total	2015 (1517.7-2512.3)
Size 2	Roof	136 (80.3-191.7)
	Lower part	946 (659.2-1232.8)
	Upper part	118 (59.5-176.5)
	Seams	16 (4.3-27.7)
	Total	1216 (909.4-1522.6)
Size 3	Roof	272 (173-371)
	Lower part	565 (440.2-689.8)
	Upper part	144 (79.1-208.9)
	Seams	14 (2.3-25.7)
	Total	995 (821.8-1168.2)
Size 4	Roof	35 (19.6-50.4)
	Lower part	249 (178.0-320)
	Upper part	18 (2.9-33.2)
	Seams	12 (1.7-22.3)
	Total	314 (236.8-391.2)

Number, CI confidence interval, % percentage

Proportionate hole index (pHI)

From the pHI classification, 48 (26.7%) nets were found to be in good condition, 29 (16.1%) needed repairs and 103 (57.2%) needed to be replaced. Overall, 42.8% of all the LLINs examined after one year of study were of serviceable condition and thus were offering protection to the users. (Table 4).

Table 4: Proportionate hole index (pHI)

Total number of LLINs inspected	180
Proportion of nets with any hole n (%, CI)	140 (77.8, 71.7-83.9)
Mean pHI	2254.8
Median Phi	1041.0
IQR	3109.0
Proportion of nets in pHI<64 (good category)	48 (26.7; 20.2-33.1)
Proportion of nets pHI ≤642 (Serviceable category)	29 (16.1; 10.7-21.5)
Proportion of nets pHI >642 (needed replacement category)	103 (57.2; 49.9-64.2)

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Factors associated with LLIN loss of physical integrity

Of the 180 nets inspected to assess the loss of physical integrity, 103 (57.2%) had lost their physical integrity and needed to be replaced. Univariable analysis results revealed several factors were associated with net replacement. These factors included the type of fire used in the household where the LLIN was found. Nets found near wood fires were significantly more likely to be completely worn out compared to those found in areas without wood fires (OR=4.1, 95% CI: 1.2-13.8, P=0.023). Furthermore, horizontal tears at the bottom were much more likely to require replacement compared to intact nets (OR=54.6, 95% CI: 12.6-237.3, P<0.001). Similarly, nets with open seams were also more likely to be replaced compared to those without (OR=3.6, 95% CI: 1.2-11.2, P=0.026). (Table 5).

The multivariable analysis confirmed that some factors remained significantly associated with net replacement after accounting for other variables. Nets found in areas with wood fires were more likely to be replaced compared to nets found in areas without wood fires (adjusted OR=7.5, 95% CI: 1.4-40.7, P=0.019). In addition, nets with horizontal tears at the bottom are more likely to be replaced compared to nets without the horizontal tears (adjusted OR=96.2, 95% CI: 9.6-966.4, P=0.026). (Table 6)

Table 5: Univariable analysis of factors associated with loss of physical integrity.

Factors	Number of replaceable nets (%), n=103	Odds ratio (95% CI)	p-value
Where net is found			
Inside	101 (98.1)	Reference	-
Outside	2 (1.9)	Insufficient observation	-
Type of floor where net is found			
Soil or sand	56 (55.5)	Reference	-
Cement (incl. vinyl)	0	Insufficient observations	-
Cement	44 (43.5)	0.6 (0.3-1.1)	0.097
Other	1 (1.0)	0.6 (0.0-9.5)	0.696
Walls of the room where net is found			
Concrete	41 (40.6)	Reference	-
Mud brick	2 (2.0)	0.6 (0.1-4.8)	0.659
Mud brick with wood frames	56 (55.5)	0.8 (0.4-1.4)	0.380
Lime plaster	2 (2.0)	0.6 (0.1-4.8)	0.659
Use of open flame where net is found			
Yes	27 (26.2)	Reference	-
No	76 (73.8)	1.7 (0.9-3.2)	0.102
Type of fire (n=27)			
Wood fire			
Yes	22 (81.5)	4.1 (1.2-13.8)	**0.023***
No	5 (18.5)	Reference	-
Charcoal fire			
Yes	19 (70.4)	Reference	-
No	8 (29.6)	2.6 (0.7-10.1)	0.157
Type of hole			
Horizontal tears at the bottom			
Yes	101 (98.1)	54.6 (12.6-237.3)	**<0.001***
No	2 (1.9)	Reference	
Holes at hanging points			
Yes	3 (2.9)	Reference	-
No	100 (97.1)	0.4 (0.0-4.3)	0.479

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Factors	Number of replaceable nets (%), n=103	Odds ratio (95% CI)	p-value
Open seams			
Yes	17 (16.5)	3.6 (1.2-11.2)	**0.026***
No	86 (83.5)	Reference	
Burn holes			
Yes	3 (2.9)	Reference	
No	100 (97.1)	0.4 (0.0-4.3)	0.479

*Significant p-value

Table 6: Multivariable analysis of factors associated with loss of physical integrity

Factor	Number of Replaceable nets (%), n=103	Adjusted Odds ratio (95% CI)	P value
Type of fire (n=27)			
Wood fire			
Yes	22 (81.5)	7.5 (1.4-40.7)	**0.019***
No	5 (18.5)	Reference	
Type of hole			
Horizontal tears at the bottom			
Yes	101 (98.1)	96.2 (9.6-966.4)	**<0.001***
No	2 (1.9)	Reference	

*Significant p-values

Washing and drying practices

A total 468 nets were recorded from all the 262 households which participated in the study. Of these, 95.1% (445 nets) was reported to have been washed at least once. At the time of the survey, 82% of the nets were reported to have been washed in the last one month prior to survey, with 74.4% of the nets reported to have been washed using local bar soap. Majority of the participants (90.8%) reported not soaking the nets before washing for. The practice of scrubbing the nets while washing was uncommon, having being reported in only 2 nets. Drying practice was mainly outside in the shade (72.1%) while those that were dried outside in the sun were 26.5% (Table 5).

Table 5: Mosquito net washing and drying practices in the households

Variable	Category	Frequency (%)
Ever been washed	Yes	445 (95.1)
	No	23 (4.9)
Duration since last washing	<1 month	365 (82.0)
	1-3 months	69 (15.5)
	3+ months	11 (2.5)
Type of soap used	Local bar soap	331 (74.4)
	Detergent powder	85 (19.1)
	Mix (bar and detergent)	29 (6.5)
Net soaking duration	Did not soak	404 (90.8)
	<1 hour	39 (8.8)
	>1 hour	2 (0.5)
Net scrubbed on hard surface	Yes	2 (0.5)
	No	443 (99.6)
Net dried	Outside in the sun	118 (26.5)
	Outside in the shade	321 (72.1)
	Inside	6 (1.4)

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Bio efficacy of Yorkool® LLINs at 12 months

After 12 months of use, the nets tested recorded a mean KD of 92% after 1 hour, and mean mortality of 86% after 24 hours. Overall, 83.3% of the nets passed the WHO efficacy cut off for mortality (≥ 80%) after 24 hours, with another 70% passing the cut off for KD (≥ 95% knockdown) after 1 hour (Table 6).

Table 6: Knock-down and mean mortality observed with WHO cone tests at 12 months

No of nets tested	30
Mean 1h % KD (95% CI)	92 (90.7-93.5)
Mean 24h % mortality (95% CI)	86 (83.2-89.7)
Nets that passed WHO cut off by KD criteria alone	21 (70%)
Nets that passed WHO cut off by Mortality criteria alone	25 (83.3%)

DISCUSSION

Long lasting insecticidal nets have played a central role in preventing mosquito bites in the malaria-endemic zones including the East Africa's Lake Victoria region. In countries where malaria is endemic, the distribution of LLINs to communities living in endemic areas has become a priority, however several factors including condition, use and maintenance of the net by the user and also the type of the net tends to affect the durability, and thus determining its ability to offer protection to the end user. This study therefore determined the physical integrity and bio efficacy of Yorkool® net after one-year of use in a malaria endemic zone in Kenya. The washing and drying practices were also assessed among the users of the nets. The study found out that a majority of the LLINs needed replacement as a result of poor physical integrity. The communities reported good net handling practices, with washing of the LLINs been done mainly using local bar soap and without soaking and scrubbing on hard surface, and drying of the nets under the shade. Handling of LLINs at the household level needs to follow the set guidelines given during distribution period to ensure sustained physical integrity of the nets. The fabric integrity is a design parameter that measures physical damage sustained by the net and coverage (Randriamaherijaona et al., 2017). Net handling practices influence the physical sustainability of the nets for the duration of use. Over-washing has been identified as one among other reasons compromising physical integrity of bed nets (Mutuku et al., 2013). Nets that are handled using rough methods may develop holes which influences the ability of the net to protect the user from mosquito bites.

A majority of the LLINs inspected in this study had at least one hole located more frequently at the lower part of the net. Previous studies on this type of LLIN have reported lower proportions of holes during the same duration of use. A study in a village in Benin that routine received Yorkool® nets reported 23% having holes after the 12 months of use (Ahogni, Salako, Akinro, et al., 2020). Another prospective cohort study in Benin designed to compare seven brands of nets reported an even lower proportion at 6.4% of holes existence in Yorkool® brand after 12 months of use (Ahogni, Aïkpon, et al., 2020). A study in Madagascar reported higher proportion of holes present in Yorkool® brand at 68.5% with 31.5% found to be intact after 12 months of use (Randriamaherijaona et al., 2017). The variation in prevalence of holes in bed nets are attributable to the differences in handling practices and the brand of the net may also have an influence.

The number and sizes of holes on the nets determine the usability of the nets in barring the mosquitoes which is evaluated using the proportionate hole index (pHI) (World Health Organization, 2011). pHI is a standardized approach that describes changes in LLIN fabric integrity, and gives threshold of good, damaged but still useful and compromised nets. In the present study, slightly higher than a quarter (26.7%) of the nets studied were in good condition while 43% were serviceable after 12 months of use. The two categories depict that these nets were still in good use and able to provide protection to

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the users. The 12-moth evaluation of Yorkool® brand has received positive approval on physical integrity in other study findings elsewhere with as high as 90.1% (Ahogni, Aïkpon, et al., 2020), 96.8% (Ahogni, Salako, Akinro, et al., 2020) and 97.7% (Ahogni, Salako, Dagnon, et al., 2020) categorized in good condition in Benin. Also, in Madagascar, 69.2% were in good condition and the rest were serviceable with none requiring replacement (Randriamaherijaona et al., 2017). Similarly, the nets evaluate in Nepal after a median duration of use of 9 months found 80.7% were in good condition and 10% too torn needing replacement (Ghimire et al., 2020).

The physical integrity is influenced by several environmental factors and handling practices. One of the two factors that were identified in this study was the use of wood fire for cooking in houses where cooking happened in the same room where there was a place to sleep that increased the risk of deterioration of nets 8-fold. This risk was expected given that the population live in a rural setting where households use wood as source of fuel. Findings from Benin showed that households where wood was used as cooking medium had pHI-value that was 16 times higher than those that used coal (Ahogni, Salako, Akinro, et al., 2020). The other factor was related to the nets with horizontal tears at the bottom were 96 times more likely to need replacement. This may refer to the handing practices which is related to the common practice of stacking the net on the side between the bed and mattress hence causing wear and tear. The lower part of the net was the most affected with holes of all sizes. This was similar to findings in another study that reported a significantly higher total hole area in the lower half of the rectangular nets (Craig et al., 2015). The reasons for deterioration in the lower part of the net is mainly due to the fact that handling more frequently occurs around this part compared to the other parts like the upper part or the roof which is almost untouched at all times.

A majority of the nets (95.1%) had been washed at least once and it was mainly in the 1 month prior to the survey time. LLINs are usually recommended to be washed at most every 3 months to avoid wearing out the insecticidal activity (Pmi, 2022). This evidence was supported by a similar study on nets impregnated with deltamethrin. Retention of insecticide power until twenty-one washings was recorded with notable mortality of mosquitoes exposed to the fibers of the bed net (Kayedi et al., 2017).The scoring system used in a study in Western Kenya outlined the ideal expectation as never washing bed nets in order to maintain their efficacy (Santos et al., 2019). This not achievable in practice given the frequency of use and handling of the nets hence the need for cleaning. Therefore, the next acceptable practice outlined was to wash with water only or bar soap with no scrubbing or beating up on hard surface and use of detergents was considered as a moderately acceptable practice (Santos et al., 2019).The current findings showed that three quarters of population in the area used local bar soap with about 20% using powder detergents. There was adequate adherence to good washing practices in Western Kenya which were evaluated based on washing location where use of bucket is preferred over river or stream, washing manner referring to gentle handling and soap type (Santos et al., 2019). Good adherence was also reported in Uganda where 97% of the nets were washed in cold water and almost all used a basin and 95% used local soap rather than a detergent and none rubbed with or on rocks during washing (Kilian et al., 2011).

Soaking nets before washing is another factor that determines the ability to retain the efficacy of insecticide activity. This study showed that about 10% of the nets were soaked before washing the last time cleaning was done with majority being done for less than 1 hour. Some studies have reported that when impregnated nets are soaked for 30-60min and washed with soap powder and tap water in the usual way, the mortality drops significantly after 4 washes (González et al., 2002).

Drying practices also determines durability of the nets. The best practice is to keep the nets indoors at all times or if there is need for drying it is done

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outside in the shade (Santos et al., 2019). This study found that over 70% of the nets were dried outside in the shade. In Uganda, an evaluation that was done more than a decade earlier showed that drying occurred outside in 99% of the cases with about one third lying flat and the rest hanging (Kilian et al., 2011). Lower levels of compliance have been reported in other settings. In Benin, it was reported that less than a half of the users were drying their nets outside in the shade (Ahogni, Salako, Dagnon, et al., 2020). Other findings in nets impregnated with deltamethrin showed that the method of washing or drying did not appear to impact deltamethrin levels with one study reporting no significant impact of three hours exposure to sunlight after washing on insecticidal activity (Craig et al., 2015; Kayedi et al., 2017).

Households visited during this survey reported good coverage of all sleeping spaces with usable mosquito nets pointing to a likelihood of protection of all sleepers. Though universal coverage of nets is necessary in households, physical integrity and bio-efficacy of the nets is important to ensure complete protection from the malaria vectors. The evaluation of the biological efficacy revealed that the Yorkool® LLINs brand studied had a good residual efficacy, since it induced a 92% rate of KD after 60 minutes and 86% mortality after 24 hours. WHO recommends ≥95% KD and/ or ≥80% mortality on vectors for an LLIN to be considered efficacious for use as a malaria prevention measure (World Health Organization, 2013). The bioassay results in this study showed a mean KD in 1 hour of 92% and mortality of 86% in 24 hours against the susceptible *Anopheles gambiae* species. This means the nets fell short of the WHO cut off in KD criteria but passed the mortality cut off. However, a high proportion of Yorkool® LLINs met the WHO criteria with 70% of the nets meeting the KD cut off(≥95%KD) and 83.3% were on target on mortality (≥80%). Various studies have shown varying bio-efficacy levels of Yorkool® nets in relation to knock-down and mortality threshold. A notably lower efficacy was reported in Benin after 12 months of use with KD cut-off of 58% and 72% for mortality (Ahogni, Aïkpon, et al., 2020). However, another study in Benin reported efficacy of 98% on KD and 97.5% on mortality (Ahogni, Salako, Dagnon, et al., 2020). In Eritrea, Yorkool® LN nets had a knock-down (KD) rate of 80.5% at 60 minutes and a 71% mortality rate after 24 hours of exposure (Mensur Yenus et al., 2024). An evaluation in Madagascar on Yorkool® LLINs showed a very low mortality rate of 14% at 12 months use (Randriamaherijaona et al., 2017). In Nepal, only 10% of the Yorkool® nets evaluated had mosquito mortality of more than 80% (Ghimire et al., 2020). Based on the several contradictory findings in relation to knock-down and mortality rates for Yorkool® nets after 12 months of use, there is need for systematic review to compare the different conditions of the evaluations to identify or rule out the possibility of extrinsic factors that may be influencing bio-efficacy of these brand of nets.

CONCLUSIONS

Yorkool® LLINs used in Seme sub-county had high physical deterioration rate with the evaluation showing about 60% of the nets needing replacement after 12 months of use. The bio-efficacy of the nets was relatively high with the mortality on vectors meeting the WHO threshold. The loss of physical integrity happened in the nets distributed in the region despite the good adherence to appropriate net handling approaches in terms of washing and drying.

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