

Influence of room air quality and microclimate on the abundance of mosquito vectors from the Sahel Region, Republic of Niger

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Abstract

Background

The transmission of vector-borne diseases such as malaria depends largely on the ability of the pathogen transmitting mosquitoes to bite and rest indoors. However, the density of mosquitoes indoors is limited by microclimate such as temperature, Relative Humidity, fine particles and volatile organic compounds in the air. In this study, we assessed the impact of environmental conditions, including temperature, Relative Humidity (RH), and indoor air quality between August and October 2024, on the abundance of *Culicidae* mosquitoes. Mosquitoes were captured using Prokopack aspirators and morphologically identified to genera levels using dichotomous keys.

Results

A total of 110 rooms were sampled and 1,803 mosquitoes were captured, including 1,702 *Anopheles*, 97 *Culex* and 4 *Aedes*. The average temperature was 29.1°C, and the Relative Humidity (RH) ranged between 45% and 65%. A negative relationship was established between mosquito abundance and room temperature ($r = -0.25$), with a sharp decline in indoor abundance observed when temperatures exceeded the average of 29.1°C. No significant correlation was found between mosquito abundance and RH ($r = 0.18$; $p > 0.05$). However, this relationship is positive for fine particles (PM_{2.5}, PM_{1.0}, and PM₁₀) (r varying between 0.21 and 0.28).

Conclusions

This study shows that the abundance of the indoor mosquitoes correlates with air quality, more specifically with the higher permissive temperature and concentration of fine particles in the air inside houses. Future studies should focus on the dynamics of the *Anopheles* populations in relation to indoor air quality, to better target the appropriate time for intervention.

Background

Vector-borne diseases (primarily represented by malaria) represent a significant global public health burden, accounting for over 17% of all infectious diseases and causing more than 700,000 deaths per year. They mainly affect populations in tropical and subtropical regions, particularly in sub-Saharan Africa. According to the World Health Organization, Africa bears the greatest share of the global burden of vector-borne diseases, accounting for approximately 95% of malaria cases and deaths, 70% of global yellow fever outbreaks, and the majority of cases of lymphatic filariasis, onchocerciasis and human trypanosomiasis [1].

Mosquitoes, with their remarkable diversity of approximately 3,600 to 3,700 species across forty genera, play a central role in sustaining this heavy burden of vector-borne diseases. However, fewer than 100

species are involved in the transmission of human diseases, mainly within the genera *Anopheles*, *Aedes* and *Culex* [2, 3]. Several studies have shown that certain species can be found inside human dwellings, which has a direct impact on the transmission of infectious diseases. Mosquito species of the genus *Anopheles*, such as *Anopheles gambiae* s.l. or *Anopheles funestus*, are species that prefer to remain or rest inside houses (endophilic) [4, 5]. Species of the *An. gambiae* complex can also coexist with one another and with other species within human dwellings. This is the case with the invasive species *Anopheles stephensi*, which was found to be sympatric with the main species of the *An. gambiae* complex in a village in southern Niger [6]. *Culex* mosquitoes, too, are often present and adapt very well to human dwellings [7, 8]. As for *Aedes* mosquitoes (notably *Aedes aegypti* and *Aedes albopictus*), they are highly domestic and anthropophilic, preferring to lay their eggs in small containers of water in and around dwellings, implying their presence indoor [9].

Their presence indoor directly contributes to their crucial role in spreading deadly diseases. Mosquitoes are of paramount importance to public health due to their role in transmitting countless diseases responsible for thousands of deaths worldwide. Species of the genus *Anopheles* are the most medically significant and are also the only competent vectors of malaria. Malaria constitutes a major public health problem. According to estimates, approximately 263 million cases and 597,000 deaths [10]. The WHO's African Region remains the most affected, with approximately 246 million cases and 569,000 deaths [10]. Mosquitoes *Culex* are responsible for transmitting West Nile fever, which is endemic in Europe, the Middle East and Africa, as well as Japanese encephalitis, which is endemic in Asia and causes approximately 100,000 cases and 25,000 deaths each year [10]. The role of *Culex* mosquito as vectors does not end there; they are also involved in the transmission of Rift Valley fever, a viral zoonosis, and lymphatic filariasis. *Aedes aegypti* and *Ae. albopictus* are involved in the transmission of the Zika virus, frequently reported in Latin America and Africa; dengue, which has caused around 96 million cases and 40,000 deaths; and chikungunya, which affects around 100 countries in Asia, Africa, Europe and the Americas [10].

Thus, beyond their well-established role in the transmission of these major arboviral diseases, the dynamics of mosquito presence within households appear to be closely linked to local environmental conditions, particularly the indoor microclimate. It has been shown that the condition of a room's interior, the presence of ventilation systems, and the coolness of the indoor air can significantly influence the abundance and activity of [11]. Study on the influence of the indoor microclimate on the survival of female mosquitoes in Kenya have shown that the microclimates of room play an important role in increasing mosquito density [12]. High Relative Humidity and low temperatures are crucial for the survival of adult mosquitoes, particularly by facilitating their resting in shaded and humid areas of dwellings. Furthermore, high ambient temperatures reduce mosquito survival and accelerate their metabolism, thereby decreasing the time required for blood digestion and shortening the gonotrophic cycle, which may increase the frequency of bites [13, 14]. By combining heat and Relative Humidity, domestic conditions can therefore create a microclimate conducive to mosquito proliferation, thereby increasing their abundance and blood-feeding activity [15]. The microclimates of dwellings can be altered by temperature and Relative Humidity, as well as by particles and gases that may affect the adaptation and development of living organisms

present in the environment. These particles include total volatile organic compounds, such as formaldehyde (HCHO), which are often found in building materials and furniture [16]. Microparticles are generated by the combustion of materials, ventilation and the infiltration of outdoor air [17, 18]. A study conducted in The Gambia, the aim of which is to examine the influence of airborne particle concentration in houses on mosquito abundance, demonstrated the significant effect of carbon dioxide concentration on the density and abundance of *Anopheles* mosquitoes in houses [19].

These findings highlight the need to consider local environmental factors in malaria control, especially in countries such as Niger, where considerable efforts are being made to combat malaria, targeting both parasites and vectors. Most entomological studies on vector activity and abundance in dwellings in Niger have not taken indoor air parameters into account (Mamane Sale et al. 2023; Labbo et al. 2016; Moustapha et al. 2025).

This entomological study was conducted with the aim of assessing the impact of indoor air quality parameters on mosquito density in the Zinder region. Temperature was found to be negatively associated with indoor mosquito abundance. Relative Humidity was found not to be associated with indoor vector abundance. While fine particles were positively associated with mosquito abundance.

Methods

Study area

This study was conducted in August to October 2024 at three (3) sites. Gayi (13°29'7.09", 9°21'22.49") located in the rural commune of Wacha. This village is surrounded to the north and east by temporary and semi-permanent ponds, [6]. Lassouri (14°01'43.2", 9°35'04.1") is one of the rural communes of the Damagaram Takaya department, the entire village is almost permanently surrounded by a pond. Gamram Sofouwa (14°58'45.61104", 8°52'48.792") located about 18 km from the department of Tanout. It is surrounded by two temporary and semi-permanent ponds to the west and east respectively (Fig. 1). This area is covered by two seasons (dry and rainy). A long dry season, which generally lasts from October to April. During this period, there is virtually no rainfall and the rainy season in these regions lasts from May to September, with rainfall of around 600 mm. These sites were selected for our study because of their water potential. The study area contains permanent and semi-permanent water sources that favour the production of larvae and the proliferation of mosquitoes.

Mosquito sampling, processing and identification to species levels

Indoor resting mosquitoes were collected from 110 rooms, over a 6-day period at each site per month between August and October 2024 using Prockopack aspirators (John W. Hock, Gainesville, Florida U.S.A). Cohorts were kept separate, based on the site, house and collection dates and transferred to laboratory where they were identified using morphological keys [22, 23] examined under a binocular microscope, using the entomological identification keys of Robert and his collaborators to determine the sex and

genus of each *Culicidae* mosquito. For *Anopheles*, A total of 16 randomly selected females (6 from each of the 3 sampling sites) were homogenized, genomic DNA (gDNA) extracted using LIVAK protocol [24][24], and used for SINE200 PCR [25].

Determination of indoor air parameters

Recording of microclimate data (temperature, Relative Humidity) and indoor air parameters such, as volatile organic compounds (TVOC), formaldehyde concentration (HCHO) and fine particles (PM1.0, PM2.5, PM10) were recorded using an AIR QUALITY DETECTOR IGERESS device (VSON, Shenzhen, China). The TVOC are chemical substances that evaporate easily at room temperature; HCHO are colour less volatile organic compounds and PM are tiny solid or liquid fine particles suspended in the air, with diameters of 1, 2.5 and 10 respectively: PM1.0, PM2.5, and PM10 [26, 27].

Study variables

The study variables recorded were (i) the number of mosquitoes captured, (ii) the proportion of different genera, and (iii) the area parameter data displayed by the device. The independent variables are climatic factors, including temperature (degrees Celsius), Relative Humidity (percentage) and indoor air quality, which is assessed using several parameters: the concentration of fine particles of different sizes (PM2.5, PM1.0 and PM10) (in μm^3), formaldehyde (HCHO) and total volatile organic compounds (TVOC) (in $\mu\text{g}/\text{m}^3$), which are indicators of chemical pollution.

Data analysis

Data were organised into Excel format and descriptive statistics was conducted for all variables, followed by a correlation analysis to identify initial relationships between different mosquito genera and microclimate data (temperature and Relative Humidity) using correlation matrices. To assess the combined influence of these factors, multiple linear regression analysis models scatterplot matrix. All these analyses were performed using R version 2024.12.0.0, with a significance threshold set at $p < 0.05$.

Results

Composition and abundance of indoor mosquitoes

From 110 rooms screened, a total of 1,803 mosquitoes were captured over 6 days, between August and October 2024, including 1,702 *Anopheles*, 97 *Culex*, and 4 *Aedes*. By sites 521 mosquitoes were recorded in Gayi, while 713 and 569 were captured in Lassouri and Gamram Sofouwa, respectively. The 4 *Aedes* mosquitoes were found in Gayi ($n = 2$), Gamram Sofouwa ($n = 1$), and Lassouri ($n = 1$), while the *Culex* mosquitoes ($n = 97$) were found in Gamram Sofouwa ($n = 7$), Gayi ($n = 88$), and Lassouri ($n = 2$). The genera *Culex* and *Aedes* were less frequent, with averages of 0.9 and 0.036 mosquitoes per house, respectively (Table 1).

Table 1

Proportion of mosquito species caught indoor between August and October 2024 in Gayi, Lassouri and Garam in Zinder, Niger

Category	Variables	Total Number	Gayi	Lassouri	Gamram	Mean	Median	Standard deviation
Total	Mosquitoes	1803	521	713	569	16.39	6.00	27.26
Mosquito abundance	<i>Anopheles</i>	1702	431	710	561	15.56	6.00	27.27
	<i>Culex</i>	97	88	2	7	0.89	0.00	1.77
	<i>Aedes</i>	4	2	1	1	0.03	0.00	0.19

SINE200 PCR, using 16 randomly selected female mosquitoes revealed presence of all three principal vectors from *An. gambiae* complex in the three sites, with *An. coluzzii* predominant in Gamram (5 females) compared with only one *An. gambiae* s.s.; while *An. coluzzii* and *An. gambiae* s.s. were equal in proportion in Gayi (3 females each); and *An. arabiensis* was predominant (4 females) over *An. coluzzii* (2 females) in Lassouri (Fig. 2).

Influence of temperature and Relative Humidity on abundance and diversity of mosquito genus

The microclimate parameters recorded during the peak transmission season (August–October 2024) for all sites showed an average temperature of 25–30°C and average Relative Humidity (RH) of 45–65% favour the endophilic behaviour of mosquitoes (Fig. 3a). The combined effect of temperature and Relative Humidity on *Anopheles* abundance shows an increase in abundance as temperature decreases. Specifically, a high mosquito presence was recorded at temperatures around 28–29.1°C, while a significant drop in density was observed as soon as indoor temperatures rose above 30°C. However, *Anopheles* abundance increases with rising Relative Humidity, peaking around 50–65% and moderate temperature (24–28°) (Fig. 3b). *Culex* are more abundant indoor where the temperature and Relative Humidity are between 40% and 65% (Fig. 3c). The abundance of mosquito *Aedes* was observed approximatively at same condition then *Culex* (40% and 65%) (Fig. 3d).

Association between indoor air parameters and mosquito species abundance

A moderate, statistically significant negative correlation was observed between indoor temperature and mosquito abundance (correlation coefficient = -0.25** $p < 0.05$), suggesting an inverse association between these variables (Fig. 4). Conversely, fine particles (PM_{2.5}, PM_{1.0} and PM₁₀) showed significant positive correlations with abundance of mosquitoes, with coefficients [0.22*, 0.24*, 0.21* ($p < 0.05$)] respectively. The abundance of mosquitoes tends to decrease with the reduction in the concentration of these fine particles. But other variables such as Relative Humidity, HCHO and TVOC concentrations showed no significant correlation with the abundance of mosquitoes respectively, [coefficient = 0.178;

-0.018 and 0.185 ($p \geq 0.05$)]. **Figure 4: Correlation between abundance of mosquitoes and temperature, Relative Humidity, fine dust particles, formaldehyde concentration, and synthetic and natural volatile organic compounds.** Mosq: abundance of mosquitoes; Temp: Temperature ($^{\circ}\text{C}$); Hum: Relative Humidity (%); PM2.5: Fine particles with a diameter of less than 2.5 μm ; (e) PM1.0: Fine particles with a diameter of less than 1.0 μm ; PM10: Fine particles with a diameter of less than 10 μm ; HCHO: Formaldehyde; and TVOC: Total Volatile Organic Compounds.

Discussion

In this study the fine particles, showed positive correlation with abundance of mosquitoes. In contrast, a study on air quality and pollutants (biomass smoke and CO) produced by biomass burning inside dwellings showed that there was no significant repellent effect on mosquito density [28] but the it is confirm that, the indoor microclimate (temperature and humidity) directly influences the physiology and survival time of *Anopheles* vectors within a room [29].

Within the context of the rapidly changing climate, extreme events such as heat waves or droughts could limit survival of mosquitoes, while floods associated with intense rainfall could increase the number of habitats suitable for their reproduction. These dynamics suggest that climate change could lead to a geographical redistribution of vectors [30, 31], thereby increasing the risks in areas previously little affected. These observations call for closer monitoring of climatic conditions and at-risk habitats. The findings of this study highlight the importance of microclimate factors, particularly temperature and Relative Humidity, in the ecological dynamics of mosquitoes. The significant negative correlation between temperature and mosquitoes abundance (coefficient = $-0.25^* p < 0.05$) confirms that high room temperature limit indoor resting of mosquitoes. Similarly, a study conducted in Zambia reported a significant negative correlation between temperature and the abundance of *Anopheles* larvae in larval habitats ($r = -0.373, p = 0.05$), suggesting that higher temperatures may reduce larval abundance [32]. Controversially, several studies indicate that higher temperatures are associated with increased abundance of mosquitoes [33–35]. Mosquitoes had varying relationships with temperature. This can be explained by the impact of extreme temperatures on their life cycle, in particular the reduction in adult survival and the slower development of aquatic stages [36]. Other studies have shown that moderate temperatures (around $25\text{--}28^{\circ}\text{C}$) are optimal for vector survival and transmission, while higher temperatures ($> 30^{\circ}\text{C}$) can be lethal for mosquitoes [37]. We observed no significant correlation between Relative Humidity and abundance of mosquitoes ($r = 0.18, p = 0.05$), probably due to timing bias, as sampling was carried out at the height of the rainy season in August when humidity is very high. This is in contrasts to other studies that have highlighted the crucial importance of Relative Humidity in the abundance and survival of mosquitoes. High Relative Humidity levels favour the survival of adult mosquitoes by reducing the risk of desiccation [38]. Studies in Nigeria and Saudi Arabia have shown positive correlation between Relative Humidity and mosquito abundance [39, 40]. In addition, wetlands increase the availability of egg-laying sites, which is essential for the life cycle of mosquitoes.

The sympatric occurrence of *An. coluzzii*, *An. gambiae* s.s., and *An. arabiensis* in our study sites aligns with recent entomological characterizations in the region. Specifically, our previous work in Gayi demonstrated

that these three major vectors coexist not only with each other but also with the invasive species *Anopheles stephensi* [6]. Furthermore, the presence of *Aedes* mosquitoes in all three sites, Gayi, Lassouri, and Gamram Sofouwa, highlights the wide distribution of *Aedes* in the Sahel, especially as they are caught resting indoor. The high diversity of the above species in the Sahel underscores the complexity of vector control in areas where multiple malaria and arbovirus vectors overlap [41].

Our findings highlight the importance of indoor microclimates in the abundance of mosquitoes, with implication for housing management. The study focuses on correlations, but did not establish causal relationships between indoor microclimate parameters and abundance of mosquitoes. Furthermore, data collection over an extended period or integrating multiple sites could provide a better understanding of seasonal and geographical variations, and capture more temperature and Relative Humidity extremes, explaining fully the roles of the microclimate. Modelling the interactions between indoor temperature, Relative Humidity, and vector dynamics could provide valuable tools for predicting the risk of malaria transmission, particularly in regions subject to extreme climatic variations.

Conclusion

This study demonstrates that room air quality and microclimate parameters influence indoor mosquito density. Specifically, we identified a moderate negative relationship between temperature and mosquito abundance, with high mosquito abundance at an average temperature of 29.1°C and a sharp decline as temperatures rose above 30°C. In contrast, fine particles were positively associated with abundance.

Future studies should consider larger sampling sites and an increased number of rooms, alongside longitudinal sampling to capture seasonal variations in temperature, RH, and fine particles. Such research would provide crucial translational relevance for more effectively targeting and controlling indoor resting *Anopheles* mosquitoes.

Declarations

Conflict of interest:

The authors declare no conflict of interest.

Ethics approval and consent to participate:

This study involves the collection and analysis of mosquito samples only. The project was approved by the Scientific Council of Université André Salifou, Zinder, Niger Republic (Ref: N°000792 June 13, 2023) in accordance with the Declaration of Helsinki.

Consent for publication:

Not applicable

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Author Contribution

LMM and SSI. Designed the study and its setting, organized the sample collection, analysed the generated data of the study. A-N HS, IYL, ADM. Collected and designed the tables and figures. HSA, MAA, ZN, ZMM, MD, MLI contributed to the writing of the manuscript.

Acknowledgement

Not applicable

Data Availability

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

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Figures

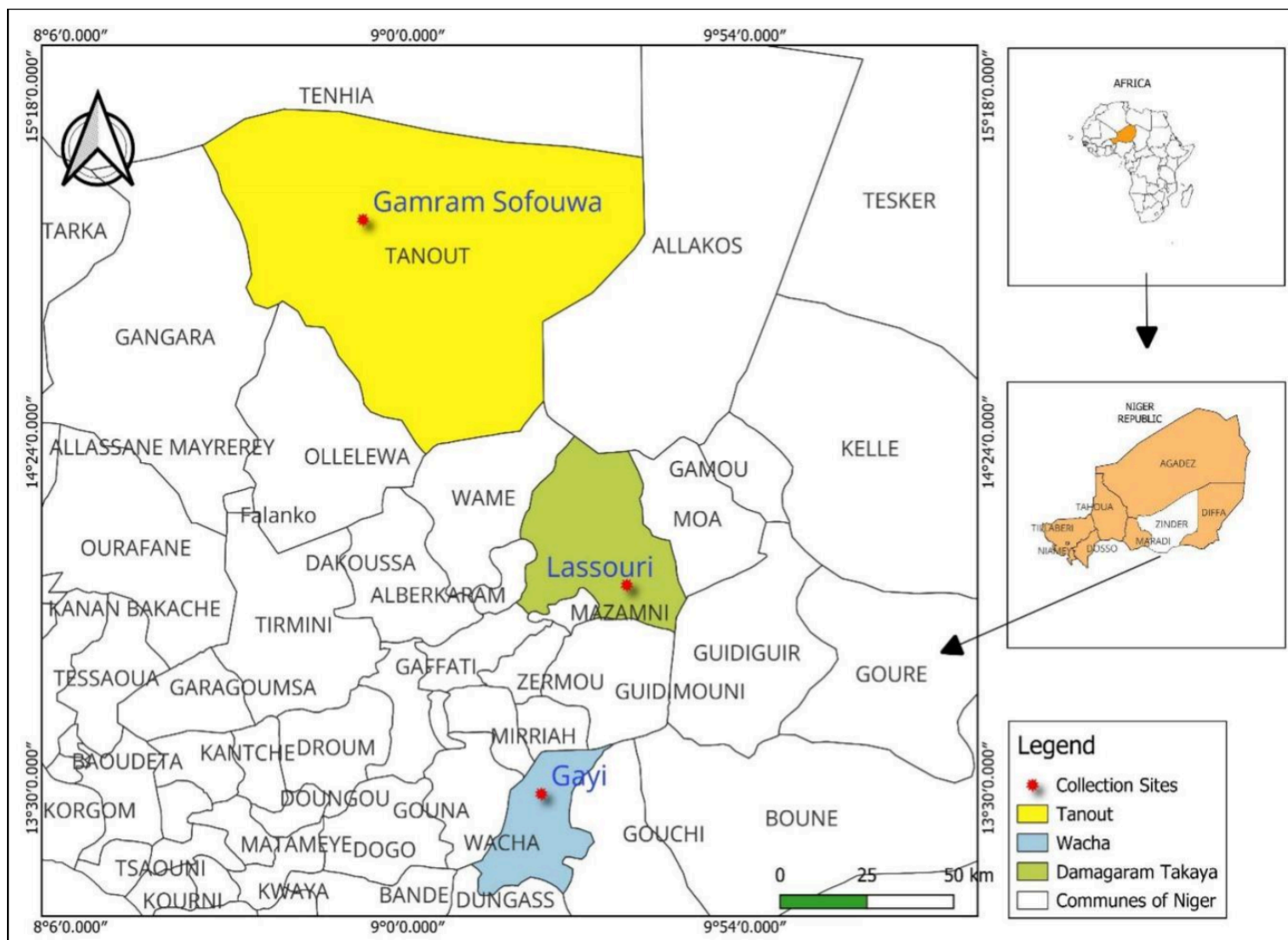


Figure 1

Map of Niger Republic showing the three study sites.

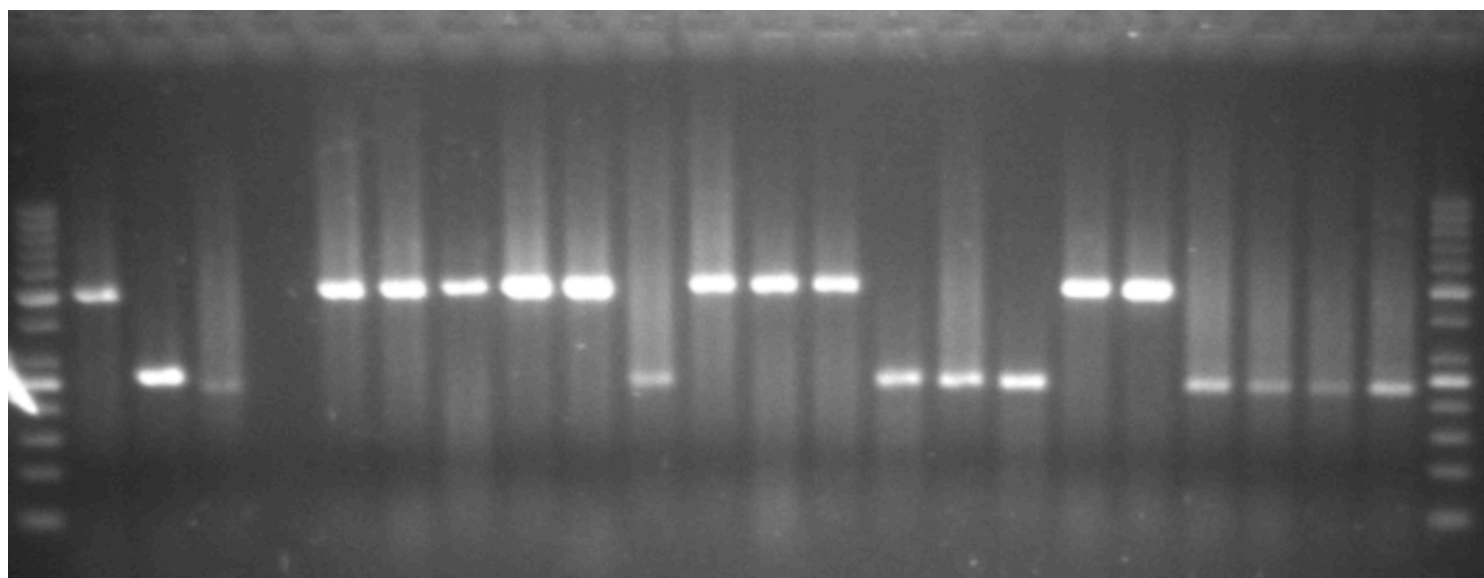


Figure 2

Agarose gel image cropped showing the results of amplification of fragments using SINE200 PCR. Lane 1 and 24: DNA ladder (50 bp); lane 2: positive control for *An. coluzzii* (479bp); lane 3: positive control for *An. gambiae* s.s.; lane 4: positive control for *An. arabiensis*; and lane 5: negative controls; **Garam:** lanes 6, 7, 8, 9 and 10: *An. coluzzii*; lane 11: *An. gambiae* s.s.; **Gayi:** lanes 12, 13 and 14: *An. coluzzii*; lane 15, 16 and 17: *An. gambiae* s.s.; **Lassouri:** lanes 18 and 19: *An. coluzzii* ; lanes 20, 21, 22 and 23: *An. arabiensis*.

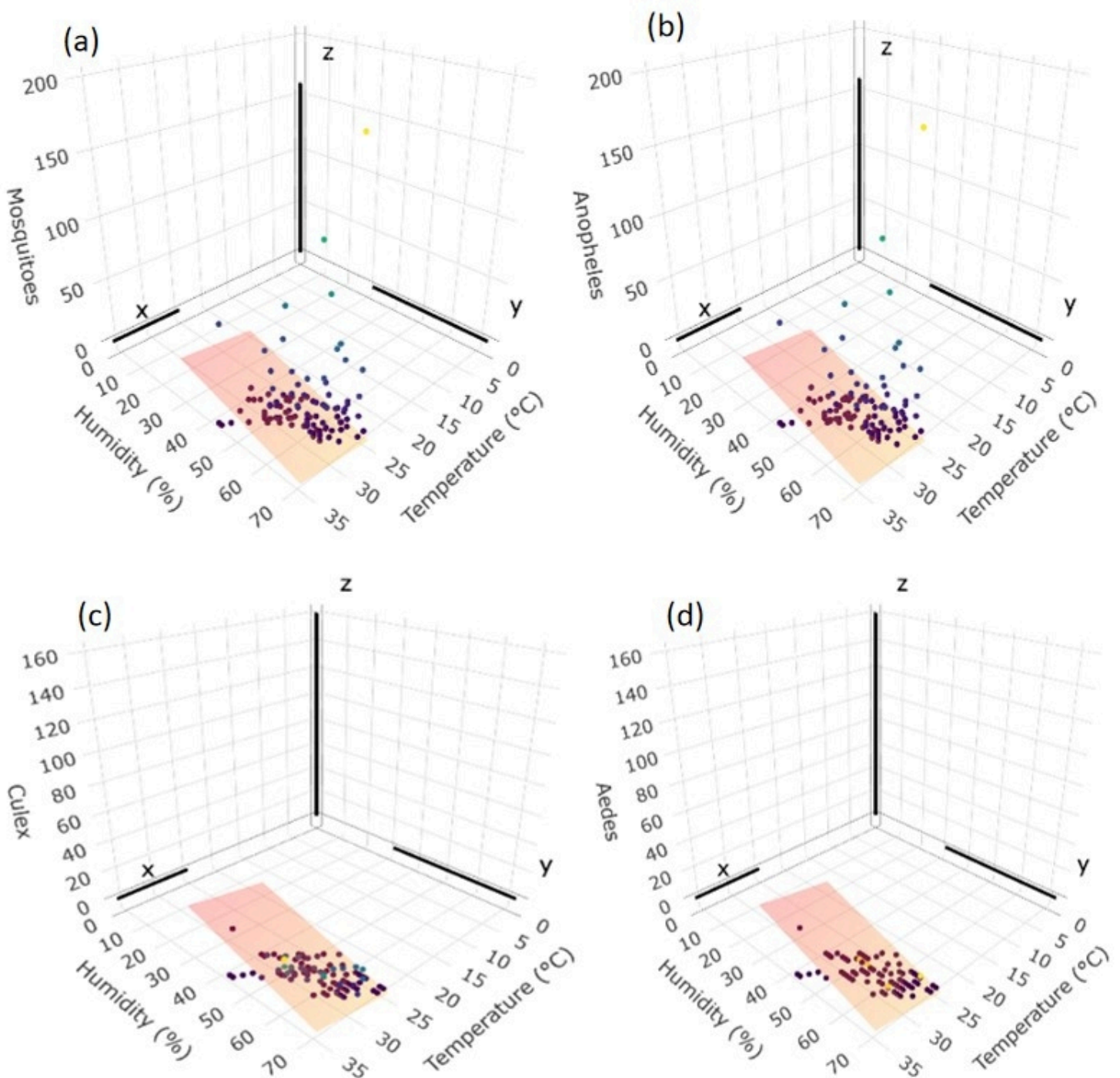


Figure 3

Impact of room microclimate on abundance of mosquito species. (a): for all mosquitoes; (b): for Anopheles; (c): for Culex; (d): for Aedes. Purple and dark data points: represent low abundances; Blue and emerald green data points: represent intermediate abundance values; The yellow data points (single or rare): represents the highest abundance.

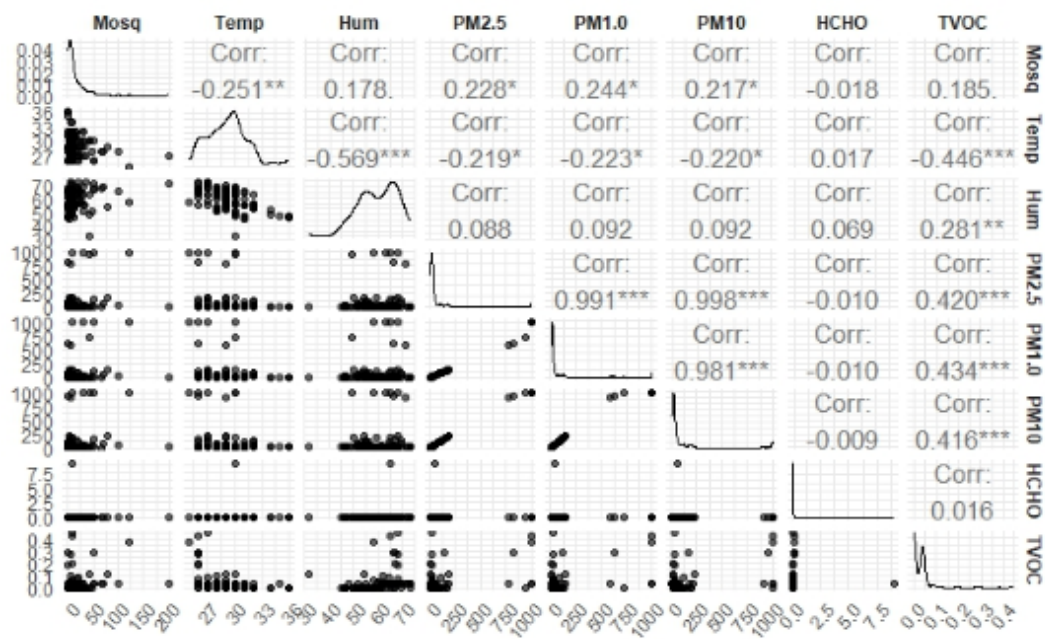


Figure 4

Correlation between abundance of mosquitoes and temperature, Relative Humidity, fine dust particles, formaldehyde concentration, and synthetic and natural volatile organic compounds. Mosq: abundance of mosquitoes; Temp: Temperature (°C); Hum: Relative Humidity (%); PM2.5: Fine particles with a diameter of less than 2.5 µm; (e) PM1.0: Fine particles with a diameter of less than 1.0 µm; PM10: Fine particles with a diameter of less than 10 µm; HCHO: Formaldehyde; and TVOC: Total Volatile Organic Compounds.

Supplementary Files

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