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# Vectorial Diversity of Indoor-resting Mosquitoes in Damboa Town, Borno State, Nigeria: Implications for Disease Transmission and Control Strategies

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***Abstract***

***One of the reasons for the reemergence of yellow fever in Nigeria in 2017, twenty-one years after the last reported outbreak, was as a result of the presence of female mosquitoes, which serve as vehicles for the transmission of not only yellow fever virus but also other arboviruses, filarial worms, and protozoa, to susceptible human hosts. Female mosquitoes, particularly the indoor-resting, due to their blood-sucking nature, are responsible for sustaining the transmission cycles of arthropod-borne diseases, particularly in regions such as Damboa, where environmental conditions and inadequate control measures facilitate the breeding and survival of these mosquitoes. The predominance of blood-fed female mosquitoes within human habitation is, therefore, indicative of the heightened risk of arboviral outbreaks and calls for targeted interventions. This study was therefore carried out to assess the vectorial diversity of indoor-resting mosquitoes in Damboa Town, towards effective management and control of mosquito-borne diseases. The sample comprised 727 mosquitoes collected indoors from human habitations in Damboa town of Borno State during the months of May to August according to the standard method described by the World Health Organization (WHO). Morphological examination of the mosquito revealed 92.30% Culex species, 7.15% Aedes aegypti, and 0.55% Anopheles gambiae. The females accounted for the majority (79.50%: 578/727) of the entire mosquito population, with 44.5% (257) being blood-fed, 6.0% (35) being gravid, 6.2% (36) being half-gravid, while 43.25% (250) were non-blood-fed. This study's findings suggest that as most female mosquitoes are blood fed, there is a high risk of mosquito-borne diseases and potential outbreaks, most especially in the absence of interventions. Therefore, this calls for an arbovirus surveillance system, mass vaccination against vaccine-preventable arboviral diseases, and the adoption of effective protective measures against mosquito bites by the individual human residents of Damboa, among other control measures.***
***Keywords: Aedes, Anopheles, Arboviruses, Damboa, mosquito, Nigeria***

## INTRODUCTION

Mosquitoes are the deadliest creatures on earth as they are responsible for the transmission of numerous viral, filarial, and protozoal pathogens (Prudêncio, 2020; Yee *et al.*, 2022) that cause diseases and even death in infected animals and humans. Mosquitoes, especially those belonging to the Culicidae family, particularly *Aedes* and *Culex* species, are the most common arthropod vectors known to transmit arboviruses (Blitvich *et al.*, 2020; Tajudeen *et al.*, 2023). However, other arthropods, which are ticks belonging to the families Ixodidae and Argasidae, biting midges of the Ceratopogonidae family, sandflies of the subfamily Phlebotominae, and cimicid bugs of the Cimicidae family (Oluwayelu *et al.*, 2018) also transmit these viruses. Arboviral diseases are primarily arthropod-borne; however, blood transfusion, organ transplant, breast-feeding, sexual contact, and vertical transmission have also been recognized as other modes of transmission (Blityich *et al.*, 2020).

Annually, vector-borne diseases accounts for more than 17% of all infectious diseases, with 700,000 attributed to arboviruses (Byaruhanga et al., 2023; WHO, 2024), making arboviral diseases a major contributor to worldwide mortality. Arboviral diseases can cause several severe health outcomes, such as hemorrhagic fever, encephalitis, and neurological disorders, and are also capable of causing long-term complications and congenital defects such as microcephaly when some of these viruses are transmitted from mother to fetus (Fauci and Morens, 2016).

The diseases usually manifest during warmer months in the world's temperate climates (Roehrig and Lanciotti, 2009). Arboviral diseases also cause unpredictable symptoms that complicate diagnosis and treatment (Magalhaes *et al.*, 2020), often presenting with symptoms similar to other diseases, such as malaria and typhoid, leading to misdiagnosis, mostly in developing countries due to limited laboratory diagnosis. This therefore, accounts for underreporting of arboviral diseases (Kolawole *et al.*, 2018), often resulting in the neglect and undermining of the health threat posed by arboviruses (Kolawole *et al.*, 2018).

Arboviruses, also referred to as and derived from arthropod-borne viruses (Artsob *et al.*, 2023), are a diverse group of zoonotic, predominantly RNA viruses (Mangat and Louie, 2023) that are principally maintained through hematophagus arthropod transmission between susceptible human and animal hosts (Artsob *et al.*, 2023). Arboviruses are the greatest major group of viruses known to cause diseases in vertebrates (Oluwayelu *et al.*, 2018). Over 500 arboviruses belonging to 14 families have been identified (Kolawole *et al.*, 2018; Madewell, 2020). However, only 150 belonging to the families *Togaviridae* (genus Alphavirus), *Flaviviridae* (genus Flavivirus), *Bunyaviridae* (Genera Orthobunyavirus, Phlebovirus, and Nairovirus), and *Reoviridae* (genera Coltivirus and Orbivirus) are of medical importance (Meltzer, 2012; Madewell, 2020; Tajudeen *et al.*,2022), with about 100 known to cause diseases in human and 40 in domestic animals (Artsob *et al.*, 2023). Since most arboviruses are zoonotic, those of medical importance may only reflect <1% of all arboviruses.

Arboviruses have a worldwide distribution but are more common in tropical climates (Girard *et al.*, 2020). However, the viruses are also prevalent in temperate regions but are mostly circulating among wildlife species (Marchi *et al.*, 2018). The most common arboviruses are Dangue virus (DENV), Chikungunya virus (CHIKV), Zika virus (ZIKV), Yellow fever virus (YFV), Japanese encephalitis virus (JEV), and West Nile virus (WNV), in that order (Franklinos, 2019). Currently, DENV, YFV, CHIKV, and ZIKV are of public health concern in tropical and sub-tropical regions inhabited by approximately 3.9 billion people (WHO, 2024). In Nigeria, numerous studies have confirmed the circulation of DENV (Onojo *et al.*, 2024), WNV (Onojo *et al.*, 2024), CHIKV (Sagay *et al.*,2024), YFV (Ajogbasile *et al.*, 2020), and Rift Valley fever virus: RVFV (Kolawole *et al.*, 2018; Adamu *et al.*, 2021).

Aside arboviruses, mosquitoes also transmit filarial worms. *Culex* species (vectors in urban and semi-urban areas) and *Anopheles* species (vectors in rural areas of Africa and elsewhere) are both well-documented vectors, specifically for *Wuchereria bancrofti* and *Brugia malayi* that cause lymphatic filariasis, (Rao *et al.*, 1981; WHO, 2024). Even though *Aedes* species are not typically recognized as major vectors of filarial worms, the mosquito species can also transmit some of these worms, especially to animals in endemic islands in the Pacific (WHO, 2024). Research by Tran *et al.* (2022) detected the dog heart worm *Dirofilaria immitis* in *Aedes increpitus* and *Aedes sierrensis*, as well as the deer body worm *Setaria yehi* in *Aedes sierrensis*.

Mosquitoes inhabit nearly every tropical and sub-tropical region of the world (Wilder-Smith *et al.*, 2020). However, their ability to transmit disease is in the blood-feeding behavior of the females, which is essentially through a blood meal, which is necessary for the acquiring of the blood required for egg production (Phasomkusolsil *et al.*, 2013; Thongsripong *et al.*, 2021). Furthermore, the preference for indoor resting of some mosquito species, such as *Anopheles*, *Aedes aegypti*, and *Culex* facilitates the likelihood of disease transmission as it brings vectors and susceptible human hosts into close contact in domestic settings (Huho *et al.*, 2013; Lindsay *et al.*, 2021). This increases the risk of infection, particularly in resource-limited regions where environmental conditions and inadequate control measures facilitate the breeding and survival of mosquitoes (Lindsay et al., 2021). Indoor resting also increases the propensity of such mosquitoes to repeatedly feed on human hosts, thereby increasing the efficiency of pathogen transmission cycles, particularly in regions with high human-vector contact rates (Huho *et al.*, 2013; Tandina *et al.*, 2018). The presence of blood-fed, indoor-resting mosquitoes presents a significant public health challenge due to the heightened risk of arboviral outbreaks and is also indicative of the adoption of targeted interventions.

Over the last three decades, there has been a spontaneous re-emergence of arboviral disease epidemics globally (Girard *et al.*, 2020), with Africa being one of the top four regions most affected by the diseases (WHO, 2024). Despite the global arbovirus control approach, namely 'The Global Arbovirus Initiative' of the World Health Organization (WHO) and its partners, the frequency and magnitude of arboviral disease outbreaks, particularly those transmitted by *Aedes* mosquitoes are on the increase (WHO, 2024). This is due to ecological, economic, and social factors. Nigeria has been recognized as a high-priority country for the global Eliminate Yellow Fever Epidemics (EYE) Strategy because it is a high-risk country for yellow fever (WHO, 2021). Despite the absence of YF in Nigeria for twenty-one years and the ongoing nationwide prevention mass vaccination campaign (PMVC) (WHO, 2021), cases of sporadic outbreak of YF since its re-emergence in 2017 have been reported in Bauchi, Adamawa, Enugu, Anambra, Ekiti, Ondo, Oyo, and Ogun as at January 2023 (Ajogbasile *et al*., 2020; CDC, 2024). The outbreaks are recorded even in areas where large-scale mass vaccination campaigns have previously been conducted but with persistent and growing gaps in immunity due to a lack of sustained population immunity through routine immunization and/or secondary to the influx of unvaccinated newcomers (WHO, 2021).

The resistance of mosquitoes, particularly *Aedes*, to insecticides is also part of the challenges of sabotaging the control of some arboviruses in many African countries, including Nigeria (Tajudeen *et al*., 2022). Despite the efficacy of the yellow fever (YF) vaccine in protecting against YF, Nigeria faces insufficient vaccine coverage, which is evident by the 54% national immunization coverage recorded in 2020. This is insufficient for conferring herd immunity and cannot prevent outbreaks as the figure (54%) is below the threshold of 80% required for the prevention of outbreaks as recommended by the WHO (2021). Furthermore, due to the weak integrated and functional arbovirus surveillance system, preparedness, and response system, accurately tracking arboviral disease prevalence in most African countries is difficult (Weetman *et al*., 2018; WHO, 2021).

Situated at the southern edge of the Sahel and within the Sudan savannah (Samdi *et al*., 2006), Damboa has favorable environmental conditions and inadequate control measures for the thriving of mosquito vectors. Being a local Government (LG) in the mostly semi-arid Borno State, Damboa has long periods of dry and hot seasons, with the hottest peak experienced in June (Samdi *et al*., 2006). Dry seasons, which are long and span from October to May, are followed by a short rainy season between the period of June to September (Bello *et al*., 2023). Even though high densities of mosquito species are commonly observed in Damboa (Samdi *et al*., 2006), the intensity is always at its peak in July. The absence of proper drainage systems and the warm and humid climates of Damboa provide favorable breeding conditions for mosquitos. Even though *Aedes* species thrive in mostly warm and tropical climates (Fillinger *et al*., 2004), and *Anopheles* species are generally present in arid (Samdi, 2012) as well as tropical and subtropical regions (Fillinger *et al*., 2004), large numbers of *Culex* species can also be observed in Damboa. This is due to their ability to adapt to various climatic conditions, from cold to temperate, compared to other mosquito species. These reasons and the inadequacy of control measures make Damboa endemic for malaria, dengue, and yellow fever (Mosquito Forecast, 2024).

Because there are re-emerging cases of sporadic outbreaks of some arboviral diseases in Nigeria, and Damboa presents unique opportunities for outbreaks, making it a hotspot for mosquito-borne disease transmission, the need for mosquito surveillance cannot be overemphasized. Therefore, This study aimed to identify the indoor-resting species that may be present within the study area and, hence, can serve as a predictive tool in preventing future reemergence of mosquito-borne diseases.

## MATERIALS AND METHODS

### Study Area

This study was conducted in Damboa town, the headquarters of Damboa Local Government Area of Borno State, Nigeria. Damboa is 85 kilometers from the capital city, located at the southern edge of the Sahel, within the Sudan savannah. It is a trading and subsistent farming community (Samdi *et al*., 2006; OCHA, 2019) with a human population of about 63,523, including 20,788 Internally Displaced Persons (IDPs) (OCHA, 2019). The climate of Borno State is mostly semi-arid, with considerable long periods of hot season, with March, April, May, and June being the hottest in most places within the state (Samdi *et al*., 2006). Dry seasons are long and span from October to May, which is followed by a short rainy season between June to September (Bello *et al*., 2023). Mosquito intensity is always at its peak in July (Mosquito Forecast, 2024).

### Study Design and Sampling

This research was a quantitative, community-based study involving mosquitoes collected within human habitation (i.e., indoors). Households were chosen based on the willingness of individual heads of households to participate in the study.

### Sample Collection and Preservation

Exactly 727 indoor-resting mosquitoes were collected early in the morning from human habitations after their knock-down by space spraying, using Mobil Pyrethrum insecticide solution, based on the WHO spray sheet collection method. Each mosquito sample was individually preserved in a silica gel-containing Eppendorf tube (WHO, 2013) and later transferred to the Nigerian Institute of Medical Research (NIMR) Maiduguri Outstation laboratory for analysis.

**Laboratory Analysis**

The morphology of the mosquitos was microscopically observed using the morphological keys of Gillies and De Meillon (1968) and Gillies and Coetzee (1987) to identify the sex and species of adult mosquitoes circulating within the study area.

Key features for the identification of females are the presence of less-bushy antennae adapted for host-seeking, long and sharp proboscis designed for host skin piecing to aid bold-feeding, as well as shorter palps compared to their proboscis, a feature not typical to some species such as *Anopheles*, where the palps of both the males and females are of similar length with the proboscis, but appear clubbed at the tips among the males. This feature is also a species-distinguishing factor for *Anopheles*. Generally, female mosquitoes are larger and possess broader abdomens that can expand to accommodate blood meals and eggs.

For species characterization of mosquitoes, *Aedes aegypti* is predominantly black with contrasting white markings on their legs, which also forms a conspicuous pattern on the thorax, featured by black and white or silvery scale, which forms a lyre-shaped marking on the lateral edges of its scutum. *Aedes aegypti* are also white-banded at the base of their abdomen's second to sixth segments. In addition, their wings lack the distinctive pale spots, being predominantly dark-scaled. *Anopheles gambiae*, on the other hand, are typically lighter in color as they are predominantly brown to dark brown. *Anopheles gambiae* has an unmarked abdomen, unbanded uniformly dark legs, and its wings have a distinctive dark and pale scale that forms clear patterns, including pale spots. *Culex* species are predominantly uniformly brownish or grayish and have uniformly dark-scaled legs and wings, with the wings also lacking distinctive pale patterns.

The Abdominal condition of all the female mosquitoes identified in this study was examined for the presence of blood or eggs. Based on the WHO's Guide for Participants on Malaria Entomology and Vector Control (2013), the females were grouped into four as: Blood-fed (i.e., abdomen contained blood and appeared bright or dark red), Non-blood-fed/unfed (i.e., abdomen not containing blood and appears flatted), Gravid (i.e., abdomen engorged with eggs, with reduced or no blood), and Half gravid (i.e., abdomen half-filled with eggs, and the remaining half occupied by blood) (Fig. 1).

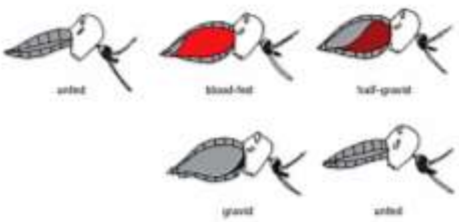

**Figure 1. Abdominal Conditions of Female Mosquitoes**
***Source: WHO's Malaria Entomology and Vector Control: guide for participants (2013)***

**Data Analysis**

Data was presented in figures and tables using relative frequencies. Data was also subjected to Shannon-Wiener Index to determine the mosquito species richness (number) and how evenly individual mosquitos were distributed among species.

Shannon-Wiener Index (H') is given as – Σ ($pi$ ln $pi$)

Where $pi$ is the proportion of individuals of species $i$

The total number of mosquitoes = 671 + 52 + 4 = 727

To determine the proportion of each species,

$p$*Culex* species = $\frac{671}{727}$ = 0.9230

$p$*Aedes aegypti* = $\frac{52}{727}$ = 0.0715

$p$*Anopheles gambiae* = $\frac{4}{727}$ = 0.0055

The $pi$ ln ($pi$) for each species is given as:

*Culex* species = 0.9230 × ln(0.9230) = 0.0740

*Aedes aegypti* = 0.0715 × ln(0.0715) = 0.1887

*Anopheles gambiae* = 0.0055 × ln(0.0055) = 0.0286

Therefore,

H' = - Σ ($pi$ ln $pi$)

= - (-0.0740 – 0.1887 – 0.0286)

Shannon-Wiener Index (H') = 0.2913

## RESULTS

### Mosquito Species Circulating within Human Habitations in Damboa Town.

Of the 727 mosquito samples collected indoors within human habitations in the study area, *Aedes aegypti*, *Culex* species, and *Anopheles gambiae* were identified. *Culex* species were found to be the highest (92%: 671/727), while *Anopheles gambiae* was the lowest (0.55%: 4/727), as shown in Figure 2.

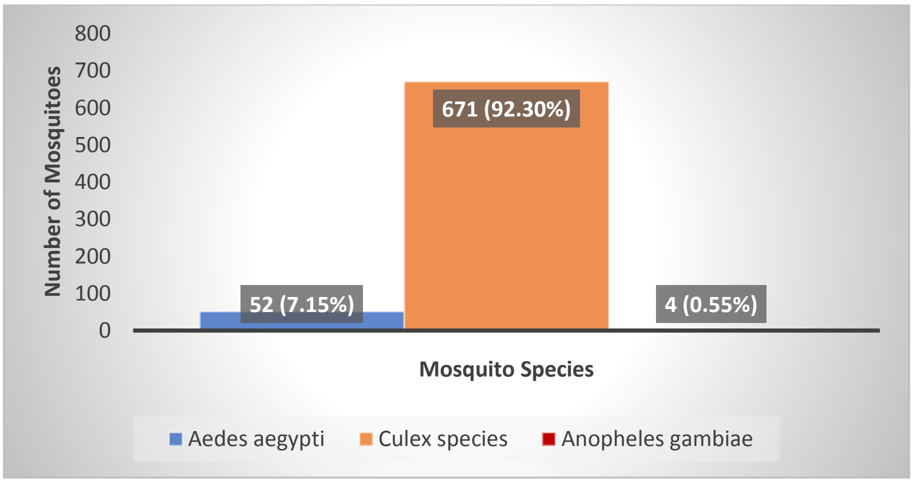


**Figure 2: Frequency Distribution of Indoor-resting Mosquito Species in Damboa.**

### Morphological Observation of Mosquitoes.

The information provided below (Table 1) depicts the morphological features used for the characterization of the mosquito species based on microscopic observation. The colour, wings, thorax, abdomen, and legs were observed for species characterization.

**Table 1: Characterization of Mosquitoes into Species**

| Morphological Feature | *Culex* Specie | *Aedes aegypti* | *Anopheles gambiae* |
|---|---|---|---|
| Wings | Uniformly dark-scaled, lacking the distinctive pale patterns | Lacks distinctive pale spots | Distinctively dark and pale scale, including pale spots |
| Colour | Brown or gray | Black | Brown to dark brown |
| Thorax | Lyre-shaped pattern featured by black and white or silvery scale, | Uniformly coloured with no white markings | Uniformly coloured with no white markings |
| Abdomen | Unmarked, no white banding | White-banded | Unmarked, no white banding |
| Legs | Unbanded and dark | White-banded | Unbanded and dark |

### Sex Characterization of the Mosquitoes Species Identified.

Table 2 below shows the sex characterization of the three species of mosquitoes identified. 79.50% (578/727) were females, and 20.50% (149/727) were males. The highest population of females was recorded among the *Culex* species (94.1%: 544), while the lowest was recorded among *Anopheles gambiae*.

**Table 2: Distribution of Mosquito Based on Sex**

| Sex | *Culex* Specie (%) | *Aedes aegypti* (%) | *Anopheles gambiae* (%) | Total (%) |
|---|---|---|---|---|
| Male | 127 (85.2) | 22 (14.8) | 0 (0) | 149 (20.50) |
| Female | 544 (94.1) | 30 (5.2) | 4 (0.7) | 578 (79.50) |
| **Total** | **671 (92.30)** | **52 (7.15)** | **4 (0.55)** | **727 (100)** |

Key: % = Percentage.

**Abdominal Content of the Female Mosquito Species Identified.**

The examination of the abdominal condition of all female mosquitoes caught revealed that 44.50% (257/578) were blood-fed, of which 75% were *Anopheles gambiae*. Gravid females were 6.05% (35/578), while those whose abdomen did not contain blood or eggs (non-blood-fed) were 43.25%: 250/578 (Table 3).

**Table 3: Distribution of Female Mosquito Species Based on Abdominal Condition**

| Mosquito Species | Blood-fed (%) | Non-blood-fed (%) | Gravid (%) | Half-gravid (%) | Total (%) |
|---|---|---|---|---|---|
| *Culex* Species | 223 (42.8) | 242 (44.5) | 33 (6.1) | 36 (6.6) | 544 (94.12) |
| *Aedes aegypti* | 21 (70%) | 7 (23.3%) | 2 (6.7) | 0 (0) | 30 (5.19) |
| *Anopheles gambiae* | 3 (75%) | 1 (25.0) | 0 (0) | 0 (0) | 4 (0.69) |
| **Total** | **257 (44.5)** | **250 (43.25)** | **35 (6.05)** | **36 (6.2)** | **578 (100)** |

Key: % = Percentage

## DISCUSSION

*Anopheles*, *Aedes*, and *Culex* are the three most dominant mosquito genera worldwide (Tandina *et* al., 2018). That explains the reason for their identification in this study. Lamidi (2009) identified the same mosquito species in Nguru, a town in Nguru Local Government Area (LGA) of the neighboring Yobe State. The same species were also identified in Nteje town of Oyi LGA of Anambra State by Irikannu *et al* (2022). These similar findings, alongside the findings of this study, provide a clue as to the most prevalent mosquito species circulating in Nigeria. Identifying these mosquito species within human habitation is critical as most mosquito-borne disease transmission cases, especially malaria, occur indoors and at night (Huho, 2013; Lindsay *et al.*, 2021) due to the preference of the vectors for indoor habitation. Therefore, this calls for decisive action by the Nigerian government, non-governmental health organizations, and the human residents of Damboa, to prevent the occurrence of diseases caused by the microbial agents carried by these mosquito species.

As most mosquito-borne diseases are not vaccine-preventable, using insecticide is important as it is effective in controlling mosquitoes (Gan *et al.*, 2021). However, numerous studies have established the resistance of these vectors, particularly *Aedes* species, to insecticides (Andreazza *et al.*, 2021; Bharati and Saha, 2021), including those used for indoor residual spraying (IRS), thereby rendering this control strategy ineffective (Tajudeen *et al.*, 2022). This may account for the observed presence of mosquitoes within human habitation and calls for the reassessment of the effectiveness of all the mosquito control measures already in use, improvement of control measures identified to have weakened effectiveness, as well as the introduction of novel, more effective, and modern control strategies.

*Culex* species being the most dominant mosquitoes recorded in this study is indicative of its highly adaptable, endophilic, and endophagic nature. This finding is in concert with the findings of Ngadjeu *et al.* (2020), Asgarian *et al.* (2021), and Krambrich *et al.* (2024), who also recorded *Culex* as the most prevalent mosquito species, accounting for 96.48%, 92.31% and 96.50% of the total mosquito collected in their respective studies. *Culex* species are adapted to breeding in polluted, stagnant, and natural or artificial - temporary waterbodies (Khatun *et al.*, 2019; Krambrich *et al.*, 2024) compared to *Aedes* which prefer clean and temporary waterbodies (Dalpadado *et al.*, 2022), and *Anopheles* which also prefers clean but permanent waterbodies (Fillinger *et al.*, 2004; Khatun *et al.*, 2022). *Culex* species are also adapted to various climatic conditions compared to *Aedes* and *Anopheles* species (Fillinger *et al.*, 2004; Samdi, 2012). The low population density of *Aedes aegypti* (52/727: 7.15%) and *Anopheles gambiae* (4/727: 0.55%) could also be attributed to the timing of sample collection as this was carried out during the rainy season when the climatic condition was not temperate enough to favour their thriving.

As this study has recorded an overall limited diversity and low evenness (0.2913) in the mosquito population as indicated by the Shannon-Wiener Index (H'), the dominance by *Culex* has health implications as it is indicative of a higher risk of *Culex-borne* diseases while those linked to the other species may have less significance in Damboa. This information is crucial for specific vector control strategies, as it highlights the species to target based on their dominance and potential health implications.

About half (44.5%: 257/578) of the population of the entire female mosquitoes identified in this study were blood-fed. This is indicative of an ongoing transmission cycle as pathogens are transmitted to susceptible hosts during a blood meal (Thongsrinpong *et al.*, 2021). This implies the heightened risk of mosquito-borne disease among the human and animal inhabitants of Damboa. Molta *et al.* (1992) and Molta *et al.* (2004) have long established the endemicity of *Plasmodium falciparum* infection in Damboa, which accounts for 85-90% of infections. The occurrence of other viral diseases, such as the *Culex*-borne WNV infection (Baba *et al.*, 2014) and the *Aedes aegypti*-borne yellow fever (Ekenna *et al.*, 2010), have also been well documented to be common in Damboa. As this study has identified blood-fed mosquitoes, there is an urgent need to reduce the mosquito population to the barest minimum, which will subsequently limit the rate of mosquito-borne diseases through the adoption of targeted control measures and interventions such as the use of insecticide-treated nets, general out-door space spraying, and IRS with effective insecticide.

The majority (78.8%) of the female mosquitos identified in this study were gravid. Similar findings were also recorded by Genoud *et al.* (2019) and Irikannu *et al.* (2022) in independent studies. The presence of egg-caring (gravid and half-gravid) female mosquitoes may be an indication of the closeness, in terms of proximity, of mosquito breeding sites with human habitation. Interestingly, as the volume of eggs in the abdomen of a mosquito is directly proportional to the volume of blood ingested (Phasomkusolsil *et al.*, 2013), this is indicative of the intense biting of humans and may necessitate the administration of prophylactic measures to such individuals to prevent mosquito-borne diseases. Identifying gravid mosquitoes is also predictive of the future increase in the mosquito population in the study area under favorable environmental conditions. Therefore, this necessitates the need for proactive control measures before laying and hatching the eggs.

Even though this study recorded few *Anopheles gambiae*, it is imperative to note that since all were females and mostly blood-fed, with the absence of routine mosquito control measures, the few numbers are enough to transmit *P. falciparum* to susceptible human hosts since their ability to do so is intact. A previous study by Samdi (2012), who also recorded a few indoor female *Anopheles* mosquitos in Damboa, confirmed the presence of *P. falciparum* and recorded a 24% prevalence rate for malaria among children.

Numerous researches have established that current mosquito control strategies are not effective in addressing the global health challenge posed by mosquito-borne diseases; this has prompted the development of innovative, modern, environmentally friendly, and self-sustaining approaches. At the forefront is the use of *Wolbachia*-infected mosquitoes with a modulated immune system that inhibits pathogen replication. Huge successes have been recorded in field trials by the World Mosquito Program (WMP) in countries such as Brazil and Indonesia, where a significant reduction in disease transmission has been observed without the use of insecticides while offering long-term solutions to vector control (Dutra *et al.*, 2016). This approach is effective against Dangue, Chikungunya, and Zika (Pinto *et al.*, 2021). Other approaches include the Sterile Insect Technique (SIT), which is based on the gene-editing strategy of CRISPR-Cas9. SIT enables the genetic modification of male mosquitoes for the purpose of reducing mosquito population through unsuccessful reproduction when such sterile males are released into the wild to mate with reproductive-competent females. Another CRISPR-Cas9 technique is the acceleration of the spread of desired traits, such as those responsible for resistance (Hammond *et al.*, 2016). Gene-editing techniques, however, are generally faced with challenges such as ethical concerns and unforeseen outcomes. These, therefore, call for continuous research to address these issues and ensure the large-scale safety of the applications.

Even though this study has confirmed the presence of blood-fed mosquitos within human habitations, its inability to integrate molecular techniques to confirm mosquito species and identify the pathogens they may be carrying might lead to misidentification and neglect of circulating pathogens within Damboa.

## CONCLUSION AND RECOMMENDATIONS

Our findings confirm the presence of disease-transmitting mosquito vectors, with *Culex* species being dominant. Strengthening vaccination coverage and community-based vector control measures are crucial to mitigating the risk of arboviral outbreaks in Damboa.

Based on the findings, the following actions are recommended:

i. Adoption of appropriate and effective vector control measures is required so as to circumvent the occurrence or outbreak of mosquito-borne diseases within the study area.

ii. There is a need for an arbovirus surveillance system so as to enable the early detection of arboviruses in mosquito populations, monitor viral activity, and assess the risk of arbovirus transmission to humans.
iii. Mass vaccination of susceptible individuals against vaccine-preventable arboviral diseases is also recommended.
iv. Adopting effective protective measures against mosquito bites by human residents in Damboa is necessary.

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