Bio-efficacy, user perception and acceptability of pyrethroid based mosquito coils in controlling *Anopheles gambiae* s.l., in some parts of Accra, Ghana

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Abstract: This study was to provide baseline information on patterns of coil usage, user acceptability and susceptibility levels of mosquito coils in some parts of Accra, Ghana. Three hundred and twenty questionnaires were administered to obtain information on knowledge and perception of respondents on the usage of mosquito coils. Adult *Anopheles gambiae* mosquitoes were tested for resistance to pyrethroid based mosquito coils using WHO standard protocol for testing household insecticide products. A total of 152 out of 320 respondents were direct users of coils. Close to 62% of this number frequently changes brands of coil they use. Over 61% of coil users indicated their willingness to continue to use coils even though there are adverse effects after use. *Anopheles gambiae* s.s. was the only species that was found in the study area. Mortalities of *An. gambiae* s.s. after exposure to coils were 37% for Angel®, 37.5% for Lord® and 15% for Heaven mosquito coil brands. More than half of the inhabitants in the area used coils to prevent mosquito bites. However, high levels of resistance was detected for all the three pyrethroid-based coils because West African *kdr* was detected in about 59% of samples of *Anopheles gambiae* s.s. that survived the exposure.

Key words: Mosquito Coil, Resistance, Bio-efficacy, user-perception, user-acceptability, *Anopheles gambiae*

INTRODUCTION

Human-mosquito contact reduction through feeding inhibition can impact positively on the control of infectious diseases transmitted through mosquito bites. A decrease in human-biting rate of mosquitoes can potentially reduce their vectorial competence with potential negative implications on their fecundity and reproductive rate (Ogoma et al., 2012). The reduction in human-mosquito contact could be as a result of a reduction in indoor density of mosquitoes in houses treated with insecticides (Ogoma et al., 2012). The impacts of these chemicals interfere with the process of seeking for host in mosquitoes making houses unattractive even in the presence of humans (Ogoma et al., 2012).

Humans use variety of techniques for protection against mosquito bites. In the simplest case, one can avoid entering mosquito infested habitats, or mosquitoes can be excluded from human living spaces by physical barriers, such as screens and nets, and by the use of building construction methods that prevent them from entry as well as chemical control (WHO, 2006).

The mosquito coil is one of the most common household insecticide formulations for the control of adult mosquitoes and has been gaining popularity in communities with both high and low malaria transmission intensities as a supplement for protection (WHO, 1998). Coils reduce the biting rate of mosquitoes through the release of small amounts of insecticides (Siegert et al., 2009). Chemicals from coils interfere with the process of seeking for hosts in disease vectors by creating a chemical barrier that prevents mosquitoes from entering houses (Pal, 1964; Hao et al., 2008; Bohbot and Dickens, 2010). According to Ogoma et al. (2012) coils containing pyrethroids prevents between 45% to 80% mosquitoes from entering houses. This can mean that a mosquito will not feed when it even lands on the host (Lucas et al., 2005).

Mosquito coils are used mainly in developing countries in Asia, South America and Africa (Narumon et al., 2003; WHO, 2008). For instance, the value share of coil use, among other insecticide usage in Asia grew from 30% in China to 500% in Indonesia between 2001 and 2011 (Global Home Insecticide Consumption, 2012). In spite of this, 30% of pesticides including coils marketed in developing countries do not meet internationally accepted quality standards (WHO,
High-income households however, have access to other private options for mosquito control, including air conditioning and screening on windows and doors but low income earners are not necessarily privileged to some of these methods (WHO, 2008).

According to Boakye et al. (2009) about 30% of households in Accra use coils to control mosquitoes. Kudom et al. (2013) also reported in a study conducted in some urban, peri-urban and rural areas in Ghana that about 63% of respondents use mosquito coils as a means of preventing mosquito bites. In spite of this seeming acceptance by a large number of the inhabitants, the efficacy of these coils are yet to be verified based on the current WHO standards for testing of household insecticide products (WHO, 2009). This study was aimed at evaluating the bio-efficacy and or resistant level, user acceptance and perceptions of mosquito coil use among inhabitants in Accra Ghana.

Materials and Methods

Study area

The study was conducted in Accra the capital of Ghana. Accra lies in the Coastal Savannah ecological zone, which is characterized by low rainfall and dry climate with geographic coordinates 5°33’21”N, 0°11’48”W. The peak rainy seasons are April to July and August to October, with annual rainfall ranging from 800 mm to 1270 mm. The relative humidity in the area ranges from 69 to 94% with an average of 75%. Temperature ranges from 25.1°C in August and 28.4°C in February and March. (Ministry of Food and Agriculture, Ghana, 2010).

Studies on malaria in Accra are far and few, even though there are some malaria prevention interventions especially vector control programs (Donovan et al., 2012). This situation has led to gaps in our understanding of the seasonality and socio-economic patterns of malaria within the Accra metropolis.

Malaria transmission in rural areas is quite higher than in urban (e.g. Accra) areas, largely due to the availability of suitable breeding sites (Lines et al., 1994). Contrary to the general believe that there are not many suitable breeding site in urban centres, studies by Kabula et al. (2011) reported that some Anopheles species have adapted to breeding in polluted water in some parts of Accra. Urban agriculture in Ghana is also a major influence in malaria transmission in both Accra and Kumasi, this is due to the fact that, pesticides used in farms often drifts into breeding sites and thereby causing resistance in mosquitoes to the same group of chemicals (mainly pyrethroids) that are used in control measures (Afriane et al., 2004; Stoler et al., 2009). This situation has the potential of increasing malaria morbidity in the metropolis if proper attention is not given to vector control.

The months of July and August poses as the months with most risks of malaria prevalence in Accra largely due to the high amounts of rainfall that creates suitable breeding conditions for mosquitoes. (Donovan et al., 2012). According to Colbourne and Edington (1954), deaths from malaria two month after wet months are higher as compared to two months after dryer months. Also years with high rainfall rates register more deaths from malaria compared to dryer years.

Questionnaires survey

Questionnaires were administered to 150 randomly selected households in four communities (Madina, Achimota, Pokuase-Amasaman and Labadi) in the Greater Accra Region of Ghana, to solicit views on coil use, its acceptability and methods of protection against mosquito bites.

These communities are located in four districts out of sixteen in the Greater Accra region of Ghana. The total population of inhabitants in these four districts where these communities are located is 454,095, which is 11.3% of the total population in the Greater Accra Region. (Ghana Statistical Service, 2012).

At least 30 households were selected for the survey in each of the areas mentioned. The survey was also to enable us select the three most commonly used coils in the area for the bioassay tests. Three hundred and twenty questionnaires were administered in total consisting of 80 in each of the stated communities. Ethical clearance was sought from Noguchi Memorial Institute for Medical Research (NMIMR), University of Ghana.

Mosquito sampling

Larvae and pupae of mosquitoes were collected from 16 temporary puddles at sites chosen randomly in Pokuase-Amasaman in Accra, using steel ladles and transported into plastic containers with holes in their lids and brought to the laboratory. Mosquitoes were sorted into new rearing basins and fed on ground tropical fish food. Pupae were collected into 50 mL beakers placed in adult emergence cages and maintained until eclosion. Two-three day old adult female Anopheles gambiae (Giles) obtained were used for the bioassays.

Identification of mosquitoes was morphologically done using keys of Giles and de Meillon (1968).

Identification of members of An. gambiae complex and kdr detection

Members of the An. gambiae complex were identified to sibling species using Polymerase Chain Reaction (PCR) methods (Scott et al., 1993). The presence of the kdr gene mutation was detected in mosquito specimen examined by PCR using the primers Agd1 and Agd2 (Oligos Etc. Inc., U.S.A.) and Agd3 and Agd4 (Oswel, UK) (Martinez-Torres et al., 1998). Extraction of the DNA from adult An. gambiae s.l. was done using the protocol described by Collins et al. (1987). Leu-Phe ‘kdr’ allele that confers knockdown resistance to pyrethroids
in West Africa was detected using PCR genotyping (Martinez-Torres et al., 1998). Gel electrophoresis on a 2% ethidium bromide agarose visualized under ultraviolet light was used to amplify the fragments.

Bioassay test on mosquito coils

Pools of two to three day old adult An. gambiae s.s. females were tested for resistance at a recommended period of 1hr after burning of the coils. The chosen coils were Lord® and Angel®, which contain 0.32% D-allethrin, and Heaven®, which contain 0.03% Dimefluthrin. Each coil was burnt separately in a Peet-Grady Chamber constructed with wood with dimensions 180×180×180 cm and totally covered with polyester mesh netting (0.5 mm). The mosquitoes were gently transferred from their cages into four other holding wooden cages of dimensions 20×20×20 cm covered with 0.5 mm hole polyester netting using an aspirator and suspended 10 cm from the sides of the holding cage and 80 cm from the top of the cage. These were then placed in a room with 250×250×250 cm dimensions. A small electric fan was placed inside the frame to ensure uniform dispersion of the smoke emitted from the coils inside the chamber. The test was done at similar times of the day in accordance with WHO recommended adult mosquito test instructions (WHO, 2009). Before each experiment, 25 mosquitoes were held in one of the four cages for one hour inside the chamber without any burnt coil (control), transferred into a paper cup, given a 10% sugar solution and later transferred into a room with 80±10% humidity and 27±2°C temperature and kept under observation for 24 hrs for mortalities. Four replicates of 25 mosquitoes were used for each test and the tests were repeated three times for each of the three selected coils and kept under similar conditions of 10% sugar solution, 80±10% humidity and 27±2°C temperature and observed for 24 hrs for mortalities. Knockdowns were observed at 5, 10, 15, 20, 30, 40, 50 and 60 mins. Three-hundred mosquitoes were exposed to each mosquito coil. Four days were allowed in between tests to ensure a complete breakdown of pyrethroids from previous test that could influence new test. Abbot formula was used to calculate for corrected mortality (Abbot, 1925). A mosquito is considered knocked down when it lays down on the floor of the carrying cage inside the Peet-Grady Chamber with little or no movement, when it is unable to fly or when it cannot maintain normal flight posture.

Data analysis

Data were analyzed using analysis of variance (ANOVA). The analysis of the results and the statistical test used was the F-test at 5% significance level using MINITAB Statistical Software Release 15 for Windows.

RESULTS

Bioassay mortality of An. gambiae s.s.

A total of 1,125 unfed female An. gambiae s.s. were used for the bioassay. All the specimens identified by PCR were An. gambiae s.s. The bioassay results indicated a mean mortality of 37% in the range of (16–45%) for Angel® Jumbo mosquito coil, 37.5% in the range of (9.5–40%) for Lord® anti-mosquito coil and 15% in the range of (4–30%) for Heaven® Jumbo coil. There was no significant difference between mean mortalities among the three different coil brands (F=1.96, P=0.05, df=2). The data also indicated a high resistance to pyrethroids in An. gambiae populations in Accra. WHO criteria for susceptibility test indicates that: 98–100% mortality means susceptible; 80–97% mortality means resistance suspected with more investigations needed; 0–79% mortality means resistance confirmed. (Table 1).

Allelic Frequency Distribution of kdr Mutation

Sixty five members from the population of survivors of the bioassay test were tested for kdr gene mutation. Thirty eight of them were found to be kdr positive with band sizes of 195 base pair and 293 base pair indicating the presence of kdr mutation that confers knockdown resistance. Percentage of survivals with the kdr gene mutation was 59. There was no significant difference in the frequency of kdr gene between mosquitoes that survived the different coils (F=1.26, P=0.05, df=2). The amino acid substitution in the tested population was found to be a single point mutation leading to a leucine-to-phenylalanine substitution (L1014F).

Table 1. Susceptibility and kdr of Anopheles gambiae s.l. to pyrethroid based coils in Accra.

| Type of coil | Active ingredient (Insecticides) | Total No of (mosquitoes) tested | Av. % Knockdown after (60 mins) (KT60) | Av. % mortality after 24 hours | Range of mortality after 24 hours | F test for mortality of the various coils after 24 hrs (5% sf and 2df) | kdr frequency (%) | No. of surviving mosquitoes used for kdr | F test value for kdr test (5% sf and 2df) |
|--------------|---------------------------------|---------------------------------|----------------------------------------|-------------------------------|----------------------------------|---------------------------------------------------------------------|------------------|--------------------------------------|----------------------------------------|
| Angel®       | D-$\text{a}$ allethrin 0.32%    | 300                             | 0.3                                    | 37.3                          | 16–45                            | 63.0                                                                | 19               | 79%                                   | 0.05, df=2                              |
| Lord®        | D-$\text{a}$ allethrin 0.32%    | 300                             | 1.3                                    | 37.5                          | 9.5–40                           | 1.96                                                                | 60.0             | 79%                                   | 0.05, df=2                              |
| Heaven®      | Dimefluthrin 0.03%              | 300                             | 0                                       | 15.0                          | 4–30                             | 54.8                                                                | 31               | 79%                                   | 0.05, df=2                              |
| Control      | No coil                         | 225                             | 4.0                                    | 0–5                           |                                  |                                                                      |                  | 79%                                   | 0.05, df=2                              |
Mosquito coil usage, coil efficacy and perceptions on mosquito coils use

A total of 320 inhabitants were interviewed on the methods of mosquito control they use, 51.6% (i.e., 165 respondents) use coils, 12.8% (i.e., 41 respondents) use Insecticide Treated Nets (ITNs), 7.5% (i.e., 24 respondents) use Aerosol sprays, 2% (i.e., 7 respondents) use other traditional herbs with 14% (i.e., 45 respondents) using fans as a physical barrier to mosquito bites (Fig. 1).

Fifty eight percent of coil users (i.e., 96 respondents and 30% of interviewed people) said they normally use two coils per night and 61.8% (i.e., 102 respondents and 31.9% of interviewed people) will change coils frequently. More than 98% (i.e., 285 respondents and 89% of interviewed people) of those who use protective measures against mosquito bites use more than one method of protection. (Fig 2)

Approximately 45.6% of the interviewed people confirmed that, the methods they use to control mosquitoes are moderately effective, 30% responded positively to the type of control methods they use with only 18% responding negatively to the type of control methods they use. The results also show that about 70% of the interviewed people wished the methods they employ were little better than it is now (Table 2). This was to seek the general view of efficacy of the various methods used by consumers, irrespective of formulation, product and use type.

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User acceptability despite adverse effects

When asked if they experienced any problems after coil usage, 48.5% (i.e., 80 respondents and 25% of interviewed people) said yes for cataarh; 6.1% (i.e., 10 respondents and 3.1% of interviewed people) said yes for headache; 42.4% (i.e., 70 respondents and 21.9% of interviewed people) said yes for flu; 1.8% (i.e., 3 respondents and 0.9% of interviewed people) said yes for eye problems.

**Discussion**

The results of the study showed that methods used to control mosquitoes in the study area are at best moderately effective. It also shows that An. gambiae s.s. were resistant to the three pyrethroid based mosquito coils used in the area. This is evidenced in the fact that more than half of coil users preferred a combination of coils to enable the increase of chemical activity in their rooms in other to have an effective control. This is in agreement with a study conducted by Phal et al. (2012)
which reported a higher knockdown and mortality rate of mosquito susceptibility test upon combinations of different concentration and different active ingredients of herbal mosquito coils. The study also agrees with other studies in the Greater Accra region which reported resistance to pyrethroid based vector control methods (Adeniran, 2002; Achonduh et al., 2008; Boakye et al., 2009). The reasons why *An. gambiae* s.s. from the study area gave very low mortalities after exposure to the three coils could be due to the fact that, this same group of insecticides is continuously used by the inhabitants in the form of aerosols or coils to control mosquitoes. Studies by Achonduh et al. (2008), Adeniran, (2002) and Boakye et al. (2009) reported that the use of pyrethroids based pesticides in farms might be contributing in conferring *kdr* in Anopheles spp. in the study area. According to Ogoma et al. (2012), coils induce up to 95% mortality in laboratory-assays compared to very low mortality observed in field-assays (3%–16%) but contrary to this study there was as low as 4% mortality in our laboratory essay. This raises a serious concern of resistance to coils in the study area. In spite of that, the majority of the respondents protected themselves from mosquito bites by using insecticide treated net (ITN), aerosols and or coils. This is in agreement with other studies in Ghana (Boakye et al., 2009; Kudom et al., 2013). According to Maclver (1964), low levels of pyrethroids are considered to have no knockdown effect unless the concentration is increased. This may be the reason for the very low knockdown rate in this study. In contrast to this study, Msangi et al. (2010) evaluated mosquito coils in Tanzania and had more than 75% feeding inhibition for *An. gambiae* s.l. even though it was an open window indoor inhibition experiment.

Confining the test mosquitoes in smaller cages might have exposed them to larger amounts of smoke which in turn exposed them to higher amount of chemical activity (Ogoma et al., 2012). The smaller areas of these test cages could have generated excess heat from the coils which could have killed the mosquitoes. This is not the ideal case because coils are used in the open or bigger rooms than these test cages. There is therefore the need to set up a field and open environment to test repellency and biting inhibition test in the study area to do more accurate evaluation of the bio-efficacy of mosquito coils.

The prevalence of *kdr* gene, 59% of survivors of bioassay test, among the *An. gambiae* s.s. population in the area is consistent with studies by Achonduh et al. (2008), Adeniran (2002) in the Accra metropolis and Diabate et al. (2002) in Burkina Faso, where the *kdr* gene was found to be highly present in *An. gambiae* s.s. in their respective areas. The single point of amino acid mutation of leucine-to-phenylalanine (L1014F) was detected to be the cause of *kdr* in the tested population. This is consisted with the findings of Martinez-Torres et al. (1998).

Problems of high mosquito incidence (91% of questionnaire respondents) in the area, was confirmed by Boakye et al. (2009) in the same metropolitan area. They reported that, close to 75% of the respondents had had malaria in the year prior to the survey. Due to the high incidence of mosquito in the study area, the use of mosquito coils had become important for malaria control in the area, because it is cheap and affordable compared to other anti-mosquito measures (Lukwa et al., 1999). Mosquito coils do not kill mosquitoes in the natural setting (except laboratory setting) (Ogoma et al., 2012), but Smith et al. (1972) observed that the proportion of mosquitoes leaving huts with burning coils were quicker and much more in numbers than those that did not have coils. This emphasizes the importance of mosquito coils in the prevention of mosquito bites through mosquito repellency.

It is however interesting to note that there has been a decline in the number of individuals and households that rely solely on coils as a means of control against mosquito bites in the Greater Accra Region since 2009 comparing the results of Avicor (2006), Boakye et al. (2009) and this study. This decline in confidence of coil use over the years could be as a result of a reduction in the efficacy of the coils. This reduction in efficacy could possibly have resulted from *kdr* gene mutation in mosquitoes in the area and or sub-standard coils that are being sold on the Ghanaian market, to unsuspecting consumers. Consumers are gradually opting for other alternative control measures such as ITN’s, sprays and aerosols and using coils as a supplement to other control methods only. This is evidenced from the response of the survey where 62% of the coil users frequently changed coils, 50% of the users believe the mosquitoes in their area are resistant to the coils and as many as 58% of the users have to use two different coils at night. This study also shows that, over 98% of the respondents that protects themselves against mosquito bite use more than one method to control mosquitoes. This could be evidence that, people in the study area keep looking for best ways of preventing mosquito bites (signs of resistance to the various methods of control apart from mosquito coils). Close to 2% only, use just a single type of control. This is mostly those who were staying in well protected buildings and having the luxury of using fans and air conditioners in their home.

Users of coils also complained of high respiratory illnesses from smoke pollution compared to non-users in the study area. This is in agreement with a study conducted in Hong Kong where the incidence of chronic sputum among primary school children who use coils was twice as much as those not using coils (Koo and Ho, 1994). On the contrary there was no effect of smoke pollution on the mothers and elderly women of these primary school children. In another study, Liu et al. (2003) reported that exposure to the smoke of some mosquito coils can pose acute and
chronic health risk by releasing as much smoke from burning 71-137 cigarettes. These contrasting results does not implicate mosquito coils as the sole reason for reports of respiratory illnesses, even though it may be a contributing factor in reported respiratory illnesses among users in the study area.

The study revealed that mosquito coils are highly patronized as a means of protection against mosquito bites and malaria incidence in Ghana despite seeming problems of side effects after usage. Despite increasing trends of resistance and side effects, close to 61% of coil users in the survey indicated their willingness to continue using them.

**Conclusion**

The *Anopheles gambiae* population in the Greater Accra Region area possibly have high levels of resistance to all the three coils that were investigated. Ghana is implementing a comprehensive array of anti-malarial interventions, including the scaling up of Insecticide Treated Nets (ITNs), even though they are at best moderately effective. Mosquito coil use however is still common among many rural as well as urban communities in controlling mosquitoes. In other for consumers and coil manufacturers to have value for money and also to properly have a good alternative vector control campaign similar to the roll back malaria campaign that promotes the use if ITN’s, there is the need for evaluation of all mosquito coils on the market before they are sold. Measures need to be put in place, and efforts made to ensure users are benefitting from the use of these coils and are not suffering the negative effects of their usage.

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**References**

Abbott, W. S. 1925. A method of computing the effectiveness of the insecticide. *J. Econ. Entomol.*, 18: 265–267.

Achondub, O. A., Gbewonyo, W. S. K., Boakye, D. A. and Wilson, M. D. 2008. Susceptibility status of *Anopheles gambiae* s.l. (diptera: culicidae) from cabbage growing areas associated with pyrethroid and organophosphate use in Accra, Ghana. *West Afr. J. Appl. Ecol.*, 12: 132–140.

Adeniran, T. A. 2002. Studies on the susceptibility status of *Anopheles gambiae* sensu stricto permethrin and propoxur insecticides in the greater Accra region of Ghana. Unpubl. Mphil thesis submitted to the African Regional Postgraduate Programme in Insect Science (ARPPIS). University of Ghana, Legon. 133 pp.

Afrane, Y. A., Klinkenberg, E., Drechsel, P., Owusu-Daaku, K., Garms, R. and Kruppa, T. 2004. Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? *Acta Trop.*, 89: 125–134.

Avice, W. S. 2006. Efficacy of pyrethroid and pyrethrin based coils for mosquito control and its effect on human health, Dilemma of the user. Unpubl. Rsc Dissertation. Department of Animal Biology and Conservation Science. University of Ghana, Legon. 64 pp.

Boakye, D. A., Appawu, M., Brown, C. A., Adasi, K. and Wilson, M. D. 2009. Patterns of household insecticide use and pyrethroid resistance in *Anopheles gambiae* sensu stricto (Diptera: Culicidae) within the Accra Metropolis of Ghana. *J. Afr. Entomol.*, 17: 125–130.

Bohbot, J. D. and Dickens, J. D. 2010. Insect repellents: modulators of mosquito odorant receptor activity. *PLoS ONE*, 5: e12138.

Colbourne, M. J. and Edington, G. M. 1954. Mortality from malaria in Accra. *J. Trop. Med. Hyg.*, 57: 203–211.

Collins, F. H., Mendez, M. A., Rasmussen, M. O., Mehaffey, P. C., Besansky, N. J. and Finnerty, V. 1987. A ribosomal RNA gene probe differentiates member species of *Anopheles gambiae* complex. *Am. J. Trop. Med. Hyg.*, 37: 37–41.

Donovan, C., Siadat, B. and Frimpong, J. 2012. Seasonal and socio-economic variations in clinical and self-reported malaria in Accra, Ghana: evidence from facility data and a community survey. *Ghana Med. J.*, 46: 85–94.

Diabate, A., Balder, T., Chandre, F., Akoobeto, M., Guiguemde, T. R., Darriet, F., Brengues, C., Guillet, P., Hemingway, J., Smith, G. J. and Hougard, J. M. 2002. The role of agricultural use of insecticides in resistance to pyrethrins in *Anopheles gambiae* s.l in Burkina Faso. *Am. J. Trop. Med. Hyg.*, 67: 617–622.

Ghana Statistical Service. 2012. 2010 Population and Housing Census: summary report of final results. 117pp. *Ghana Statistical Service, Accra.*

Gilles, T. M. and de Meillon, D. B. 1968. The *Anopheles* of Africa South of Sahara (Ethiopian Zoogeographic Region). 344pp. Afr. Inst. Med. Res., Johannesburg.

Global Home Insecticides Consumption (GHIC). 2012. *Euromonitor International*. Accessed on August, 12, 2013. Available from: http://euromonitor.typepad.com/files/sampledeck-23.pdf

Hao, H., Wei, J., Dai, J. and Du, J. 2008. Host-seeking and blood-feeding behavior of *Aedes albopictus* (Diptera:Culicidae) exposed to vapors of geraniol, citral, citronellal, eugenol or anisaldehyde. *J. Med. Entomol.*, 45: 533–539.

Kabula, I. B., Attah, P. K., Wilson, M. D. and Boakye, D. A. 2011. Characterization of *Anopheles gambiae* s.l. and insecticide resistance profile relative to physicochemical properties of breeding habitats within Accra Metropolis, Ghana. *Tanzania J. Health Res.*, 13: 163–187.

Koo, C. L. and Ho, H.-C. J. 1994. Mosquito coil smoke and respiratory health among Hong Kong Chinese: Results of three epidemiological studies. *Indoor Built Environ.*, 3: 304–310.

Kudom, A. A., Mensah, A. B. and Nunoo, J. 2013. Assessment of anti-mosquito measures in households and resistance status of *Culex* species in urban areas in southern Ghana: Implications for the sustainability of ITN use. *Asian Pacific J. Trop. Med.*, 6: 859–864.

Lines, I., Harpham, T., Leake, C. and Schofield, C. 1994. Trends, priorities and policy directions in the control of vector-borne diseases in urban environments. *Health Policy Plan.*, 9: 113–129.

Liu, W., Zhang, J., Hashim, J. M., Jalaludin, J., Hashim, Z. and Goldstein, B. D. 2003. Mosquito coil emissions and health implications. *Environ. Health Perspect.*, 111: 1454–1460.

Lucas, J. R., Shono, Y., Iwasaki, T., Ishiwatari, T. and Spero, N. 2005. Field evaluation of metofluthrin—a new mosquito repellent. In Fifth International Conference on Urban Pests; Malaysia. Robinson C-Y.L.WH. Malaysia (eds), Perniagaan Pitang @ P and Y Design, New York.
Lukwa, N., Nyazema, N. Z., Curtis, C. F., Mwaiko, G. L. and Chandiwana, S. K. 1999. People's perceptions about malaria transmission and control using mosquito repellent plants in a locality in Zimbabwe: it's relevance to malaria control. *Cent. Afr. J. Med.*, 45: 64–68.

Maclver, D. R. 1964. Mosquito coils, part ii: studies on the action of mosquito coil smoke on mosquitoes. *Pyrethrum Post.*, 7: 7–14.

Martinez-Torres, D., Chandre, F., Williamson, M. S., Darriet, F., Bergé, J. B., Devonshire, A. L., Guillett, P., Pasteur, N. and Pauron, D. 1998. Molecular characterization of pyrethroids knockdown resistance (*kdr*) in the major malaria vector *Anopheles gambiae* s.s. *Insect Mol. Biol.*, 7: 179–184.

Ministry of Food and Agriculture. Republic of Ghana. 2010. Greater Accra Region: demographics, weather, land use. Accessed on February, 4th, 2014. Available online: http://mofa.gov.gh/site/?page_id=650

Msangi, S., Mwang’onde, B. J., Mahande, A. M. and Kweka, E. J. 2010. Field evaluation of the bio-efficacy of three pyrethroid based coils against wild populations of anthropophilic mosquitoes in Northern Tanzania. *J. Global Infect. Dis.*, 2: 116–120.

Narumon, K., Sampas, N., Somjai, L., Supatra, T. and Raweewan, S. 2003. Repellent efficiency of a mosquito coil with emphasis on coverage area in laboratory conditions. *J. Trop. Med. Parasitol.*, 26: 9–12.

Ogoma, B. S., Moore, S. J. and Maia, F. M. 2012. A systematic review of mosquito coils and passive emanators: defining recommendations for spatial repellency testing methodologies. *Parasites and Vectors.*, 5: 287.

Pal, R. 1964. Methods for studying the behaviour of malaria vectors under the impact of residual insecticides. Geneva: WHO.

Phal, D., Naik, R., Deobhankar, K., Vitonde, S. and Ghatpande, N. 2012. Laboratory evaluation of herbal mosquito coils against *Aedes aegypti* mosquito. *Bull. Env. Pharmacol. Life Sci.*, 1: 16–20.

Scott, J. A., Brogdon, W. G. and Collings, F. H. 1993. Identification of single specimens of the *Anopheles gambiae* complex by polymerase chain reaction. *Am. J. Trop. Med. Hyg.*, 49: 520–529.

Siebert, P. Y., Walker, E. and Miller, J. R. 2009. Differential behavioral responses of *Anopheles gambiae* (Diptera: Culicidae) modulate mortality caused by pyrethroid-treated bednets. *J. Econ. Entomol.*, 102: 2061–2071.

Smith, A., Hudson, E. J. and Esozed, S. 1972. Trials with pyrethrum mosquito coils against *Anopheles gambiae* Giles, *Mansonia uniformis* Theo. and *Culex fatigans* Wied. entering verandah-trap huts. *Pyrethrum Post.*, 11: 111–115.

Stoler, J., Weeks, J. R., Getis, A. and Hill, A. G. 2009. A distance threshold for the effect of urban agriculture on elevated self-reported malaria prevalence in Accra, Ghana. *Am. J. Trop. Med. Hyg.*, 80: 547–554.

World Health Organization. 1998. Insecticide monitoring in malaria vectors, bio-efficacy and persistence of insecticide on treated surfaces. Geneva, Switzerland. Accessed on November, 20th, 2013. Available from: http://whqlibdoc.who.int/hq/1998/WHO_CDS_CPC_MAL_98.12.pdf

World Health Organization. 2006. Malaria vector control and personal protection: report of a WHO study group. Technical report series no. 936. pp. 62. Geneva, Switzerland.

World Health Organization. 2008. Training package for the health sector. Accessed in July 15th, 2013. Available from: http://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf

World Health Organization. 2009. Pesticide evaluation scheme. January, 12th 2014. Available from: http://whqlibdoc.who.int/hq/2009/WHO_HTM_NTD_WHOPES_2009.3_eng.pdf

World Health Organization. 2011. Guidelines on public health pesticide management policy for the WHO African Region. Accessed on February, 4th 2014. Available from: http://whqlibdoc.who.int/publications/2011/9789241501231_eng.pdf