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Uncovering the Blood Meal Preferences of Malaria Vectors in Bauchi State, Nigeria

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Abstract

Understanding the blood-feeding preferences of the malaria vector mosquitoes is essential to predict the transmission dynamics and to develop targeted control interventions. This study identified the blood meal sources of *Anopheles gambiae* sensu lato collected from nine Local Government Areas (LGAs) in Bauchi State, Nigeria, between June 2019 and December 2021. A total of 6,935 adult mosquito samples were collected by pyrethrum spray collections of which 2,841 (41%) were identified as *Anopheles gambiae* s.l. Of these, 1,000 blood fed females were analyzed by direct ELISA to determine the source of host blood. The human blood meal was the most common (52.4%) followed by goat (12.8%), cow (9.2%), sheep (7.5%) and pig (1.6%). Feeding patterns varied by LGA with some sites showing mixed zoophagy. Species composition ($p < 0.001$), blood-fed rates ($p < 0.01$) and blood-meal distributions ($p < 0.001$) differed significantly in statistical analyses. The dominance of anthropophagy highlights the importance of *Anopheles gambiae* s.l. in the transmission of malaria in Bauchi State. The findings emphasize the need to improve vector control, especially indoor residual spraying and long-lasting insecticidal nets, in areas with high human-feeding fractions.

INTRODUCTION

Malaria remains a major public health problem in Nigeria. Malaria accounts for approximately one quarter of all deaths from malaria and one third of all cases of malaria globally [1]. The country still has a disproportionate number of malaria cases around the world even after several decades of elimination of this vector. The problem is caused by a combination of factors such as the right climate for the vector, many mosquitoes, widespread poverty and a weak health system. The primary transmission is due to the highly anthropophilic vectors *Anopheles gambiae*, *Anopheles coluzzii* and *Anopheles arabiensis* of the *Anopheles gambiae* complex, where these vectors are considered as one of the most efficient malaria vectors in the world. This efficiency is due to their high competence, strong preference for human blood and tendency to feed and rest indoors [2,3]. Feeding behaviour has a great impact on the vectorial capacity which influences the longevity of mosquitoes, number of eggs they lay, frequency of contact with hosts, and development of Plasmodium sporozoites in the vector's midgut and salivary glands [4]. Thus even small

changes in feeding behaviour can lead to large changes in transmission intensity. Information on blood meal sources of malaria vectors is very important to understand the frequency and circumstances under which humans are exposed to them, the availability of hosts and the efficacy of vector control strategies such as long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS).

Anopheles gambiae s.s. and *Anopheles coluzzii* are mainly endophilic and anthropophilic, which is conducive to the success of indoor interventions. However, *Anopheles arabiensis* is more flexible; it feeds on more animals and bites outside [5-7]. This behavioral flexibility makes the mosquito harder to control and less likely to encounter insecticides applied inside dwellings. Previous studies in West, East and Southern Africa showed considerable spatial variability in host feeding patterns, influenced by ecological factors, livestock distribution, human behavior and specific local species composition [8,9]. This variation emphasizes the need for context-specific entomological data to guide tailored management measures.

The mode of blood feeding by mosquitoes is important in determining the likelihood of malaria transmission but evidence from northeastern Nigeria is insufficient to bridge the gap. For example, Bauchi State has many varied ecological zones ranging from Sudan and Sahel savanna landscapes to areas with different patterns of rainfall, human settlement and livestock populations. Any of these things could influence the behavior of vectors. However, entomological monitoring data in this area are still scarce especially regarding blood meals analysis. The non-existence of local data makes it difficult to develop efficient vector control plans that take into account the ecological conditions of the state.

The work fills the gap by identifying the sources of mosquito blood meals in different ecological zones in Bauchi State. This is valuable information that can be used to inform evidence-based malaria control interventions.

METHODS

Study Area

Bauchi State spans 49,119 km² across Sudan and Sahel savanna zones, with rainfall ranging from 700 mm in northern LGAs to 1,300 mm in southern regions. The heterogeneous ecology influences vector distribution and feeding behavior.

Mosquito Collection

Adult mosquitoes were collected from June 2019 to December 2021 using pyrethrum spray collections (PSC) in bedrooms where occupants had slept the previous night (Fig. 1), following CDC procedures [10]. Mosquitoes were sorted, sexed, and identified morphologically.

Blood-Meal Identification

Blood-fed females were categorized by abdominal status (unfed, freshly fed, half gravid, gravid). Only freshly fed mosquitoes were analyzed via direct ELISA following Beier et al. [11]. Host-specific IgG conjugates were used to detect human, cow, sheep, pig, and goat blood. Absorbance values were recorded at 405 nm after substrate incubation.

Statistical Analysis

Statistical analyses were conducted using chi-square tests to compare species composition and blood-meal distribution across the study areas, while Kruskal–Wallis tests were applied to assess variations in blood-fed rates among the mosquito populations. Spearman's rank correlation was used to examine the relationship between mosquito density and the prevalence of blood feeding, providing insight into how vector abundance may influence feeding success and transmission potential. All analyses were performed using R statistical software version 4.1.2.

RESULTS

A total of 6,935 adult mosquitoes were collected across the nine LGAs, of which 2,841 (41.0%) were identified as *Anopheles gambiae* sensu lato. The proportion of *Anopheles gambiae* s.l. varied substantially by location, ranging from 21.9% in Jama'are to 59.9% in Dambam. Out of all identified *Anopheles gambiae* s.l., 1,000 were confirmed to be blood-fed, representing an overall blood-fed rate of 35.2%.

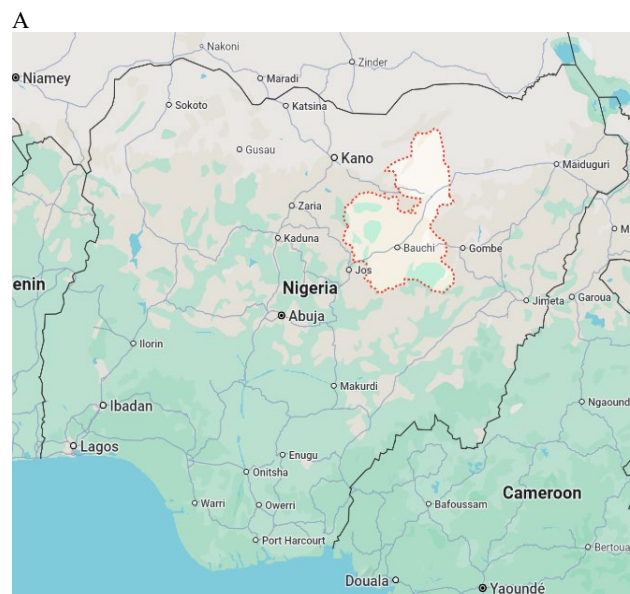
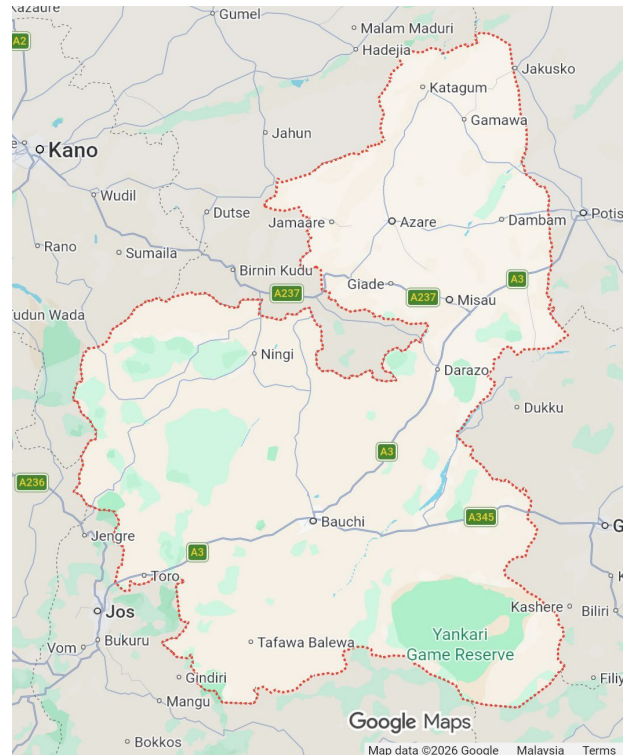


Fig. 1. Map of Bauchi State (A) in Nigeria (B).

Dambam recorded the highest proportion of blood-fed females (59.4%), indicating a higher level of human–vector contact and potentially greater transmission intensity in this area. Dass and Jama'are also showed elevated blood-fed rates (44.9% and 53.9%, respectively), whereas Gamawa exhibited the lowest proportion of blood-fed mosquitoes at 16.7%. These findings reflect clear spatial heterogeneity in vector abundance and feeding success across the state (Table 1).

Table 1. Mosquito collection and blood-fed fractions across LGAs.

LGA	Total Adult Mosquitoes	<i>Anopheles gambiae</i> s.l. (n, %)	Blood-fed Females (n, %)
Bauchi	1,200	401 (33.4%)	140 (34.9%)
Dass	865	267 (30.9%)	120 (44.9%)
Kirfi	601	197 (32.8%)	50 (25.4%)
Misau	701	331 (47.2%)	100 (30.2%)
Ganjuwa	648	298 (46.0%)	100 (33.6%)
Dambam	506	303 (59.9%)	180 (59.4%)
Katagum	742	399 (53.8%)	140 (35.1%)
Gamawa	911	478 (52.5%)	80 (16.7%)
Jama'are	761	167 (21.9%)	90 (53.9%)
Total	6,935	2,841 (41.0%)	1,000 (35.2%)

Blood-meal analysis of the 1,000 fed *Anopheles gambiae* s.l. revealed notable variability in host selection across LGAs. Human blood was the predominant source, detected in 524 mosquitoes (52.4%), affirming strong anthropophagic tendencies among vector populations. Goat blood was the second most common source (12.8%), followed by cow (9.2%), sheep (7.5%), and pig (1.6%). Dambam exhibited a distinct feeding profile characterized by high human feeding (107 individuals) and substantial goat feeding (63 individuals), with no non-reactive samples, indicating optimal sample quality and strong detection rates. In contrast, Gamawa showed extremely low human-feeding levels (4 individuals) and a high number of non-reactive samples (30), suggesting both greater zoophagy and possible antigen degradation. Several LGAs—including Kirfi, Ganjuwa, and Misau—demonstrated mixed zoophagic feeding patterns, indicating opportunistic host use. Overall, the observed variation in host preference reflects localized ecological and host availability differences across the study region (Table 2).

Table 2. Blood-meal sources identified by ELISA.

LGA	Human	Cow	Sheep	Pig	Goat	Non-reactive	Total
Bauchi	64	14	6	12	0	44	140
Dass	81	2	4	4	2	27	120
Kirfi	24	13	4	0	6	3	50
Misau	51	11	12	0	2	24	100
Ganjuwa	64	9	12	0	6	9	100
Dambam	107	0	10	0	63	0	180
Katagum	101	21	0	0	16	2	140
Gamawa	4	22	12	0	12	30	80
Jama'are	28	0	15	0	21	26	90
Total	524	92	75	16	128	165	1000

DISCUSSION

The present study reports a detailed investigation of blood-meal sources of *Anopheles gambiae* s.l. in nine LGAs of Bauchi State, giving an insight into the patterns of human-vector contacts and transmission dynamics in an area with high malaria endemicity. The high prevalence of human blood meals (52.4%) identified by ELISA is in agreement with the classical descriptions of *Anopheles gambiae* s.s and *Anopheles coluzzii* as highly anthropophilic, endophagic and endophilic vectors [5,6]. This is consistent with observations in other African settings where human blood indices are generally >50–90%, particularly in humid savanna and peri-urban areas with high indoor resting densities [12–15]. These patterns further support the importance of the members of the *Anopheles gambiae* complex as the major vectors of *Plasmodium falciparum* across sub-Saharan Africa.

The feeding behaviour of the present study varied widely among LGAs indicating the ecological heterogeneity in Bauchi State. The high human blood indices (HBIs) observed in LGAs like Dambam, Dass and Katagum indicated dominance of endophagic-endophilic feeding cycles and close association with human dwellings. This finding is in line with the vector behavior in Benin, Ghana, Mali and Zambia, where *Anopheles coluzzii*

and *Anopheles gambiae* are highly anthropophilic, particularly in areas with low livestock presence or housing structures conducive to indoor resting [5, 12, 16]. High human feeding rates are epidemiologically important because they directly influence the entomological inoculation rate (EIR). In addition, this also increases vectorial capacity by facilitating frequent mosquito-host contact.

In contrast, Gamawa and Kirfi LGAs showed high degree of zoophagic feeding, especially on goat and cow blood. The results indicates the probable dominance of *Anopheles arabiensis* or changes in local host availability. *Anopheles arabiensis* is ecologically plastic. This vector often demonstrates opportunistic host selection and exophagic behavior in arid and semi-arid areas [7,17]. The results are in line with Bauchi State's ecological gradients, with the northern LGAs being located in the drier Sahelian zones, This location is more suited to pastoral livelihoods and higher livestock densities. In these settings, mosquitoes may become more zoophagous when animal hosts are readily available. These settings reduces human-vector contact but making vector control strategies that rely primarily on indoor interventions such as LLINs and IRS more difficult.

The presence of mixed blood meals in some LGAs suggests partial or interrupted feeding cycles. The interrupted feeding cycle behaviors can be exhibited when hosts are restless or when vector populations are exposed to environmental stressors (e.g., smoke, insecticide residues, or high LLIN coverage). In the regions of Ethiopia, Malawi and Tanzania, observations of mixed feeding has been observed to be related to an increased in outdoor biting or behavioural avoidance of treated netting [9,14]. Importantly, such mixed feeding may reduce individual mosquito pathogen transmission efficiency. However, this reduction in transmission efficiency reflects behavioral adaptations that could undermine classical vector control programs focused indoors. The high percentage of non-reactive samples (16.5%) is probably due to the antigen degradation due to the digestion time, a known drawback of ELISA based assays. The detection of host-specific antibodies is known to be significantly reduced 24–48 hours post-feeding as a result of the progression of midgut proteolysis [15,18].

Storage duration, temperature changes and desiccation conditions can also affect the stability of antigens. This would imply that the real proportion of human and animal feeding could be even higher than detected and the use of complementary PCR-based blood-meal identification, providing higher sensitivity at > 48 hours post-feeding [9,11,16], could be of benefit for future studies.

The variation in blood fed rates between LGAs, with Dambam approaching 60% suggests different levels of transmission intensity associated with local human behaviour, house design, sleeping habits and livestock management. Two critical components of vectorial capacity are high feeding success and potentially high survival rates of vector populations, a results of high blood-fed rates [4,13]. This local heterogeneity suggests that a “one-size-fits-all” approach to vector control may not be adequate in Bauchi State, and interventions may need to be tailored to the LGA-specific ecology, human–vector interactions and livestock distribution [13,14].

Zoophagic tendencies in northern LGAs suggest an emerging interest in the control of malaria in the form of zooprophylaxis and veterinary targeted interventions. Zoophagy in *Anopheles arabiensis* and related species can serve to divert mosquito biting from humans but can also maintain vector

populations if adequate nutrients for reproduction are derived from the abundance of livestock [7,9]. In some regions, livestock treatment with endectocides (e.g. ivermectin) has been shown to reduce vector survival and break transmission cycles [17,18]. More studies are required to ascertain the efficacy of such strategies in Bauchi State.

The strong anthropophilic signal detected across most LGAs reinforces the need for high LLIN coverage and sustained IRS, particularly in areas such as Dambam, Dass and Katagum where vectors appear to be strongly endophagic [1,5]. However, the evidence of considerable zoophagic feeding also indicates that supplementary outdoor control measures may be required. These include larval source management, environmental sanitation and outdoor mosquito control tools, such as spatial repellents or odour baited traps [1,2].

Overall, the results highlight the complexities of malaria vector feeding behavior in Bauchi State. Differences between LGAs are a reflection of ecological boundaries, cultural practices, livestock management patterns and species composition of the *Anopheles gambiae* complex [9,14]. Understanding these patterns is crucial for the design of customized, evidence-based control strategies based on real-life vector behavior [1,13]. This study provides a useful baseline information and suggests the need for continuous entomological monitoring, molecular identification of species and integration of new vector control tools to complement existing interventions [1,2].

CONCLUSION

This study shows that the feeding pattern of *Anopheles gambiae* sensu lato populations in Bauchi State is predominantly anthropophilic. This feeding habits thereby reinforces its important role in maintaining malaria transmission throughout the region. Most identified blood meals were human blood, but the large degree of spatial heterogeneity among Local Government Areas reflects the importance of ecological variation and host availability in shaping mosquito feeding behavior. High human-feeding rates were recorded in LGAs such as Dambam and Dass, indicating increased human–vector contact and higher transmission potential, but some LGAs showed evidence of mixed zoophagy, suggesting behavioral flexibility within vector populations. These results indicate that malaria control strategies in Bauchi State need to be adapted to local vector ecology and not applied uniformly. Effective control will require integrating targeted vector interventions such as IRS and increasing LLIN coverage in high risk areas, strengthening longitudinal entomological surveillance to monitor shifts in species composition and infection rates, and enhancing community engagement to promote environmental sanitation and protective behaviors. Additional molecular studies, such as species identification and sensitive PCR-based blood-meal analysis, will be needed to improve our understanding of vector dynamics and to guide adaptive, evidence-based control efforts. These findings provide a baseline knowledge of vector feeding ecology in Bauchi State and explicit direction to improve malaria prevention strategies in this endemic region.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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AUTHORS' CONTRIBUTIONS

A.A.O.: Conceptualization, Methodology, Writing – Original Draft, Supervision, Funding Acquisition. A.A.B.: Data Curation, Formal Analysis, Investigation, Software. U.A.M.: Resources, Validation, Visualization, Writing – Review & Editing. U.A.: Investigation, Validation, Writing – Review & Editing. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

Data available on request

AI USAGE DECLARATION

The authors used generative AI for language editing only. The authors take full responsibility for the content.

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