



Evaluation of Insecticides Resistance in Culex Mosquitoes to DDT, Deltamethrin, Permethrin and PBO (Synergy) in Gombe Metropolis, Nigeria

Christopher Danladi ^{a*}, William Nuhu ^a,
Emmanuel Chinedu Nnadi ^b and Lazarus J Goje ^a

^a Department of Biochemistry, Faculty of Science, PMB 127 Gombe State University, Nigeria.

^b Department of Science Laboratory Technology, University of Nigeria Nsuka, Enugu State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/sajp/2024/v7i4204>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/127609>

Original Research Article

Received: 02/10/2024

Accepted: 04/12/2024

Published: 11/12/2024

ABSTRACT

Aims: To evaluate the resistance of Culex mosquitoes in Zagaina, Gombe State, to commonly used insecticides, providing insights for managing insecticide resistance in disease vector control.

Study Design: Cross-sectional susceptibility bioassay study.

Place and Duration of Study: This study was conducted Gombe State University Malaria Vector Sentinel Laboratory over three months (October-December).

Methodology: Approximately 600 Culex mosquito larvae and pupae were collected from blocked and improperly maintained drainages in Zagaina community using standard dipping techniques.

*Corresponding author: E-mail: danladichristopher425@gmail.com;

Cite as: Danladi, Christopher, William Nuhu, Emmanuel Chinedu Nnadi, and Lazarus J Goje. 2024. "Evaluation of Insecticides Resistance in Culex Mosquitoes to DDT, Deltamethrin, Permethrin and PBO (Synergy) in Gombe Metropolis, Nigeria". *South Asian Journal of Parasitology* 7 (4):401-10. <https://doi.org/10.9734/sajp/2024/v7i4204>.

The collected mosquitoes were reared to adulthood in an insectary at Gombe State University. Female *Culex* mosquitoes were separated and subjected to a time-course exposure bioassay using CDC bioassay tubes, following WHO guidelines for evaluating insecticide resistance in vectors. WHO-impregnated papers were used to test susceptibility to four insecticides: DDT, Permethrin, Deltamethrin, and Piperonyl Butoxide (PBO). The knockdown rate was assessed followed by Mortality rate of 24 hours post-exposure, with no correction needed as control mortality was zero.

Results: High resistance was observed across all tested insecticides, with mortality rates of 15% for DDT, 7% for Permethrin, 65% for Deltamethrin, and 69% for PBO. These results indicate that *Culex* mosquitoes in Zagaina community exhibit significant resistance to DDT and Permethrin, moderate resistance to Deltamethrin, and lower resistance to PBO.

Conclusion: The insecticide resistance observed in *Culex* mosquitoes indicate an urgent need to investigate the genetic or metabolic mechanisms of resistance. Monitoring resistance patterns over time is essential for developing effective vector control strategies to combat mosquito-borne diseases.

Keywords: Insecticides resistance; culex mosquitoes; DDT; deltamethrin; permethrin; PBO (synergy).

1. INTRODUCTION

“Mosquitoes represent a critical danger for millions of people around the world. They are significant vectors of human diseases such as malaria, filariasis, yellow fever, dengue fever and encephalitis, besides allergic responses include local skin and systemic reactions such as angioedema, and urticaria” [1,2,3]. “Mosquito-borne diseases, such as filariasis, and arboviruses, are major public health concerns worldwide, contributing significantly to morbidity and mortality, especially in tropical regions. Among the various mosquito species, *Culex* mosquitoes are key vectors of diseases such as lymphatic filariasis and West Nile Virus, posing a considerable threat to both human and animal populations” [4]. *Culex pipiens* (Diptera: Culicidae) is one of the most common mosquito insects in rural and urban zones [5]. “*Culex* mosquitoes are vectors of several pathogens causing infectious diseases of public health importance. These includes lymphatic filarial nematodes and arboviral infections. Blocked and improperly maintained drainages have been reported to serves as habitats for the *Culex* species and other disease vectors” [6]. “Globally, *Culex* mosquitoes have been implicated in the transmission of diseases, which has led to significant outbreaks in various parts of the world” [7]

“A large number of studies have shown that multiple, complex resistance mechanisms in particular, increased metabolic detoxification of insecticides and decreased sensitivity of the target proteins or genes are likely responsible for insecticide resistance. Gene overexpression and amplification, and mutations in protein coding-

gene regions, have frequently been implicated as well. Six classes of insecticides namely, organochlorines, organophosphates (OP), carbamates, pyrethroids, pyrroles, and phenyl pyrazoles are recommended for use against adult mosquitoes [8]. Indoor residual spraying and long-lasting insecticidal nets treated with pyrethroids are the two most important measures for human protection from malaria-carrying mosquitoes” [8]. “In the past, massive sprayings of insecticides greatly limited mosquito-borne diseases and even eradicated lymphatic filariasis and malaria in a few areas. However, the widespread development of resistance in mosquitoes to the most commonly used insecticides is now causing serious problems in many areas” [9]. This has resulted in a number of outbreaks of mosquito-related diseases in recent years [10]. “The use of insecticides is the corner stone of mosquito-borne diseases control, either as indoor residual spraying (IRS) or the long-lasting insecticidal nets (LLINs). However, rampant insecticides resistance reported across the world [4], e.g. in Northern Nigeria” [11] is threatening the success of VBDs control. The use of agricultural pesticides has led to the increasing insecticide resistance. “The knowledge of the distribution of VBDs and their insecticides resistance profile is important before using any of the above control tools. Vector control is a very important part of the global strategy for management of mosquito associated diseases, and insecticide application is the most important component in this effort. However, mosquito-borne diseases are now resurgent, largely because of the insecticide resistance that has developed in mosquito vectors and the drug resistance of pathogens Numerous studies have shown that insecticide resistance in mosquitoes

is often due to complex mechanisms, including increased metabolic detoxification and reduced sensitivity of target proteins. Gene overexpression, gene amplification, and mutations in coding regions of resistance-associated genes are common contributors” [12]

Culex mosquito is known to be a major vector that transmit zoonotic diseases which affect humans and wild and domestic animals, such as lymphatic filariasis [13] commonly found in Gombe. “Mosquito bite has been a major public health problem with malaria and lymphatic filariasis as major diseases in Nigeria and Gombe state in particular” [14]. Available literature on the disease from both the North and Central parts of Nigeria and the report of a postal survey by the Nigerian Lymphatic Filariasis Elimination Programme (NLFEP) have shown that lymphatic filariasis is endemic [15]. “Lack of information on the distribution and degree of risk of the disease in the country are the greatest challenges confronting the NLFEP. Despite extensive research on mosquito resistance, there is limited data on the resistance patterns of Culex mosquitoes in northern Nigeria, particularly in Gombe State. Understanding these patterns is crucial for developing localized mosquito control programs and for reducing the spread of mosquito-borne diseases. Previous studies have focused more on Anopheles mosquitoes, leaving a gap in the comprehensive understanding of resistance in Culex species. In Gombe State, the frequent use of insecticides for agricultural and domestic purposes may contribute to the development of resistance in Culex mosquitoes. The lack of updated, localized data on resistance levels hinders the development of effective vector control strategies in the region” [16].

The main objectives of this study, is to evaluate the insecticide susceptibility and resistance status of adult Culex mosquitoes to deltamethrin, permethrin and DDT. Additionally, it will assess the potential synergistic effects of piperonyl butoxide (PBO) on insecticide efficacy to inform public health interventions. Specifically, it will assess the resistance status of local mosquito populations using standard bioassay techniques.

2. MATERIALS AND METHODS

2.1 Study Site

This cross-sectional research was conducted in Zagaina, Akko Local Government Area, Gombe State, Nigeria, within the period of November–

December 2022. Akko is one of the 11 local governments of Gombe State. The state is bounded to the North by Yobe State, North-East by Borno State, South by Taraba State, South-East by Adamawa State, and in the West by Bauchi State. The state has an area of 20,265km² and a population of around 1.8 million. The state is characterized by two distinct seasons, which are dry season (November to December) and wet season (April to October) [17].

2.2 Sampling Locations

Gombe State is located in the North Eastern part of Nigeria and lies in Sudan savannah vegetations with eleven (11) local governments. Samples were collected within 3 different breeding sites located at Zagaina, Akko local government of Gombe State with the following specification: Latitude: 10° 61'60" N and Longitude: 10°57 59.99'E

2.3 Sample Collection (Culex Larva)

Third to fourth instar larva and pupae of Culex mosquito larvae were collected from Zagaina community. Culex larvae were collected from natural breeding sites (small pools and puddles) using dipping method during the month of October to December, 2022. Coordinate of the study sites were established using global positioning system (GPS). The immature Culex mosquitoes collected were transported to Gombe State University Malaria Vector Sentinel Lab, they were reared to adult. The emerging adult Culex mosquitoes were placed in adult cage using mouth aspirator and fed with 10% sugar solution soaked in cotton wool.

2.4 Adult Feeding

10% sucrose was used to feed adult mosquitoes in the lab. The sugar solution was provided by soaking cotton with sucrose solution and then placed on top of a cage. Cotton was wet enough with sucrose and allowed the mosquitoes sucked it.

2.5 Insecticide Bioassays

Insecticide susceptibility bioassays were performed as per WHO standard guideline (WHO 2016). Three to five days old, non-blood-fed female Culex mosquitoes were exposed to insecticide impregnated papers with discriminating concentrations of deltamethrin

(0.05%), permethrin (0.75%), DDT (4.0%) and POB synergy (4.0%) using WHO standard assays [8]

A total of 600 mosquitoes in 4 replicates were used for the insecticide bioassays. 25 unfed female *Culex* mosquitoes of 3-5 days old were introduced into four(4) CDC holding tubes coated with a white clean paper and four (4) control tubes coated with a clean white paper too. This were provided by Center for Disease Control (CDC) Atlanta Georgia as describe by the guidelines for evaluating insecticides resistance in vector using CDC tube bioassay([8]. The *Culex* mosquitoes earlier introduced into eight (8) holding tube(replicate) were exposed in the holding tube for 30mins, Bioassays were carried out at $25\pm 2^{\circ}\text{C}$ and $75 \pm 10\%$ RH.

The *Culex* mosquitoes were then exposed CDC tubes coated with the insecticides (impregnated papers) and was exposed for 1 hour. The knockdown after 60 minutes was observed. The number of dead and live mosquitoes were monitored at different time interval (10, 15, 20, 30, 40, 50, & 60)mins. The mortality of test sample was calculated by summing the number of dead mosquitoes across all exposure replicates and then expressing this as a percentage of the total number of exposed mosquitoes.[8]

Observed Mortality(%) = Total number of dead mosquitoes / Total sample size X 100

The knockdown percentage for the test mosquitoes were calculated using the formula bellow

Knockdown (%) = Number of mosquitoes that died / Total number of mosquitoes x 100

The control mortality was zero (0), so there was no need for abbot's correction. This allow determination of total %mortality against time for all replicates. The tested mosquitoes were stored in microcentrifuge for further analysis.

2.6 Synergist Bioassay

Synergist bioassays were performed to assess possible involvement of insecticide resistance mechanisms in field-collected, *Culex* mosquitoes from study area. One synergy was used in this study, namely PBO (Sigma, USA) an inhibitor of monooxygenases. The synergist (4%) impregnated papers and insecticide-impregnated

papers were procured from VCRU. Two treatments were compared for each test: insecticide alone and synergist + insecticide combination. In the insecticide alone, test mosquitoes were exposed to insecticide-impregnated papers for 1hr and during the synergist + insecticide combination assay mosquitoes were exposed for first 1hr to synergist impregnated papers followed by 1hr to the insecticide impregnated papers. After exposures mosquitoes were transferred to holding tubes for 24-h holding period and analyzed to determine percentage mortality.

2.7 Statistical Analysis

The percentage mortality of the mosquitoes exposed to each of the insecticides was calculated as the proportion of mosquitoes that died at the diagnostic time for each of the insecticides. Correction with Abbott's formula was not necessary as control mortalities was less than 5% throughout the test, mortality of replicates were determined for each insecticide. The WHO criterion for evaluating resistance or susceptibility was used mortality of less than 80% indicate resistance, while those greater than 98% indicate susceptibility. The Knock down data was subjected to probit analysis using statistical software (Statsdirect, 2013) to compute the KDT_{50} and KDT_{90} (Time taken to knock down 50% and 90% of the exposed mosquitoes. Analysis of Variance (ANOVA) was also used to compare the mortalities across the insecticide.

3. RESULTS

3.1 Susceptibility Bioassay

The KDT_{50} and KDT_{90} results of female *Culex* mosquitoes exposed to DDT, Permethrin, Deltamethrin and PBO as well as the percentage mortality recorded after 24 hours exposure period are presented in Table 1. The Table 1 presents the mortality rates and knockdown times (KDT) for different insecticides, with superscripts indicating significant differences between treatments. Lower letters (a, b, c, d) denote higher mortality or faster knockdown.

The results of the susceptibility bioassay shows varying levels of insecticide effectiveness against *Culex* mosquitoes in Gombe Metropolis. Using the WHO (2013) criteria for insecticides susceptibility or resistance assessment of mosquitoes, the 24hour post exposure results indicate that Piperonyl butoxide (PBO) showed

the highest efficacy, with a 24hour mortality rate of 69% and relatively fast knockdown times (KDT₅₀ of 26.50 minutes and KDT₉₀ of 65.00 minutes). Deltamethrin has also shown moderate effectiveness, with a 65% mortality rate, although its knockdown times were slower (KDT₅₀ of 99.81 minutes and KDT₉₀ of 8083.52 minutes), suggesting it may not act as quickly as PBO in controlling mosquito populations. DDT, despite its

fast knockdown times (KDT₅₀ of 19.11 minutes and KDT₉₀ of 52.95 minutes), had only a 15% mortality rate while Permethrin showed the least effectiveness, with a very low mortality rate of 7% and extremely prolonged knockdown times (KDT₅₀ of 1056.19 minutes and KDT₉₀ of 10,804,686.41 minutes), indicating substantial resistance in the mosquito population.

Table 1. Knockdown times (reported in percentages) of Culex mosquitoes across the different classes of insecticides used

Time(mins)	Control(%)	Knockdown time			
		DDT	Deltamethrin	Permethrin	PBO(synergy)
10	0	7	7	6	1
15	0	11	7	7	8
20	0	12	7	8	9
30	0	13	9	8	17
40	0	13	10	8	17
50	0	13	11	8	19
60	0	14	11	8	21
24hrs	0	15	65	7	69

Table 2. Mortality rates and Knockdown Time KDT for different insecticides

Insecticides	Mortality after 24hours (%)	KDT ₅₀ mins	KDT ₉₀ mins
DDT	15 ^c	19.11 ^a	52.95 ^a
Permethrin	07 ^d	1056.19 ^d	10804686.41 ^d
Deltamethrin	65 ^b	99.81 ^c	8083.52 ^c
PBO	69 ^a	26.50 ^b	65.00 ^b

Different superscript letter indicate significant difference ($P < 0.05$).

Note: Value followed by different letters in the same column are significantly different ($P < 0.05$)

Note: 98-100% mortality indicate susceptibility, 80_97% mortality implies is suggestive of the existence of resistance and further investigation is needed and <80% mortality implies resistance R- Resistant (WHO, 2013).

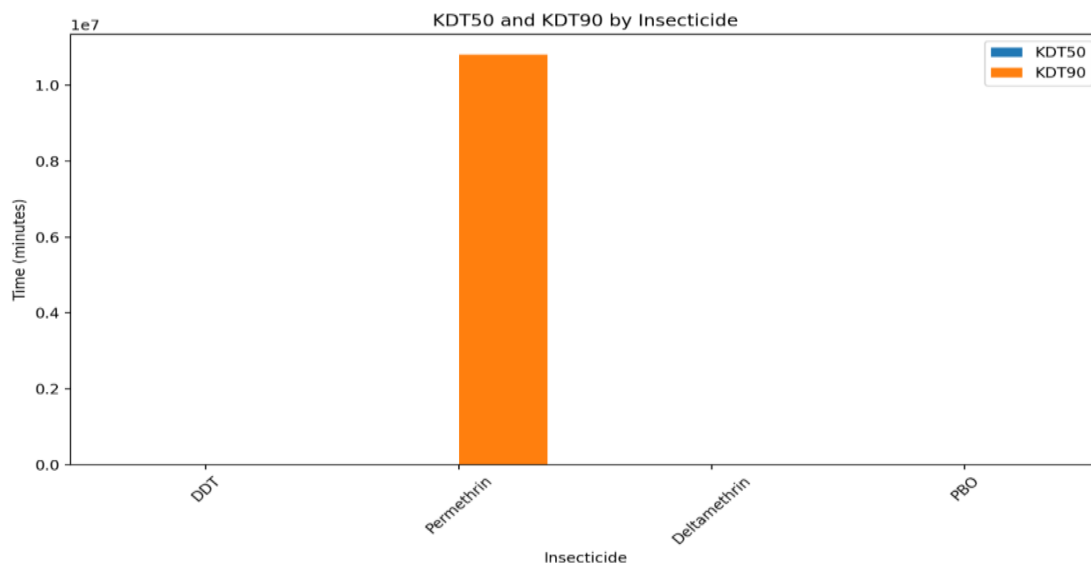


Fig. 1. The knockdown rates at KTD₅₀ mins and KDT₉₀ mins

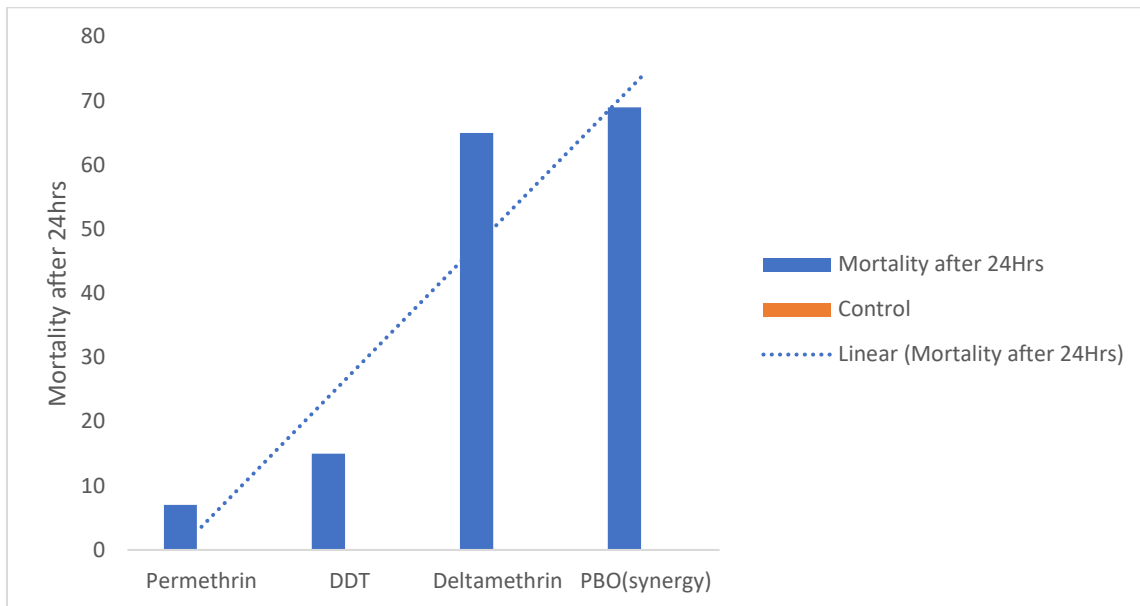


Fig 2. Percentage mortality rate of Permethrin, DDT, Deltamethrin and PBO (Synergy) after 24hrs of exposure

DDT showed the fastest knockdown times (KDT₅₀ = 19.11 min), while Permethrin showed very high KDT values, indicating significant resistance. PBO and Deltamethrin showed intermediate knockdown times, with PBO being more effective overall.

4. DISCUSSION

Many insecticides of the class organophosphate (*primiphos-methyl, malathion, fenthion*), organochlorine (DDT), and *pyrethroid (alphacypermethrin, deltamethrin, permethrin, lambda-cyhalothrin)* have been used in mosquitoes control programme and for other vector control management. Checking the susceptibility status is a good indicator for the early detection of resistance [8]. The result of the knockdown assessment in Table 2. shows that the tested insecticidal papers induced knockdown of the adult culex mosquito, suggesting that knockdown mechanisms could be operating in the mosquitoes found in Gombe. This confirms earlier studies which indicates the knockdown effects of impregnated papers against mosquitoes in Nigeria [11,18]. The knockdown of the mosquitoes exposed to insecticidal papers indicates the presence of knockdown resistance (KDR) mechanism [19] operating in population of culex mosquitoes at Zagaina, Gombe metropolis. This could have been responsible for the level of resistance displayed by these mosquitoes to the

insecticides evaluated. The results of the susceptibility bioassay shows varying levels of insecticide effectiveness against *Culex* mosquitoes in Gombe Metropolis. Using the [8] criteria for insecticides susceptibility or resistance assessment of mosquitoes, the 24hour post exposure results indicate that Piperonyl butoxide (PBO) showed the highest efficacy, with a 24hour mortality rate of 69% and relatively fast knockdown times (KDT₅₀ of 26.50 minutes and KDT₉₀ of 65.00 minutes). This indicates that PBO is the most effective insecticide among those tested, having both high mortality and reasonable knockdown speed. Deltamethrin has also shown moderate effectiveness, with a 65% mortality rate, although its knockdown times were slower (KDT₅₀ of 99.81 minutes and KDT₉₀ of 8083.52 minutes), suggesting it may not act as quickly as PBO in controlling mosquito populations.

Conversely, DDT, despite its fast knockdown times (KDT₅₀ of 19.11 minutes and KDT₉₀ of 52.95 minutes), had only a 15% mortality rate, indicating that while *Culex* mosquitoes are knocked down initially, they likely recover, showing signs of resistance. Permethrin showed the least effectiveness, with a very low mortality rate of 7% and extremely prolonged knockdown times (KDT₅₀ of 1056.19 minutes and KDT₉₀ of 10,804,686.41 minutes), indicating substantial resistance in the mosquito population. This is in agreement with other researchers who have lamented on the growing resistance of many

mosquito species to DDT [20]. This is also in agreement with other documented evidence of *Culex* mosquitoes resistance to DDT [21] and deltamethrin [22]. The results from this study shows significant resistance to DDT and Permethrin in *Culex* mosquitoes in this region, with PBO emerging as a more viable alternative for effective mosquito control.

The delayed action in the KDT₅₀ and KDT₉₀ across all the tested insecticides may indicate a resistance mechanism initially preventing knockdown but not sufficient enough to prevent mortality at the tested concentration. This discrepancy between initial KDT and final mortality agrees with the observation by Rahimi et al. [23] who noted similar patterns in mosquitoes population subjected to organophosphate and hypothesized that metabolic resistance mechanism could be active initially. Remarkably the probit analyses using (statedirects) utilized in this study allowed precise estimation of the knockdown time for 50% and 90% respectively for the population tested. The significant difference between KDT of 50% and 90% across all insecticides are indicative of important implications with regards to understanding population dynamics and resistance level within *Culex* mosquitoes.

“Summary of insecticide resistance cases and number of countries reporting this have constantly been on the rise. However, a consideration of factors (usage of ITN, IRS, agricultural pesticides) previously reported selecting for insecticide resistance” [24] provided a reasonable clue of what could be the driver of insecticide resistance in Southern Gombe. Utilization of insecticidal nets by person in Gombe is 34%, which is just below the national average of 37%. Gombe state ranked 8th out of the 38 states with the highest percentage of households with at least one ITN [25]. “There is a significant usage of Insecticide treated nets in Gombe state in Nigeria hence, these insecticide-based tools may have contributed to the insecticide pressure in selecting for resistance in the mosquitoes population” [26]. “The resistance might be explained by a long standing, massive use of DDT house-spraying in several districts of the country during the WHO malaria eradication in the 1950s. Moreover, the rapid expansion of urban agriculture couple with cotton production in west Africa could be one of the major factors that contributed to a large distribution of pyrethroids resistance in *Culex* mosquitoes. The resistance

might also be caused by the massive free campaign of beds nets impregnated with permethrin and deltamethrin as the major control strategy against *Wuchereria bancrofti* transmitted by *Culex* mosquitoes” [27] could also explain the resistance of *Culex* to pyrethroids. This hypothesis has been confirmed by the findings of [28] with increasing of *leu-phe* knockdown resistance mutation in *anopheles gambiae* from Niger following the Nationwide Long-lasting Insecticides-treated nets implementation, may be as a result of widespread utilization of chemical compound against mosquitoes and other domestic insects and pests. These chemicals tend to remain in the soil environment for month to several years and these mosquitoes become resistance to them by activating any of the two recent discovered major mechanisms that are involved in insecticide resistance: (a) target-site insensitivity, and (b) increased metabolic detoxification of insecticides. Target-site insensitivity result from structural modification or mutation(point mutation) of genes that encode target proteins that interact with the insecticides [29] while metabolic detoxification involves three major metabolic detoxification gene families: cytochrome p450, esterases, glutathione S-transferases(GSTs). A significant feature of the mosquitoes p450 and GSTs is their transcriptional upregulation which results in increased level of protein production and enzymatic activities. This in turn enhances the metabolic detoxification of the insecticides and plant toxins in the insects which leads to the development of insecticide resistance.

Moreover, Pyrethroid has been extensively used in agriculture since 1980's [30] particularly cotton and vegetable fields in Gombe. In fact, cultivation of vegetables and cotton requires intensive use of pesticides including insecticides belonging to the two main classes recommended for vector control in public health (organophosphate and pyrethroids) and which mostly were used indiscriminately to control vegetable and cotton pest. During treatment, insecticides residues in vegetables or cotton fields are washed into mosquitoes breeding sites, thus exerting a huge selection pressure on mosquito larvae populations, which result in the emergence of insecticides resistance in *Culex* mosquitoes [31]. This may most likely cause selection on strong resistance in *Culex* mosquitoes to DDT, permethrin, deltamethrin and PBO(Synergist) particularly in cotton and vegetable growing areas.

5. CONCLUSION

This study shows that there is high resistance to DDT, Permethrin, Deltamethrin and PBO by *Culex* mosquitoes. The results from the PBO synergistic assay carried out indicated an increase in percentage mortality yet resistance to *Culex* mosquitoes. The current findings will help for decision making in National vector Control Program particularly in the choice of insecticides to use during campaigns of Indoor residual Spaying in Gombe. This information is essential in the monitoring of the development of insecticide resistance in Nigeria. There is a need for continued surveillance to find out the resistance factors present in these mosquitoes specie.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ETHICAL APPROVAL

This study received ethical approval from Gombe State university, Nigeria.

ACKNOWLEDGEMENT

The authors would like to publicly thank and acknowledge Professor KP Yoriyo department of Zoology, Gombe State University, for his generous provision of WHO Insecticides Bioassay Kits and his facilitation of access to Gombe State University Malaria Vector Sentinel Laboratory. These contributions were significant in facilitating our experiments and it has also impacted the outcome of this project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Benelli G. Research in mosquito control: current challenges for a brighter future. *Parasitology Research*. 2015;114(8):2801–2805.
2. Benelli G, Mehlhorn H. Declining malaria, rising of dengue and Zika virus: Insights for mosquito vector control. *Parasitology Research*. 2016;115(5):1747–1754.
3. Benelli G, Lo Iacono A, Canale A, Mehlhorn H. Mosquito vectors and the spread of cancer: an overlooked connection? *Parasitology Research*. 2016;115(6):2131–2137.
4. Kudom AA, Mensah BA, Froeschl G, Rinder H, Boakye D. DDT and pyrethroid resistance status and laboratory evaluation of bio-efficacy of long lasting insecticide treated nets against *Culex quinquefasciatus* and *Culex decens* in Ghana. *Acta tropica*. 2015;150:122-30.
5. Zahran HEDM, Abou-Taleb HK, Abdelgaleil SAM. Adulticidal, larvicidal, and biochemical properties of essential oils against *Culex pipiens* L. *Journal of Asia-Pacific Entomology*. 2017;20(1):133–139.
6. Amao H, Idowu ET, Oyeniyi T, Otubanjo OA, Awolola TS. Relative abundance, distribution, and diversity of *Culex* (Diptera: Culicidae) mosquito species in Lagos, Southwest Nigeria. *Niger J Entomol*. 2018;34:39–49.
7. Centers for Disease Control and Prevention (CDC). CDC releases final West Nile virus national surveillance data for 2012. *Media Advisory*. May 13, 2013.
8. World Health Organization (WHO). Test procedures for insecticide resistance monitoring in malaria vector mosquitoes. Geneva: World Health Organization; 2013.
9. Zaim M, Guillet P. Alternative insecticides: an urgent need. *Trends Parasitol*. 2002;18:161–163.
10. Irving H, Riveron JM, Ibrahim SS, Lobo NF, Wondji CS. Positional cloning of rp2 QTL associates the P450 genes CYP6Z1, CYP6Z3, and CYP6M7 with pyrethroid resistance in the malaria vector *Anopheles funestus*. *Heredity*. 2012;109:383–392.
11. Ibrahim KT, Popoola KO, Adewuyi OR, Adeogun AO, Oricha AK. Susceptibility of *Anopheles gambiae sensu lato* to permethrin, deltamethrin, and bendiocarb in Ibadan city, Southwest Nigeria. *Curr Res J Bio Sci*. 2013;5(2):42–44.
12. Atting IA, Ekpo ND, Akpan ME, Bassey BE, Asuquo MJ, Usip LPE, Inyama PU, Samdi LM. Insecticide Susceptibility Profile of Malaria Vector Populations from the Coastal and Mainland Areas of Akwa Ibom State, Nigeria. *J. Adv. Med. Med. Res.* [Internet]. 2019;29(7):1-11.

- Available: <https://journaljammr.com/index.php/JAMMR/article/view/3356>
[cited 2024 Nov. 25]
13. Zित्रा C, Flechl E, Kothmayer M, Vitecek S, Rossiter H, Zechmeister T. ecological characterization and molecular differentiation of culex pipiens complex taxa and culex torrentium in eastern Austria. *Parasites & Vectors*. 2016;9:197.
 14. Jacob P, Yoriyo KP. Susceptibility status of culex quin air fascia the (Say) to DDT and Propoxur in Gombe state. *Journal of policy review and curriculum Development*. 2015;5:2
 15. Anosike JC, Azoro VA, Nwoke BEB, Keke RI, Okere AN, Oku EE, Ogbulie JN, Tony-Njoku RF, Okoro OU, Nwosu DC. Dracunculiasis in the north-eastern border of Ebonyi State, South-Eastern Nigeria. *An Int J Hyg Environ Health*. 2003;206(1):45–51.
 16. Adedayo Olatunbosun-Oduola, Ezra Abba, Olukayode Adelaja, Adeolu Taiwo-Ande, Kennedy Poloma-Yoriyo, Taiwo Samson-Awolola. Widespread report of multiple insecticide resistance in Anopheles gambiae s.l. mosquitoes in eight communities in Southern Gombe, North-Eastern Nigeria. *J Arthropod-Borne Dis*. 2019;13(1):50–61.
 17. Adedayo O, Ezra A, Olukayode A, Adeolu T, Kennedy P, Taiwo s. Widespread Report of Multiple Insecticide Resistance in Anopheles gambiae s.l. Mosquitoes in Eight Communities in Southern Gombe, North-Eastern Nigeria. *J Arthropod-Borne Dis*, March 2019, 13(1): 50–61
 18. Umar A, Kabir BGJ, Amajoh CN, Inyama PU, Ordu DA, Barde AA, et al. Susceptibility test of female Anopheles mosquitoes to ten insecticides for indoor residual spraying (IRS) baseline data collection in Northeastern Nigeria. *J Entomol Nematol*. 2014;6(7):98–103.
 19. Awolola TA, Oduola IO, Oyewole JB, Obansa C, Amajoh L, Koekemoer LL, et al. Dynamics of knockdown pyrethroid insecticide resistance alleles in a field population of Anopheles gambiae s.s. in southwestern Nigeria. *J Vect Borne Dis*. 2007;44:181–188.
 20. Ekwegh NT, Egbuche CM, Amoke OC, Okoye KC, Idigo MA. Insecticides resistance status of the most prevalent mosquitoes species in Akwa, Anambra State. *South Asian Journal of Parasitology* 20247 (3): 260-62
 21. Somboon P, Prapanthadara LA, Suwonkerd W. Insecticide susceptibility tests of Anopheles minimus s.l., Aedes aegypti, Aedes albopictus, and Culex quinquefasciatus in northern Thailand. *Southeast Asian J Trop Med Public Health*. 2006;37:97–101.
 22. Nazni WA, Lee HL, Azahari AH. Adult and larval insecticide susceptibility status of Culex quinquefasciatus (Say) mosquitoes in Kuala Lumpur, Malaysia. *Trop Biomed*. 2005;22(1):63–68.
 23. Rahimi S, Vatandoost H, Abai MR, Raeisi A, Hannafi-Boojd AA. Status of resistance and knockdown of West Nile vector, Culex pipiens complex to different pesticides in Iran. *Journal of Arthropod-borne Disease*. 2019;13(3):2-8
 24. Abuelmaali SA, Elaagip AH, Basheer MA, Frah EA, Ahmed FTA, Elhaj HFA, et al. Impacts of agricultural practices on insecticide resistance in the malaria vector Anopheles arabiensis in Khartoum State, Sudan. *PLoS One*. 2013;8(12):e83177.
 25. National Population Commission (Nigeria), Federal Ministry of Health (Nigeria), National Bureau of Statistics (Nigeria), and Institute for International Programs at Johns Hopkins Bloomberg School of Public Health. A verbal/social autopsy study to improve estimates of the causes and determinants of neonatal and child mortality in Nigeria. Abuja, Nigeria, and Baltimore, Maryland, USA; 2014.
 26. Oduola AO, Obansa JB, Ashiegbu CO, Otubanjo OA, Awolola TS. High level of DDT resistance in the malaria mosquito: Anopheles gambiae s.l. from rural, semi-urban, and urban communities in Nigeria. *J Rural Trop Public Health*. 2010;9:114–120.
 27. Yadouleton A, Asidi A, Djouaka R, Braima J, Agossou C, Akogbéto M, et al. Impact of insecticide-treated bed nets on the transmission of Wuchereria bancrofti and the resistance of Culex. 2009;163.
 28. Czeher T, Labbo R, Arzika I, Duchemin JB, Martin P, Adamou M, et al. Increase of leu-phe knockdown resistance mutation in Anopheles gambiae from Niger following the nationwide long-lasting insecticides-treated nets implementation. *Malaria Journal*. 2008;7(1):101-105.
 29. Casida JE, Durkin KA, Smith R, Lee T, Zhao Q, Wang Y, et al.

- Mechanisms of insecticide resistance. Annual Review of Entomology. 2013; 58:185-208.
30. Maigari AH, Umar A, Musa S, Ali JK, Abubakar MS, Bashir A., et al. Extensive use of pyrethroids in agriculture and their implications for mosquito resistance in Gombe, Nigeria. Journal of Agricultural and Environmental Sciences. 2021; 17(3):87-94.
31. Corbel V, N'Guessan R, Boko P, Yakoubou S, Akogbéto M, Chandre F, et al. The role of agricultural pesticides in the resistance of Culex mosquitoes to insecticides. Tropical Medicine and International Health. 2007;12(5):676-682.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:

<https://www.sdiarticle5.com/review-history/127609>