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Feeding behaviour of malaria vectors in association with weather conditions in Qua'an-Pan Local Government Area of Plateau State, North Central Nigeria

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Abstract
Understanding malaria vectors preferred feeding point will effectively go a long way in the management of malaria transmission. Hence, this research investigated mosquito species makeup and the feeding behaviour of *Anopheles* mosquitoes in association with some weather factors in Qua'an-Pan Local Government Area of Plateau State, North Central Nigeria. Mosquitoes were sampled using Center for Disease Control light trap from dusk to dawn. The mosquitoes trapped were identified morphologically by using a standard entomological keys. A total of 1,528 specimens of *Anopheles* species were collected, comprising of five distinct species: *Anopheles gambiae*, *Anopheles funestus*, *Anopheles coustani*, *Anopheles rufipes*, and *Anopheles pretoriensis*. Among the five species identified, *Anopheles gambiae* most dominant 1,009 (66%) individuals followed by *An. funestus* 237 (15.5%) whereas *An. pretoriensis* was the least abundant 47 (3.1%). A notable significant difference ($\chi^2 = 195.875$, df = 4, P = 0.0001) was observed in abundance between *Anopheles* species. *Anopheles* mosquitoes were found feeding throughout the night with its peak feeding time between 10:00pm and 11:00pm. Mosquitoes were trapped more indoor 954 (62.43%) than outdoor 574 (37.56%) and differences showed no significant variation ($P>0.05$). Relative humidity positively influenced the abundance of mosquitoes in both indoor and outdoor points while temperature had a negative effect on mosquitoes population in both points. The results of this study indicate the necessity for comprehensive education regarding sanitation, environmental health, and the proper use of insecticide treated mosquito bed nets in both indoor and outdoor points in order to minimize vector-human interactions in the study area.

Keywords: Malaria vectors, nocturnal feeding behaviour, CDC light trap, bed net, indoor and outdoor points, weather conditions, Qua'an-Pan LGA, Plateau State, Nigeria

Introduction
Mosquitoes are blood-feeding insects that are important carriers of harmful pathogens (Becker *et al.*, 2020). Malaria is caused by *Plasmodium* parasites and is spread through the bites of female *Anopheles* mosquitoes that have fed on infected blood (WHO, 2022) [26]. The disease is recognized as the most critical parasitic disease affecting public health on a global scale (WHO 2022) [26]. In 2020, the World Health Organization reported approximately 241 million cases of malaria and 627,000 mortalities worldwide indicating that nearly half of the global population was at risk (WHO, 2021) [25]. Nigeria recorded the highest number of malaria cases with 27% and malaria mortality with 32% in 2020 worldwide (WHO, 2021) [25]. The disease persists year-round within the country, affecting nearly the entire population, with children are particularly at risk. The blood-feeding habits of malaria vectors are influenced by the vertebrate host that the mosquito encounters, which in turn affects the spatial distribution of the disease (Richards *et al.*, 2006) [18]. Host selection and the resulting success in feeding are influenced by the availability of hosts (Main *et al.*, 2016) [14]. The feeding behaviour of mosquitoes can affect the vectorial potential of malaria vectors (Koutsos *et al.*, 2007) [11]. The behaviour of mosquitoes concerning resting and feeding is crucial for the effectiveness of

control strategies (Ombugadu *et al.*, 2020) [15]. The expansion of long-lasting insecticidal nets and the extensive implementation of indoor residual spraying have contributed to a decrease in the burden of malaria (Bhatt *et al.*, 2015) [2]. However, these interventions can only be applied indoor. Residual transmission is promoted by outdoor mosquito bites, which significantly influences the overall effectiveness of strategies aimed at preventing mosquito-borne diseases, as reported by Sherrard-Smith *et al.* (2019) [21]. Mosquito surveillance plays a fundamental role in integrated vector management, serving as a critical foundation for the establishment of mosquito control initiatives (WHO, 2012) [24]. Therefore, continuous monitoring of mosquito populations is essential for understanding their biodiversity and for the prediction and prevention of diseases transmitted by mosquitoes (van der Beek *et al.*, 2020). The research was conducted to evaluate mosquito species composition and feeding behaviour of *Anopheles* mosquitoes in association with some weather factors in Qua'an-Pan Local Government Area (LGA) of Plateau State, Nigeria, in order to provide information on preferred feeding point and its implication on residual malaria transmission among inhabitants in the study area. Also, the outcome of this research will guide the implementation of effective malaria vectors control practices by the people and agencies.

Materials and Methods

Study Area

Qua'an-Pan LGA has a landmass of 2,478 km^2 with population of 196,926 as of 2006 census. The people of the area are predominantly farmers. They are known for high production of Yam, Rice, Guinea corn among others. The region experiences a sub-humid climate characterized by two distinct seasons: a wet season from April to October and a dry season from November to March. The average temperature in this area is 28°C, and it is situated at an elevation of 218 meters (715 feet). Its geographical coordinates are approximately 8°48' to 8.800°N latitude and 9°9' to 9.150°E longitude (Figure 1).

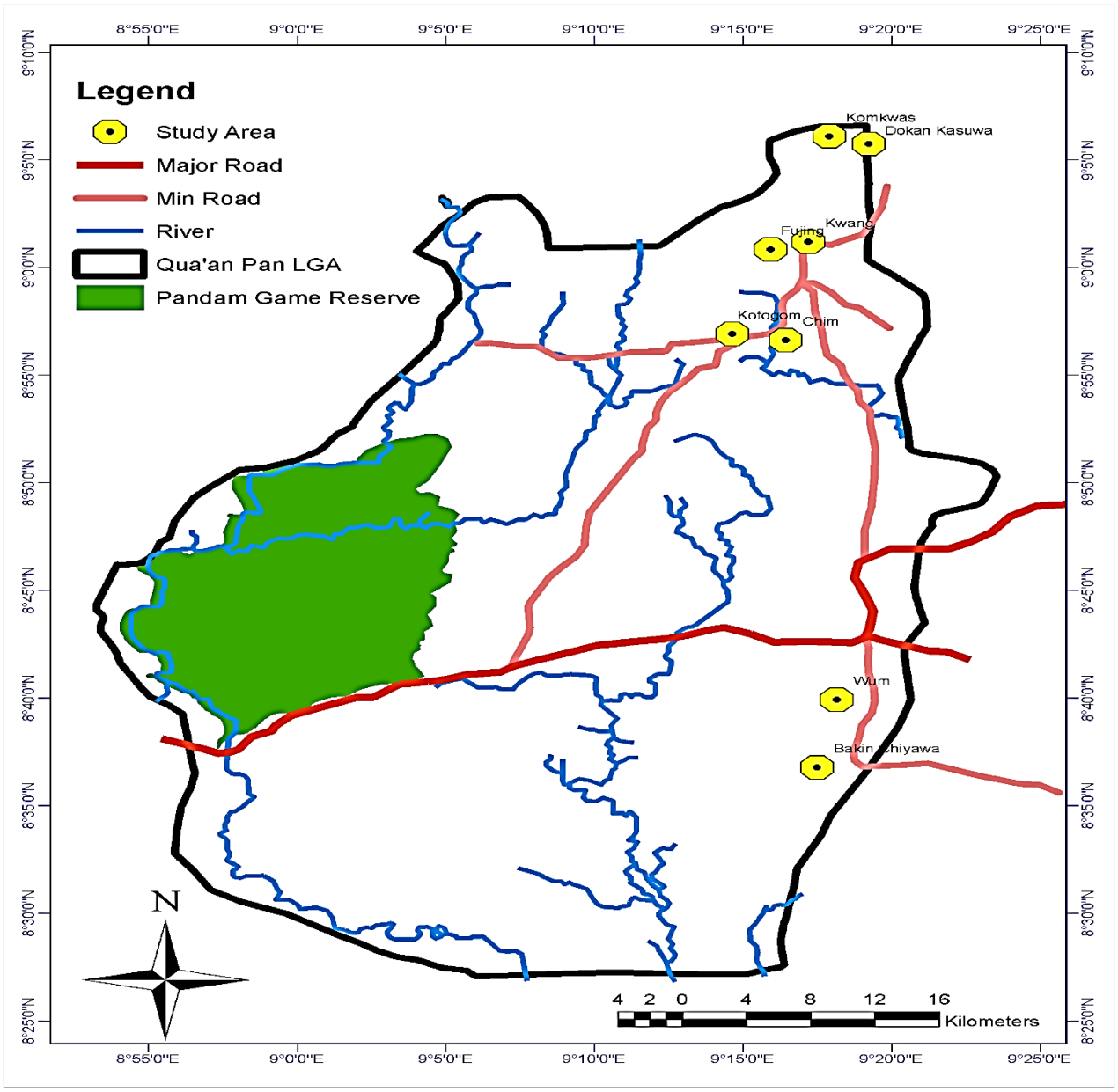

Fig 1: Sites Surveyed for Malaria Vectors in Qua'an-Pan LGA, Plateau State, Nigeria

Study Design

A longitudinal entomological survey was carried out in Qua'an-Pan Local Government Area of Plateau State, Nigeria for twelve (12) months. Four districts were selected randomly and sampled for entomological study. Mosquitoes were collected in three different structures in each district, for both indoor and outdoor collection between the hours of 06:00pm-06:00am.

Ethical Considerations

Ethical clearance was collected from Plateau State Specialist Hospital Ethics Review Committee with approval number of (Ref. No. PSSH/ADM/ETH.CO/2019/005 and Reg. No. NHREC/05/01/2010b). Permission was also obtained from the first class chief of the area where letters of notification were distributed to the district heads prior to the study. Consent from the community leaders and the house owners were also sought while the privacy of the household members was highly protected.

Mosquito Collection using CDC light traps technique

CDC Light Traps were employed to catch mosquitoes from 6pm to 6am Nigerian time. The set up was done 30 minutes prior to the commencement of the activity. The trap was suspended 1.5 to 2 meters above the ground, positioned next to an occupied untreated bed net, oriented towards the feet of the bait. A digital thermo-hygrometer was used to record hourly temperature and relative humidity. The light intensity in the CDC light trap as well as the body odour and sweat of baited human host in an untreated bed net served as an attraction to the mosquitoes that were trapped. Mosquitoes trapped in the CDC light trap hood were aspirated at hourly intervalinto a well labeled paper cup for sorting and identification.

Morphological Identification of Mosquitoes

Morphological identification was done using a dissecting microscope and an identification key by Gilles and Coetzee (1987) and Coetzee (2020). *Anopheles* mosquitoes were distinguished into species base on the morphological characteristics of their maxillary palps, the patterns of spots on the wings, and the interuptions/bands on the legs. Each mosquito sample was preserved individually in an Eppendorf tubes containing silica gel desiccant for further studies.

Diversity Index

The diversity of mosquito species was assessed using the Shannon-Wiener diversity index, as described by Begon *et al.* (2003) and Lamead (2011).

$$H' = -\sum_{i=1}^{S} (Pi)\,(\ln Pi)$$

Where

H' represents the diversity index. Pi denotes the proportion of individual species, while *S* indicates the total number of species present in the habitat. The variable *i* refers to the proportion of the *S* species. The diversity index ranges from 0 to 5, with values between 0 and 2.4 indicating low diversity, and values from 2.5 to 5 reflecting high diversity.

Statistical Analysis

Data collected was analyzed using Minitap statistical software (version 21.2) and STATA (version 14.0). The abundance of mosquitoes across species was compared using Pearson's Chi-square test. The abundance of *Anopheles* between feeding locations was analyzed using t-test. Pearson correlation analysis was used to determine the relationship between *An. gambiae* abundance and weather factors in each feeding point. The level of significance was established at $P<0.05$.

Results

Composition and Relative Abundance of *Anopheles* Species in the Study Area

A total of 1528 *Anopheles* species were collected during the study, five species namely *Anopheles gambiae*, *Anopheles funestus*, *Anopheles coustani*, *Anopheles rufipes*, and *Anopheles pretoriensis* (Table 1). Among the five species identified, *Anopheles gambiae* was the most abundant species 1009(66%), followed by *An. funestus* 237(15.5%) and the least abundant species was *An. pretoriensis* with 47(3.1%). Thus, there was significant difference ($\chi^2 = 195.875$, df = 4, P = 0.0001) in the mosquitoes abundance in relation to species.

Table 1: Compostion and Relative Abundance of *Anopheles* Species in the Study Area

District	*An. gambiae*	*An. funestus*	*An. coustani*	*An. rufipes*	*An. pretoriensis*	Total (%)
Dokan/Kasuwa	319	58	64	28	22	491(32.1)
Kwalla	201	47	31	12	11	302(19.8)
Kwande	275	71	23	26	10	405(26.5)
Kwang	214	61	37	14	4	330(21.6)
Total (%)	1009(66)	237(15.5)	155(10.1)	80(5.2)	47(3.1)	1528(100)

Feeding Behaviour of *Anopheles* Species in Relation to Time and Point: Results of the feeding behaviour revealed that *Anopheles* mosquitoes feed from dusk hour to dawn displaying their nocturnal behaviour. However, the mosquitoes attained the feeding peak between the hours of 10-11pm with 182(11.9%) *Anopheles* mosquitoes trapped followed by the hours of 4-5am in which 173(11.3%) *Anopheles* mosquitoes were trapped while the least feeding behaviour was observed between the hours of 12am-1am with 67(4.3%) *Anopheles* mosquitoes trapped (Table 2). The abundance of *Anopheles* species based on feeding location revealed that more *Anopheles* mosquitoes were trapped indoor 954(62.43%) than outdoor 574(37.56%) showcasing their endophagic nature (Table 2). Hence, there was significant variation (t = 2.55, df = 1, P = 0.027) in the number of *Anopheles* species collected based on feeding points.

Table 2: Feeding Behaviour of Female *Anopheles* Mosquitoes in Relation to Time and Feeding Points

Time	No. of Mosquitoes based on Feeding Points		Total
	Indoor	Outdoor	
6-7pm	43	77	120
7-8pm	67	83	150
8-9pm	47	54	101
9-10pm	117	45	162
10-11pm	144	38	182
11pm-12am	70	54	124
12-1am	48	19	67
1-2am	49	19	68
2-3am	102	34	136
3-4am	107	52	159
4-5am	121	52	173
5-6am	39	47	86
Total	954	574	1528

Feeding Behaviour of *Anopheles gambiae* based on Hour of Collection: The feeding behaviour of *Anopheles gambiae* in relation to hourly collection time revealed that the *Anopheles gambiae* had high feeding peak between 10-11pm and 8-9pm in both indoor and outdoor points with 102 and 48 species, respectively (Figure 2). Also, *Anopheles gambiae* fed less between 6-7pm for both indoor and outdoor points with 31 and 7 individual mosquitoes, respectively (Figure 2).

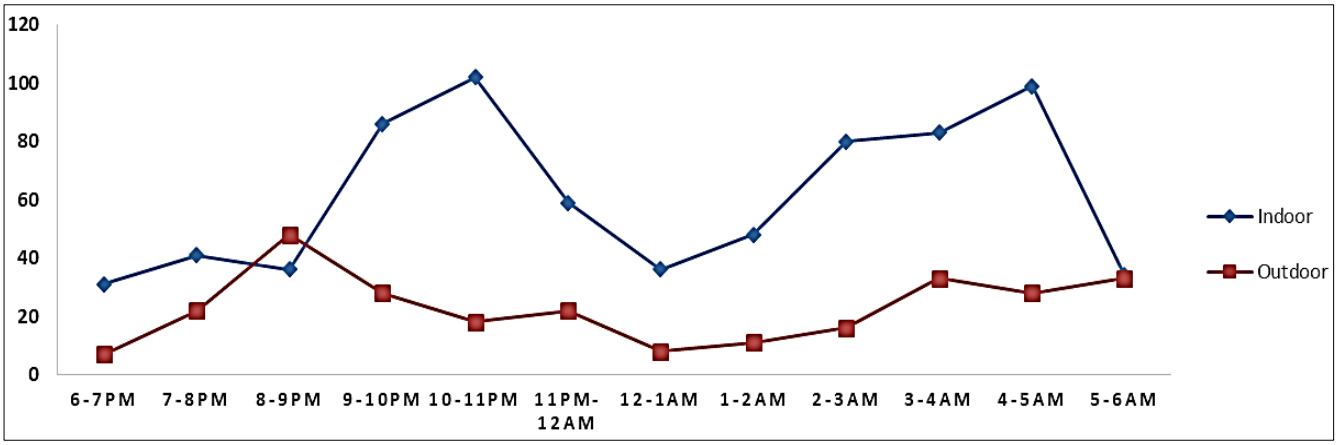

Fig 2: Feeding behaviour of *Anopheles gambiae* based on hour of collection

Feeding behaviour of *Anopheles funestus* Based on hour of collection: The feeding activity of *An. funestus* based on hour of collection revealed that the *An. funestus* had high feeding peak between 10-11pm and 6-7pm in both indoor and outdoor points with 36 and 21 mosquitoes, respectively (Figure 3). However, *An. funestus* feed less between 1-2am for both indoor and outdoor points with 1 and 3 mosquitoes, respectively.

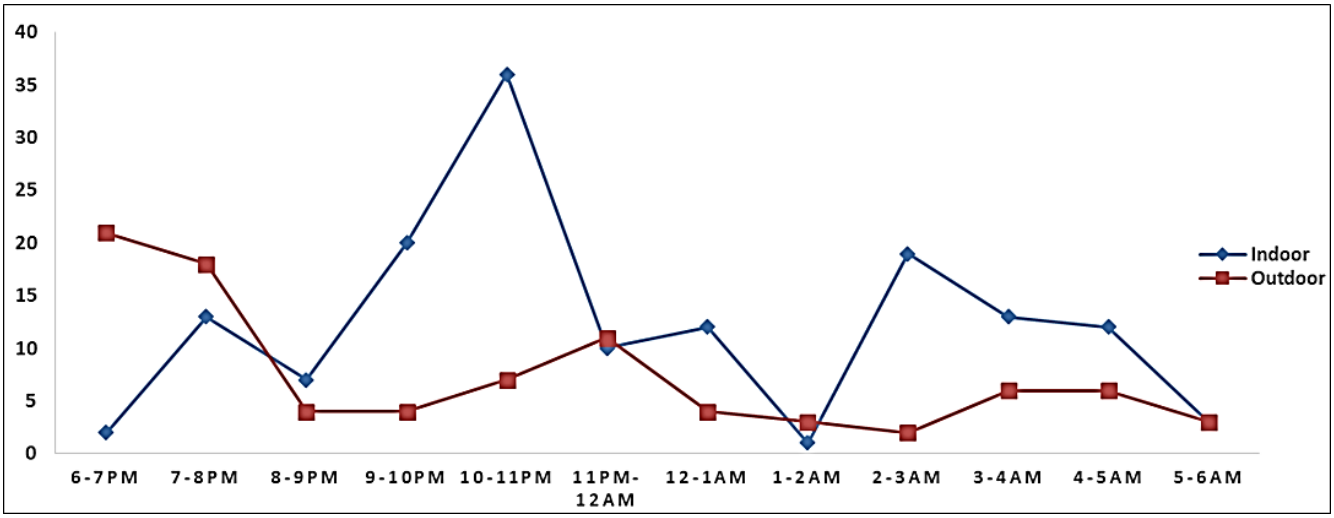

Figure 3: Feeding behaviour of *An. funestus* based on hour of collection

Relationship between Weather Conditions and Abundance of *Anopheles gambiae*

A non-significant positive influence of relative humidity (RH) on the abundance of *An. gambiae* was observed in both indoor and outdoor points, respectively, as shown in Figure 4 (indoor RH: r = 0.0456, P = 0.7295; outdoor RH: r = 0.0766, P = 0.5475) whereas temperature (T) had an insignificant negative correlation on the abundance of *An. gambiae* in both points (indoor T: r = -0.2978, P = 0.2627; outdoor T: r = -0.0962, P = 0.6701, Figure 5).

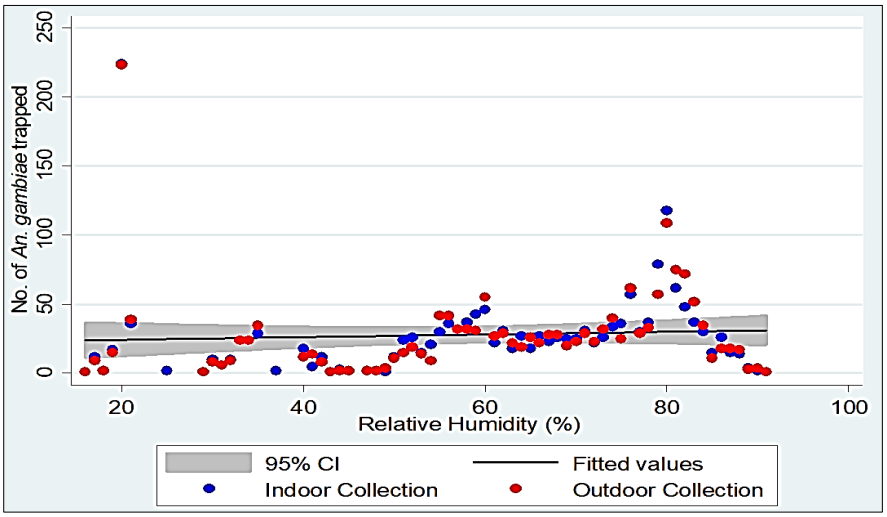

Fig 4: The Relationship between Relative Humidity and Female *An. gambiae* Abundance Indoors and Outdoors

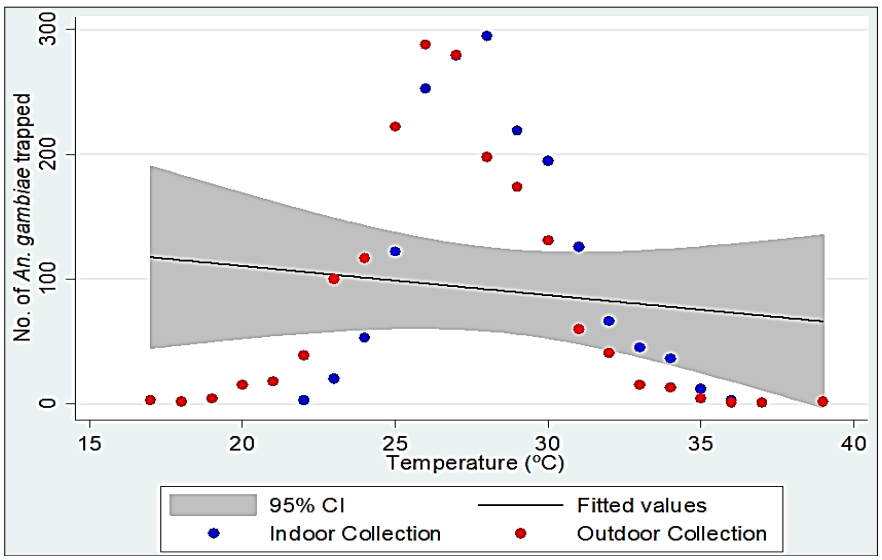

Fig 5: The Relationship between Temperature and Female *An. gambiae* Abundance Indoors and Outdoors

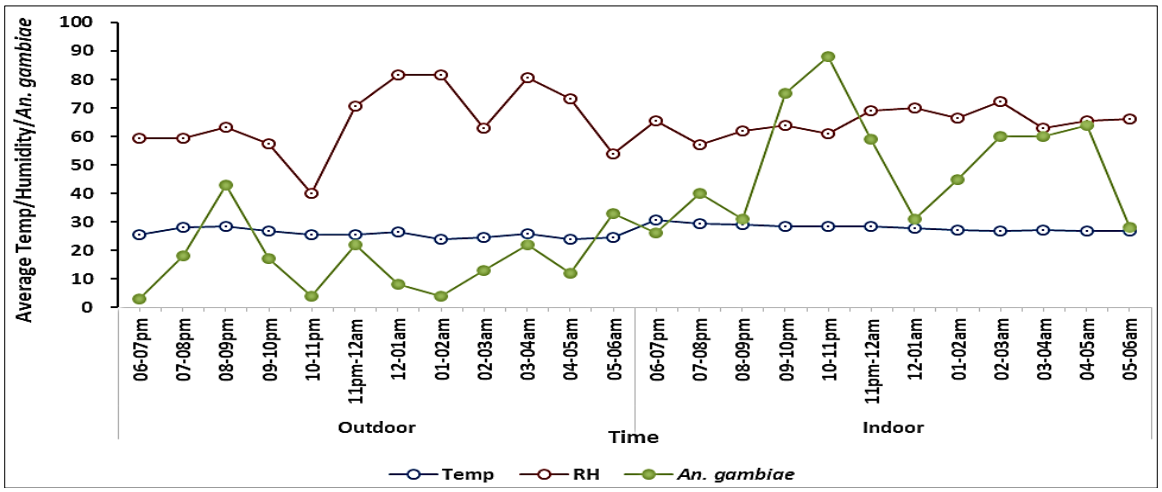

Fig 6: Interactive Chart Showing Indoor and Outdoor Activities of Weather Conditions in Relation with Mosquitoes Abundance

Species Diversity Level of *Anopheles* Mosquitoes in the Study Area

Shannon-Wiener diversity index (H′) showed that *Anopheles* species diversity was relatively low (H′ = 1) as shown in Table 4.

Table 3: Diversity of *Anopheles* Species in the Qua'an-Pan LGA, Plateau State

Species	Total	Pi	In(pi)	Pi[In(pi)]
An. gambiae	1009	0.660	-0.415	-0.273
An. funestus	237	0.155	-1.864	-0.288
An. coustani	155	0.101	-2.292	-0.231
An. rufipes	80	0.052	-2.956	-0.153
An. pretoriensis	47	0.030	-3.506	-0.105
Total	1528	0.998	-11.033	-1.05

H′ = - (-1.05) H′ = + 1.05 ∴ H′ ≈ 1

Discussion

Mosquito species collected in the study area are similar to what has been reported from other studies in some parts of Northern Nigeria (Lapang *et al.*, 2019; Umar *et al.*, 2021; Ombugadu *et al.*, 2024) [12, 23, 27]. Among the five species identified in this study, *Anopheles gambiae* was the most abundant species 1,009 (66%). The results of this study aligned with the findings of Chikezie *et al.* (2021) and Ombugadu *et al.* (2024) [17] identified *Anopheles gambiae* as the most predominant mosquito species. Garba *et al.* (2020) [6] and Hien *et al.*, (2020) [8] also reported that *An. gambiae* as dominant malaria vector in Africa, particularly in Nigeria in areas where the impact of malaria infection is notably significant. The presence and abundance of *Anopheles* species in the research area could be as a result of numerous breeding sites available for *Anopheles* mosquitoes to reproduce. Contrary to the findings of the present study, Kawada *et al.* (2021) [10] in their study on indoor resting places of the major malaria vectors in western Kenya reported more female *An. funestus s. l.* than female *An. gambiae s. l.* Also, Sail *et al.* (2023) [20] in their study on *Anopheles rufipes* implication in malaria transmission both indoors and outdoors alongside *Anopheles funestus* and *Anopheles arabiensis* in rural part of South-East Zambia recorded more *An. funestus* than *An. gambiae.*

The result of the feeding behaviour revealed that *Anopheles* mosquitoes feed from dusk hour to dawn during which feedingpeaked at 10:00 pm - 11:00 pm. This possibly affirms the implication of *Anopheles* mosquitoes in the transmission of lymphatic filariasis due to their feeding peak time that correlates with the periodicity of *Wuchereria bancrofti*. This is consistent with the finding of Tomas *et al.* (2022) [22] who reported a feeding peak of *Anopheles* mosquito to be from10:00 pm - 11:00 pm. The finding of this study is also within the range of the finding of Chakim and Pumpaibool (2019) who reported the peak or biting time of *Anopheles* mosquitoes to be from 9:00 pm - 1:00 am which are sleeping hours and likely to be the time when mosquitoes transmit the *Plasmodium* parasite. Contrary to the finding of this study, Ombugadu *et al.* (2020a) [15] reported indoor and outdoor mosquitoes feeding peaks of 9:00 pm - 10:00 pm and 3:00 am - 4:00 am, respectively, in Mararraba-Akunza, Lafia Local Government Area, Nasarawa State, Nigeria. Haruna *et al.* (2020) [7] reported that *Anopheles* mosquito species were observed to attain their first peak at 3:00 am - 4:00 am which is contrary to what was obtained in this study.

The mosquitoes feeding activity in this research later declined from 12:00 am - 2:00 am probably due to a decline in temperature and a little increase in relative humidity. This finding is similar to the finding of Bedasso *et al.* (2022) [1] who reported a decline in the feeding activity of malaria vector from 12:00 am - 2:00 am in selected sentinel sites of Ethiopia. The decline in feeding activity could be due to the impact of climatic elements like temperature and relative humidity. Relative humidity (RH) affects longevity, blood feeding behaviour, mating, dispersal and oviposition of mosquitoes (Drakou *et al.*, 2020) [5].

The abundance of *Anopheles* species based feeding point revealed that more *Anopheles* mosquitoes were trapped the more indoors 954 (62.43%) than outdoors 574 (37.56%). This could be due to endophilic and endophagic disposition of *Anopheles* species. According to Loaiza *et al.*, (2008) [13], *Anopheles* mosquitoes tend to be more endophagic, endophilic and anthropophagic to avoid the hash environmental conditions outdoor. The result of this study is in tandem with the finding of Ruiz *et al.*, (2022) [19] who recorded higher mosquito richness and abundance indoors than outdoors in the rural site of Yucatan State, Mexico. The study is also in agreement with the findings of Ezeigwe *et al.* (2015) who reported more *Anopheles* mosquitoes indoor than outdoor in six states of Nigeria. Contrary to the finding of this study, Ombugadu *et al.* (2020a) [15] reported high mosquitoes outdoor than indoor in Mararraba-akunza, Lafia Local Government Area, Nasarawa State, Nigeria. Ruiz *et al.* (2022) [19] also reported higher mosquito abundance outdoor than indoor in the urban site of Yucatan State, Mexico. *Anopheles* mosquitoes were tending to bite humans outdoor than indoor (Tomas *et al.*, 2022) [22].

Anopheles species diversity in the study area was quite low based on the diversity value found (H′ = 1.0) which could be attributed to high anthropogenic activities such as the continuous application of pesticides and herbicides by farmers in order to control pest and weeds which have a negative on the breeding ecology of mosquitoes in agricultural landscapes. This is in line with the finding of Lapang *et al.* (2019) [12] and Ombugadu *et al.* (2020b) [16] who reported low species diversity (H′ ≈ 1.0) in their studies in Shendam LGA of Plateau State and in students' hostels of Federal University of Lafia, Nasarawa State, Nigeria, respectively. However, the report by Irikannu *et al.* (2023) [9] was much lower than the finding of this study.

Conclusion

The five species identified during the course of this study include *Anopheles gambiae, An. funestus, Anopheles coustani, Anopheles rufipes,* and *Anopheles pretoriensis.* The number of malaria vectors collected using CDC light trap in this study shows that the trap is an effective tool for mosquitoes sampling. The dominant species collected was *Anopheles gambiae,* this is an indication that the area is a possible foci zone for malaria transmission. Majority of the mosquitoes were caught indoors than outdoors, this affirms that *Anopheles* species are endophagic in nature. The feeding patterns of mosquitoes in relation to time indicate that vectors feed throughout the night displaying their nocturnal behaviour with the feeding peak between the hours of 10pm -11pm. There is a positive relationship between relative humidity and *Anopheles gambiae* abundance in both indoor and outdoor points. This study reveals that the inhabitant of the area need

to be educated on the benefit of sanitation, waste water treatment and the danger caused by mosquitoes.

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