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Risk Factors Associated With House Entry of Malaria Vectors in an Area of Burkina Faso With High, Persistent Malaria Transmission and High Insecticide Resistance

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Research

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Abstract

Background: In rural Burkina Faso, the malaria vector *An. gambiae* s.l. is primarily thought to feed indoors at night. Identification of factors which influence mosquito house entry could lead to development of novel malaria vector control interventions. A study was therefore carried out to identify risk factors associated with house entry of *An. gambiae* s.l. in south-west Burkina Faso, an area of high insecticide resistance.

Methods: Mosquitoes were sampled monthly during the malaria transmission season using CDC light traps in 252 houses from 10 villages, each house sleeping at least one child aged five to 15 years old. Putative risk factors for house entry of *An. gambiae* s.l. were measured, including socio-economic status, caregiver's education and occupation, number of people sleeping in the same room as the child, use of anti-mosquito measures, house construction and fittings, proximity of mosquito aquatic habitats and presence of animals near the house. Mosquito counts were compared using a generalised linear mixed-effect model with negative binomial and log link function, adjusting for repeated collections.

Results: 20,929 mosquitoes were caught, of which 16,270 (77.7%) were *An. gambiae* s.l. Of the 6,691 *An. gambiae* s.l. identified to species, 4,101 (61.3%) were *An. gambiae* and 2,590 (38.7%) *An. coluzzii*. Having an electricity supply (incidence rate ratio, IRR = 0.4, 95% CI = 0.3–0.7, p = 0.001) and a metal-roofed house (IRR, = 0.6, 95% CI = 0.4–1.0, p = 0.034) were associated with fewer malaria vectors inside the home.

Conclusion: This study demonstrated that there were fewer *An. gambiae* s.l. in homes with electricity and a metal roof compared to those that did not. Brightly-lit, well-built houses with metal roofs may reduce entry of malaria mosquitoes compared to dimly-lit, poorly-built thatched roofed houses.

Introduction

Despite large reductions in the malaria burden across sub-Saharan Africa from 2000-2015 [1], some countries continue to experience extremely high malaria transmission [2]. In Africa, malaria transmission is highly efficient because of the wide distribution of *Anopheles gambiae* s.l., an effective malaria vector that readily feeds readily on people indoors at night, where about 79% of malaria transmission typically occurs [3]. The indoor density of malaria mosquitoes is dependent on numerous environmental and household factors, including the abundance and proximity of aquatic habitats of malaria mosquitoes [4, 5], presence of large domesticated animals who may serve as alternative hosts [6], typology of houses [7, 8], use of anti-mosquito measures in the house [5], the number of residents [9] and variability in the attractiveness of individual people [10] (Figure 1).

Burkina Faso is an area of intense seasonal malaria transmission, and cases are increasing [11-13] despite high coverage of vector control tools, including three national insecticide-treated net (ITN) mass distribution campaigns in 2010, 2013 and 2016 [14]. Resistance to pyrethroids, the main insecticide class used for treating ITNs, is high in *An. gambiae* s.l., and in the study area near Banfora town exposure to

ITNs has no impact on the lifelong survival of malaria vectors [15]. New tools are urgently needed to reduce the burden of malaria in Burkina Faso and other countries in sub-Saharan Africa.

Several studies have demonstrated that malaria mosquito house entry can be reduced through simple changes to house design such as closing eaves and screening windows and doors [16]. The use of personal protective measures such as ITNs and spatial repellents may also reduce transmission [17, 18]. There is a lack of evidence, of whether such methods will reduce house entry of malaria vectors in settings of high insecticide resistance, such as the study site in south-west Burkina Faso. A risk factor survey was conducted to identify variables associated with indoor density of *An. gambiae s.l.* during the malaria transmission season in an area of intense malaria transmission in Burkina Faso. Findings from this study might identify potential opportunities for improving malaria control in Burkina Faso and other countries in sub-Saharan Africa experiencing persistently high malaria transmission.

Methods

Study site

The study was conducted in Banfora Health District, in the Cascades Region, south-west Burkina Faso (Figure 2). This is an area of Sudanian savannah covering 6,295 km^2 with an estimated population of 407,073 inhabitants [13]. Malaria transmission is intense and seasonal, occurring mainly during the rainy season, from May to November [19]. *Plasmodium falciparum* accounts for 90% of cases [19]. The main malaria vectors are *An. gambiae* s.s. and *An. coluzzii* [20]. In 2016, approximately 1 year before this study took place, a universal coverage campaign distributed ITNs with permethrin or deltamethrin (Sumitomo Chemical, Vestergaard and BASF) at a rate of one net for every two people at risk. No additional ITNs were distributed by the study. No indoor residual spraying was conducted. Typically, single room houses each housing a family are organised into compounds, consisting of on average 4 houses, led by a compound head.

Study design

The study was nested in a cohort study of risk factors for *P. falciparum* infection in children aged five to 15 years [21]. This study reports on the household and environmental risk factors associated with the density of *An. gambiaes.l.* in the children's sleeping room over six months of high malaria transmission from July to December 2017.

Recruitment of study cohort

Sampling and recruitment of the study cohort is described elsewhere [22]. In brief, a random sample of 10 villages were selected from a list of villages in the study area using a two-stage process. Firstly, five health centres in the study area were selected, each with a catchment radius of 10 km. Secondly, two villages, at least 3 km apart, were selected from each catchment area. An enumerated list of children in the study villages was obtained from the Banfora Demographic and Health Surveillance System. From each village, a random sample of 30 children aged five to 15 years were chosen. Each child was selected from a separate house, and, where possible, a separate compound. Children were included in the study if they were of the appropriate age, were likely to remain resident in the village over the duration of the transmission season and the caregiver provided informed consent to participate in the study. 252 children who were successfully cleared of *P. falciparum* infection were included in the cohort study and this current study reports on the entomological surveillance from the children's sleeping rooms.

Entomological surveillance

CDC light traps (John Hock, Gainsville, USA) were used to estimate indoor mosquito densities in the study child's sleeping room. These traps were placed with the bulb 1500 mm above the floor, approximately 500 mm from the foot end of a bed with an ITN occupied by the study child. Houses were sampled from 19.00 h to 06.00 h every four weeks. Typically, houses were sampled once a month, but in some cases two collections were performed. Two villages (Nofesso and Ouangolodougou) were inaccessible for two weeks at the start of the study period due to flooding. Mosquitoes were taken to the laboratory in cool boxes, killed by freezing at −20°C, and identified morphologically using established keys [22]. The presence of circumsporozoites protein (CSP) in *An. gambiae s.l.* were identified using an enzyme-linked immunosorbent assay [23] and *An. gambiae s.l.* females typed to species by PCR [24, 25].

Risk factor assessment

In June, a questionnaire was administered to the caregiver of the study child to collect information on ethnicity, education level and occupation of caregivers, ITN use during the previous night, use of other protective measures (e.g. insecticide knockdown spray, mosquito coils, traditional spatial repellent), number of people sleeping in the room with the child, roof, wall and floor construction of the child's sleeping room, whether the eaves (the gap between the top of the wall) were open or closed, presence of mosquito screening and electricity supply. Information was also collected from the head of the child's household on asset ownership and household characteristics, following standard procedures used in the Burkina Faso Malaria Indicator Survey [26]. The number and type of large domestic animals (cattle, goats, sheep, pig, dog, donkeys or horses) tethered within 5 m of the house was recorded by a fieldworker. The house was geo-located using a handheld global positioning system (GARMIN eTrex 20). Larval surveys were carried out in each village in September, during the peak of the transmission season. All water bodies within 1 km from a village were mapped, including irrigated fields, streams and ponds, puddles, and foot or hoof prints. The presence of anopheline larvae was recorded with a dipper.

Data management and statistical analysis

Data were collected on Android personal digital assistants programmed using the KoboCollect system and included drop down boxes and consistency checks to reduce data entry errors. Following cleaning, the dataset was locked and saved in Microsoft Access. The primary outcome was the number of *An. gambiaes.l*. collected in each child's sleeping room per night. QGIS Geographic Information System (QGIS Development Team (2019), Open Source Geospatial Foundation Project) was used to determine distances between the child's home and aquatic habitats. Principal component analysis (PCA) was used to calculate the socio-economic status (SES) factor score of the head of the child's household. SES factor scores were ranked, and households divided into five equal wealth quintiles, from 1, the poorest, to 5, the least poor. The entomological inoculation rate (EIR) or estimated number of infectious bites per study child during the transmission season was calculated using the formula EIR=*MaSd* where *Ma* is the human biting rate, estimated from the arithmetic mean number of female *An. gambiae* s.l. caught per light trap night across the six-month transmission season, where *S* is the proportion of female *An. gambiae* s.l. found to be CSP positive by village and *d* is the number of days in the transmission season (n). Mean values were compared using a t-test and proportions compared using chi-squared tests. A generalised linear mixed-effect model with a negative binomial distribution, to account for overdispersion, and log link function was used to identify risk factors associated with the mean number of *An. gambiaes.l.* per catch night per house each month. Risk factors were selected *a priori* based on importance for malaria vector house entry. These were SES quintile, ITN use, use of other protective measures, number of people sleeping in the room with the child, roof, floor and wall material in the sleeping room, eaves (open or closed), electricity supply, presence of large domesticated animals within 5 m of the house and proximity of habitats positive for anopheline larvae. A random effect for study child ID number was used to account for repeated measures on the same house and village was included as a fixed effect. Following univariate analysis, each risk factor with P<0.1 was incorporated into a multivariate model which was refined through a process of backwards stepwise elimination using a likelihood ratio test. Interactions were tested between a subset of variables that were thought to be biologically relevant to explore. Means and 95% confidence intervals were calculated. Statistical analysis was carried out in Stata 15 (Statacorp, Texas, USA). The study is reported following STROBE guidelines [27].

Results

As reported elsewhere [21], a total of 20,929 mosquitoes were caught from 1,151 trap collections in the 252 study houses, with 16,270 of these being *An. gambiae* s.l. (77.7%). Of the 6,691 *An. gambiae* s.l. identified to species (excluding 924 lost and non-identified samples), 4,101 were *An. gambiae* s.s. (61.3%) and 2,590 *An. coluzzii* (38.7%). 3.3% of *An. gambiae* s.l. were CSP positive and the overall EIR in the study area was 80.4 infective bites/child over the six-month transmission season. The village-level EIR ranged from 40.8 in Timperba to 191.9 in Tondoura.

The ethnic composition of the study population was Gouin (38.9%), Karaboro (21.8%), Mossi (11.5%), Turka (9.1%), Fulani (6.3%), Senoufo (4.4%) and other ethnic groups (7.9%) (Table 1). Caregivers were predominantly illiterate (79.0%) and farmers (95.2%). 80.6% of caregivers reported that their child slept under an ITN the previous night, while 15.9% reported using mosquito coils and 6.4% insecticide knockdown spray. Children's sleeping rooms were constructed with predominantly brick walls (57.9%), cement or tiled floors (70.6%), metal roofs (75.8%) and open eaves (54.8%). Window screening was rare (0.4%). 67.1% of households had large domestic animals (cattle, goats, sheep, dogs, pig, donkeys or horses) within 5 m of the house. 50.4% of child’s households were located within 300 m of an aquatic habitat containing anophelines.

Table 1: Characteristics of the study participants and their houses

Characteristic		Number (%) N=252
Socio-demographic characteristics		
Ethnicity	Gouin	98 (38.9%)
	Karaboro	55 (21.8%)
	Mossi	29 (11.5%)
	Turka	23 (9.1%)
	Fulani	16 (6.3%)
	Senoufo	11 (4.4%)
	Others	20 (7.9%)
Caregivers education level	Illiterate	199 (79.0%)
	Primary school	45 (17.9%)
	Secondary school or above	8 (3.2%)
Caregivers occupation	Farmer	240 (95.2%)
	Non-farmer	12 (4.8%)
Number of people sleeping in the child room (including child)	≤6	55 (21.8%)
	7-12	118 (46.8%)
	>12	79 (31.3%)
Use of personal protective measures		
Reported ITN use	Used ITN usually	215 (85.3%)
	Used an ITN the previous night	203 (80.6%)
Use of other personal protection methods	Coils	40 (15.9%)
	Insecticide spray	16 (6.4%)
	Traditional repellent (non-topical)	2 (0.8%)
	None	184 (73.0%)
House construction		
Roof material of child’s sleeping room	Metal	191 (75.8%)
	Non-metal (Thatch/mud)	52 (20.6%)
Wall material of child’s sleeping room	Mud	65 (25.8%)

	Brick	146 (57.9%)
	Cement blocks (plastered or painted)	32 (12.7%)
Floor material of child's sleeping room	Cement/tile	178 (70.6%)
	Mud	65 (25.8%)
Eave status of child's sleeping room	Closed	102 (40.5%)
	Open	138 (54.8%)
Window screening of child's sleeping room	Absent	242 (96.0%)
	Present	1 (0.4%)
Electricity supply in the child's sleeping room	Present	115 (45.6%)
	Absent	111 (44.0%)
	Missing	26 (10.3%)
Environmental factors		
Presence of large domestic animals within 5 m of the household	Present	169 (67.1%)
	Absent	80 (31.7%)
Proximity to anopheline positive larval habitats	<300 m	127 (50.4%)
	≥300 m	125 (49.6%)

Sleeping spaces in metal roofed houses were more likely to have walls and floors made of finished materials, open eaves, be less crowded and have an electricity supply than thatch roof sleeping spaces. 81.7% of sleeping spaces with a metal roof had a cement or tiled floor compared to 42.3% of those with a thatch roof ($p<0.001$). Metal roof sleeping spaces were also more likely to have brick or cement walls (77.0%) compared to thatch roof sleeping spaces (55.8%, $p<0.001$). Sleeping spaces with a metal roof were also more likely to have open eaves (66.0%) and an electricity supply (51.8%) than sleeping spaces with a thatch roof (23.1% and 28.8% respectively, $p<0.001$ and $p=0.003$). 26.2% of sleeping spaces with a metal roof had more than 12 people sleeping in them compared to 38.5% of sleeping spaces with a thatch roof ($p<0.001$). There was no association between metal roof sleeping spaces and distance from the nearest anopheline larvae positive habitat.

Univariate analysis of putative risk factors showed that there was an association between *An. gambiae s.l.* abundance and roof and floor materials, electricity supply, and proximity of positive larval habitats (Table 2). There was a 40% reduction in the rate of *An. gambiae* s.l. if the child slept in a room with a metal roof (IRR = 0.6, 95% CI 0.4 – 0.9, p = 0.026), increasing to a 60% reduction if there was an electricity supply in the sleeping room of the child (IRR = 0.4, 95% CI 0.3 – 0.7, p = 0.001). A mud floor was associated with 1.5 times the rate of *An. gambiae* s.l. compared to a cement or tiled floor (IRR = 1.5, 95%

CI 1.0 – 2.4, p=0.043). There was 50% increase in the rate of *An. gambiae* s.l. when the child's house was >300 m from a larval habitat containing anopheline mosquitoes (IRR = 1.5, 95% CI 1.0 – 2.3, p = 0.032).

In the final multivariate model, having an electricity supply in the child's sleeping room (IRR = 0.4, 95% CI 0.3 – 0.7 p < 0.001) and a metal roof (IRR = 0.6, 95% CI 0.4 – 1.0, p = 0.034) were associated with fewer malaria vectors indoors (Table 2). Inclusion of eave status did not improve the model fit or alter the IRR substantially and an interaction between roof type and eave status was not significant.

Table 2: Risk factors for *An. gambiae s.l.* abundance in study children's sleeping room

Variable	Mean mosquito density per month (95% CI)	Univariate analysis		Multivariate analysis	
		IRR (95% CI)	P value	IRR (95% CI)	P value
Socio-economic status of child's household					
Poorest	23.0 (10.0 – 36.1)	1			
Poor	14.1 (6.8 – 21.3)	0.8 (0.4 – 1.4)	0.4		
Middle	11.8 (7.7 – 15.9)	0.9 (0.5 – 1.7)			
Rich	11.5 (7.3 – 15.8)	0.7 (0.4 – 1.4)			
Richest	12.4 (5.6 – 19.1)	0.7 (0.3 – 1.5)			
ITN use the previous night					
No	7.1 (4.5 – 9.8)	1			
Yes	15.8 (11.7 – 19.8)	1.2 (0.6 – 2.3)	0.6		
Use of other personal protection measures (insecticide knockdown spray, mosquito coils, traditional spatial repellent)					
No	15.8 (11.4 – 20.2)	1			
Yes	9.6 (6.3 – 13.0)	0.9 (0.6 – 1.6)	0.8		
Number of people sleeping in the same room as the study child					
≤6	13.5 (9.6 – 17.4)	1			
7-12	17.1 (10.3 – 23.8)	1.1 (0.7-1.9)	0.7		
>12	10.4 (7.5 – 13.3)	0.8 (0.4 – 1.3)	0.3		
Roof material of child's sleeping space					
Non-metal	14.3 (8.1 – 20.6)	1		1	
Metal	14.4 (10.3 – 18.4)	0.6 (0.4 – 0.9)	0.03	0.6 (0.4 – 1.0)$	0.03
Floor material of child's sleeping space					
Cement/tile	13.3 (9.1 – 17.5)	1			
Mud	17.4 (11.4 – 23.3)	1.6 (1.0 –	0.04		

		2.4)			
Wall material of child's sleeping space					
Mud	17.4 (11.3 – 23.4)	1			
Brick	13.6 (8.5 – 18.6)	1.0 (0.6 – 1.6)	1.0		
Cement	11.6 (7.0 – 16.1)	0.8 (0.4 – 1.7)	0.6		
Eaves of child's sleeping space					
Open	13.8 (9.8 – 17.7)	1			
Closed	14.9 (9.6 – 20.3)	1.0 (0.6 – 1.6)	0.9		
Electricity supply of child's sleeping space					
No	17.9 (11.1 – 24.7)	1		1	
Yes	11.8 (8.9 – 14.8)	0.4 (0.3 – 0.7)	0.001	0.4 (0.3 – 0.7)[&]	0.001
Presence of large domestic animals near the house					
Yes	14.9 (10.1 – 19.7)	1			
No	12.7 (9.3 – 16.0)	1.1 (0.8 – 1.7)	0.6		
Distance to positive larval habitat					
<300m	9.5 (7.3 – 11.8)	1			
>300m	18.6 (12.4 – 24.9)	1.5 (1.0 – 2.3)	0.03		

IRR: incidence rate ratio, CI: confidence interval, *adjusted for repeated measures and village as fixed effect, $adjusted for electricity supply, repeated measures and village as fixed effect, &adjusted for roof material, repeated measures and village as fixed effect

Discussion

Our findings demonstrate highly intense transmission of malaria in the study area with a person sleeping without an ITN experiencing a seasonal EIR varying from 40.8 infectious bites per person in Timperba village to 191.9 in Toundoura village [26]. Malaria vector abundance rises in July after the start of the rains in May, reaching a peak in August, before declining to low levels in November and December.

Having a supply of electricity in the sleeping room of the child and a metal roof were both associated with fewer *An. gambiae* s.l. malaria vectors entering houses. Fewer *An. gambiae* s.l. found in houses with electricity may be due to the use of electric lights or fans and this hypothesis requires further investigation. The relationship between electrification and malaria is not well established and there are only a few, low quality studies on this topic, with most indicating a higher risk of malaria given electrification [28-30]. Electrification was associated with a two-fold increase in the odds of clinical malaria in a case control study in Burkina Faso [31]. An increase in malaria may results from mosquitoes being attracted to light. For example, the CDC light trap is thought to be attractive at distances of 5 m [32], and may increase indoor catches of mosquitoes if the light is seen from outside the house [33]. Qualitative studies suggest that outdoor lighting and ownership of televisions may also increase in malaria risk due to the extension of the period of outdoor activity [34, 35]. Alternatively, there is evidence that lighting is protective against mosquitoes. The disappearance of malaria in England was associated with improvements in housing including better lighting, improved ventilation, drier and more spacious rooms, better ceiled and plastered and less crowded bedrooms [36]. Responses of mosquitoes to light is likely to be more nuanced, depending not only on the intensity and frequency of the light, but on the time of day a mosquito perceives the light. For example, *An. gambiae* s.s. exposed to white light for 10 min at the start of the night interrupted feeding activity for two to four hours [37]. The use of electric fans is also likely to reduce collections of mosquitoes by light traps since the powerful air current generated by a fan will prevent or greatly disturb mosquito flight. There may also be other explanations for our finding that are more straightforward. Firstly, the use of electricity, as suggested by Yamamoto and co-workers, may lead to a shift away from use biomass fuels and creation of smoke that would repel malaria vectors from entering the house [31]. Secondly, the use of electricity may simply be a proxy for higher socio-economic status and a more mosquito-proof house, along the lines suggested by James in 1920 [36]. Clearly further research is needed to clarify what is contradictory evidence.

Finding fewer mosquitoes in houses with metal roofs compared with thatched roofs has been reported in several studies, including a Tanzanian study where metal roofed houses had 33% less *An. arabiensis* than thatched-roof houses [38], and a Ugandan study where there were 38-43% fewer *An. gambiae* s.l. in metal-roofed houses [39]. Results are, however, contradictory in other studies. In The Gambia metal-roofed houses were not associated with fewer mosquitoes [6], and in an experimental study, metal roofed houses with closed eaves and mud walls had similar numbers of mosquitoes as thatched-roofed houses with open eaves and mud walls [7]. Whether a metal-roofed house has more or less mosquitoes than a thatched-roof house ultimately depends on how porous the house is to mosquitoes and the extent of ventilation [16]. In general, since metal-roofed houses are hotter before midnight than thatched-roofed houses, metal-roofed houses will generate more carbon dioxide from people sleeping in the houses, and therefore attract more mosquitoes, than cooler thatched-roofed houses [7, 40]. However, metal-roofed houses are often better built, with fewer mosquito entry points, than thatched-roofed houses. In such cases, metal-roofs may simply be a marker for a better quality home that is less porous to mosquitoes.

The lower *An. gambiae* s.l. density in metal-roofed houses compared to thatch houses in this study appeared to be operating independently of eave status, since, thatched roofs were more likely to have closed eaves and an interaction between eave status and roof type was not significant. A final consideration is that there is evidence that the high temperatures experienced in metal roof houses in the hot humid tropics, increases the mortality of malaria vectors resting indoors during the day [41]. Thus, the reduction in mosquitoes found in metal-roofed houses may be partly due to the higher temperatures experienced indoors.

The study has several limitations. Firstly, both electricity supply and metal-roofed houses are associated with high SES. Adjusting the final model for SES quintile did not impact on the results. Despite this, the SES quintile is a crude measure and there may be other features of wealth that reduce malaria mosquito numbers in houses with electricity supply and metal roofs. Second, ITN use the previous night was assessed by asking the caregiver which may be prone to social desirability bias [42]. The use of an ITN will usually vary over the transmission season, but we only measured use during the baseline survey. This may have impacted on our ability to identify an association between ITN usage and indoor density of malaria vectors.

The cohort study in which this entomological study was nested did not identify strong risk factors for *P. falciparum* infection, with only overnight travel and higher SES factor score being associated with higher rates of *P. falciparum* infection [21]. It is difficult to reconcile the entomological and epidemiological findings and further studies are needed. It is perhaps unsurprising that the risk factors for malaria vector density and *P. falciparum* infection in children differed, since higher indoor vector density does not automatically imply higher infection risk. The indoor density of malaria vectors may be less important in this study area due to the observation of increasing outdoor biting with some studies suggesting ~54% of *An. gambiae* s.l. host seeking outdoors [43]. Research also suggests that the study communities spend more time outside in the peri-domestic environment during peak biting times than previously thought [44].

What are the implications of the study findings for vector control and future research? Increased access to electricity in sub-Saharan Africa raises questions about the impact on vector behaviour (e.g. whether lights attract mosquitoes or leads to mosquito avoidance behaviour), human behaviour (e.g. alteration of time to bed or use of fans) and malaria risk which are complex and yet to be understood. Further research on this topic is needed. The risk factor study also highlights the potential of improved housing to reduce malaria transmission and supports the results of systematic and multi-country research studies on this topic [45, 46]. Housing improvements tend to be implemented as a package and, in line with this, our study found that metal roof sleeping spaces were more likely to have floors and walls made of finished materials, be less crowded and have an electricity supply than thatch roof sleeping spaces. Improving house construction should be a focus for malaria reduction [47], with increasing evidence in support of screened, self-closing doors, closed eaves, raising buildings off the ground, screened windows on either side of building for ventilation and solid roofs [16]. As well as contributing to the development agenda, there is also evidence that improved housing can reduce risk of other major causes of death in children including diarrhoea, growth failure and anaemia [48]. While other vector control tools such as dual-active ITNs are now being deployed in the study area, the study results highlight the importance of non-insecticidal interventions such as house improvement to increase long-term resilience against malaria and for insecticide resistance management.

Conclusion

This study in south-west Burkina Faso demonstrates reduced indoor density of malaria vectors in houses with electricity and a metal roof. Further research is needed to unpack the implications of electrification and metal roof housing on malaria risk; however, this study adds to the growing evidence base supporting the use of housing improvement against malaria.

Abbreviations

CI: confidence interval, CSP: circumsporozoite protein, ITN= insecticide treated-net, IRR: incidence rate ratio, PCR= Polymerase chain reaction, SES= Socio-economic status.

Declarations

Ethics approval and consent to participate

Permission to enter the communities was sought from village leaders. The caregivers of study participants provided informed consent (or assent of child if aged 12-15 years) to participate in the cohort study and for collection of mosquitoes from the child's sleeping room. Study documents were approved by the Burkina Faso Ministry of Health Research Ethics Committee (Deliberation No 2016-12-137), CNRFP Institutional Bioethics Committee (No2016/000007/MS/SG/CNRFP/CIB), Durham University Department of Biosciences Ethics Committee (SBBS/EC/MIRA) and Liverpool School of Tropical Medicine Ethical Committee (Protocol number: 16/047). The study was conducted in compliance with principles set out by the International Conference on Harmonization Good Clinical Practice, the Declaration of Helsinki and the regulatory requirements of Burkina Faso

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests. All authors declare that they had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Authors' contributions

Conceived and designed the study: SWL, ALW, ABT, NFS, HR. Conducted field and laboratory work: JBY, ABT, KHT, AS, WMG. Conducted data analysis: JBY, ALW, SWL, ABT, AO, EA, JB. Contributed to and approved the final manuscript: JBY, ALW, SWL, ABT, AO NFS, HR, KHT, AS, WMG, AE. All authors read and approved the final manuscript.

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Figures

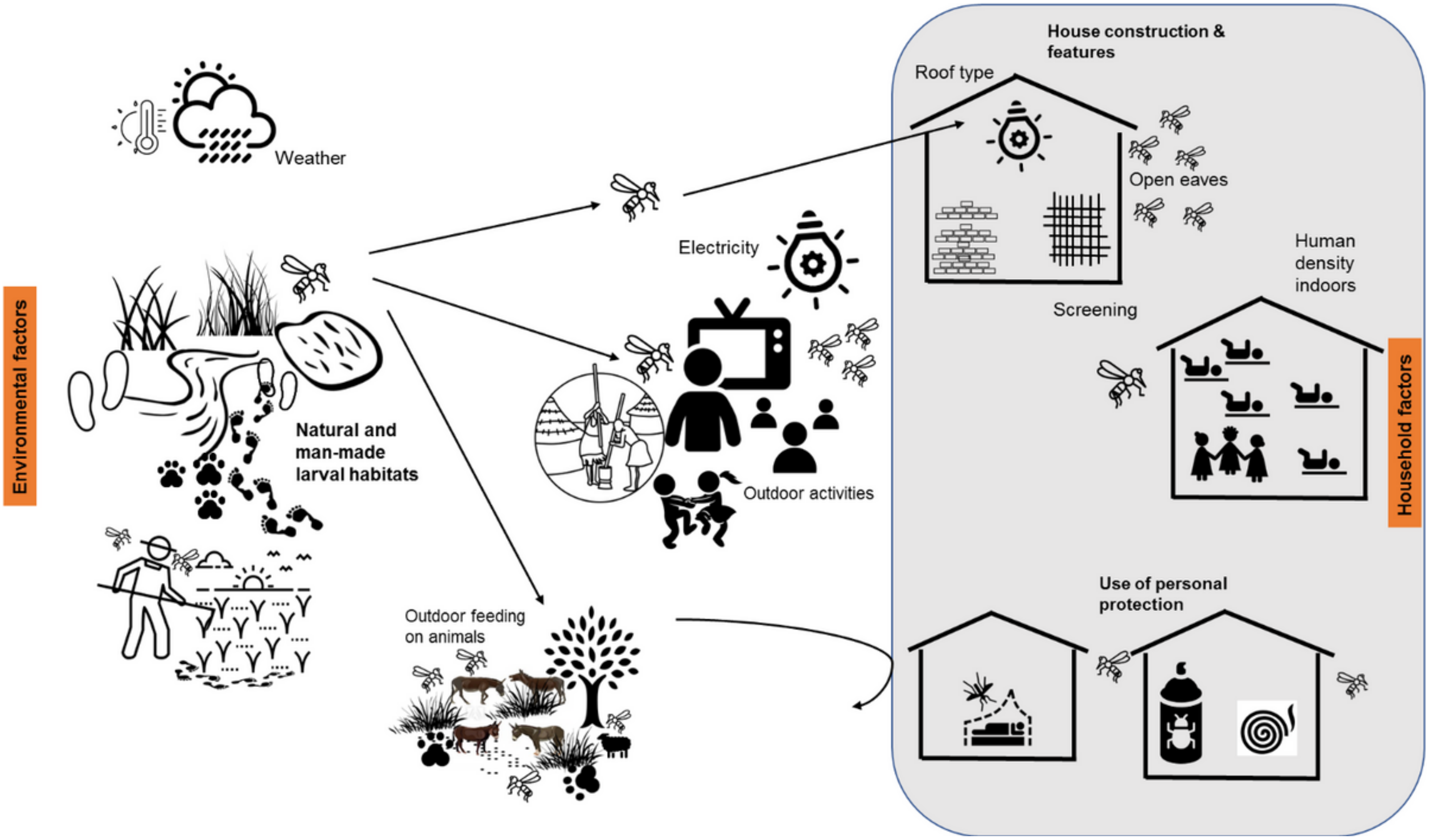

Figure 1

Environmental and household factors affecting the abundance of malaria vectors indoors

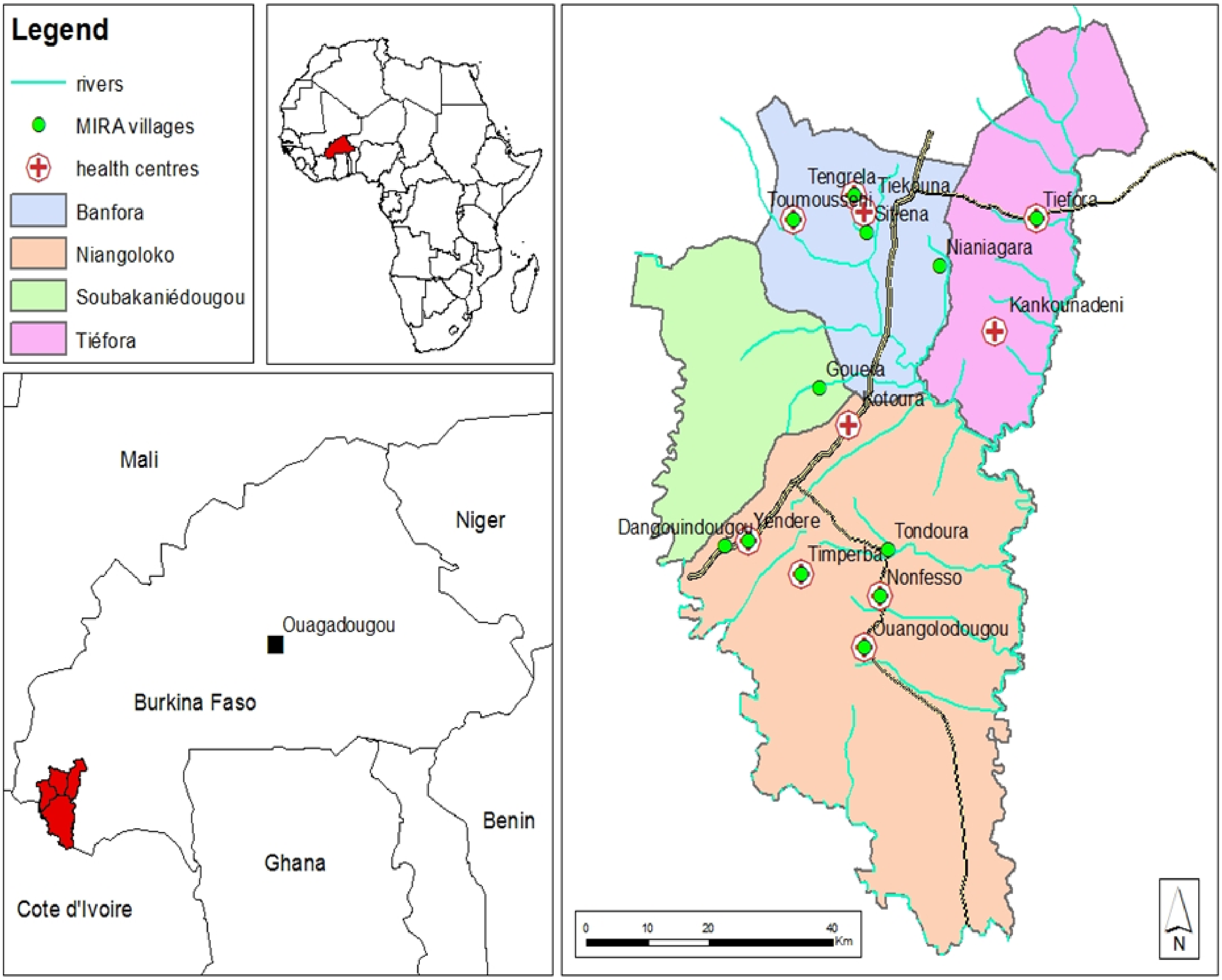

Figure 2

Map of study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.