

Impact of Indoor Residual Spraying with Bendiocarb (FICAM WP 80) on Entomological Indicators of Malaria Transmission in Senegal

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How to cite this paper: Lo, C., Ndiaye, A., Diop, A., Konate, L., Faye, O., Niang, E.H.A. and Dia, I. (2025) Impact of Indoor Residual Spraying with Bendiocarb (FICAM WP 80) on Entomological Indicators of Malaria Transmission in Senegal. *Advances in Entomology*, 13, 396-415. <https://doi.org/10.4236/ae.2025.134026>

Received: July 30, 2025

Accepted: October 10, 2025

Published: October 13, 2025

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Abstract

Indoor residual spraying (IRS) with insecticides is a key vector control strategy for malaria prevention. We assessed the impact of IRS using the carbamate bendiocarb (FICAM 80), on entomological of malaria transmission in intervention areas in Senegal between 2012 to 2014. Three treated districts were selected and compared to their untreated control districts. Entomological monitoring was conducted through pyrethrum spray catches (PSC) and human landing collection (HLC) after IRS. Over the study period, a total of 6,224 females *Anopheles* mosquitoes were collected by HLC and PSC. Five *Anopheles* species were identified, with *An. gambiae s.l.* being the predominant malaria vector (97.7%). Across the 2012, 2013 and 2014 IRS campaigns, indoor resting densities (IRD) were consistently higher in control districts compared to treated ones. Biting rates were significantly higher in Kaffrine than to Koungeul during the fifth month of follow-up in 2012 and at the beginning of follow-up in July 2013. In 2012, parity rates decreased significantly treated districts compared with controls during the second and third months of follow-up. Blood meals analysis indicated that most meals were taken on horses or on humans. Anthropophilic rates declined in treated districts compared with controls, with no statistical significant difference. IRS with bendiocarb significantly reduced key entomological indicators of malaria transmission in Senegal. Treated areas exhibited a marked decrease in biting rates and a sharp reduction in infection risk, largely due to lower parity rate in *An. gambiae s.l.*

females, as well as reductions in resting and biting densities induced by bendiocarb.

Keywords

Indoor Residual Spraying, Bendiocarb, *An. gambiae s.l.*, Malaria Transmission

1. Introduction

Malaria remains a major public health problem and one of the leading causes of mortality and morbidity worldwide. According to the latest World Malaria Report by the World Health Organization (WHO), there were an estimated 263 million cases and 597,000 malaria deaths worldwide in 2023 [1]. This represents about 11 million more cases in 2023 compared to 2022, and nearly the same number of deaths. Approximately 95% of the deaths occurred in the WHO African Region [1].

In Senegal, malaria remains a major public health problem despite the considerable progress achieved through the implementation and scale-up of effective control strategies. These efforts include rapid diagnosis and effective case management, as well as preventive interventions such as universal coverage with long-lasting insecticidal nets (LLINs) and targeted indoor residual spraying (IRS). Between 2009 and 2016, a substantial decline in parasite prevalence was observed, dropping from 3% to 1% [2]. However, this overall decline masks disparities, with malaria transmission remaining heterogeneously distributed across the country.

As in several other sub-Saharan African countries, IRS has played an important role in malaria prevention in Senegal, supported financially by the from the U.S. President's Malaria Initiative (PMI) [3], in line with the WHO Roll Back Malaria Partnership's *Global Malaria Action Plan* [4]. Historically, IRS has been one of the main vector control tools and a cornerstone of the WHO Global Malaria Eradication Program launched in the 1950s, contributing to the elimination or substantial reduction of malaria in parts regions of Europe, Asia, and Latin America [5]. In Africa, both historical and recent studies have demonstrated the effectiveness of IRS, particularly in southern Africa, with significant reductions in malaria transmission [6]-[11]. However, many of these studies lacked appropriate control groups, limiting the accuracy of the estimated impact of IRS. A recent Cochrane review applying strict inclusion criteria identified only four eligible studies in Africa, three from areas of stable transmission, including two randomized controlled trials [5].

In Senegal, IRS was first introduced in 2007 in selected districts [12]. Pyrethroids were initially used until 2010 [13], and then due to the emergence and spread of pyrethroid resistance [14] [15], carbamates (bendiocarb, FICAM WP 80) were adopted from 2011 to 2014 in six health districts: Nioro du Rip, Guinguineo, Malem Hodar, Kounghoul, Koumpentoum, and Vélingara.

This study retrospectively evaluates the impact of IRS with bendiocarb (FICAM WP 80) on malaria transmission in intervention areas in Senegal.

2. Materials and Methods

2.1. Study Area

The study was conducted in six health districts in Senegal where IRS with bendiocarb (FICAM WP 80) was implemented between 2011 and 2014. District selection was carried out in collaboration with the medical officers of each district hospital, based on the following criteria: i) malaria epidemiology sentinel villages; ii) geographical characteristics of the district; iii) presence of a health facility capable of supporting parasitological and clinical studies; and, iv) availability of previous entomological and/or parasitological data.

For analysis, three of the six treated districts were selected and compared with untreated control districts (Figure 1). Specifically, Malem Hodar and Kounghoul were compared with the untreated control district of Kaffrine, located in central Senegal (Sudanian zone), while Vélingara was compared with the untreated control district of Kolda, situated in the south (Sudano-Guinean savanna zone). These districts reported an annual malaria incidence exceeding 25%.

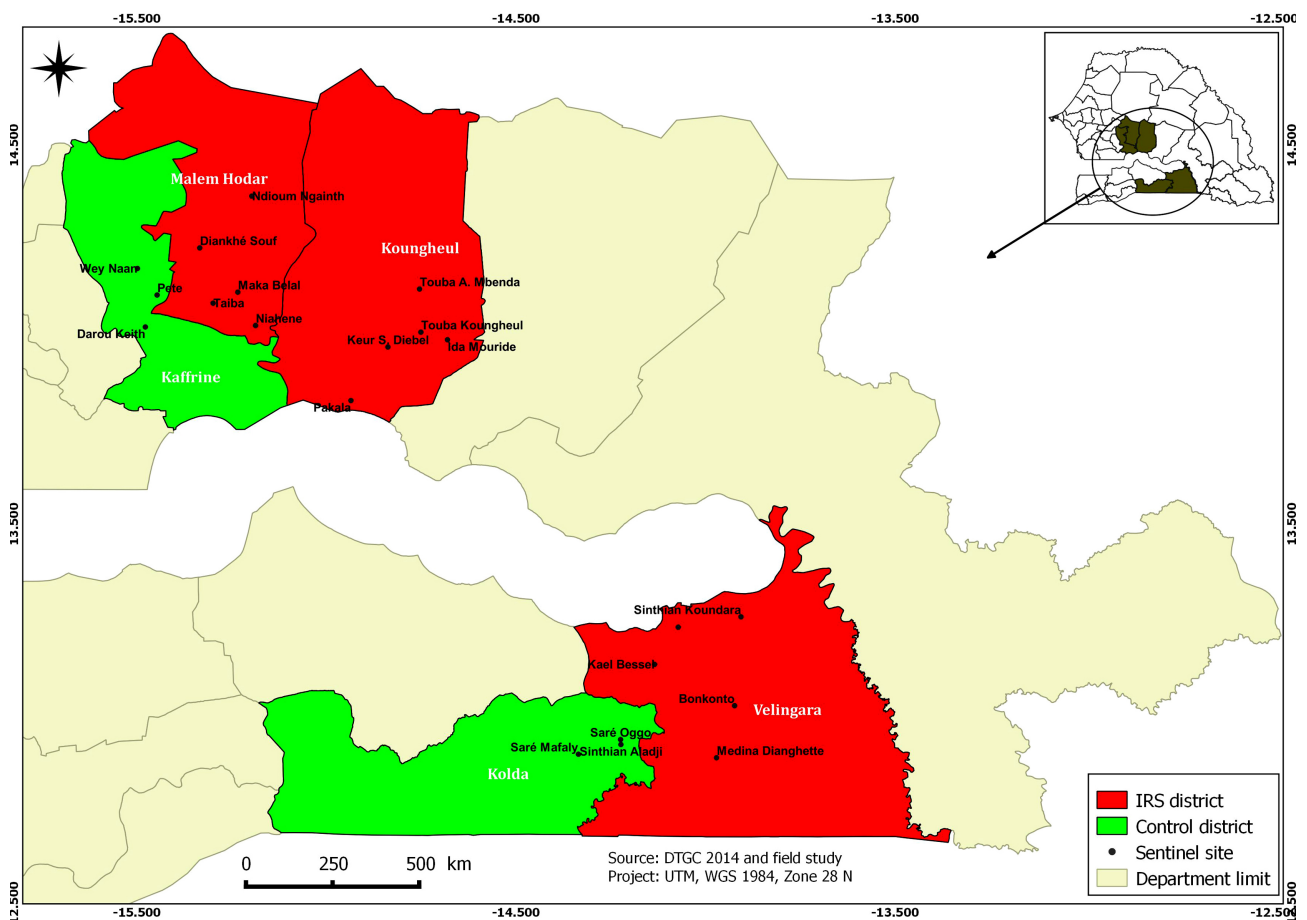


Figure 1. Geographic location of treated and untreated districts.

A total of 15 treated villages (five per treated district) and six untreated villages (three per control district) were included in entomological monitoring to assess the bionomics of malaria vector populations in relation to malaria transmission. The surveys started one month after IRS operations, which were conducted between June and August depending on the district.

2.2. Mosquito Sampling

2.2.1. Collection of Endophilic Mosquitoes by PSC

In each selected village, 10 rooms were randomly selected as collection points for endophilic mosquitoes. Resting mosquitoes were sampled using pyrethrum spray catches (PSC) from a total of 300 rooms in treated sites (50 per district) and 60 houses in untreated control districts (30 per district) throughout the study period.

2.2.2. Collection of Host-Seeking Females by HLC

In both treated and control districts, three villages were selected for indoor and outdoor nighttime collection of host-seeking female mosquitoes using the human landing catch (HLC) method. Collections were performed by adult volunteers during two consecutive nights from 9:00 p.m. to 6:00 a.m. [16].

Entomological surveys were conducted in parallel with post-spray monitoring of residual IRS efficacy with bendiocarb [15]. Pairwise comparisons of transmission parameters between the treated districts of Malem Hodar and Kounghoul and their untreated control, Kaffrine were carried out during the 2012, 2013, and 2014 IRS campaigns. In contrast, for Velingara and its untreated control, Kolda, comparisons were performed only in 2012 and 2013, as IRS was discontinued in Velingara after the 2013 campaign.

2.3. Field Processing

Collected mosquitoes were morphologically identified to genus and species using a standard identification key [17], then sorted, counted, and classified by sex. The abdomens of blood-fed females collected by PSC were crushed onto Whatman filter papers, which were stored with silica gel for subsequent identification of blood meal sources in the laboratory. approximately 40-50% of host-seeking females collected by HLC were dissected to determine parity status [18].

2.4. Laboratory Processing

Detection of *Plasmodium falciparum*-infected females was performed using the enzyme-linked immunosorbent assay circumsporozoite (ELISA CSP) method [19] [20]. Blood meal origins were determined using the indirect ELISA method [21].

2.5. Data Analysis

All field and laboratory data were recorded in an Excel database. Malaria transmission parameters (biting rate per human per night [B/H/N], indoor resting density [IRD], parity rate, endo/exophagy rate, anthropophilic rate, and infection

rate) were estimated for each district [16], then compared between treated districts and their respective controls.

Mean resting and biting densities of *An. gambiae s.l.* were compared between sites and treatment status using analysis of variance (ANOVA). All statistical analyses were conducted with R software version 3.3.1 [22], applying a significance threshold of 5%.

3. Results

3.1. *Anopheles* Fauna and Relative Abundance

Between 2012 and 2014), a total of 6,224 *Anopheles* mosquitoes were collected using HLC and PSC in the five study districts. Six species were identified, with *An. gambiae s.l.* being the predominant vector, accounting for 97.7% of the total catch. The remaining species included *An. funestus* (1%), *An. pharoensis* (0.8%), *An. rufipes* (0.4%), and *An. nili* (0.1%) (Table 1).

Table 1. Anopheline species composition and relative abundance collected by HLC and PSC in the study districts (2012-2014).

Districts	<i>An. gambiae</i>		<i>An. funestus</i>		<i>An. pharoensis</i>		<i>An. rufipes</i>		<i>An. nili</i>	
	n	%	n	%	n	%	n	%	n	%
Kaffrine	685	98	7	1	4	0.6	3	0.4	0	0
Koungheul	400	98	0	0	1	0.2	7	1.8	0	0
Malem Hodar	914	99	3	0.3	7	0.7	0	0	0	0
Kolda	2297	96.2	35	1.4	36	1.5	16	0.7	2	0.2
Velingara	1785	98.8	18	0.9	3	0.2	0	0	1	0

3.2. Indoor Resting Densities (IRD) of *An. gambiae s.l.* in Treated and Control Districts

Given its predominance in all districts (97.7% of collected *Anopheles*), the analysis of entomological parameters focused on *An. gambiae s.l.* Peak mean indoor resting densities (IRD, expressed as females per room, F/R) were 3.5 F/R; 2 F/R, and 1.7 F/R in Malem Hodar, and 3.1 F/R; 4.2 F/R, and 0.6 F/R in Koungheul, and 5.5 F/R; 6.1 F/R, and 2.9 F/R in Kaffrine during 2012, 2013, and 2014 campaigns, respectively (Figure 2 and Figure 3). In Vélingara, peak IRDs reached 3.1 F/R in 2012 and 4.4 F/R in 2013, compared to 6.2 F/R and 7.4 F/R in the control district of Kolda (Figure 4).

During the 2012 season, IRDs were significantly higher in Kolda (control) compared with Velingara (treated) during the second month of follow-up ($p = 0.036$) (Figure 4), and in Kaffrine compared with Malem Hodar at the end of follow-up in November ($p = 0.032$) (Figure 3). In 2013, IRDs were significantly higher in Kaffrine compared with Koungheul in September ($p = 0.032$) (Figure 2), and at the beginning of follow-up ($p = 0.032$) in Kolda compared with Velingara ($p = 0.032$) (Figure 4). In 2014, IRDs were significantly higher in Kaffrine compared

with Kougheul both at the beginning (August, $p = 0.016$) and at the end of follow-up (November, $p = 0.017$) (Figure 2).

In the treated districts (Kougheul, Malem Hodar and Vélingara), the highest IRDs were generally observed during the third month post-treatment (Figures 2-4). In contrast, in the control districts of Kaffrine and Kolda, peak IRDs occurred mainly in August and September, coinciding with the wettest months of the year (Figures 2-4).

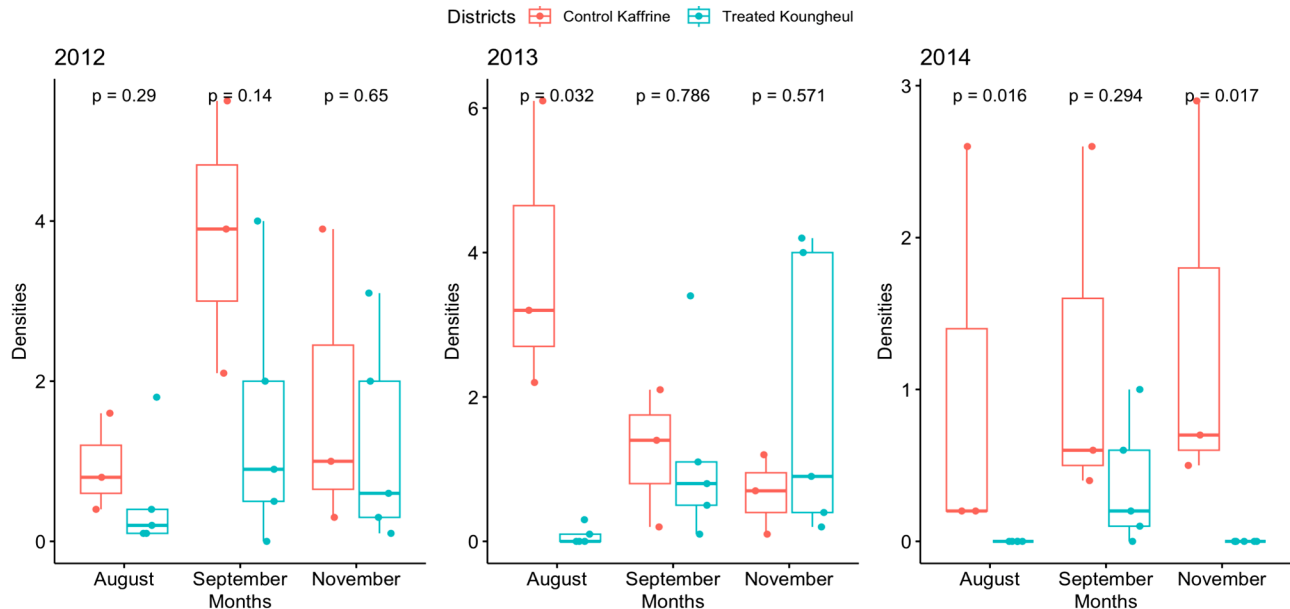


Figure 2. Variations in mean indoor resting densities of *An. gambiae s.l.* between Kougheul (treated) and Kaffrine (control) during the 2012, 2013 and 2014 campaigns.

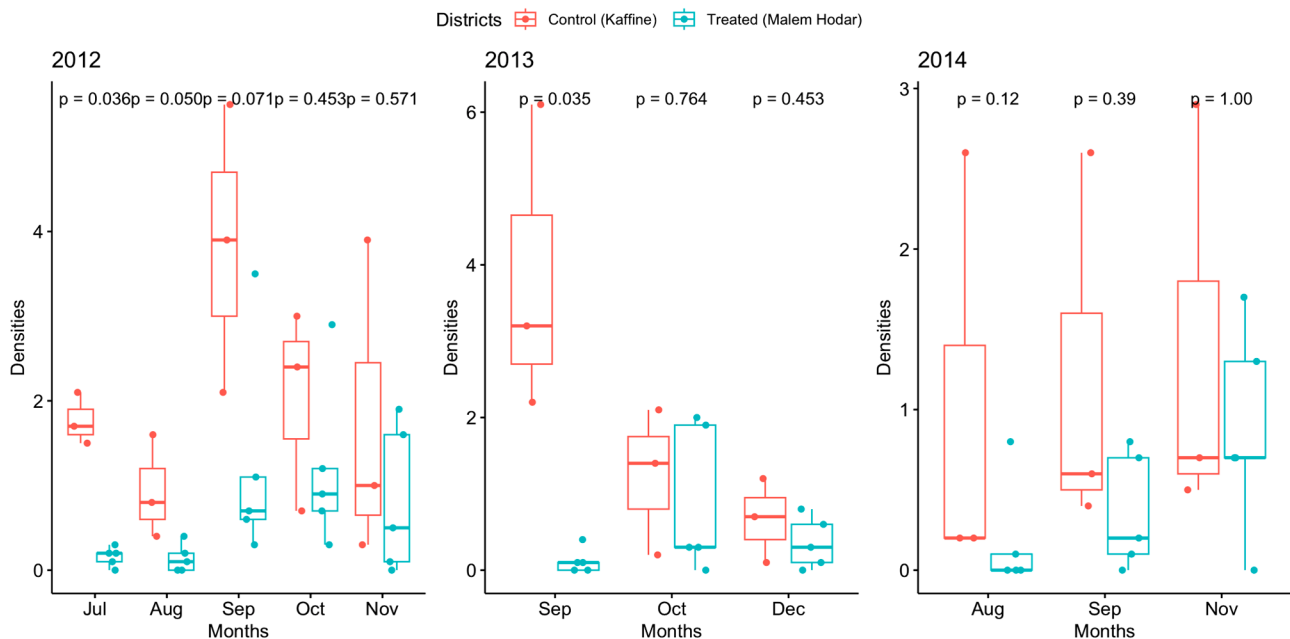


Figure 3. Variations in mean resting densities of *An. gambiae s.l.* between Malem Hodar (treated) and Kaffrine (control) during three campaigns 2012, 2013 and 2014 campaigns.

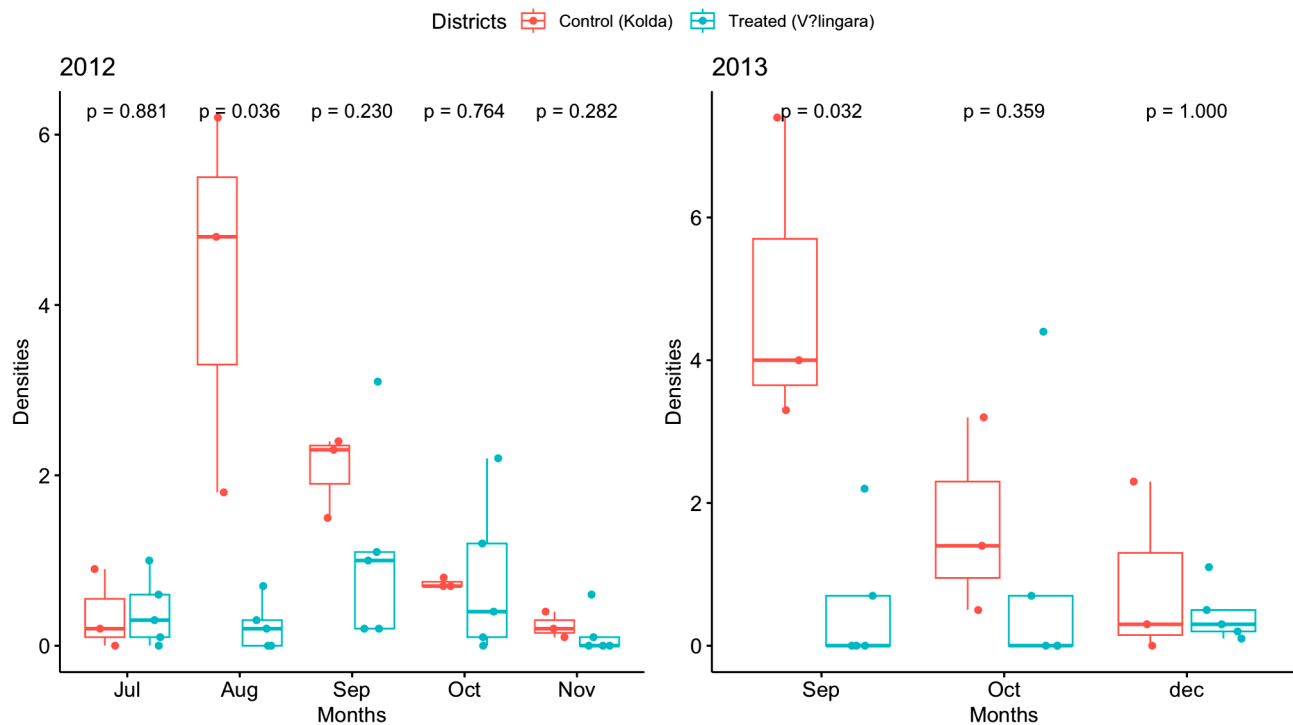


Figure 4. Variations in mean resting densities of *An. gambiae s.l.* between V?lingara (treated) and Kolda (control) during the 2012 and 2013 campaigns.

3.3. Biting Densities between Treated and Untreated Control

During the study campaigns, the highest mean biting rates of *An. gambiae s.l.* females were recorded as follows: 1.25 B/H/N; 0.83 B/H/N and 0.25 B/H/N in Malem Hodar, 3.1 B/H/N; 4.2 B/H/N and 0.6 B/H/N in Koungheul, and 2.58 B/H/N; 5.25 B/H/N and 2 B/H/N in Kaffrine, respectively, in 2012, 2013, and 2014 (Figure 5 and Figure 6).

During the 2012 and 2013 seasons, the highest mean biting rates were observed in V?lingara (30.5 B/H/N in 2012 and 13.5 B/H/N in 2013) and in its control district Kolda (14.5 B/H/N in 2012 and 20.83 B/H/N in 2013) (Figure 7).

Biting densities were significantly higher in Kaffrine compared to Koungheul at the fifth month of follow-up in 2012 ($p = 0.030$) and at the beginning of the monitoring period in July 2013 ($p = 0.026$) (Figure 5). In the treated districts, peaks in biting densities were mainly observed from the third month after treatment. In contrast, in the control districts, the highest peaks were generally observed in August and September, corresponding to the wettest months of the year.

3.4. Endophagy and Exophagy Rates between Control and Treated Sites

Endophagy and exophagy rates were assessed in the treated districts of Koungheul and Malem Hodar, as well as in their untreated control, Kaffrine, over three consecutive years 2012, 2013, and 2014 (Figure 8 and Figure 9). Similar monitoring

was conducted in the treated district of Vélingara and its untreated control, Kolda, during two years (2012 and 2013) (Figure 10). Although reductions in endophagy rates of *An. gambiae s.l.* females were observed in the treated sites, these differences were not statistically significant ($p > 0.05$) throughout the follow-up.

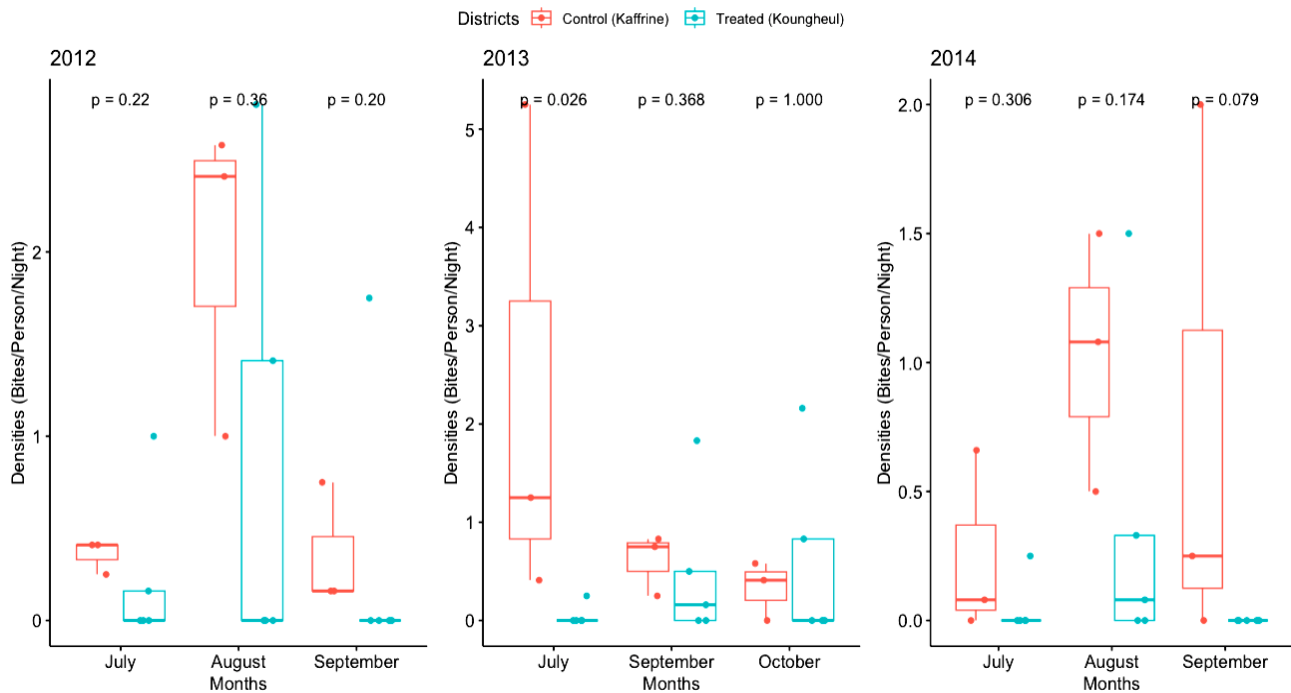


Figure 5. Variations of *An. gambiae s.l.* biting rates between Kaffrine (control) and Koungheul (treated) during the 2012, 2013 and 2014 according to the monitoring months.

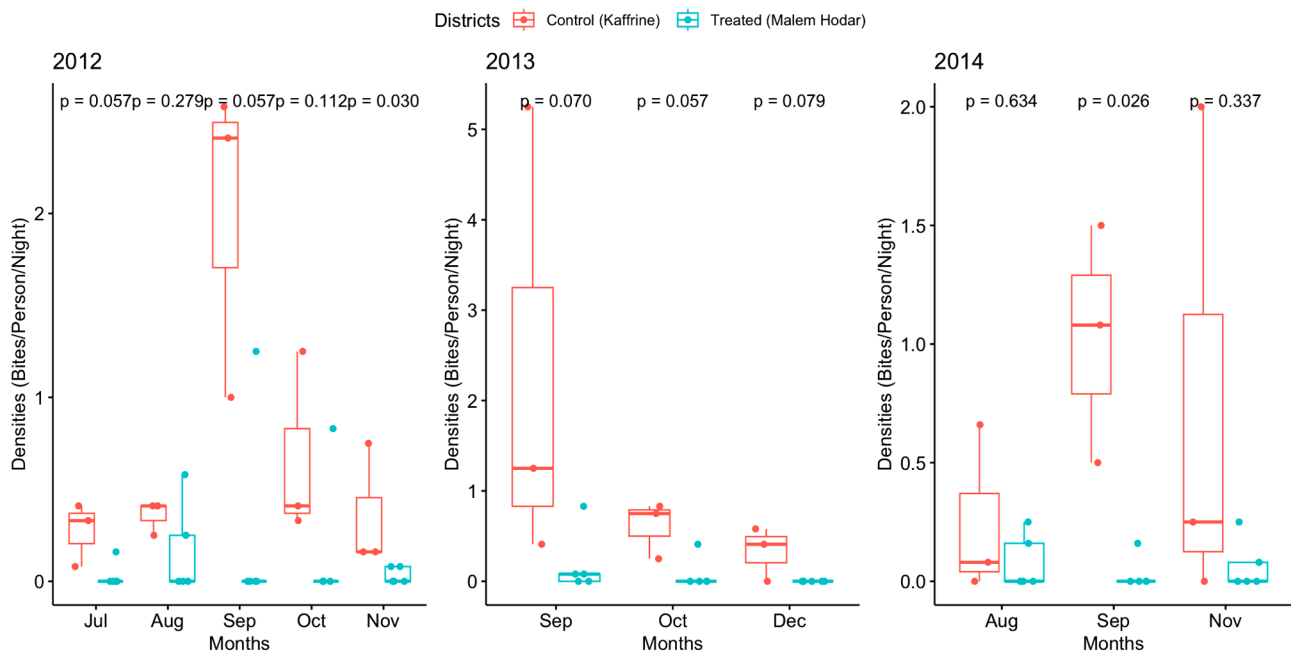


Figure 6. Variations of *An. gambiae s.l.* biting rates between Kaffrine (control) and Malem Hodar (treated) during the 2012, 2013 and 2014 campaigns according on the months of monitoring.

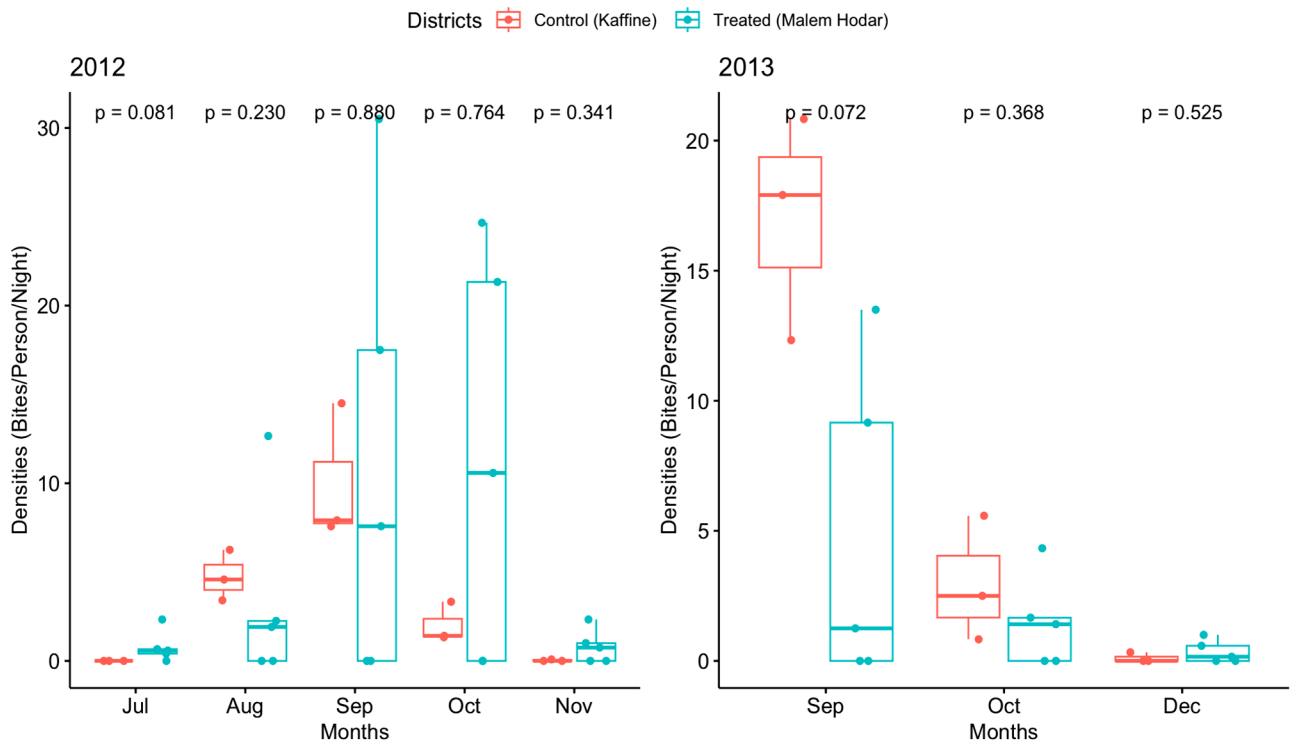


Figure 7. Variation of *An. gambiae s.l.* biting rates in Kolda (control) and Vélingara (treated) during the 2012 and 2013 campaigns according to the months of monitoring.

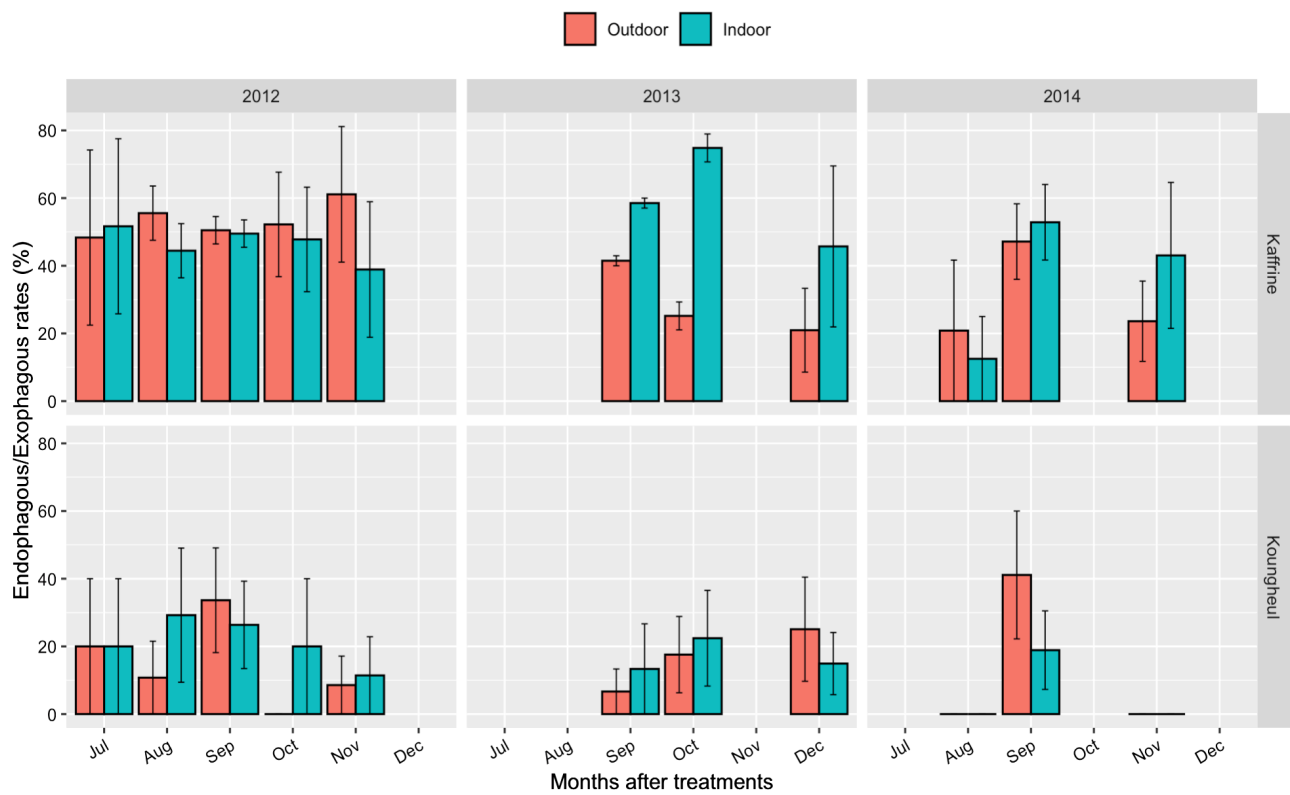


Figure 8. Comparison of exophagy and endophagy rates of *An. gambiae s.l.* between Kounghoul (treated) and Kaffrine (control). The bars represent the 95% confidence interval.

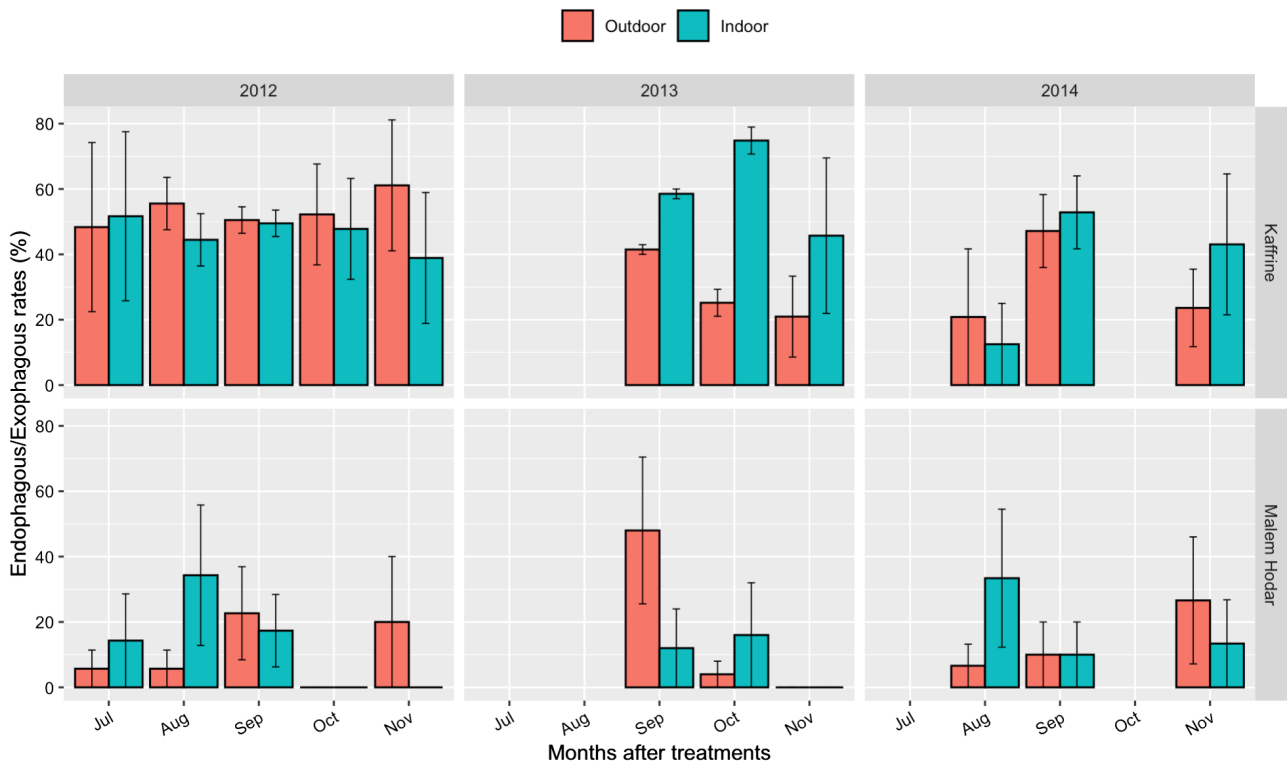


Figure 9. Comparison of exophagy and endophagy rates between Malem Hodar (treated) and Kaffrine (control). The bars represent the 95% confidence interval.

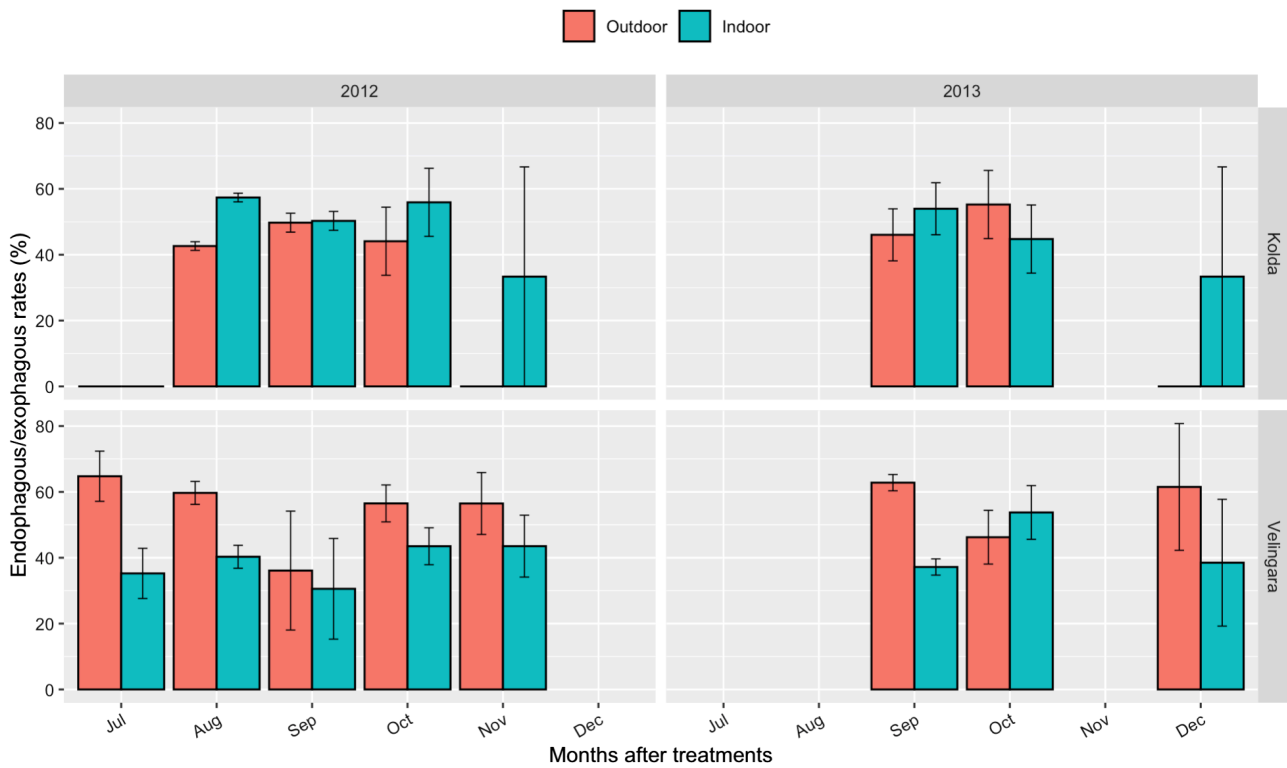


Figure 10. Comparison of exophagy and endophagy rates between Velingara (treated) and Kolda (control). The bars represent the 95% confidence interval.

3.5. Parity Rates of *An. gambiae* between Control and Treated Sites

Parity rates were assessed in the treated districts of Kougheul and Malem Hodar, along with their untreated control in Kaffrine, over three years (2012, 2013, and 2014) (Figure 11 and Figure 12). The same monitoring was conducted in the treated district of Vélingara and its untreated control, Kolda, for two years (2012 and 2013) (Figure 13).

During the follow-up, a significant decrease in parity rates was observed in Vélingara at the second ($\chi^2 = 3.91$, $ddl = 1$, $p = 0.05$) and third ($\chi^2 = 4.05$, $df = 1$, $p = 0.04$) monitoring points in 2012 (Figure 13). In 2013 and 2014, although lower parity rates were generally observed in the treated districts, the only significant difference was recorded in Kaffrine at the second month post-treatment ($\chi^2 = 14.82$, $ddl = 1$, $p = 0.0001$) in 2013 in Kaffrine (Figure 11 and Figure 12).

3.6. Anthropophilic Rate between Control and Treated Sites

The comparative study of trophic preferences was conducted during the 2012 campaign in treated districts (Kougheul, Vélingara and Malem Hodar) and in untreated controls (Kaffrine and Kolda) (Figure 14). The origin of the blood meals of 425 engorged female mosquitoes collected inside human dwellings was determined using direct ELISA. The blood meals were tested against five vertebrate hosts (human, bovine, ovine, chicken and equine). No blood meal was detected from chicken, and the percentage of unidentified meals was estimated at 0.23%.

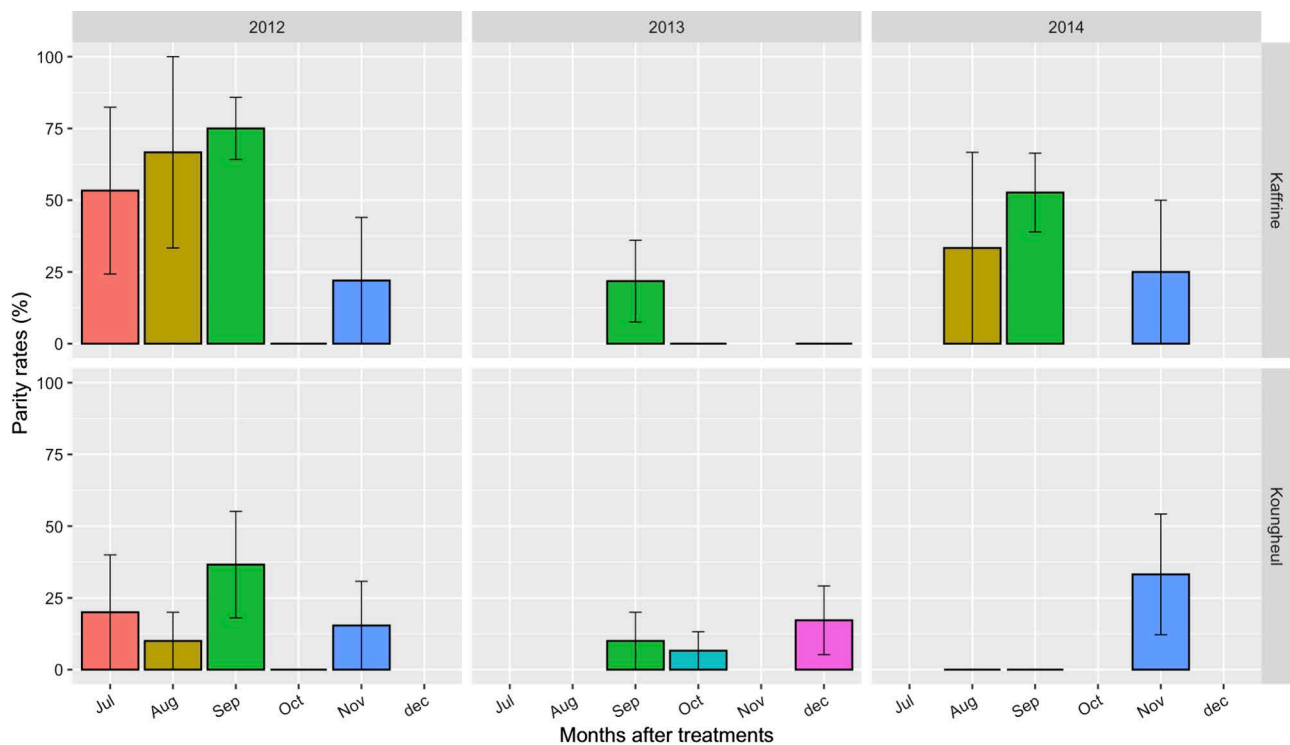


Figure 11. Comparison of parity rates of *An. gambiae s.l.* between Kougheul (treated) and Kaffrine (control). Error bars represent the 95% confidence intervals.

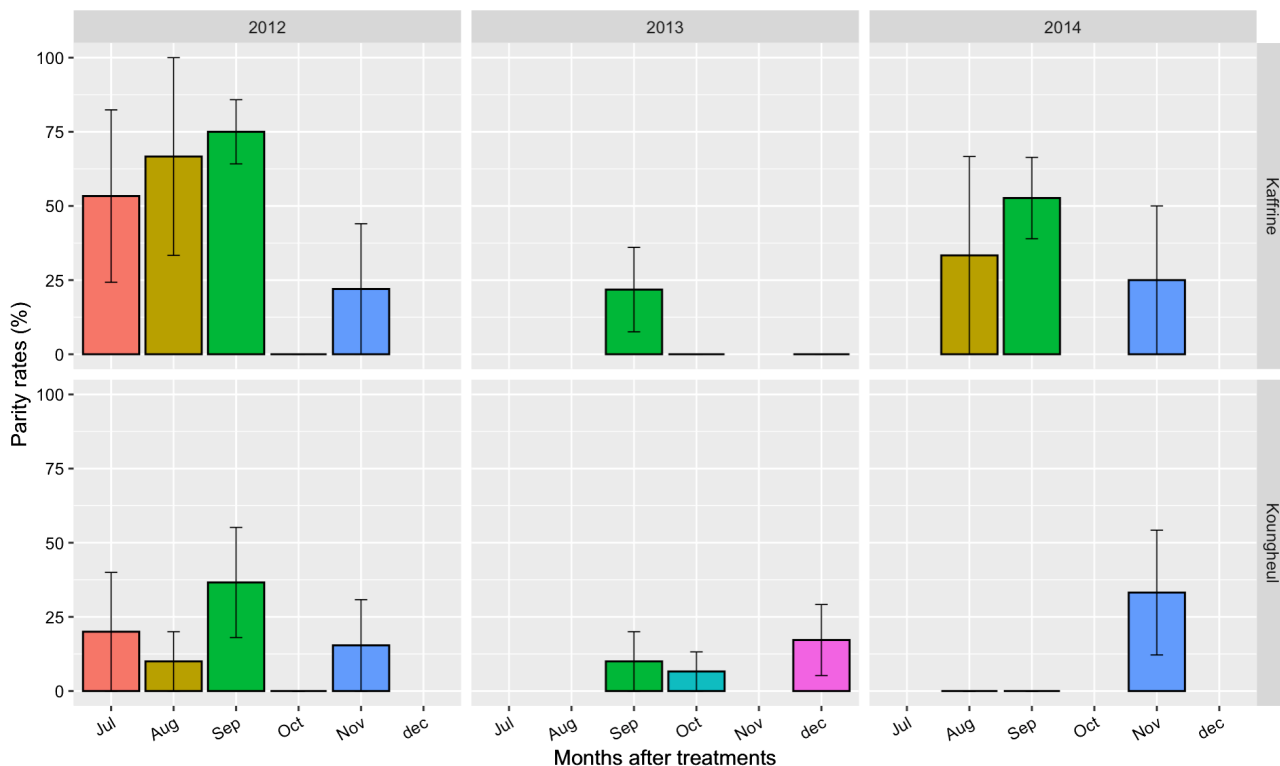


Figure 12. Comparison of parity rates of *An. gambiae s.l.* between Malem Hodar (treated) and Kaffrine (control). Error bars represent the 95% confidence intervals.

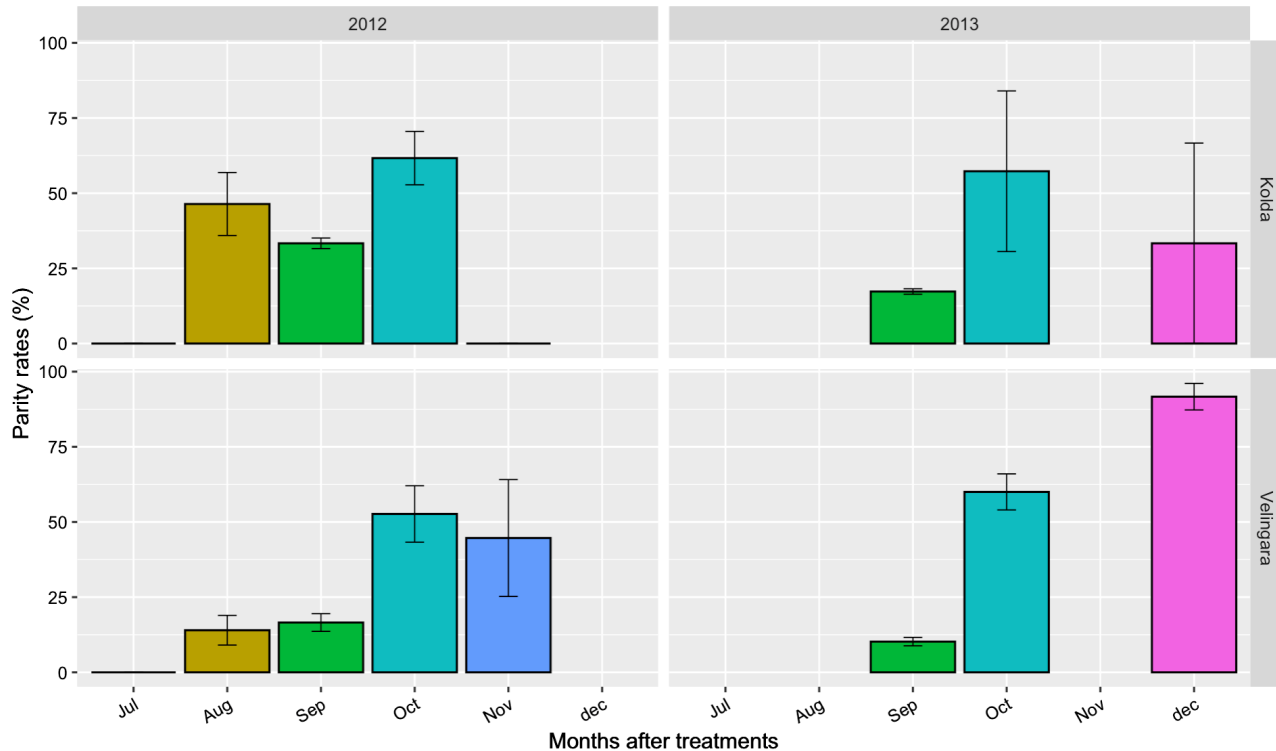


Figure 13. Comparison of parity rates of *An. gambiae s.l.* in Vélingara (treated) and Kolda (control). Error bars represent the 95% confidence intervals.

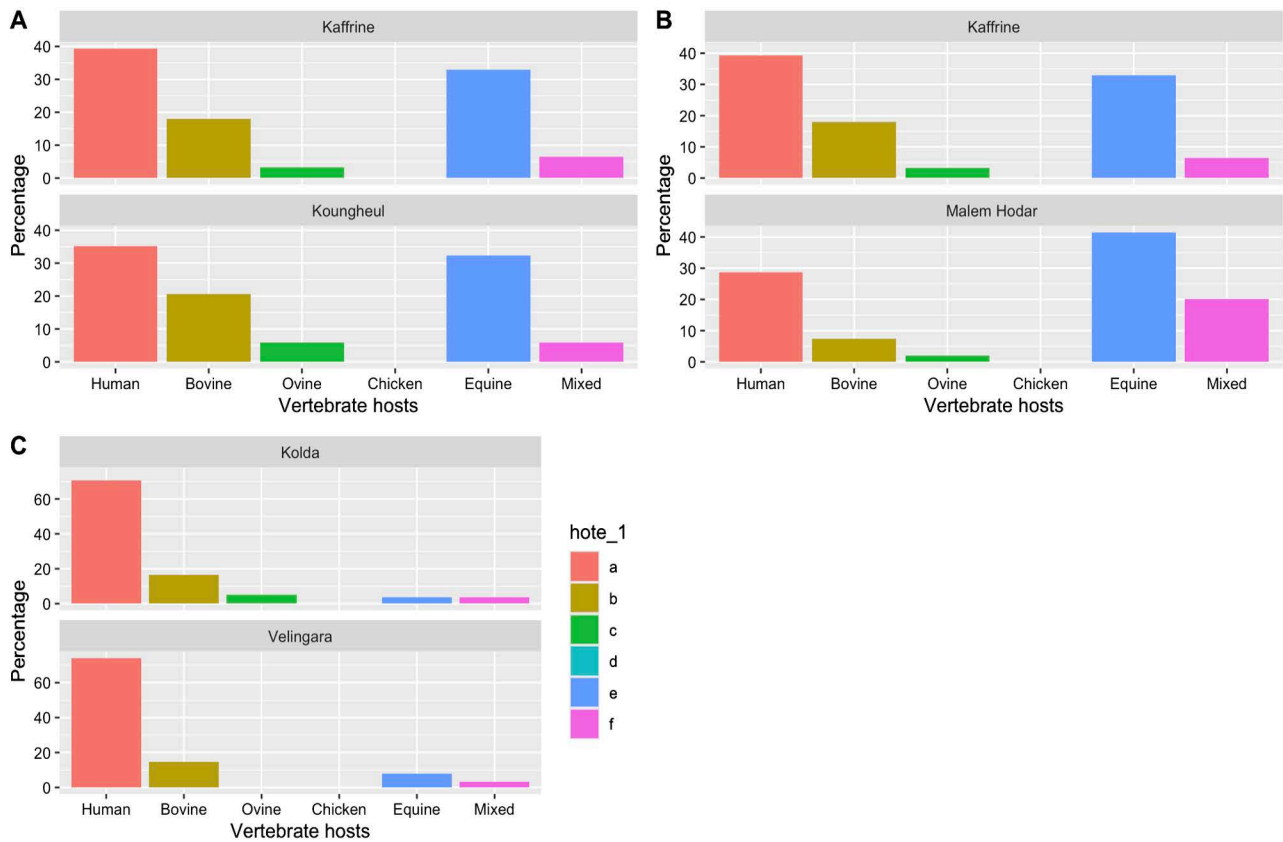


Figure 14. Origin of blood meals of *An. gambiae s.l.* females collected at rest inside human dwellings in treated districts (Koungheul, Vélingara, Malem Hodar) and untreated controls (Kaffrine, Kolda) during the 2012 campaign.

Across the study sites, most blood meals were taken either from horses (notably in Malem Hodar) or from humans (in Kaffrine, Kolda and Vélingara) (Figure 14). A small proportion of specimens (8.5%) fed on at least two hosts. No significant difference was found in the anthropophilic rate between Kaffrine and the treated districts of Malem Hodar ($\chi^2 = 0.19$, $df = 1$, $p = 0.66$) and Koungheul ($\chi^2 = 0.02$, $df = 1$, $p = 0.90$). Similarly, no significant difference was observed between Kolda and Vélingara, ($\chi^2 = 0.009$, $df = 1$, $p = 0.92$) (Figure 14).

3.7. Infection Rates between Treated and Control Districts

The comparison of infection rates was carried out during the 2012 campaign (Table 2). A total of 2571 *An. gambiae s.l.* females collected by HLCs were tested by ELISA for the presence of *P. falciparum* circumsporozoite protein (CSP). Except for the Kolda and Vélingara sites, no infected females were detected in the other districts (Table 2). CSP antigen was detected in 56 *An. gambiae s.l.* specimens, corresponding to an infection rate of 1.9% in Kolda (13/691) in Kolda and 2.6% (43/1636) in Vélingara. No significant difference was observed between the infection rates between in these two sites ($\chi^2 = 0.86$, $ddl = 1$, $p = 0.35$) (Table 2).

Table 2. Infection rates of biting *An. gambiae s.l.* females tested for Plasmodium Falciparum circumsporozoite antigen during the 2012 campaign.

Sites	Tested	Positive	SI (%)
Kaffrine	132	0	0
Kolda	691	13	1.9
M. Hodar	40	0	0
Koungheul	72	0	0
Vélingara	1636	43	2.6

Sporozoite Index (SI).

4. Discussion

The objective of this study was to monitor the post-treatment evolution of key entomological parameters, including species composition, abundance, parity rates, plasmodial infection rates, and biting and resting densities of female vectors, particularly *An. gambiae s.l.*

Post-treatment monitoring of species composition and abundance revealed the presence of *An. gambiae s.l.*, *An. funestus*, *An. pharoensis*, *An. rufipes*, and *An. nili*, with a clear predominance of *An. gambiae s.l.* across all treated and control districts. Such predominance has already been reported throughout sub-Saharan Africa [23] [24], in several ecological zones of Senegal: coastal [25], Sahelian [26], Senegal River basin [27] [28], Sahelo-Sudanian [29] [30], Sudano-Guinean zone [31], where *An. gambiae* members are considered major malaria vectors. This predominance can be explained by the availability of their preferred larval habitats, namely temporary, shallow and sunlit water collections linked to rainfall [17].

The low numbers of *An. funestus* may be related to the scarcity of its preferential sites (permanent habitats such as swamps, lakes and pond margins, grassy riverbanks and flooded zones) [32]. Similarly, the rarity of *An. pharoensis* in our study sites is consistent with its known distribution in Senegal, where it is more abundant in the Senegal River delta [25]. The very limited presence of *An. nili* could be explained by the absence of its preferred well-oxygenated running waters [33]. Finally, the very low numbers of *An. rufipes* observed may reflect its zoophilic behavior, as reported in Dielmo [34], although this species has been described as a potential vector in other African regions [17].

The low biting and resting densities of *An. gambiae s.l.* observed in treated districts could be explained by the stressful environment created large-scale spraying, which deters mosquitoes from entering sprayed houses [35]-[37]. Nevertheless, a fraction proportion of females still manage to enter rooms, obtain a blood meal, and rest briefly before escaping. The gradual increase in densities observed from the third month post-treatment likely reflects the progressive loss of residual activity of bendiocarb on treated walls [38].

In untreated districts, the high vector densities recorded August, September, and October coincide with peak rainfall, confirming the strong seasonality of

Anopheles populations, as also reported in Ghana in 2008 [39] and Cameroon in 2015 [40].

The reduced resting densities in treated houses are consistent with the deterrent effect of IRS. However, slight increase in endophagic rates of *An. gambiae s.l.* observed from the first to the third month post-treatment in Vélingara, without significant differences compared to Kolda (control), may also reflect the decline in bendiocarb efficacy. Similar results have been reported in Bénin in 2011 [35], where IRS with bendiocarb created an unfavorable indoor environment, leading to increased exophilic. Other studies in Equatorial Guinea in 2011 [41] and Tanzania in 2011 [42] have also shown that IRS can shift mosquito behavior towards exophily.

This study also revealed decreased parity rates in treated districts. Such reductions have been documented in other IRS programs [43], reflecting decreased mosquito survival. However, the subsequent increase in parity rates from the fourth month onward may reflect the waning efficacy of bendiocarb.

Regarding blood meal sources, *An. gambiae s.l.* females fed on different vertebrate hosts but preferentially on humans, horses or cattle, depending on the site. The decrease in strictly human blood meals in some treated districts could be explained by both the impact of spraying on host-seeking behavior and the availability of alternative animal hosts. In Vélingara, however, the combination of exophily and high biting rates resulted in higher anthropophilic rates.

The high infection rates recorded in Vélingara, but not in other treated districts, are consistent with these anthropophily findings. Such results corroborate previous hut trials demonstrating the efficacy of carbamates against *An. gambiae s.l.* [34] [44] [45].

Although molecular identification of *An. gambiae* complex members was performed, entomological parameter comparisons in this study were conducted at the complex level, thus, these results were presented separately. Infection rates could only be compared for one district pair and one campaign year as these were the only data collected in parallel.

5. Conclusions

The study demonstrates that indoor residual spraying with bendiocarb significantly impacted entomological parameters in treated areas of Senegal. In particular, biting rates decreased markedly, resting densities were reduced, and parity rates declined. These effects likely contributed to the strong reduction in infection rates observed. However, results from Vélingara highlight that *An. gambiae s.l.* populations in this area exhibit marked exophily, which may limit the impact of IRS. Despite the short residual activity of bendiocarb, our findings confirm that it remains a promising tool for controlling pyrethroid-resistant malaria vectors. Nevertheless, it should not be deployed as a standalone strategy.

Thus, based on these results, the following recommendations can be made:

- 1) implement at least two rounds of IRS to cover the full malaria transmission

season, given the short persistence of bendiocarb;

2) combine IRS with long-lasting insecticide-treated nets to maximize protection and reduce malaria transmission in Senegal.

Authors' Contributions

Cheikh Lo, Ibrahima Dia, and Omar Faye designed and supervised the study. Cheikh Lo, Assane Ndiaye, El Hadji Amadou NIANG, and Ibrahima Dia performed field and laboratory activities. Cheikh Lo and Ibrahima Dia carried out the data analysis. All authors drafted, revised, and approved the final version of the manuscript.

Acknowledgements

We are grateful to the inhabitants of the studied villages for their cooperation and active participation in this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] WHO (2024) World Malaria Report 2024. World Health Organization. <https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2024>
- [2] PNLP (2016) Plan stratégique national de lutte contre le paludisme au Sénégal 2016-2020. <https://www.sante.gouv.sn/sites/default/files/pspnlp.pdf>
- [3] PMI-VectorLink (2020) The President's Malaria Initiative (PMI) VectorLink Project. Senegal Annual Entomology Report (January 2020-December 2020).
- [4] PNLP (2010) Plan stratégique national 2011-2015. https://clr.africanchildforum.org/policy%20per%20country/senegal/senegal_malaria_2011-2015_fr.pdf
- [5] Pluess, B., Tanser, F.C., Lengeler, C. and Sharp, B.L. (2010) Indoor Residual Spraying for Preventing Malaria. *Cochrane Database of Systematic Reviews*, **2010**, CD006657. <https://doi.org/10.1002/14651858.cd006657.pub2>
- [6] Kleinschmidt, I., Schwabe, C., Shiva, M., Segura, J.L., Sima, V., Mabunda, S.J.A., *et al.* (2009) Combining Indoor Residual Spraying and Insecticide-Treated Net Interventions. *The American Journal of Tropical Medicine and Hygiene*, **81**, 519-524. <https://doi.org/10.4269/ajtmh.2009.81.519>
- [7] Kouznetsov, R.L. (1977) Malaria Control by Application of Indoor Spraying of Residual Insecticides in Tropical Africa and Its Impact on Community Health. *Tropical Doctor*, **7**, 81-91. <https://doi.org/10.1177/004947557700700216>
- [8] Mabaso, M.L.H., Sharp, B. and Lengeler, C. (2004) Historical Review of Malarial Control in Southern African with Emphasis on the Use of Indoor Residual House-Spraying. *Tropical Medicine & International Health*, **9**, 846-856. <https://doi.org/10.1111/j.1365-3156.2004.01263.x>
- [9] Sharp, B., Van Wyk, P., Sikasote, J.B., Banda, P. and Kleinschmidt, I. (2002) Malaria Control by Residual Insecticide Spraying in Chingola and Chililabombwe, Copperbelt

- Province, Zambia. *Tropical Medicine & International Health*, **7**, 732-736. <https://doi.org/10.1046/j.1365-3156.2002.00928.x>
- [10] Teklehaimanot, H.D., Teklehaimanot, A., Kiszewski, A., Rampao, H.S. and Sachs, J.D. (2009) Malaria in São Tomé and Príncipe: On the Brink of Elimination after Three Years of Effective Antimalarial Measures. *The American Journal of Tropical Medicine and Hygiene*, **80**, 133-140. <https://doi.org/10.4269/ajtmh.2009.80.133>
- [11] Tseng, L.F., Chang, W.C., Ferreira, M.C., Wu, C.H., Rampão, H.S. and Lien, J.C. (2008) Rapid Control of Malaria by Means of Indoor Residual Spraying of Alphacypermethrin in the Democratic Republic of São Tomé and Príncipe. *The American Journal of Tropical Medicine and Hygiene*, **78**, 248-250. <https://doi.org/10.4269/ajtmh.2008.78.248>
- [12] PNLP (2009) Rapport annuel des activités de lutte contre le paludisme. <https://dhsprogram.com/pubs/pdf/MIS5/MIS5%5BRevised30Sep2009%5D.pdf>
- [13] PNLP (2017) Plan national de gestion de la résistance des vecteurs du paludisme aux insecticides au Sénégal 2017-2020. <https://www.medbox.org/document/plan-national-de-gestion-de-la-resistance-des-vecteurs-du-paludisme-aux-insecticides-au-senegal-2017-2020>
- [14] Dia, A.K., Guèye, O.K., Niang, E.A., Diédhiou, S.M., Sy, M.D., Konaté, A., et al. (2018) Insecticide Resistance in *Anopheles arabiensis* Populations from Dakar and Its Suburbs: Role of Target Site and Metabolic Resistance Mechanisms. *Malaria Journal*, **17**, Article No. 116. <https://doi.org/10.1186/s12936-018-2269-6>
- [15] Lo, C., Dia, A.K., Dia, I., Niang, E.H.A., Konaté, L. and Faye, O. (2019) Évaluation de l'efficacité résiduelle de la pulvérisation intradomiliaire de bendiocarbe (FICAM WP 80) dans six districts sanitaires du Sénégal. *Malaria Journal*, **18**, Article No. 198.
- [16] Niang, E.H.A., Konaté, L., Faye, O., Diallo, M. and Dia, I. (2019) Vector Bionomics and Malaria Transmission in an Area of Sympatry of *An. arabiensis*, *An. coluzzii* and *An. gambiae*. *Acta Tropica*, **189**, 129-136. <https://doi.org/10.1016/j.actatropica.2018.10.005>
- [17] Gillies, M.T. and De Meillon, B. (1968) The Anophelinae of Africa South of the Anophelinae of Africa South of the Sahara (Ethiopian Zoogeographical Region). 343.
- [18] Detinova, T.S. (1962) Age-Grouping Methods in Diptera of Medical Importance: With Special Reference to Some Vectors of Malaria. *The Journal of Parasitology*, **48**, Article No. 456. <https://doi.org/10.2307/3275215>
- [19] Burkot, T.R., Williams, J.L. and Schneider, I. (1984) Identification of *Plasmodium falciparum*-Infected Mosquitoes by a Double Antibody Enzyme-Linked Immunosorbent Assay. *The American Journal of Tropical Medicine and Hygiene*, **33**, 783-788. <https://doi.org/10.4269/ajtmh.1984.33.783>
- [20] Wirtz, R.A., Zavala, F., Charoenvit, Y., Campbell, G.H., Burkot, T.R., Schneider, I., Esser, K.M. and Andre, R.G. (1987) Comparative Testing of Monoclonal Antibodies against *Plasmodium falciparum* Sporozoites for ELISA Development. *Bulletin of the World Health Organization*, **65**, 39-45.
- [21] Beier, J.C., Perkins, P.V., Wirtz, R.A., Koros, J., Diggs, D., Gargan, T.P., et al. (1988) Bloodmeal Identification by Direct Enzyme-Linked Immunosorbent Assay (Elisa), Tested on Anopheles (Diptera: Culicidae) in Kenya. *Journal of Medical Entomology*, **25**, 9-16. <https://doi.org/10.1093/jmedent/25.1.9>
- [22] R Core Team R (2016) A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. <http://www.R-project.org/>
- [23] Le Bras, M., Soubiran, G., Baraze, A., Meslet, B., Combe, A., Giap, G. and Fabre, A.

- (1986) Paludisme urbain et rural au Niger. Le cas du département de Maradi. *Bulletin de la Société de Pathologie Exotique*, **79**, 695-706.
- [24] Robert, V., Gazin, P., Ouedraogo, V. and Carnevale, P. (1986) Le paludisme urbain à Bobo-Dioulasso (Burkina Faso). *Cahiers ORSTOM série entomologie médicale et parasitologie*, **24**, 121-128.
- [25] Faye, O., Gaye, O., Fontenille, D., Sy, N., Konate, L., Hébrard, G., Hervé, J.P., Trouillet, J., Diallo, S. and Mouchet, J. (1995) Comparaison de la transmission du paludisme dans deux faciès épidémiologiques au Sénégal: La zone côtière sahélienne et la zone méridionale soudanienne. *Dakar Médical*, **40**, 201-207.
- [26] Dia, I., Konate, L., Samb, B., Sarr, J., Diop, A., Rogerie, F., et al. (2008) Bionomics of Malaria Vectors and Relationship with Malaria Transmission and Epidemiology in Three Physiographic Zones in the Senegal River Basin. *Acta Tropica*, **105**, 145-153. <https://doi.org/10.1016/j.actatropica.2007.10.010>
- [27] Vercruysse, J. (1985) Etude entomologique sur la transmission du paludisme humain dans le bassin du fleuve Sénégal (Sénégal). *Annales de la Société Belge de Médecine Tropicale*, **65**, 171-179.
- [28] Petrarca, V., Vercruysse, J. and Coluzzi, M. (1987) Observations on the *Anopheles gambiae* Complex in the Senegal River Basin, West Africa. *Medical and Veterinary Entomology*, **1**, 303-312. <https://doi.org/10.1111/j.1365-2915.1987.tb00359.x>
- [29] Konate, L., Diagne, N., Brahim, K., Faye, O., Legros, F., Rogier, C., et al. (1994) Biologie des vecteurs et transmission de *Plasmodium falciparum*, *P. malariae* et *P. ovale* dans un village de savane d'Afrique de l'ouest (Dielmo, Sénégal). *Parasite*, **1**, 325-333. <https://doi.org/10.1051/parasite/1994014325>
- [30] Fontenille, D., Lochouart, L., Diagne, N., Sokhna, C., Lemasson, J., Diatta, M., et al. (1997) High Annual and Seasonal Variations in Malaria Transmission by Anophelines and Vector Species Composition in Dielmo, a Holoendemic Area in Senegal. *The American Journal of Tropical Medicine and Hygiene*, **56**, 247-253. <https://doi.org/10.4269/ajtmh.1997.56.247>
- [31] Dia, I., Diop, T., Rakotoarivony, I., Kengne, P. and Fontenille, D. (2003) Bionomics of *Anopheles gambiae* Giles, *An. arabiensis* Patton, *An. funestus* Giles and *An. nili* (Theobald) (Diptera: Culicidae) and Transmission of *Plasmodium falciparum* in a Sudano-Guinean Zone (Ngari, Senegal). *Journal of Medical Entomology*, **40**, 279-283. <https://doi.org/10.1603/0022-2585-40.3.279>
- [32] Hamon, J., Abonnenc, E. and Noël, E. (1955) Contribution à l'étude des Culicidés de l'Ouest du Sénégal. *Annales de Parasitologie Humaine et Comparée*, **30**, 278-308. <https://doi.org/10.1051/parasite/1955303278>
- [33] Hamon, J. and Mouchet, J. (1961) Les vecteurs secondaires du paludisme humain en Afrique. *Médecine Tropicale*, **21**, 643-660.
- [34] Konaté, L., Faye, O., Gaye, O., Sy, N., Diop, A., Diouf, M., et al. (1999) Zoophagie et hôtes alternatifs des vecteurs du paludisme au Sénégal. *Parasite*, **6**, 259-267. <https://doi.org/10.1051/parasite/1999063259>
- [35] Akogbeto, M., Padonou, G.G., Bankole, H.S., Gazard, D.K. and Gbedjissi, G.L. (2011) Dramatic Decrease in Malaria Transmission after Large-Scale Indoor Residual Spraying with Bendiocarb in Benin, an Area of High Resistance of *Anopheles gambiae* to Pyrethroids. *The American Society of Tropical Medicine and Hygiene*, **85**, 586-593. <https://doi.org/10.4269/ajtmh.2011.10-0668>
- [36] N'Guessan, R., Boko, P., Odjo, A., Chabi, J., Akogbeto, M. and Rowland, M. (2010) Control of Pyrethroid and DDT-Resistant *Anopheles gambiae* by Application of Indoor Residual Spraying or Mosquito Nets Treated with a Long-Lasting Organophos-

- phate Insecticide, Chlorpyrifos-Methyl. *Malaria Journal*, **9**, Article No. 44. <https://doi.org/10.1186/1475-2875-9-44>
- [37] Djènontin, A., Chandre, F., Dabiré, K.R., Chabi, J., N'Guessan, R., Baldet, T., *et al.* (2010) Indoor Use of Plastic Sheeting Impregnated with Carbamate Combined with Long-Lasting Insecticidal Mosquito Nets for the Control of Pyrethroid-Resistant Malaria Vectors. *The American Society of Tropical Medicine and Hygiene*, **83**, 266-270. <https://doi.org/10.4269/ajtmh.2010.10-0012>
- [38] WHO (2015) Indoor Residual Spraying: An Operational Manual for Indoor Residual Spraying (IRS) for Malaria Transmission Control and Elimination. <https://www.who.int/publications/i/item/9789241508940>
- [39] Klinkenberg, E., McCall, P., Wilson, M.D., Amerasinghe, F.P. and Donnelly, M.J. (2008) Impact of Urban Agriculture on Malaria Vectors in Accra, Ghana. *Malaria Journal*, **7**, Article No. 151. <https://doi.org/10.1186/1475-2875-7-151>
- [40] Akono, P.N., Tonga, C., Mbida, J.A.M., Hondt, O.E.N., Ambene, P.A., Ndo, C., *et al.* (2015) *Anopheles gambiae*, vecteur majeur du paludisme à Logbessou, zone péri-urbaine de Douala (Cameroun). *Bulletin de la Société de Pathologie Exotique*, **108**, 360-368. <https://doi.org/10.1007/s13149-015-0452-3>
- [41] Reddy, M.R., Overgaard, H.J., Abaga, S., Reddy, V.P., Caccone, A., Kiszewski, A.E., *et al.* (2011) Outdoor Host Seeking Behaviour of *Anopheles gambiae* Mosquitoes Following Initiation of Malaria Vector Control on Bioko Island, Equatorial Guinea. *Malaria Journal*, **10**, Article No. 184. <https://doi.org/10.1186/1475-2875-10-184>
- [42] Russell, T.L., Govella, N.J., Azizi, S., Drakeley, C.J., Kachur, S.P. and Killeen, G.F. (2011) Increased Proportions of Outdoor Feeding among Residual Malaria Vector Populations Following Increased Use of Insecticide-Treated Nets in Rural Tanzania. *Malaria Journal*, **10**, Article No. 80. <https://doi.org/10.1186/1475-2875-10-80>
- [43] Hamon, J. and Garrett-Jones, C. (1963) La résistance aux insecticides chez des vecteurs majeurs du paludisme et son importance opérationnelle. *Bulletin of the World Health Organization*, **28**, 1-24.
- [44] Djènontin, A., Chabi, J., Baldet, T., Irish, S., Pennetier, C., Hougard, J., *et al.* (2009) Managing Insecticide Resistance in Malaria Vectors by Combining Carbamate-Treated Plastic Wall Sheeting and Pyrethroid-Treated Bed Nets. *Malaria Journal*, **8**, Article No. 233. <https://doi.org/10.1186/1475-2875-8-233>
- [45] Akogbéto, M.C., Padonou, G.G., Gbénou, D., Irish, S. and Yadouleton, A. (2010) Bendiocarb, a Potential Alternative against Pyrethroid Resistant *Anopheles gambiae* in Benin, West Africa. *Malaria Journal*, **9**, Article No. 204. <https://doi.org/10.1186/1475-2875-9-204>

Abbreviations

B/H/N	Bites per human per night
ELISA CSP	Enzyme-Linked Immunosorbent Assay circumsporozoite
F/R	females per room
HLC	Human landing catch method
IRS	Indoor residual spraying
IRD	indoor resting densities
SI	Sporozoite Index
LLINs	Long-lasting insecticidal nets
PSC	Pyrethrum Spray Catch
WP	wet powder
WHO	World Health Organization