Original Article

LARVICIDAL POTENTIAL OF BOTANICAL EXTRACTS OF *Syzygium aromaticum, Sida acuta* AND *Codiaeum variegatum* AGAINST *Anopheles gambiae s.l.* AND *Aedes aegypti* IN IKORODU AND ALIMOSHO LGAs, LAGOS STATE, NIGERIA.

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ABSTRACT

Botanical larvicides are becoming popular due to development of resistance to insecticides used for larviciding. This study characterised the chemical constituents and evaluated the larvicidal activity of botanical extracts of Syzygium aromaticum (clove), Sida acuta (wire weed) and Codiaeum variegatum (variegated croton) against third-instar larvae of Anopheles gambiae s.l. and Aedes aegypti collected from Ikorodu and Alimosho Local Government Areas, Lagos State, Nigeria. Leaves of S. acuta and C. variegatum were extracted with n-hexane in a Soxhlet apparatus, clove buds were hydrodistilled in a Clevenger-type apparatus, and the chemical constituents were profiled by gas chromatography–mass spectrometry (GC-MS). Larvae were exposed to 200, 400 and 600 ppm of each extract following the World Health Organization larval susceptibility protocol, mortality was recorded at 24, 48 and 72h, and lethal concentrations were estimated by probit analysis. Eugenol (55.26%), eugenyl acetate (18.00%) and caryophyllene (12.09%) were the main constituents of clove oil, whereas the extracts of S. acuta and C. variegatum were dominated by fatty acids and their esters. Clove oil was the most toxic to An. gambiae larvae (72-h LC_{50} = 284.1 ppm; LC_{90} = 1,723.8 ppm), followed by S. acuta (LC_{50} = 2,138.0 ppm), while no lethal concentrations could be estimated for C. variegatum. Against Ae. aegypti, only clove oil yielded estimable values (LC_{50} = 568.7 ppm; LC_{90} = 1,062.6 ppm). Larval mortality increased with concentration and exposure time. These findings identify clove essential oil as a promising botanical larvicide for the management of malaria and yellow fever vectors in Lagos and support its evaluation in semi-field and field trials.

KEYWORDS: Anopheles Gambiae, Aedes Aegypti, Larvicidal Activity, Clove, Wire Weed, Variegated Croton, Botanical Extracts, Essential Oils, GC-MS, Vector Control.

INTRODUCTION

Mosquitoes are insects of major medical importance, responsible for the transmission of several parasitic and arboviral diseases such as malaria, lymphatic filariasis, dengue, yellow fever and Rift Valley fever (Juliano and Lounibos, 2005). The World Health Organization (WHO) estimated 282 million malaria cases and 610,000 deaths worldwide in 2024, with about 95% of the deaths occurring in the WHO African Region, where Nigeria is among the countries carrying the heaviest burden (WHO, 2025). Children under five years of age and pregnant women are the groups most vulnerable to the disease (Ryg-Cornejo *et al.,* 2016; WHO, 2021).

Anopheles gambiae complex (Diptera: Culicidae) are the principal vectors of malaria in Nigeria of which *An. gambiae* s.s., *An. coluzzii* and *An. arabiensis* (Okorie *et al.,* 2011; Olayemi *et al.,* 2011; Obi *et al.,* 2017; Oduola *et al.,* 2019). *Aedes aegypti*, a vector of yellow fever and dengue viruses, also occurs in Lagos State (Ayorinde *et al.,* 2015). Vector control remains a cornerstone of prevention, and long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) are the main tools used against adult mosquitoes (WHO, 2018). These tools depend on a small number of synthetic insecticide classes (organochlorines, organophosphates, carbamates and pyrethroids), and resistance to these insecticides has been widely reported in Nigerian populations of Anopheles vectors (Djouaka *et al.,* 2016; Adeogun *et al.,* 2017; Awolola *et al.,* 2018; Oduola *et al.,* 2019). In addition, synthetic insecticides are associated with environmental contamination, effects on non-target organisms and high operational costs (Benelli, 2015).

Adult-targeted interventions are further limited by the fact that treated nets are used indoors, whereas many people in Nigeria are bitten outdoors (Omotayo *et al.,* 2021). Larval source management, which targets the aquatic stages before they emerge as biting adults, is therefore an important complementary strategy (Walker and Lynch, 2007). Larvicides of plant origin are particularly attractive for this purpose because they are biodegradable, target-specific, readily accessible and cost-effective (Kamaraj *et al.,* 2010; Soonwera and Phasomkusolsil, 2017), and because they contain mixtures of bioactive constituents, they may be less likely to select for resistance. Numerous plant extracts and essential oils have been reported to be toxic to mosquito larvae (Pratheeba *et al.,* 2019), including those of An. gambiae (Aina *et al.,* 2009; Akinkurolere *et al.,* 2011; Ileke and Ogungbite, 2015; Adelaja *et al.,* 2021). However, insecticidal activity depends on the plant species, the plant part used, the geographical origin of the plant, the extraction method and the polarity of the extraction solvent (Abirami *et al.,* 2017), which makes local evaluation of candidate plants necessary.

Syzygium aromaticum (clove; Myrtaceae), *Sida acuta* (wire weed; Malvaceae) and *Codiaeum variegatum* (variegated croton; Euphorbiaceae) are widely available in Nigeria and have documented bioactivity. Clove buds are rich in essential oil, in which eugenol, eugenyl acetate and β-caryophyllene are the main constituents (Cortés-Rojas *et al.,* 2014). A methanolic leaf extract of *S. acuta* has shown larvicidal and repellent activity against *Culex quinquefasciatus*, *Ae. aegypti* and *Anopheles stephensi* (Govindarajan, 2010), and essential oils of *C. variegatum* are terpene-rich and possess insecticidal activity (Lawal *et al.,* 2018). Nevertheless, there is little information on the larvicidal effects of these three plants against members of the *An. gambiae* complex and *Ae. aegypti* in Lagos State.

This study was designed to characterised the chemical constituents, by GC-MS, and evaluated the larvicidal activity of botanical extracts and essential oils of *S. aromaticum*, *S. acuta* and *C. variegatum* against third-instar larvae of *An. gambiae* s.l. and *Ae. aegypti* collected from Ikorodu and Alimosho Local Government Areas (LGAs) of Lagos State. The findings provide baseline information on the chemical composition and larvicidal potency of these botanicals and contribute to the identification of promising candidates for plant-based larval source management in malaria and yellow fever vector control.

The study was conducted in Lagos State (6.5142° N, 3.3710° E). Mosquito larvae were collected from two LGAs, Ikorodu (peri-urban) and Alimosho (urban), which were selected to represent contrasting ecosystems and because of reported high malaria endemicity and mosquito abundance. Larval rearing, morphological identification, extraction of the botanicals and the larvicidal bioassays were carried out at the insectary and laboratories of the Nigerian Institute of Medical Research (NIMR), Yaba, Lagos. Extraction of the plant materials and GC-MS analysis were conducted at the Pharmacognosy Laboratory, College of Medicine, University of Lagos (CMUL). All field collections and laboratory analyses were conducted between June and December 2025.

MATERIALS AND METHODS

Study Area

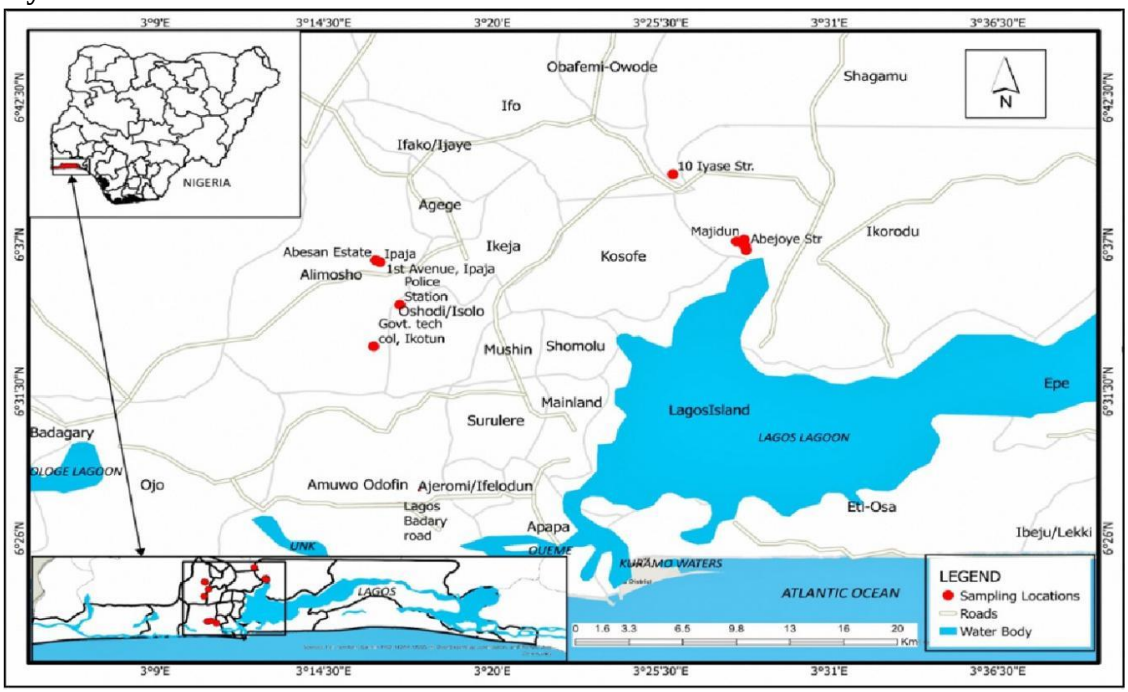


Figure 1. *Map of the study area in Alimosho and Ikorodu Local Goverment Areas of Lagos State, Nigeria*

Collection and identification of mosquito larvae

Mosquito larvae were collected from stagnant water, small temporary rain pools and man-made containers in Ikorodu and Alimosho LGAs using the dipping technique, in which a dipper is lowered gently at an angle of 45° just below the water surface so that water flows in together with any larvae present. The water samples

were transported to the NIMR insectary, where the larvae were separated from debris, transferred into clean non-chlorinated distilled water and sorted for identification.

Larvae were identified morphologically at the NIMR insectary by an insect taxonomist using standard identification keys. Anopheles larvae were recognised by the absence of a respiratory siphon and by their characteristic position parallel to the water surface, in contrast to the non-anopheline larvae, which hang from the surface by their posterior siphon with the body pointing downwards. *Anopheles gambiae* s.l. larvae from Ikorodu and *Ae. aegypti* larvae from Alimosho were used for the bioassays, and active third-instar larvae were selected for testing.

Plant collection, identification and extraction

Fresh, mature leaves of *S. acuta* and *C. variegatum* were collected at Alimosho LGA, Lagos State, and dried flower buds of *S. aromaticum* were purchased from Ketu market, Lagos. The plants were identified and authenticated at the Herbarium of the Department of Botany, University of Lagos, Akoka, Yaba. The plant materials were air-dried under laboratory shade to reduce their moisture content and were then pulverised to a powder using an electric blender.

The bioactive constituents of the leaves of *S. acuta* and *C. variegatum* were extracted by the Soxhlet method. One kilogram of the powdered leaves was placed in a thimble and extracted with n-hexane. In this continuous extraction, the solvent is heated to reflux, condenses into the thimble containing the sample and, as the chamber fills, siphons back into the boiling flask carrying the dissolved compounds with it. After extraction, the mixture of extract and solvent was placed in a water bath to evaporate the solvent and retain the extract. One kilogram of the powdered clove buds was subjected to hydrodistillation in a Clevenger-type apparatus to obtain the essential oil. Residual water was removed from the oil with anhydrous sodium sulphate (Na2SO4), and the extracts and oil were stored in tightly closed amber bottles at 4 °C until used for GC-MS analysis and the bioassays.

Characterisation of the extracts by GC-MS

The chemical constituents of the three botanicals were characterised using a GC-MS 6890-5975 system (Agilent Technologies, Palo Alto, CA, USA) equipped with an HP-5MS fused silica capillary column (30 m × 0.25 mm i.d., 0.25 μm film thickness). Electron ionisation was used for detection, with an ionisation energy of 70 eV. Helium was the carrier gas at a flow rate of 1 mL/min, and the injector and mass transfer line temperatures were set at 250 °C and 280 °C, respectively. A 1 μL aliquot of each sample in hexane was injected. The column temperature was held at 40 °C for 1 min, increased to 250 °C at 3 °C/min and maintained at 250 °C for 20 min. Kovats indices were calculated for the volatile components using a homologous series of n-alkanes (C8–C25) on the HP-5MS column. Compounds were identified by co-injection with standards where available and by comparison with the Wiley (version 7.0) and National Institute of Standards and Technology (NIST, version 2.0) mass spectral libraries on the basis of Kovats indices. The relative concentration of each compound was calculated from its integrated peak area.

Preparation of test solutions and larvicidal bioassay

The larvicidal bioassays followed the WHO standard protocol for larval susceptibility tests (WHO, 2005). Stock solutions of the botanical extracts were

prepared by dissolving 200 mg of extract in 20 mL of absolute acetone (1% stock solution) and were diluted with distilled water to give test concentrations of 200, 400 and 600 ppm.

Twenty five (25) active third-instar larvae (n = 25) were transferred with a dropper into white enamel cups containing each test concentration. Each concentration was tested in duplicate, and controls were maintained in distilled water only. The cups were kept at 27 ± 2 °C and 75 ± 10% relative humidity under a 12 h light : 12 h dark photoperiod, and no food was provided to the test or control larvae during the experiment. Dead larvae were counted after 24, 48 and 72 h of exposure. Larvae were considered dead when they were immobile, unable to reach the water surface and unresponsive to prodding with a probe.

Percentage mortality was calculated as: percentage test mortality (%) = (number of dead larvae / total number of larvae used) × 100, and mortality was corrected for control mortality using Abbott's (1925) formula: corrected mortality (%) = [(% test mortality − % control mortality) / (100 − % control mortality)] × 100.

Ethical considerations

Ethical approval was obtained from the University of Lagos Animal Care and Use Research Ethics Committee (UNILAGACUREC/2026/02/AP23) before the commencement of mosquito larvae collection. Informed consent was obtained from community heads and individuals who volunteered for sampling mosquitoes in breeding sites. The consenting larvae collectors were already on anti-malarial treatments as part of the WHO requirements prior to commencement of the study.

Statistical analysis

The mortality data were compiled in Microsoft Excel® and analysed using SPSS (version 25). Probit analysis (Finney, 1971) was used to estimate the lethal concentrations that killed 50% (LC50) and 90% (LC90) of the larvae after 72 h of exposure, together with the probit regression line (probit = intercept + slope × log10 concentration), the slope ± standard error and the 95% confidence limits (lower and upper confidence limits, LCL and UCL). Differences in mortality among treatments were compared using one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test, and differences were considered significant at $P \leq 0.05$.

RESULTS

Chemical composition of the botanical extracts

GC-MS analysis showed that the chemical composition of the three botanicals differed markedly (Tables 1 – 3).

***Syzygium aromaticum* (clove)**

Fourteen compounds were identified in the essential oil of *S. aromaticum* (Table 1). Eugenol was the major constituent (55.26%), followed by eugenyl acetate (18.00%) and caryophyllene (12.09%). Humulene (5.05%), anethole (3.06%), 6-methoxy-3-methylbenzofuran (1.90%) and caryophyllene oxide (1.12%) were present in smaller amounts, and D-limonene accounted for 0.73% of the essential oil.

Table 1: GC-MS chemical profile of the essential oil of Syzygium aromaticum (clove)

S/N	Chemical name	Retention time (min)	Peak area (%)
1	D-Limonene	3.974	0.73
2	Methyl salicylate	6.211	0.52
3	Anethole	7.333	3.06
4	Cinnamaldehyde, (E)-	7.796	0.31
5	Eugenol (3-allyl-6-methoxyphenol)	8.271	55.26
6	Caryophyllene	9.072	12.09
7	Humulene / cycloundecatriene derivative	9.410	5.05
8	6-Methoxy-3-methylbenzofuran	9.645	1.90
9	Eugenyl acetate (phenol, 2-methoxy-4-(2-propenyl)-, acetate)	10.080	18.00
10	Caryophyllene oxide	10.720	1.12
11	1-Methyl-2-methylene-trans-decalin	10.903	0.52
12	Dimethylbicycloundecanol derivative	11.235	0.60
13	Decahydronaphthalene derivative	11.396	0.45
14	Octahydronaphthalenylpropanol derivative	11.533	0.38

***Sida acuta* (wire weed)**

Twenty-two peaks were detected in the hexane extract of S. acuta (Table 2). Apart from n-hexane (24.43%), the extraction solvent, the profile was dominated by fatty acids and their esters, notably pentadecanoic acid, 14-methyl-, methyl ester (16.46%) and methyl stearate (14.59%), together with ethyl 9,12,15-octadecatrienoate (3.33%), cis-vaccenic acid (2.42%), n-hexadecanoic acid (2.13%) and hexadecanoic acid, ethyl ester (1.40%). Notable volatile and phenylpropanoid constituents included eugenol (6.42%), anethole (4.08%) and D-limonene (detected as two peaks, 3.60% and 7.17%).

Table 2: GC-MS chemical profile of the hexane extract of Sida acuta (wire weed)

S/N	Chemical name	Retention time (min)	Peak area (%)
1	Azoxypyridine derivative	0.962	1.25
2	Pentane, 3-methyl-	1.065	1.58
3	n-Hexane	1.454	24.43
4	D-Limonene	3.926	3.60
5	D-Limonene	4.058	7.17
6	Benzoic acid, methyl ester	4.951	2.33
7	Estragole	6.255	0.53
8	Anethole	7.348	4.08
9	Eugenol	8.132	6.42
10	Caryophyllene	8.870	0.58
11	trans-Isoeugenol	9.866	1.18
12	Neophytadiene	12.881	0.68
13	Pentadecanoic acid, 14-methyl-, methyl ester	13.660	16.46
14	n-Hexadecanoic acid	14.026	2.13
15	Hexadecanoic acid, ethyl ester	14.220	1.40
16	Neophytadiene	15.176	2.76
17	Methyl stearate	15.290	14.59
18	Ethyl 9,12,15-octadecatrienoate	15.616	3.33

19	cis-Vaccenic acid	16.000	2.42
20	Pentamethyl-eicosapentaene derivative	19.227	1.40
21	Z-8-Methyl-9-tetradecenoic acid	19.994	1.02
22	Di-n-octyl phthalate	20.217	0.66

***Codiaeum variegatum* (variegated croton)**

Thirteen compounds were identified in the hexane extract of *C. variegatum* (Table 3). The most abundant were n-hexadecanoic acid (26.20%) and cis-vaccenic acid (25.92%), followed by 9-octadecenoic acid (Z)-, methyl ester (11.87%), pentadecanoic acid, 14-methyl-, methyl ester (10.79%) and octadecanoic (stearic) acid (7.52%). Other components included 9,12-octadecadienoic acid, methyl ester (5.13%), phytol (4.12%), methyl stearate (2.43%) and patchouli alcohol (1.25%).

Table 3: GC-MS chemical profile of the hexane extract of Codiaeum variegatum (variegated croton)

S/N	Chemical name	Retention time (min)	Peak area (%)
1	Patchouli alcohol	11.195	1.25
2	Tetradecanoic acid	12.031	1.14
3	2-Pentadecanone, 6,10,14-trimethyl-	12.672	1.19
4	Pentadecanoic acid, 14-methyl-, methyl ester	13.341	10.79
5	n-Hexadecanoic acid	13.787	26.20
6	9,12-Octadecadienoic acid, methyl ester (E,E)	14.720	5.13
7	9-Octadecenoic acid (Z)-, methyl ester	14.766	11.87
8	Phytol	14.875	4.12
9	Methyl stearate	14.943	2.43
10	cis-Vaccenic acid	15.172	25.92
11	Octadecanoic acid (stearic acid)	15.315	7.52
12	cis-Vaccenic acid (derivative)	15.453	1.22
13	Phthalic acid derivative (plasticiser)	19.487	1.22

Larvicidal activity of the botanical extracts

The botanicals differed in their toxicity to the larvae of both mosquito species. Larval mortality increased with increasing concentration and exposure time, and the increase was significant for *S. aromaticum* and *S. acuta*.

***Anopheles gambiae* larvae (Ikorodu LGA)**

The 72-h lethal concentrations of the botanicals against *An. gambiae* larvae from Ikorodu are presented in Table 4. Clove essential oil was the most toxic, with an LC_{50} of 284.126 ppm and an LC_{90} of 1,723.764 ppm (probit $Y = -4.016 + 1.637x$; slope = 1.637 ± 1.194; Figure 1). The extract of *S. acuta* was considerably less toxic, with an LC_{50} of 2,138.032 ppm and an LC_{90} of 7,564.603 ppm ($Y = -7.777 + 2.335x$; slope = 2.335 ± 2.811); these values lie above the highest concentration tested (600 ppm) and are therefore extrapolated. No LC_{50} or LC_{90} values could be estimated for the extract of *C. variegatum*. Clove oil was therefore the most potent larvicide against *An. gambiae.*

Table 4: Relative toxicity of the botanical extracts to third-instar Anopheles gambiae larvae (Ikorodu LGA) after 72 h of exposure

Treatment (extract)	LC_{50} (ppm)	LC_{90} (ppm)	Probit line of equation	df	Slope ± SE
S. aromaticum (clove)	284.126	1,723.764	$Y = -4.016 + 1.637x$	1	1.637 ± 1.194
S. acuta (wire weed)	2,138.032[a]	7,564.603[a]	$Y = -7.777 + 2.335x$	1	2.335 ± 2.811
C. variegatum (variegated croton)	–	–	–	–	–

LC_{50} and LC_{90} are the concentrations causing 50% and 90% mortality; probit Y = intercept + slope × x, where x is the $\log_{10}$ of the concentration in ppm; df = degrees of freedom; SE = standard error. [a]Extrapolated beyond the highest concentration tested (600 ppm). – = no value could be estimated.

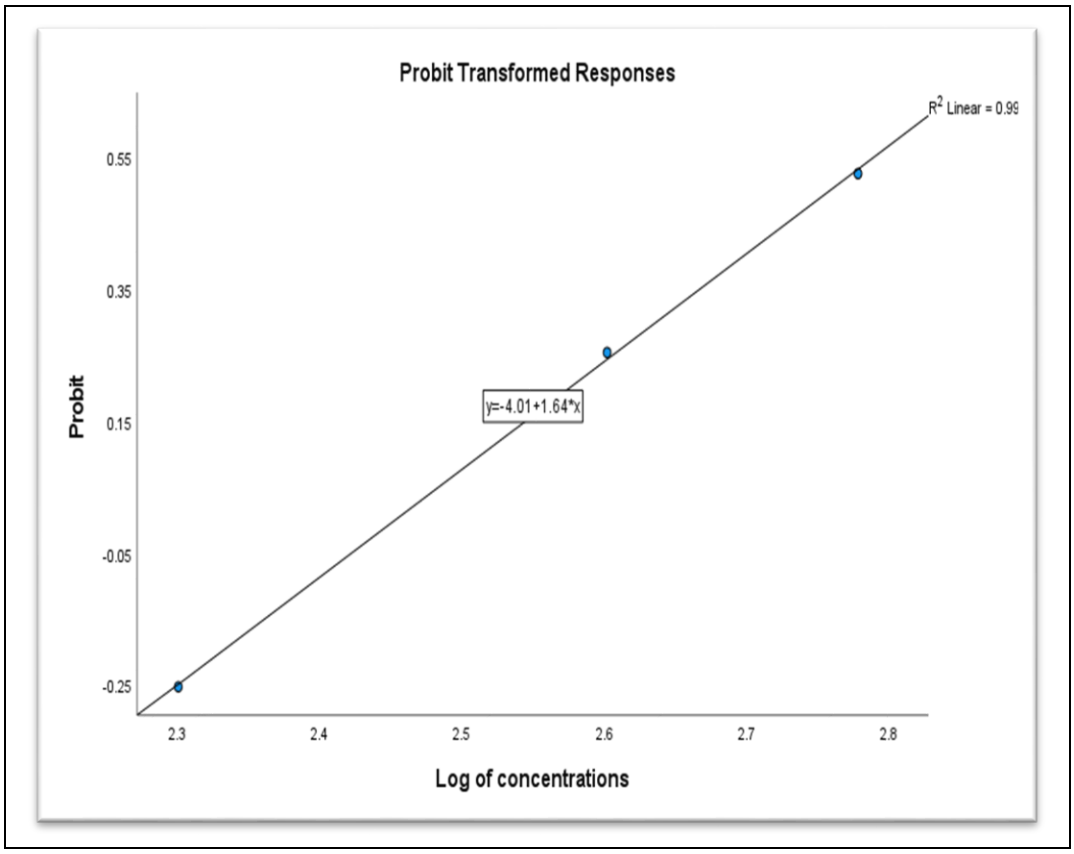


Figure 1: *Probit-transformed mortality of Anopheles gambiae larvae plotted against the log_{10} concentration of Syzygium aromaticum (clove) essential oil.*

***Aedes aegypti* larvae (Alimosho LGA)**

Only clove essential oil produced estimable lethal concentrations against *Ae. aegypti* larvae from Alimosho (Table 5). The LC_{50} was 568.745 ppm (95% CL: 431.050–3,054.178) and the LC_{90} was 1,062.644 ppm (95% CL: 687.804–565,218), with a probit line of Y = −13.005 + 4.721x and a slope of 4.721 ± 2.127 (Figure 2). No LC values could be estimated for the extracts of *S. acuta* and *C. variegatum.* Based on the LC_{50}, *An. gambiae* larvae were approximately twice as susceptible to clove oil as *Ae. aegypti* larvae (284.126 versus 568.745 ppm).

Table 5: Relative toxicity of the botanical extracts to third-instar Aedes aegypti larvae (Alimosho LGA) after 72 h of exposure

Treatment (extract)	**LC_{50} (ppm) (95% CL)**	**LC_{90} (ppm) (95% CL)**	**Probit line of equation**	**df**	**Slope ± SE**
S. aromaticum (clove)	568.745 (431.050–3,054.178)	1,062.644 (687.804–565,218)	$Y = -13.005 + 4.721x$	1	4.721 ± 2.127
S. acuta (wire weed)	–	–	–	–	–
C. variegatum (variegated croton)	–	–	–	–	–

CL = 95% confidence limits; probit Y = intercept + slope × x, where x is the $\log_{10}$ of the concentration in ppm; df = degrees of freedom; SE = standard error. – = no value could be estimated.

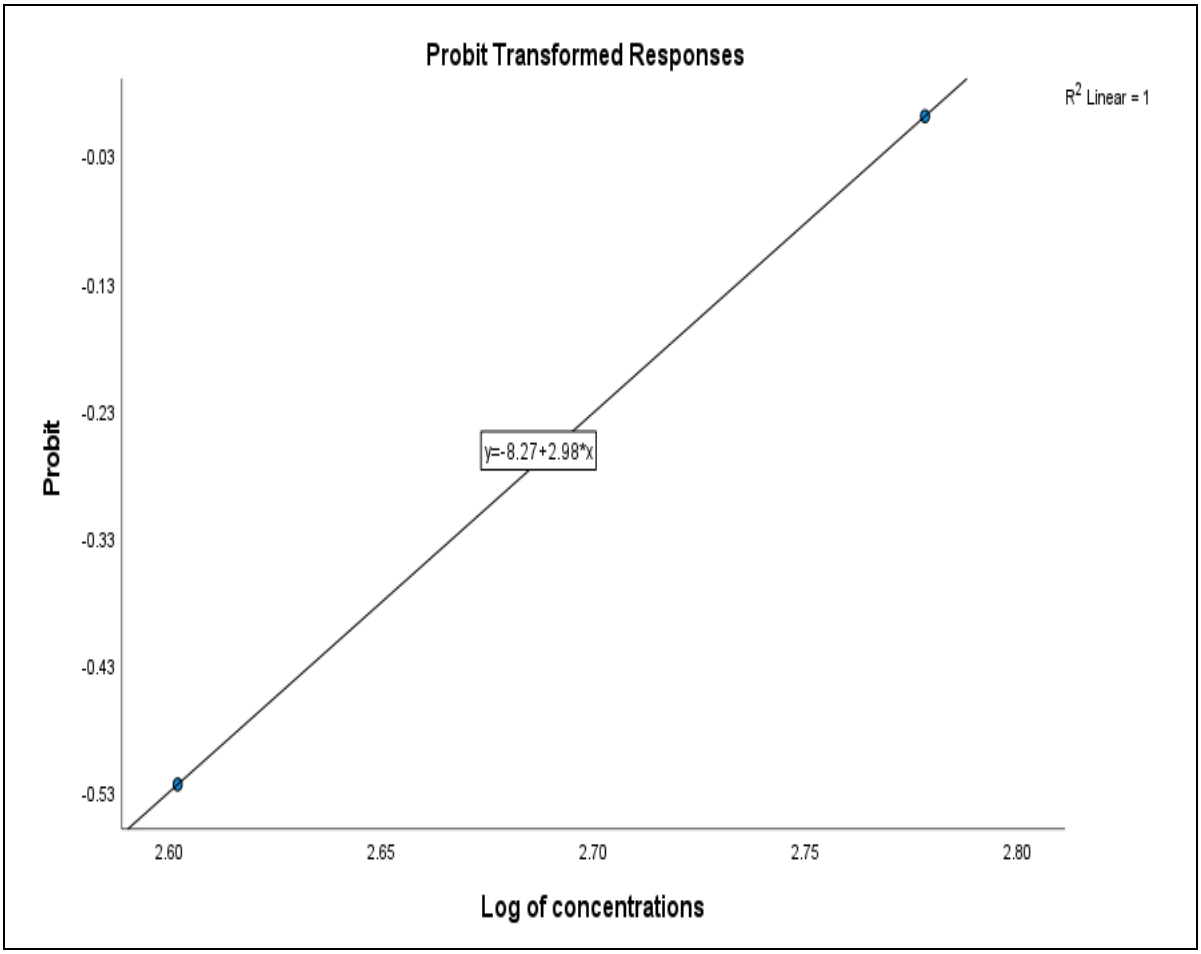


Figure 2: *Probit-transformed mortality of Aedes aegypti larvae plotted against the $\log_{10}$ concentration of Syzygium aromaticum (clove) essential oil. Concentrations causing 0% or 100% mortality cannot be probit-transformed and are not plotted; the line shown is the least-squares fit to the plotted points, while the model parameters (maximum likelihood) are given in Table 6.*

DISCUSSION

This study characterised the chemical constituents and evaluated the larvicidal activity of extracts and essential oils of *S. aromaticum*, *S. acuta* and *C. variegatum* against *An. gambiae* s.l. and *Ae. aegypti* larvae from Lagos State. The bioactivity of plant products against mosquito larvae varies with the plant species, the plant part used, the extraction solvent and method, and the mosquito species (Abirami *et al.*, 2017), and this was reflected in the marked differences in potency among the three botanicals.

Clove essential oil was the most toxic to the larvae of both mosquito species (LC_{50} = 284.126 ppm for *An. gambiae* and 568.745 ppm for *Ae. aegypti*). Its GC-MS profile, with eugenol (55.26%), eugenyl acetate (18.00%) and caryophyllene (12.09%) as the main constituents, corresponds to the characteristic composition of clove oil, in which these compounds are considered responsible for its bioactivity (Cortés-Rojas *et al.*, 2014; Taleuzzaman *et al.*, 2021). The relative proportions of the constituents of clove oil depend on the variety, agro-ecological conditions and extraction process (Hatami *et al.*, 2019). The high larvicidal activity observed is therefore probably associated with the high content of eugenol and related constituents, although the contribution of individual compounds, or of synergy among the major and minor constituents, was not tested in this study. Toxicity of hexane-prepared plant extracts to *Ae. aegypti* larvae has also been reported for *Piper guineense*, which killed 77% and 95% of larvae after 1 and 24 h, respectively.

Larvae of *An. gambiae* were approximately twice as susceptible to clove oil as those of *Ae. aegypti.* Because the two species were collected from different LGAs, this difference may reflect species-specific susceptibility, differences between the field populations, or both, and the present design cannot separate these effects. Ikorodu and Alimosho are residential zones characterised by poor drainage and waste management, which provide abundant larval habitats, and the susceptibility of larvae from such habitats to botanical products may differ from that of larvae from other environments.

The hexane extract of *S. acuta* showed weak larvicidal activity against *An. gambiae* (LC_{50} = 2,138.032 ppm, extrapolated beyond the tested range) and no estimable LC values against *Ae. aegypti*. This contrasts with the strong larvicidal and repellent activity reported for a methanolic leaf extract of S. acuta against *Cx. quinquefasciatus*, *Ae. aegypti* and *An. stephensi* (Govindarajan, 2010). The difference may be related to the extraction solvent: the phenolic compounds, flavonoids and other polar constituents reported from *S. acuta* (Tcheghebe *et al.*, 2017) are extracted more efficiently by methanol than by non-polar n-hexane, which yielded mainly fatty acids and their esters in the present study. The monoterpene D-limonene and the phenylpropanoids eugenol and anethole detected in the extract are noteworthy, as monoterpenes are known to be toxic to *An. gambiae* larvae (Kweka *et al.*, 2016), but their concentrations in the extract may have been too low to cause substantial mortality within the concentration range tested.

The hexane extract of *C. variegatum*, which was dominated by n-hexadecanoic (palmitic) acid, cis-vaccenic acid, fatty acid methyl esters and stearic acid, did not yield estimable LC values against either mosquito species. Lawal *et al.* (2018) reported insecticidal activity for essential oils of four Nigerian varieties of *C. variegatum*, but those oils were terpene-rich, whereas the solvent extract analysed here contained only small proportions of terpenoids (phytol, 4.12%; patchouli alcohol, 1.25%). This suggests that the extraction method, and hence the chemical composition of the product, strongly influences its larvicidal

activity, and the phytochemical composition of *C. variegatum* is also known to vary among cultivars (Ogunwenmo *et al.,* 2007; Babatunde *et al.,* 2017). Hydrodistilled essential oil of *C. variegatum* may therefore be worth testing against these vectors.

Larval mortality increased with concentration and exposure time for the active botanicals, which agrees with earlier reports on plant extracts tested against *An. gambiae* larvae in Nigeria (Aina *et al.,* 2009; Akinkurolere *et al.,* 2011). Some limitations should nevertheless be noted. Only three concentrations (200 – 600 ppm) were tested, with five larvae in each of two replicates, so the dose-response curves were fitted with one degree of freedom and the confidence limits, particularly for the LC_{90} of clove oil against *Ae. aegypti*, are wide. The lethal concentrations should therefore be regarded as preliminary estimates. In addition, the compounds responsible for the observed toxicity were not isolated or tested individually.

In conclusion, of the three botanicals evaluated, the essential oil of *S. aromaticum* was the most effective larvicide against both *An. gambiae* s.l. and Ae. aegypti, the extract of *S. acuta* had weak activity against *An. gambiae*, and the hexane extract of *C. variegatum* did not yield estimable lethal concentrations. Because clove is readily available in Nigerian markets, its essential oil is a promising candidate, as a biodegradable alternative to synthetic insecticides, for plant-based larval source management in malaria and yellow fever vector control. Further studies are needed with a wider range of concentrations and larger numbers of larvae, on the mode of action, on the effects of combinations of the botanicals, and on their safety to non-target aquatic organisms, followed by semi-field and field trials to confirm their efficacy under natural breeding conditions.

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