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Essential Oils From Five Local Plants: An Alternative Larvicide for *Anopheles gambiae* s.l. (Diptera: Culicidae) and *Aedes aegypti* (Diptera: Culicidae) Control in Western Burkina Faso

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Introduction: Malaria and dengue are two main vector-borne infectious diseases transmitted by *Anopheles gambiae* and *Aedes aegypti*, respectively, in tropical and subtropical regions. The concern for environmental safety and the increasing development of resistance to the chemical in main arthropod vectors raises interest in the search for botanicals such as essential oils (EOs) that can be used in vector control.

Methods: Larvicidal bioassays were performed according to the WHO standard methods using *Ae. aegypti* and *An. gambiae* larvae collected from Bobo-Dioulasso and in the Kou Valley (VK), respectively, two areas located in Houet Province of western Burkina Faso. Kisumu and Bora bora, the susceptible strains of *An. gambiae* and *Ae. aegypti*, respectively, were used as controls. OEs extracted from leaves of five aromatic plants, *Cymbopogon citratus*, *Cymbopogon nardus*, *Eucalyptus camaldulensis*, *Lippia multiflora*, and *Ocimum americanum*, naturally growing in Burkina Faso were tested. The pyriproxyfen was used as a positive control.

Results: As a result, the lethal concentrations (LC_{50}) for *Ae. aegypti* from Bobo-Dioulasso and *An. gambiae* from VK ranged from 41.9 to 103.8 ppm and 39.5 to 138.1 ppm, respectively. As for LC_{90} values, they ranged from 74.6 to 311.3 ppm for *Ae. aegypti* from Bobo-Dioulasso and from 90.2 to 328.9 ppm for *An. gambiae* from VK. Among the EOs tested, *L. multiflora* showed the highest activity against all the strains of *An. gambiae* and *Ae. aegypti* larvae. No difference in terms of LC_{50} values was found between *L. multiflora* and pyriproxyfen used as a positive control on *An. gambiae* larvae. It is not the case for *Aedes aegypti* populations, where pyriproxyfen remains the most toxic. Overall, *An. gambiae* populations were the most susceptible to EOs tested as compared to *Ae. aegypti* populations.

Conclusion: Our study furthers our knowledge of the larvicidal activity of EOs in the western part of Burkina and opens new avenues in their putative use in vector control strategies.

Keywords: resistance, essential oils, larvicidal activities, lethal concentration, Bobo-Dioulasso

BACKGROUND

Vector-borne diseases are human diseases caused by parasites, viruses, or bacteria transmitted by vectors. Each year, more than 700,000 deaths occur worldwide due to vector-borne diseases such as dengue, yellow fever, Japanese encephalitis, leishmaniasis, Chagas disease, onchocerciasis, malaria, schistosomiasis, and human African trypanosomiasis (1). Among these diseases, malaria remains the most serious vector-borne disease, affecting between 300 and 500 million people, and 1.4 to 2.6 million deaths annually throughout the world were recorded. More than 40% of the world's population lives in malarious areas (2).

According to the epidemiological bulletin, in the first half of 2018, Burkina Faso recorded 3,501,245 cases of malaria, including 1,002 deaths, for a case-fatality rate of 0.7% (3). The same is true for dengue, where the number of reported cases worldwide peaked in 2019, and all WHO regions were affected (4). In Burkina Faso, an increase in the weekly incidence of dengue cases was noted from week 31 of the year 2017 (5).

Current mosquito control strategies depend primarily on chemical insecticides. The discovery, development, and use of chemicals have reduced the interest in plant products. However, widespread use of these insecticides in public health and agriculture for the control of vector and pest species has favored many concerns such as the increasing physiological resistance in major vector species, environmental pollution, and toxic hazards to human and other non-target organisms due to their broad spectrum of activity (6–9). As a result, there has been an increased interest in developing potential alternative or additional control methods/tools that are effective against the target vector species, which are environmentally safe, biodegradable, and low cost and can be used by individuals and communities in specific situations (10, 11). Therefore, in recent years, various workers have been concentrating their efforts on the search for natural products derived from plants as an alternative to conventional insecticides used in controlling vectors for which resistance was detected (12). Among many natural products, essential oils (EOs) and their constituents have received considerable attention in the search for new pesticides and have been found to possess an insecticidal potential (13).

EOs show several interesting properties. First, they easily penetrate insect cuticles, which increases their bioavailability (14). This property could be of interest if it results in a shortened stay of insects on treated surfaces. Second, EO compounds such as acyclic or monocyclic monoterpenes are small and volatile molecules that might have spatial repellency properties. For example, insect sensilla are specialized for detecting odorants and have been shown to respond to volatile monoterpenes (14). Finally, active compounds in EOs may have a specific mode of action, which makes them good alternatives to the use of pyrethroids.

The EO of *Lippia multiflora* is used as a spice, a meal condiment, a drink flavoring (15), and a mouthwash. In addition to insecticidal activities, Abena et al. (16) found analgesic, antipyretic, and anti-inflammatory effects of *L. multiflora* oil. *Cymbopogon citratus* EO has antimicrobial activity against *Helicobacter pylori*, a bacterium responsible for gastroduodenal diseases (17). *Cymbopogon nardus* is a medicinal plant because of its analgesic effect and is widely used in gastronomy (18). Also, several studies noticed the insecticidal properties of EO of *C. nardus*, *C. citratus*, *Ocimum americanum*, and *Eucalyptus camaldulensis* (18–21).

In Burkina Faso, some studies on the insecticidal effects of EOs with mosquitoes in general and mosquito larvae in particular have involved strains restricted to Ouagadougou (21–23). Little is known about the EO susceptibility in *Anopheles* and *Aedes* populations in the western part of this country. Moreover, previous studies did not take into account the positive control in the various tests.

Our study aimed at evaluating the larvicidal activities of EOs of five local aromatic plants from Burkina Faso, including *C. citratus*, *C. nardus* (DC.) Stapf, *E. camaldulensis* Dehn, *L. multiflora*, and *O. americanum* (Wild.) A.J. Paton in terms of lethal concentrations (LC_{50} and LC_{90}) upon field populations of *Aedes aegypti* from Bobo-Dioulasso and *Anopheles gambiae* from the Vallée du Kou (VK).

MATERIAL AND METHODS

Mosquito Larval Collection and Rearing

An. gambiae larvae were collected from district number 7 of the Vallée du Kou (Bama) (11°24′N and 4°24′O), a rice-growing area located 30 km north of Bobo-Dioulasso. *Ae. aegypti* larvae were collected from tires in various urban settings in Bobo-Dioulasso, the economic capital city of Burkina Faso. Bobo-Dioulasso and Bama are two localities in the province of Houet in western Burkina Faso. The larvae were collected from June to October 2021 and transported to the insectary of the Institute of Research in Health Sciences (IRSS) located in Bobo-Dioulasso where 3 and 4 larval instars were sorted according to Filho (24). Larvae from laboratory reference strains were used as controls. The insectary conditions were 27°C ± 2°C temperature, 80% ± 10% relative humidity, and 12-h light and 12-h dark photoperiod.

Plant Materials and Essential Oil Procurement

The five plant species tested, *C. citratus*, *C. nardus* (Linn.), *E. camaldulensis*, *L. multiflora*, and *O. americanum*, were used in

this current study. They were chosen firstly due to endogenous data provided from informants questioned in areas investigated as well as the data from the literature. These plants were collected from the garden of the Research Institute of Applied Sciences and Technologies (IRSAT). The identification of the plants and extraction of EOs were performed by IRSAT. All the EOs were extracted from the leaves of the test plants by hydrodistillation (HD) using a *clevenger*-type apparatus and stored in a dark glass bottle at 4°C prior to use. The oils thus obtained were separated from water in the condenser and stored in airtight containers under refrigeration (4°C) till their later use for larval bioassays. The major compounds of these EOs were obtained by gas chromatography–mass spectrometry (GC-MS).

Larvicidal Bioassays in the Laboratory

The larval bioassay tests were carried out following the standard WHO larval bioassay test method (25). They were carried out in the laboratory of the Institute of Research in Health Sciences located in Bobo-Dioulasso. Clear plastic cups with capacities of 200 ml each were used for the larvicidal bioassays. An appropriate amount of each EO was dissolved in acetone to prepare 1 ml of stock solution. Fresh stock solutions of each of the above stock solutions were prepared by adding distilled water to produce the required concentrations (50, 100, 150, and 200 ppm). Four replicates were carried out for each test concentration and species of mosquito larvae. Twenty active third and fourth larval instars of *An. gambiae* and *Ae. aegypti* in 10 ml of distilled water were transferred into each clear plastic cup that contained 139 ml of distilled water. One milliliter of the mixing solution of EO and acetone was added to each cup that contained 149 ml of distilled water to give a final solution of 150 ml with the desired concentrations. Two replicates of the control were carried out simultaneously with 149 ml of distilled water and 1 ml of acetone. Pyriproxyfen, the reference chemical larvicidal, was used at different concentrations as a positive control.

Data Analysis

Analyses were performed by using the statistical software XLSTAT version 2,015.1.01. The LC_{50}, LC_{90}, and the 95% CIs were calculated by probit analysis using the same statistical software in order to compare the larvicidal potency of the plants and susceptibility of the test mosquito larvae. LC_{50} and LC_{90} values were judged as significantly different between the EOs ($p < 0.05$) if the CIs did not overlap (14, 26). In all the tests, no control mortality was detected after the 24-h exposure; hence, no correction was required based on Abbot's formula.

RESULTS

Chemical Characterization of the Essential Oils

The major compounds of the 5 EOs are summarized in **Table 1**. The EO of *C. citratus* was found to be rich in geranial (48.1%), neral (35.8%), and myrcene (11%). The EO of *C. nardus* was predominantly composed of citronellal (41.7%), geraniol (20.8%), and β-elemene (11%). The EO of *E. camaldulensis* was rich in 1,8-cineole (59.5%) and α-pinene (9.17%). The OE of *L. multiflora* was characterized by *p*-cymene (25.27%), β-caryophyllene (12.7%), and thymol (11.88%). *O. americanum* EO was characterized by a high percentage of 1,8-cineole (31.22%) followed by camphor (12.73%).

Larvicidal Activities of Essential Oils Against *Anopheles gambiae*

EOs from 5 plant species demonstrated larvicidal activities against susceptible strains and field-collected 3 and 4 larval instars of *An. gambiae*. Overall, five EOs were the most toxic on 3 and 4 larval instars of *An. gambiae* susceptible strain. On the susceptible strain larvae of *An. gambiae* (Kisumu), the LC_{50} and LC_{90} values were from 3.9 to 75.8 ppm and from 29.5 to 193.5 ppm, respectively (**Table 2**). On field-collected larvae of *An. gambiae* (VK), the LC_{50} and LC_{90} values were between 39.5 to 138.1 ppm and from 90.2 to 328.9 ppm, respectively (**Table 3**).

Regarding LC_{50} and LC_{90} values, *L. multiflora* exhibited the highest larvicidal activity against the 2 strains of *An. gambiae* (LC_{50} = 3.9 ppm, LC_{90} = 29.5 ppm for Kisumu larvae and LC_{50} = 39.5 ppm and LC_{90} = 90.2 ppm for VK larvae).

As for *O. americanum*, it exhibited the weakest larvicidal activity (LC_{50} = 75.8 ppm; LC_{90} = 193.5 ppm) for Kisumu larvae, while *C.*

TABLE 1 | Major compounds of the 5 essential oils tested on larvae of *Anopheles gambiae* and *Aedes aegypti*.

Essential oils	Major compounds	Retention time (min)	Percentage (%)
Cymbopogon citratus	Geranial	21.181	48.1
	Neral	21.130	35.8
	Myrcene	12.481	11
Cymbopogon nardus	Citronellal	18.994	41.7
	Geraniol	22.121	20.8
	β-Elemene	24.880	11
Eucalyptus camaldulensis	1,8-Cineol	14.022	59.55
	α-Pinene	10.505	9.17
Lippia multiflora	*p*-Cymene	13.740	25.27
	β-Caryophyllene	25.116	12.70
	Thymol	21.791	11.88
Ocimum americanum	1,8-Cineol	14.022	31.22
	Camphor	17.733	12.73

TABLE 2 | Median and 90% lethal concentrations and their Confidence Limits (CLs) of plant essential oils against 3 and 4 larval instars of *Anopheles gambiae* susceptible strain from Kisumu.

Treatment	LC_{50} (ppm)	Confidence limit 95%	LC_{90} (ppm)	Confidence limit 95%	X^2(df)	Slope (± SE)
Pyriproxyfen	3.4[a]	0.8–5.8	13.6[a]	9.5–18.4	16.6	2.2 ± 0.52
Cymbopogon citratus	49.1[c]	42.1–54.8	87.6[c]	78.2–102.9	53.6	5.0 ± 0.69
Cymbopogon nardus	30.7[b]	17.9–40.0	74.7[c]	63.1–90.8	26.4	3.3 ± 0.64
Ocimum americanum	75.8[d]	65.4–85.5	193.5[d]	164.6–244.4	74.8	3.1 ± 0.36
Lippia multiflora	3.9[a]	1.5–6.6	29.5[b]	22.0–40.8	38.5	1.4 ± 0.23
Eucalyptus camaldulensis	29.4[b]	15.6–40.1	90.3[c]	75.3–113.1	27.4	2.6 ± 0.50

LC (lethal concentration) in ppm (part per million). LC values followed by different letters are significantly different.

citratus showed the weakest larvicidal activity (LC_{50} = 138.1 ppm; LC_{90} = 328.9 ppm) on VK larvae.

Furthermore, oils from *E. camaldulensis*, *C. nardus*, and *C. citratus* still showed strong larvicidal activities after *L. multiflora* with LC_{50} values <50 ppm and LC_{90} values <91 ppm on Kisumu larvae. On VK larvae, EOs of *C. nardus*, *O. americanum*, and *E. camaldulensis* showed strong larvicidal activities after *L. multiflora* with LC_{50} values <140 ppm and LC_{90} values <270 ppm.

Only the EO of *L. multiflora* gives LC_{50} and LC_{90} values close to that of the positive control pyriproxyfen against Kisumu and VK larvae.

Based on the overlap of the CIs of the LC_{50} and LC_{90} values, no significant difference was observed between *L. multiflora* and pyriproxyfen on the two *An. gambiae* strains tested.

Larvicidal Activities of Essential Oils Against *Aedes aegypti*

All EOs from five (5) plant species exhibited toxicity against susceptible strain larvae and 3 and 4 larval instars of *Ae. aegypti* field-collected strain. **Tables 4** and **5** show the LC_{50} and LC_{90} values of the EOs of five (5) plants tested against susceptible strains and 3 and 4 larval instars of *Ae. aegypti* field-collected strain.

As in the case of *An. gambiae* populations, among the EOs tested, *L. multiflora* was the most toxic EO on the two (2) strains of *Ae. aegypti* tested. Indeed, LC_{50} and LC_{90} values were 42 and 74.6 ppm, respectively, for *L. multiflora* tested on the susceptible strain of *Ae. aegypti* (Bora bora) and 3 and 4 larval instars of *Ae. aegypti* field-collected strain from Bobo-Dioulasso and lower for those from other EOs tested where the LC_{50} and LC_{90} values ranged from 61.5 to 103.8 ppm and 108.8 to 311.3 ppm, respectively.

For the Bora bora strain, LC_{50} and LC_{90} values were 61.5, 62.4, 91.8, 41.9, and 101.3 ppm and 132, 108.8, 180.9, 68.5, and 188.8 ppm for EOs from *C. citratus*, *C. nardus*, *E. camaldulensis*, *L. multiflora*, and *O. americanum*, respectively (**Table 4**). These values were close to those obtained with the field strain collected from Bobo-Dioulasso (LC_{50} and LC_{90} values were 74.6, 63.5, 79.4, 41.9, and 103.8 ppm and 152.3, 148.5, 226.3, 74.6, and 1,053.6 ppm with EOs from *C. citratus*, *C. nardus*, *E. camaldulensis*, *L. multiflora*, and *O. americanum*, respectively) (**Table 5**). EO of *E. camaldulensis* remains the least toxic to both strains of *Ae. aegypti* regarding the LC_{50} and LC_{90} values above 100 and 188 ppm, respectively.

Based on the overlap of the CIs of the LC_{50} and LC_{90} values, there were no significant differences between *L. multiflora* and pyriproxyfen at LC_{90} with Bora bora. Also, there were no significant differences between *C. citratus* and *C. nardus* regarding LC_{50} and LC_{90} values with the two *Ae. aegypti* strains tested. Also, there were no significant differences between *E. camaldulensis* and *O. americanum* regarding LC_{90} with the two *Ae. aegypti* strains tested and LC_{50} with Bora bora. It is also the same with *C. citratus* and *C. nardus*, in regard to LC_{50} and LC_{90} values found in two *Ae. aegypti* strains tested.

DISCUSSION

Up to now, long-lasting insecticidal nets (LLIN) and indoor residual spraying (IRS) remain the two main tools targeting mainly adults *An. gambiae* and to lesser extent *Ae. aegypti* vectors. Thus, there is an urgent need to develop innovative tools and techniques including EOs used against eggs, larvae instar, and adults in order to increase the success of vector control (11).

Our study aimed at evaluating the bioefficacy of five EOs on *Ae. aegypti* and *An. gambiae* larvae according to the WHO standard methods. Most studies have already performed the larvicidal tests but did not include the chemical control pyriproxyfen, an insect growth regulator (IGR). IGR acts by mimicking one of these hormones or directly perturbating cuticle formation/deposition or lipid biosynthesis.

TABLE 3 | Median and 90% lethal concentrations and their Confidence Limits (CLs) of plant essential oils against 3 and 4 larval instars of *Anopheles gambiae* from VK, field strain.

Treatment	LC_{50} (ppm)	Confidence limit 95%	LC_{90} (ppm)	Confidence limit 95%	X^2(df)	Slope (± SE)
Pyriproxyfen	23.7[a]	9.3–35.5	83.3[a]	66.6–106.2	11.5	1.4 ± 0.41
Cymbopogon citratus	138.1[c]	124.5–155.3	328.9[c]	267.4–451	72.4	3.3 ± 0.39
Cymbopogon nardus	76.5[b]	67.6–84.9	163[b]	143.9–193.5	97.5	3.9 ± 0.39
Ocimum americanum	89.3[b]	81.1–97.4	173.0[b]	154.2–201.4	114.0	4.4 ± 0.41
Lippia multiflora	39.5[a]	28.6–47.8	90.2[a]	78.3–108	45.1	3.2 ± 0.48
Eucalyptus camaldulensis	121.1[c]	109.9–133.6	267.3[c]	226.6–339.4	87.7	3.7 ± 0.39

LC (lethal concentration) in ppm (part per million). LC values followed by different letters are significantly different.

TABLE 4 | Median and 90% lethal concentrations and their Confidence Limits (CLs) of plant essential oils against 3 and 4 larval instars of *Aedes aegypti* susceptible strain from the Bora bora.

Treatment	LC_{50} (ppm)	Confidence limit 95%	LC_{90} (ppm)	Confidence limit 95%	X^2(df)	Slope (± SE)
Pyriproxyfen	9.5[a]	6.4–12.3	43.3[a]	34.0–61.8	49.7	1.9 ± 0.27
Cymbopogon citratus	61.5[c]	51.4–70.4	132.0[b]	119.4–150.1	71.9	3.2 ± 0.38
Cymbopogon nardus	62.4[c]	50.2–72.5	108.8[b]	98.4–124.0	74.2	3.09 ± 0.35
Ocimum americanum	91.8[d]	83.3–100.3	180.9[c]	160.8–211.5	112.3	4.3 ± 0.41
Lippia multiflora	41.9[b]	31.8–48.7	68.5[a]	61.3–84.2	39.5	2.2 ± 0.35
Eucalyptus camaldulensis	101.3[d]	73.1–132.7	188.8[c]	169.5–217.6	120.1	1.2 ± 0.31

LC (lethal concentration) in ppm (part per million). LC values followed by different letters are significantly different.

In this current study, all EOs tested exhibited variable insecticide activity against the larvae of *An. gambiae* and *Ae. aegypti*. Regarding LC_{50} and LC_{90} values, the EOs from *C. citratus*, *C. nardus*, *E. camaldulensis*, *L. multiflora*, and *O. americanum* exhibited higher larvicidal activities against third and fourth instar laboratory-reared larvae of *An. gambiae* and *Ae. aegypti* after 24 h of exposure, the most toxic of all being that of *L. multiflora*. LC_{50} of EO from *E. camaldulensis* was the least toxic against *Ae. aegypti*, whereas *C. citratus* remains the least toxic against *An. gambiae*. These data are not in agreement with those found by Manh et al. (27), who reported that on *Ae. aegypti* larvae, *C. citratus* EO (LC_{50} = 120.6 ppm) was less effective than that of *E. camaldulensis* (LC_{50} = 33.7 ppm).

Our results obtained with *C. nardus* on *An. gambiae* in this study were below those obtained by Ahouansou et al. (19), who obtained a value of 97.3 ppm for LC_{50} on *An. gambiae*. Our results were similar to those reported by Solon et al. (28) on *Ae. aegypti* populations. In their study, *O. americanum* and *C. citratus* exhibited values of LC_{50} equaling 67 and 69 ppm, respectively. However, the results with *O. americanum* were below those reported by Wangrawa et al. (21) on *An. gambiae* whose LC_{50} was 209.84 ppm.

The LC_{50} and LC_{90} values obtained with the *L. multiflora* in this current study were lowest than those reported by Bassole et al. (23). Recently, the same trend was observed by Yameogo et al. (22), who showed also the toxic effect of *L. multiflora* against *Ae. aegypti* populations from Tabtenga, Ouagadougou.

Interestingly, the high toxicity of the *L. multiflora* EO could result in the presence of three major components: thymol, *p*-cymene, and β-caryophyllene. According to Folashade (29), thymol, germacrene D, *p*-cymene, thymyl acetate, and sabinene were found in EOs of *L. multiflora* in Ghana and seem to be involved in *Lippia* toxicity. Conversely, the lower larvicidal activities of *C. citratus*, *C. nardus*, *E. camaldulensis*, and *O. americanum* oils could be explained by the minor effect of piperitone, geraniol, and 1.8-cineole against *Ae. aegypti* and *An. gambiae* larvae. This could explain the differences observed in biological activity among the EOs.

Regarding the LC_{50} and LC_{90} values, the bioefficacy of *L. multiflora* on *An. gambiae* strains is closer to that of the positive control used in this study, which is pyriproxyfen, the reference larvicide used against larvae. This would open new alternatives for mosquito control.

Globally, in *An. gambiae* strain populations, the laboratory-reared larvae were found to be the most susceptible to EOs than those from the field population (VK), known for their resistance to pyrethroid (30–32).

As observed in *An. gambiae* populations, *Ae. aegypti* larvae were the most susceptible to *L. multiflora* after the chemical pyriproxyfen. The LC_{50} values found in this study were slightly lower than those observed in *Ae. aegypti* populations from Ouagadougou (22), explaining the occurrence of the phenotypic resistance to the main chemical.

As shown by Namountougou et al. (33), tests performed with deltamethrin on *Ae. aegypti* populations collected from Bobo-Dioulasso showed mortality rates reaching 89.62% and 82.72% for 2013 and 2014, respectively. Mortality rates of *Ae. aegypti* collected from Ouagadougou were 50.7% and 20.7% for 2013 and 2014, respectively. All these values were lower than 90%, suggesting a resistance. It is very urgent to search for an alternative to chemicals. Our data will help to develop innovative strategies based on EOs.

CONCLUSION

Our results showed that the use of EOs as larvicides is a promising strategy. Therefore, they could be the object of

TABLE 5 | Median and 90% lethal concentrations and their Confidence Limits (CLs) of plant essential oils against 3 and 4 larval instars of *Aedes aegypti* from Bobo-Dioulasso, field strain.

Treatment	LC_{50} (ppm)	Confidence limit 95%	LC_{90} (ppm)	Confidence limit 95%	X^2(df)	Slope (± SE)
Pyriproxyfen	11.04[a]	8.2–13.7	43.2[a]	35.3–56.1	80.8	2.1 ± 0.24
Cymbopogon citratus	74.6[c]	67.7–81.2	152.3[c]	131.9–186.0	116.2	5.1 ± 0.48
Cymbopogon nardus	63.5[c]	57.3–69.4	148.5[c]	128.4–182.6	74.2	5.4 ± 0.54
Ocimum americanum	79.4[e]	67.6–90.2	226.3[d]	186.9–302.9	64.4	2.8 ± 0.35
Lippia multiflora	42[b]	33.4–47.3	74.6[b]	65.3–92.5	22.0	6.0 ± 1.28
Eucalyptus camaldulensis	103.8[d]	95.4–112.3	311.3[d]	238–503.1	18.3	4.9 ± 0.45

LC (lethal concentration) in ppm (part per million). LC values followed by different letters are significantly different.

particular attention in the search for new natural, selective, and biodegradable larvicidal products that can be used in public health vector control programs against *An. gambiae* and *Ae. aegypti* in particular.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MB and OG designed the study. DS critically supervised the study. MB, HK, GM, and OT carried out the laboratory experiments. MB, SD, and OG analyzed and interpreted the data and drafted the manuscript. OG, RD, and MN revised the manuscript. All authors contributed to the article and approved the submitted version.

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