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The Uganda housing modification study - association between housing characteristics and malaria burden in a moderate to high transmission setting in Uganda

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Abstract

Background Scale up of proven malaria control interventions has not been sufficient to control malaria in Uganda, emphasizing the need to explore innovative new approaches. Improved housing is one such promising strategy. This paper describes housing characteristics and their association with malaria burden in a moderate to high transmission setting in Uganda.

Methods Between October and November 2021, a household survey was conducted in 1500 randomly selected households in Jinja and Luuka districts. Information on demographics, housing characteristics, use of malaria prevention measures, and proxy indicators of wealth were collected for each household. A finger-prick blood sample was obtained for thick blood smears for malaria from all children aged 6 months to 14 years in the surveyed households. Febrile children had a malaria rapid diagnostics test (RDT) done; positive cases were managed according to national treatment guidelines. Haemoglobin was assessed in children aged < 5 years. Households were stratified as having modern houses (defined as having finished materials for roofs, walls, and floors and closed eaves) or traditional houses (those not meeting the definition of modern house). Associations between malaria burden and house type were estimated using mixed effects models and adjusted for age, wealth, and bed net use.

Results Most (65.5%) of the households surveyed lived in traditional houses. Most of the houses had closed eaves (85.5%), however, the use of other protective features like window/vent screens and installed ceilings was limited (0.4% had screened windows, 2.8% had screened air vents, and 5.2% had ceiling). Overall, 3,443 children were included in the clinical survey, of which 31.4% had a positive smear. RDT test positivity rate was 56.6% among children with fever. Participants living in modern houses had a significantly lower parasite prevalence by microscopy (adjusted prevalence ratio [aPR = 0.80]; 95% confidence interval [CI] 0.71 – 0.90), RDT test positivity rate (aPR = 0.90, 95%CI 0.81 – 0.99), and anaemia (aPR = 0.80, 95%CI 0.65 – 0.97) compared to those in traditional houses.

Conclusion The study found that even after adjusting for wealth, higher quality housing had a moderate protective effect against malaria, on top of the protection already afforded by recently distributed nets.

Keywords Malaria burden, Modern houses, Traditional houses

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Background

The scale up of proven control interventions including long-lasting insecticidal nets (LLINs), indoor residual spraying of insecticides (IRS), effective case management using artemisinin-based combination therapy (ACT) and prevention of malaria in pregnancy through intermittent preventive therapy (IPTp) resulted in marked reductions in the global malaria burden between 2000 and 2015 [1]. However, the progress in disease reduction has stalled over the past few years, especially in high-burden countries, and even reversed in others, including Uganda [1].

Uganda has some of the highest rates of malaria transmission in the world and currently ranks as the third highest contributor to the global annual number of malaria cases [1]. Malaria is a leading cause of morbidity and mortality in Uganda, accounting for 30–50% of outpatient visits and 15–20% of hospital admissions [2]. Like many other African countries, Uganda has recently strengthened its efforts for malaria control, however, despite the renewed commitment to malaria control, the burden of malaria remains high in the country with almost 19 million cases reported in 2021 in a total population of 45.5 million [1]. Most worrying is the observed increase in the number of estimated cases in areas with sustained control interventions [3, 4] and the emergence of partial artemisinin resistance in some regions in the country [5, 6]. These observations highlight the need to explore innovative approaches for malaria control, in addition to maximizing the current control efforts in the country.

One promising strategy for malaria control is housing modification, which works by preventing the entry of mosquitoes at the house level. Studies on improved housing, ranging from structural house modifications aimed at reducing mosquito house entry to improved housing quality and modern housing construction, have documented a positive relationship of improved housing characteristics and malaria risk [7–11]. A multi-country analysis of survey data collected between 2008 and 2015 from 21 sub-Saharan African countries showed that modern housing was associated with a 9% to 14% reduction in the odds of malaria infection controlling for wealth and bed net usage [10]. A more recent Cochrane review on the effects of house modifications on malaria disease and transmission showed that screening of windows, doors, eaves, ceilings or any combination of these interventions reduced the risk of clinical malaria incidence, anaemia, malaria parasitaemia, and the entomological inoculation rate (EIR) [12]. Additionally, a few studies that have evaluated the costs of the intervention have shown that the strategy is cost-effective especially in the longer term [13, 14]. Despite these benefits, housing modification for malaria prevention remains underutilized in most malaria endemic settings.

To assess the degree to which housing modification may offer protection as a malaria control intervention in moderate to high malaria transmission settings, a cluster-randomized trial to evaluate the impact of housing modification interventions on malaria burden was conducted in eastern Uganda. Two housing modification interventions, including (1) full screening (defined as screening of eaves, ventilation bricks/openings and windows) and (2) eave tubes (PVC tubes with a diameter of 15 cm, fitted with electrostatic mesh inserts coated with insecticides installed in the outer wall of occupied rooms), are being evaluated versus a control arm. The impact of the interventions is being assessed through a cohort study, repeated cross-sectional community surveys, and entomological surveillance. Using the data from the baseline cross-sectional community survey, the housing characteristics and their associations with malaria burden in the outset of the study are described.

Methods

Study design

Between October and November 2021, a baseline cross-sectional community survey was conducted in 1500 randomly selected households in 60 trial clusters spread over ~ 30 × 20 km area in Jinja and Luuka districts in eastern Uganda, the site of the housing modification trial. The purpose of the survey was to characterize the households in study area, including the distribution of housing types, and to describe the malaria and anaemia prevalence in the study area.

Study setting

Jinja and Luuka districts are located in East Central region of Uganda and the two districts were purposively selected based on the following criteria: (1) no ongoing or planned IRS programme; (2) high parasite prevalence; (3) presence of pyrethroid resistance; (4) willingness of district health leadership to take part in the studies; and (5) availability of stable health infrastructure (well-staffed public health facilities).

Jinja is a peri-urban district along the northern shores of Lake Victoria. The district is subdivided into six sub-counties, of which two, Buyengo and Buwenge, were included in the study. Malaria transmission in Jinja district is perennial with low transmission areas in Walukuba sub-county (aEIR 2.8 infective bites/person/year) [15] to moderate to high transmission areas in the northern sub-counties where this study is taking place (aEIR 15.2 infective bites/person/year in sub-counties) [16]. Luuka is a rural district bordering Jinja on the East. The district consists of seven sub-counties, of which two, Nawampiti and Irongo, were included in the study. Malaria burden in Luuka district is not well described, however, according to the most recent Malaria Indicator Survey conducted in 2019/2020, parasite prevalence was estimated at 21% by microscopy in children under 5 years of age [17]. Malaria control interventions in the two districts (Jinja and Luuka) have included malaria case management with ACTs, universal distribution of free LLINs through mass campaigns in 2013, 2017, and 2020/21 as well as through antenatal care services, and promotion of IPTp.

Study site and cluster selection

Four adjacent rural sub-counties (Buyengo, Buwenge, Nawampiti and Irongo) serviced by 5 level III/IV public health facilities were purposively selected for the study. All households and key features within the four participating sub-countries were enumerated and mapped to provide a base for the selection of 60 study clusters to be randomized 1:1:1 to the two housing modification interventions and one control arm of the cluster-randomized trial. The 5 health facilities (Buwenge, Ikonia, Irongo, Kakaire, Magamaga) servicing this area served as the focus for cluster selection. Twelve enumeration areas (cluster) were selected from the catchment areas of each Health facility using spatially driven convenience sampling. This selection was informed by the data from the enumeration and mapping exercise. Clusters were defined as villages or sub-villages with approximately 100 households (range 80–120 households). Sub-villages were generated by splitting large villages into smaller units based on findings from the enumeration and mapping exercise. Clusters were selected if they fulfilled the following criteria: (1) cluster boundaries allowed for a buffer zone of ~ 500 m between clusters to minimize the spillover effects between the interventions and control arms; (2) were located within easy access (defined as under 5 km as traveled by road) to the study health facilities; and (3) willingness of local council chairman (LCI) to take part in the study. The distribution of clusters included in the baseline survey is presented in Supplement Fig. 1.

Survey enumeration and mapping

Using a digital map of the boundaries of each of the clusters as a reference, all households within were enumerated and assigned an identification number. A household was defined as a person or group of people living together in a single or multiple permanent or semi-permanent dwelling structures that generally cook and eat together. Household locations (longitude, latitude, and elevation) were mapped using hand-held GPS receivers. Readings were taken from the door of the main household structure, if possible, or from a point that was most representative of the household. At each household, three readings were taken and the most consistent was recorded. A list of all the households identified and mapped was generated to be used as a sampling frame for the survey.

Study population and data collection

Using the enumeration list, a random sample of 25 households from each of the 60 clusters was selected to participate in the baseline cross-sectional survey. At each selected household the purpose of the study was explained to the head of the household (or their designee) in the appropriate language, and the household was screened for eligibility to join the study. Households were eligible to join if they fulfilled the following eligibility criteria: (1) had at least one household resident between 6 months and 14 years of age; (2) had at least one adult aged 18 years or older present on the survey day; (3) the adult present was a usual resident who slept in the sampled household on the night before the survey; (4) agreement was given to provide informed consent for the household survey. Households were excluded if dwellings were vacant, destroyed, or not found, or if there was no adult resident at home on 3 or more occasions.

Once eligibility was established, a detailed informed consent discussion was held with the head of the household/their designee in the appropriate language. If interested, the respondent was asked to sign a written consent form to participate in the survey. If the respondent was unable to read or write their fingerprint was substituted for a signature and an impartial witness was included in the consent discussion. A household questionnaire adapted from prior cross-sectional community surveys conducted in Uganda, including the national Malaria Indicator Survey [17], was administered to the head of the household/ their designee, using a hand-held tablet computer. The questionnaire gathered information on the house structure, household, and resident characteristics, proxy indicators of wealth including ownership of assets, and ownership and use of malaria control interventions including LLINs. LLIN use was confirmed if a bed net was observed hung above the sleeping space of the participant.

Following the household questionnaire, a clinical survey was carried out in eligible children, according to the following criteria: (1) aged 6 months to 14 years; (2) usual resident and slept in the sampled household on the night before the survey; (3) parent/guardian agreed to provide informed consent for clinical assessment and malaria treatment; (4) child aged 8 years or older agreed to provide assent. Children were excluded if they were not home on the day of survey. Presence of fever

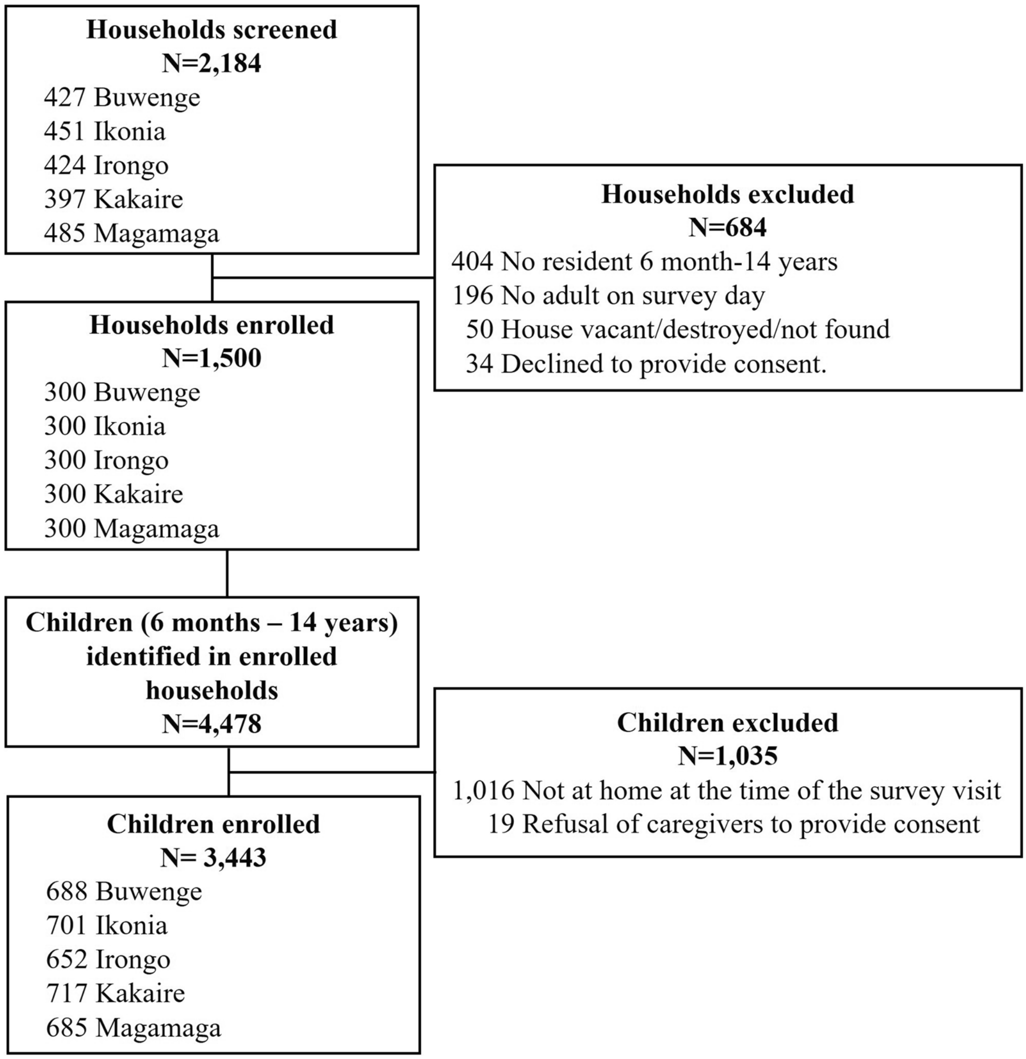

Fig. 1 Flow diagram

(defined as history of fever in the past 48 h or a temperature of ≥ 38.0 °C) was assessed for all eligible children. A finger-prick blood sample was collected from all eligible children for a thick blood smear, haemoglobin measurement, and storage on a filter paper as a dried blood spot. A malaria rapid diagnostic test (SD Bioline RDT) was performed by study personnel according to the specifications of the manufacturer on all febrile participants. The results of the RDT tests were provided to the participant or their parent/guardian verbally and were recorded on the appropriate case record form. Participants with a positive RDT and no evidence of severe malaria were provided with a full course of artemether-lumefantrine (AL) according to the national treatment guidelines [18] and were counselled to go to the nearest health facility if their illness worsened. Participants with a positive RDT and evidence of danger signs of severe disease or other concerning clinical symptoms were referred to the designated public health centre III/IV for further evaluation.

Laboratory procedures

Thick blood smears were made by placing a drop of blood in the middle of a frosted glass slide. An applicator stick was used to spread the blood into a spot of approximately 1 cm in diameter. Blood smears were dried on a slide tray, in a dust-free environment. All smears were stained with 2% Giemsa for 30 min using a standard protocol and evaluated for the presence of asexual and sexual (gametocytes) parasites. Parasite densities were calculated from thick blood smears by counting the number of asexual and sexual parasites, respectively, per 200 leukocytes (or per 500, if the count is less than 10 parasites per 200 leukocytes), assuming a leukocyte count of 8,000/ µl. A thick blood smear was considered negative when the examination of 100 high power fields did not reveal parasites. For quality control, all slides were read by a second microscopist, and a third reviewer settled any discrepant readings.

Haemoglobin concentration was measured on site in all participating children using a drop of blood collected from a finger-prick. The test was conducted using a battery-operated portable HemoCue analyzer (HemoCue, Anglom, Sweden) which provides a result within one minute. The haemoglobin results were provided to the caregiver verbally and were recorded on the appropriate case record form. Participants found to have anaemia levels requiring treatment (per WHO age-specific definitions) were referred to the local health facilities to obtain further care.

Statistical analysis

All data were collected using hand-held computers which were programmed to include range checks, structure checks and internal consistency checks. The data collection software was GIST software. This software is a proprietary electronic data collection software developed by the Infectious Diseases Research Collaboration and is based on the C# programming language and Microsoft Access Database. Data analyses were performed using Stata, version 14 (Stata Corporation, College Station, Texas, USA) and SAS® 9.4 (SAS Institute, Cary, USA). Baseline descriptive statistics included proportions for categorical variables and median (range) values for continuous variables. Clinical outcomes, including RDT positivity rate and the prevalence of parasitaemia and anaemia, were stratified by age categories (0.5–4 and 5–14 years). The prevalence of microscopic parasitaemia/gametocytaemia was calculated as the proportion of all blood smears examined that were positive for asexual parasites or sexual parasites. Clinical malaria, defined as RDT positivity in children with fever, was calculated as a proportion of all febrile participants with a positive RDT. Anaemia was defined based on World Health Organization (WHO) as haemoglobin less than 11.0 g/dl in children 6–59 months of age [19].

The wealth index was estimated using Principal Component Analysis and was stratified into tertiles (poorest, middle poor, and least poor). Housing construction characteristics were excluded from wealth index calculation for this analysis to be able to examine the association between housing characteristics and wealth. Households were stratified as modern houses (defined as having finished materials for roofs, walls, and floors, and having closed eaves) or traditional houses (defined as having unfinished materials for walls or roofs or floors or having open eaves) as previously defined by Tusting et al. (supplement Table 1) [10]. Association between malaria parasite prevalence, clinical malaria, and anaemia and house type were estimated using mixed effects generalized linear models with a negative binomial distribution and adjusted for age, wealth, and bed net use. A p-value of < 0.05 (two-sided) was considered statistically significant.

Results

Characteristics of the households enrolled in the survey

Between October and November 2021, 2184 households were screened for eligibility to join the study of which 1500 (68.7%) were enrolled (25 per cluster, 300 per catchment area of each of the 5 clinics), Fig. 1. The commonest reasons for exclusion were ineligibility due to having no resident aged between 6 months and 14 years in the household (404/684, 59.1%) and households having no adult aged 18 years or older present on the survey day (196/684, 28.7%). Among 8466 household members residing in the enrolled households, 4478 children aged between 6 months and 14 years were eligible to join the study. Of these, 3443 (76.9%) were included in the clinical survey. The commonest reason for exclusion was not being at home during the survey (1016/1035; 98.2%). Given the high numbers of exclusions, the characteristics of the children enrolled versus those excluded on the main predictor variables were compared (Supplement Table 2) and no difference in the key exposure variables (wall, floor and roof materials and on the house-type) was observed. A difference in the age estimates was observed; however, this and other predictors were adjusted for in the multivariate model.

Of the 1500 households, 983 (65.5%) lived in traditional houses (Table 1, Fig. 2A). The proportion of traditional houses per cluster ranged from 24 to 92% (Fig. 2A), with higher traditional house concentration in Luuka district (Irongo and Ikona HCIII catchment areas).

Households had a median of 6 members (interquartile range [IQR]; 2–15); a median of 2 rooms were used for sleeping (IQR; 1–8). Most households were headed by males (75.7%) and the majority of household heads had received at least primary education (83.5%). Almost all households had at least one bed net (98.3%) but only 993 (66.2%) had adequate number of bed nets (at least one LLIN per two persons). Modern households were more likely to have adequate bed nets than traditional households (72.3% vs 62.9% $p = < 0.001$). Characteristics of the study households and household members are presented in Table 1.

Characteristics of the house structures and construction materials

The majority of households had a single house structure (81.7%) in their compound, followed by two structures

Table 1 Baseline characteristics of households enrolled

Characteristic	n (%)
Number of households	1500
Located n (%)	
Sub-county	
Buwenga	575 (38.3)
Buyego	275 (18.3)
Irongo	475 (31.7)
Nawampiti	175 (11.7)
Household characteristics n (%)	
Type of house	
Traditional	983 (65.5)
Modern	517 (34.5)
Median no. of sleeping rooms (range)	2 (1–8)
Median no. of household members, (range)	6 (215)
Eaves	
Open	218 (14.5)
Closed	1282 (85.5)
Roof	
Unfinished	21 (1.4)
Finished	1479 (98.6)
Floor	
Unfinished	902 (60.1)
Finished	598 (39.9)
Walls	
Unfinished	199 (13.3)
Finished	1301 (86.7)
Control interventions, n (%)	
At least 1 net in the house	
No	26 (1.7)
Yes	1474 (98.3)
1 LLIN per 2 persons	
No	507 (33.8)
Yes	993 (66.2)
Head of household, n (%)	
Gender	
Male	1135 (75.7)
Female	365 (24.3)
Education level	
None	246 (16.5)
Primary	742 (49.8)
Secondary	450 (30.2)
Tertiary	51 (3.4)

(15.6%); only a few (40) households had 3–4 structures. (Table 2). Households living in modern houses were more likely to have more than a single structure in their compound compared to those in traditional houses (21.5% vs 16.6%; p = 0.020). Iron sheets were the most popular construction materials for roofs in both traditional and modern houses. In 21 of the traditional houses, temporary materials including grass, leaves, tin, and tarpaulin were used for roofing while none of the modern houses had temporary materials used for roofing. Of interest, the houses that were roofed with temporary materials including the one without a roof were always used for sleeping by household members.

Unlike the roofing materials, materials used for the floors varied significantly between the modern and traditional houses, with earth/sand being the most popular material for the traditional houses (895/983, 91.1%) and cement screed being the most popular among the modern houses (401/517, 77.5%). Most of the houses had their walls constructed with burnt bricks and cement (100% of the modern houses and 74.3% of the traditional houses). One-quarter (253, 25.7%) of traditional houses had walls constructed with mud or unburnt bricks.

Many of the houses had windows 1317 (87.8%). Nearly all the windows had covers, mostly of either glass or wood (1259/1317; 95.6%). Only 58 (3.9%) households had uncovered windows. Only 6 (0.5%) of the 1317 households with windows had screens installed in the windows. Most of the houses had air ventilation bricks (83.9%) with modern houses more likely to have vents (93.0%) compared to the traditional houses (79.1%). Only 43/1259 (3.4%) houses with vents had screens installed in the air vents. Only 78 (5.2%) households had an installed ceiling and 66/78 (84.6%) of the houses with a ceiling were modern houses.

The burden of malaria in children included in the clinical survey

Table 3 summarizes the findings from the clinical surveys. The mean age of the 3443 children included in the survey was 6.6 (standard deviation [SD]; 3.9) years, 51.7% were female and most (81.1%) had slept under a bed net the night before the survey. Of the 3443 children surveyed, 1851 (53.8%) were febrile (had history of fever in the past 48 h or a documented temperature of $\geq$ 38.0 ^{0}C) on the survey day. All febrile children had an RDT test done on-site, and the test was positive in 1047 (56.6%) of the children. Although children under 5 years (6–59 m) were more likely to be febrile than the school-aged children (5–14 years) (66.7% vs 46.0%; $p < 0.001$), RDT positivity was significantly higher in the febrile school-aged children compared to the children under 5 years of age (62.7% vs 49.5%; $p < 0.001$).

All the children participating in the clinical survey had a blood smear collected and in 1080 the blood smear was positive for malaria parasites giving an overall parasite prevalence of 31.4%. The cluster-level parasite prevalence varied across the study site, ranging from 4 to 67%, and was lowest in Buwenge catchment area (Jinja) and highest in Irongo (Luuka) (Fig. 2B). Similar to the RDT

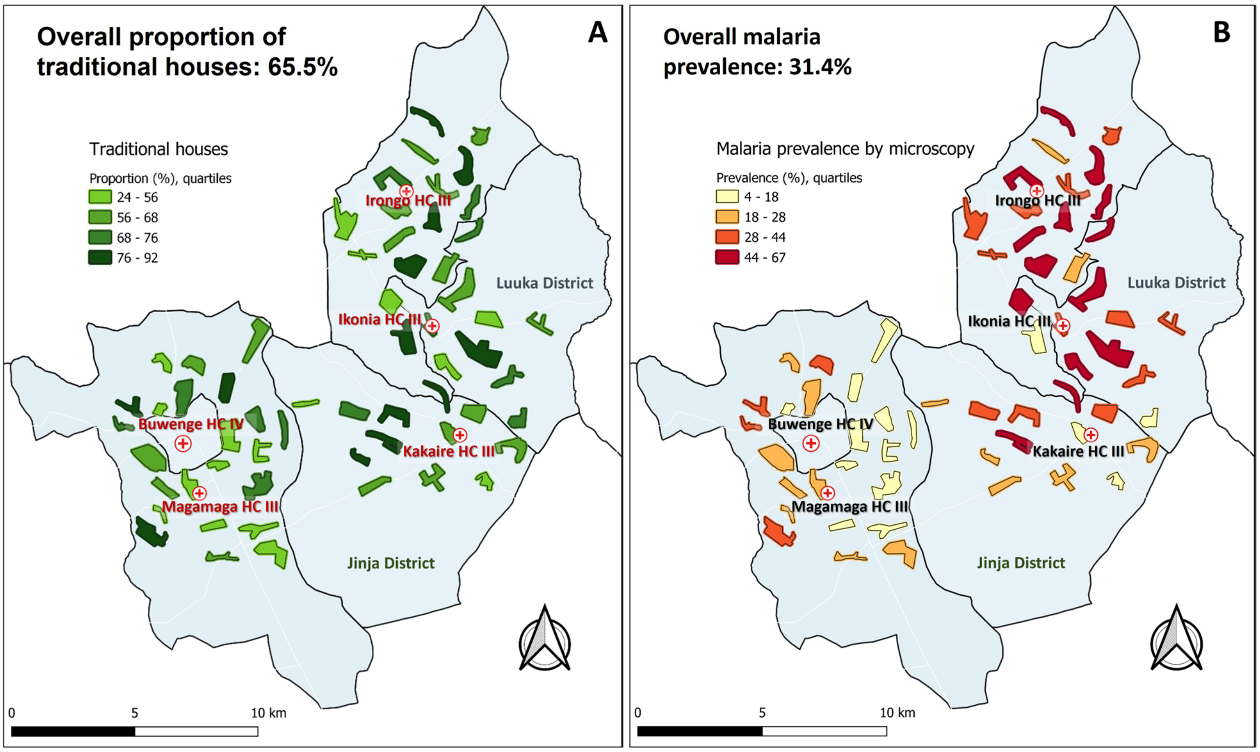

Fig. 2 Cluster-level distribution of proportion of traditional houses **A** and malaria prevalence **B** in 60 clusters across the study site

findings, school-aged children had a significantly higher parasite prevalence by microscopy compared to children under five years of age (36.5% vs 22.7%; $p < 0.001$). Anaemia was recorded in 415 (32.4%) of children under 5 years of age.

Association between house characteristics and markers of malaria infection and disease

At the cluster-level, there was a significant positive correlation between the prevalence of malaria parasitaemia (infection) and the proportion of all houses that are traditional (Pearson correlation 0.39, 95%CI 0.15–0.58, $p = 0.002$, Fig. 3), quantifying the patterns observed in Fig. 2A–B.

Participants living in modern houses had significantly lower parasite prevalence, RDT test positivity rates, and anaemia prevalence, compared to those in traditional houses (Fig. 4). Specifically, after adjusting for age, bed net use, and household wealth, children living in modern houses had a 20% lower parasite prevalence compared to those in traditional houses (adjusted prevalence ratio [aPR] = 0.80; 95% confidence interval [CI] 0.71–0.90, $p < 0.001$). In addition, children living in modern houses had a 10% lower RDT test positivity rate compared to those in traditional houses (aPR = 0.90; 0.82–0.99, $p = 0.02516$). The prevalence of anaemia was 24% lower in children under 5 years living in modern houses compared to those living in traditional houses (aPR = 0.76; 0.65–0.97, $p = 0.023$).

Children staying in households with finished floor materials had significantly lower microscopic parasitaemia (aPR = 0.78; 95% CI 0.69–0.87, $p < 0.001$) and RDT test positivity rates (aPR = 0.8; 95% CI 0.80–0.97, $p = 0.009$) compared to children in houses with unfinished floor materials, with a similar non-significant trend for anaemia (Fig. 4). Living in houses with finished wall materials or closed eaves was associated with significantly lower prevalence of anaemia (finished wall materials: aPR = 0.76, 95% CI 0.64–0.90, $p = 0.002$; closed eaves: aPR = 0.74, 95% CI 0.61–0.89, $p = 0.001$) compared to those living in houses with unfinished wall materials, with no significant association for either housing characteristics for parasite prevalence or RDT positivity rate.

Discussion

The malaria prevalence was high (31.4% by microscopy) and heterogeneous (4% to 67% across 60 clusters) in this geographically small (~30 × 20 km) area. This finding is consistent with what has been documented before in other studies conducted in the study area [8, 16].

Table 2 House construction materials and features in the study area

Characteristic	Traditional N = 983 n (%)	Modern N = 517 n (%)	Combined N = 1500 n (%)
Number of structures in the compound			
1 structure	820 (83.4)	406 (78.5)	1,226 (81.7)
2 structures	138 (14.1)	138 (18.6)	234 (15.6)
3 structures	24 (2.4)	13 (2.5)	37 (2.5)
4 structures	1 (0.1)	2 (0.4)	3 (0.2)
Main materials used for the roof of the main house			
No roof	1 (0.1)	0 (0.0)	1 (0.1)
Thatched (Grass/palms/leaves)	18 (1.8)	0 (0.0)	18 (1.2)
Tins	1 (0.1)	0 (0.0)	1 (0.1)
Tarpaulin	1 (0.1)	0 (0.0)	1 (0.1)
Iron sheets	962 (97.9)	514 (99.4)	1,476 (98.3)
Asbestos sheets	0 (0.0)	2 (0.4)	2 (0.1)
Roof shingles	0 (0.0)	1 (0.2)	1 (0.1)
Main materials used for the floor of the main house			
Earth/Sand	895 (91.1)	0 (0.0)	895 (59.6)
Dung	7 (0.7)	0 (0.0)	7 (0.5)
Palms/Bamboo	0 (0.0)	1 (0.2)	1 (0.1)
Concrete	22 (2.2)	110 (21.3)	132 (8.8)
Ceramic tiles	2 (0.2)	5 (1.0)	7 (0.5)
Cement screed	57 (5.8)	401 (77.5)	458 (30.5)
Main materials used for the wall of the main house			
Dirt	3 (0.3)	0 (0.0)	3 (0.2)
Unburnt bricks/poles and mud	196 (19.9)	0 (0.0)	196 (13.1)
Unburnt bricks with cement/plaster	54 (5.5)	0 (0.0)	54 (3.6)
Burnt bricks with mud Burnt bricks with cement/plaster	202 (20.6) 526 (53.5)	14 (2.7) 498 (96.3)	216 (14.4) 1,024 (68.4)
Cement blocks	2 (0.2)	0 (0.0)	2 (0.2)
reused wood	0 (0.0)	1 (0.2)	1 (0.1)
Windows on the main house			
Has Windows			
No	171 (17.4)	12 (2.3)	183 (12.2)
Yes	812 (82.6)	505 (97.7)	1,317 (87.8)
Window covered			
Open	36 (3.7)	22 (4.3)	58 (3.9)
Covered by glass/wood	776 (78.9)	483 (93.4)	1,259 (83.9)
No windows	171 (17.4)	12 (2.3)	183 (12.2)
Windows have improved screening			
No	810 (82.4)	501 (96.9)	1,311 (87.4)
Yes	2 (0.2)	4 (0.8)	6 (0.4)
N/A	171 (17.4)	12 (2.3)	183 (12.2)
Vents			
Has vents			
No	205 (20.9)	36 (7.0)	241 (16.1)
Yes	778 (79.1)	481 (93.0)	1,259 (83.9)
Vents screened			
No	754 (76.7)	462 (89.4)	1,216 (81.1)
Yes	24 (2.4)	19 (3.7)	43 (2.8)
N/A	205 (20.9)	36 (7.0)	241 (16.1)

Table 2 (continued)

Characteristic	Traditional N = 983 n (%)	Modern N = 517 n (%)	Combined N = 1500 n (%)
Ceiling			
Has a ceiling			
No	971 (98.8)	451 (87.2)	1,422 (94.8)
Yes	12 (1.2)	66 (12.8)	78 (5.2)
Type of ceiling			
Netted	2 (0.2)	3 (0.6)	5 (0.3)
Ceiling board	7 (0.7)	37 (7.2)	45 (3.0)
Concrete	3 (0.3)	26 (5.0)	28 (1.9)
N/A	971 (98.8)	451 (87.2)	1,422 (94.8)

Table 3 Measures of infection and disease

Characteristics	Age-group		
	0.5 – 4 years	5–14 years	Overall
Characteristics of the children enrolled			
Number of participants	1288	2155	3443
Sex; n (%)			
Male	628 (48.8)	1033 (47.9)	1661 (48.2)
Female	660 (51.2)	1122 (52.1)	1782 (51.7)
Slept in a bed net the night before survey			
No	184 (14.3)	467 (21.7)	651 (18.9)
Yes	1104 (85.7)	1688 (78.3)	2792 (81.1)
Measures of malaria infection and disease			
Blood smear results n (%)			
Negative	995 (77.3)	1368 (63.5)	2363 (68.6)
Positive	292 (22.7)	787 (36.5)	1080 (31.4)
Gametocyte present by microscopy, n (%)			
No	1231 (95.6)	2057 (95.4)	3288 (95.5)
Yes	57 (4.4)	98 (4.6)	155 (4.5)
Febrile on survey day; n (%)			
No	429 (33.3)	1163 (54.0)	1592 (46.2)
Yes	859 (66.7)	992 (46.0)	1851 (53.8)
[a]RDT results; n (%)			
Negative	434 (50.5)	370 (37.3)	804 (43.4)
Positive	425 (49.5)	622 (62.7)	1047 (56.6)
Anaemia			
No	868 (67.7)		
Yes	415 (32.4)		

[a] Only in febrile participants

Recent studies have documented higher odds of malaria infection and disease in residents of traditional houses compared to modern houses [10–12]. This study shows that: (1) traditional houses are the predominant type of housing in the study area; (2) the prevalence of microscopic parasitaemia and prevalence of anaemia was ~ 20% lower in children living in modern houses compared to children living in traditional houses; and (3) the RDT test positivity rates were 10% lower in febrile children living in modern houses. These observations were maintained even after controlling for wealth, age, and bed net use and the findings add to the body of evidence on the benefits of improved housing on malaria control.

Housing characteristics in the study area

In this rural study area, traditional houses were the predominant housing type, accounting for almost two thirds of all the houses. Most of the roofs of the houses in the study area were constructed with finished materials, and similar to findings from other studies in Uganda iron sheets were the commonest materials used for the roofs [11]. However, unlike findings from previous studies which show that most houses in rural settings were constructed with unfinished/natural wall materials, the findings from this study show a higher proportion of walls constructed using finished materials, with burnt bricks being the most common material used for walls. This improving trend in housing quality has been observed by other studies in sub-Saharan Africa [9, 11, 20], including the study by Rek et al. in Tororo, Uganda which showed a significant increase in the proportion of houses having finished wall materials in 2016 compared to what was observed in 2013 [11].

Association between housing characteristics and malaria

A lower prevalence of malaria parasitaemia and anaemia was observed in children residing in modern houses as compared to children residing in traditional houses. In addition, febrile children living in modern houses had lower RDT test positivity rates compared to those in traditional houses. These results are consistent with previous study findings on the relationship between house design and malaria [8–10, 20, 21]. Several mechanisms have been suggested to contribute to the protective effect of modern houses against malaria including: modulating exposure

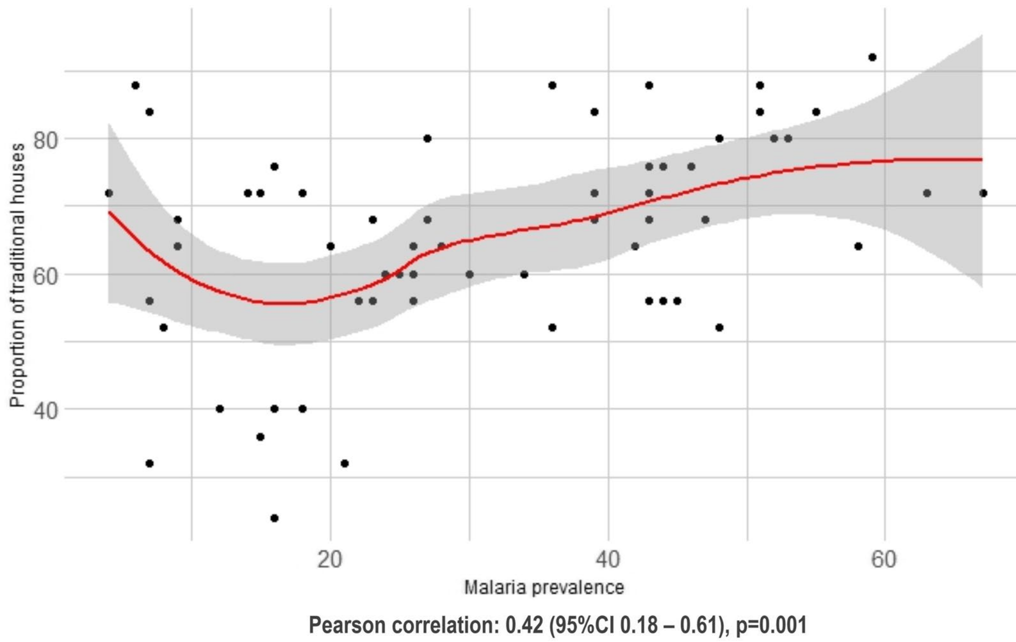

Fig. 3 Correlation between cluster-level malaria prevalence and proportion of traditional houses

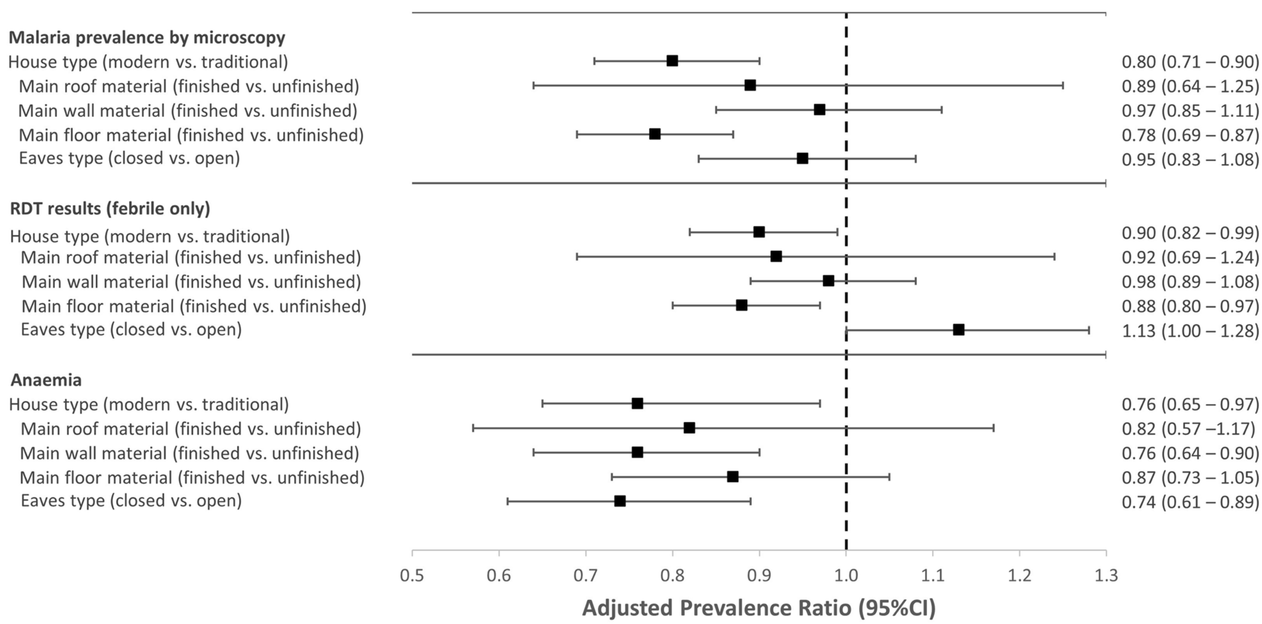

Fig. 4 Association between markers of malaria infection/disease and house type. Only one of these exposure variables was included in each model (with an exception of modern/traditional variable) and all models were adjusted for household wealth, bed net use, and age. **Only in febrile participants

of populations to mosquitoes [8, 22]; differences in the microclimate conditions in the modern versus traditional houses [23]; and differences in socio-economic status that enable greater access to healthcare and personal protection measures for children living in modern versus traditional houses. It is important to note that the protective effect of modern housing was maintained in this study after adjusting for wealth level and use of bed nets.

Although many studies have evaluated the relationship between housing type and malaria burden, few have ascertained which building improvements are the most effective. This study evaluated the relationship between the materials used for the walls, floors, and roofs and the malaria burden in this study area. Results from the study show that using finished floor materials was significantly associated with lower parasite prevalence and RDT test positivity rates in children living in modern houses compared to those living in traditional houses. In addition, children living in houses constructed using finished wall materials had significantly lower prevalence of anaemia than children living in houses with unfinished wall materials. There are several potential mechanisms that have been used to explain the protective effects of using finished construction materials and the risk of malaria. For example, unfinished materials like mud walls are likely to have holes, gaps making them permeable to mosquitos while finished materials like wood, brick and stone walls are less permeable to mosquitoes. In addition, finished materials alter the attractiveness of the interior environment to mosquitoes or provide fewer resting sites for mosquitoes than unfinished materials. It has also been hypothesized that metal-roofed homes are hotter and less conducive for mosquito survival, however, in this study this association could not be established because > 98% of houses had iron sheet roofs.

Additional house features such as window screening, installed ceiling, and closed eaves have been shown to be protective against malaria [24–27]. In this study, majority of the houses had closed eaves, and children living in houses with closed eaves had significantly lower prevalence of anaemia. However, other house features protective against malaria were vastly underutilized in this population, an observation comparable to what has been reported in other studies with similar settings [27]. The lack of screens in windows/doors and lack of installed ceilings may lead to mosquito entry through these openings especially when left open for ventilation. The reasons for the underutilization of these additional features in the construction of houses in this setting were not explored. However, other studies have documented several reasons for this including the lack of funds to meet the associated costs and decision-makers being unaware of the impact of improved housing on malaria control [28, 29]. Generally, improved housing is not well appreciated as a malaria reduction strategy by most communities. A study exploring the knowledge of house screening for self-protection against malaria vectors in neighbouring Kenya showed that lack of awareness was the major reason given for not screening houses [29]. Other studies especially in endemic settings had similar findings [30]. The previously documented reasons for limited use of screening and other protective features in house construction may not be much different in this setting.

The study was not without limitations. First, the cross-sectional nature of the survey design does not allow to explore the temporal relationships between the housing and malaria burden in the study area. However, the design allows to comprehensively describe the study setting, the malaria burden in the area, and the association between malaria and anaemia outcomes and the housing characteristics prior to housing modification study. Second, estimating the differences in entomological measures between modern and traditional houses was not part of this survey, but will be explored through entomological surveillance separately. However, in the analysis, known confounders collected including age, bed net use, and wealth were adjusted to control for their effect on the outcome. Third, the survey took place in all 60 trial clusters identifies (100% selection), therefore was not sampled in a way to be formally representative of the study area population (non-random, non-weighted selection), however, the nature of the selection of clusters in the contiguous study area provides a reasonable description of the rural population in the 4 sub-counties. Fourth, an association between malaria infection and the floor type is observed, however, there is no association between anaemia and floor type despite malaria infections being highly correlated with anaemia. This lack of association is due to limits in sample size for anaemia which was only measured in children under 5 years in leading to the failure to reject the null.

Conclusion

This study found that after adjusting for wealth, higher quality housing had a moderate protective effect against malaria, on top of the protection already afforded by recently distributed bed nets. These findings highlight the role that housing quality plays in malaria dynamics and the importance of improved housing in the prevention of malaria at the household level.

Abbreviations

aPR	Adjusted prevalence ratio
AL	Artemether-lumefantrine
ACT	Artemisinin-based combination therapy
CI	Confidence interval
EIR	Entomological inoculation rate
IRS	Indoor residual spraying of insecticides
IPTp	Intermittent preventive therapy
LCI	Local council chairman
LLINs	Long-lasting insecticidal nets
RDT	Rapid diagnostics test
SD	Standard deviation
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12936-024-05051-5.

Supplementary Material 1. Figure 1: Distribution of the 60 clusters included in the baseline survey

Supplementary Material 2. Table 1: Characteristics of the houses in relation to house types. Table 2: Comparison of the characteristics of the excluded versus included participants

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JIN, SG, MRK, NW: supported the design of the study, supported the data collection, led the data analysis, drafted the manuscript, approved final draft of manuscript. PM, MN, AK:

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Availability of data and materials
Data from both cohort studies are available through a novel open-access clinical epidemiology database resource, ClinEpiDB: https://clinepidb.org/ce/app

Declarations

Ethical approval and consent to participate.
The study received ethics approval from the School of Public Health Higher Degrees, Research and Ethics Committee, Makerere University College of Health Sciences (HDREC Ref: 887), the Uganda National Council for Science and Technology UNCST (HS1072ES), the London School of Hygiene and Tropical Medicine Ethics Committee (LSHTM Ethics Ref: 22813–1), and the protocol clearance by U.S. Centers for Disease Control and Prevention. Written informed consent was obtained for all participants prior to enrolment into the study.

Competing interests
The authors declare no competing interests.

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