

## Larvicide potential of essential oils from Brazilian plants against *Aedes aegypti*

Potencial larvicida de óleos essenciais de plantas brasileiras contra o *Aedes aegypti*

Potencial larvicida de aceites esenciales de plantas brasileñas contra el *Aedes aegypti*

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### Abstract

The arboviruses Dengue, Chikungunya and Zika virus are present in several tropical regions and are transmitted by the *Aedes aegypti* mosquito. The containment of these diseases is done by fighting the vector, usually using chemical insecticides, such as organophosphates and organochlorines. These provoke the resistance of the transmitter, have a high accumulation rate in the body of non-target populations, and promote the contamination of ecosystems. The application of materials of natural origin with larvicidal activity, such as essential oils, is a promising alternative to replace the use of chemical insecticides. In this systematic review, we sought to present the larvicidal properties of essential oils from botanical species of Brazilian flora against *Ae. aegypti*. The search resulted in 36 papers selected as articles of interest. The 65 plants described in the selected articles showed larvicidal activity mostly excellent (27 were classified as strongly active) or satisfactory (13 were moderately active, and 24 were effective), while only one was inactive. The species that showed the highest larvicidal activity were: *Anacardium occidentale* L. (0.01 ppm); *Copaifera langsdorffii* Desf. (0.04 ppm); *Carapa guianensis* Aubl. (0.06 ppm); *Cymbopogon winterianus* Jowitt. (0.10 ppm); *Ageratum conyzoides* L. (0.15 ppm); *Tagetes minuta* L. (0.21 – 0.25 ppm); and *Siparuna guianensis* Aubl. (1.76, 0.98 and 2.46 ppm). Studies on the essential oils of Brazilian plants are of great relevance to combat arboviruses. The Brazilian flora, despite its vast biodiversity, is still little known and explored, possessing a huge potential for the development of eco-friendly, environmentally safe, and low-cost products.

**Keywords:** *Aedes aegypti*; Arboviruses; Larvicides; Brazilian flora; Essential oils.

### Resumo

As arboviroses Dengue, Chikungunya e Zika vírus estão presentes em várias regiões tropicais e são transmitidos pelo mosquito *Aedes aegypti*. A contenção destas doenças é feita pelo combate ao vetor, geralmente utilizando inseticidas químicos, como organofosforados e organoclorados. Estes provocam a resistência do transmissor, têm uma alta taxa de acúmulo no corpo de populações não-alvo e promovem a contaminação dos ecossistemas. A aplicação de materiais de origem natural com atividade larvicida, tais como óleos essenciais, é uma alternativa promissora para substituir o uso de inseticidas químicos. Nesta revisão sistemática, procuramos apresentar as propriedades larvicidas dos óleos essenciais de espécies botânicas da flora brasileira contra o *Ae. aegypti*. A pesquisa resultou em 36 artigos selecionados como artigos de interesse. As 65 plantas descritas nos artigos selecionados mostraram atividade larvicida em sua maioria excelente (27 foram classificadas como fortemente ativas) ou satisfatória (13 foram moderadamente ativas, e 24 foram efetivas), enquanto apenas uma foi inativa. As espécies que apresentaram a maior atividade larvicida foram: *Anacardium occidentale* L. (0,01 ppm); *Copaifera langsdorffii* Desf. (0,04 ppm); *Carapa guianensis* Aubl. (0,06 ppm); *Cymbopogon winterianus* Jowitt. (0,10 ppm); *Ageratum conyzoides* L. (0,15 ppm); *Tagetes minuta* L. (0,21 - 0,25 ppm); e *Siparuna guianensis* Aubl. (1,76, 0,98 e 2,46 ppm). Os estudos sobre os óleos essenciais das plantas brasileiras são de grande relevância para combater as arboviroses. A flora brasileira, apesar de sua vasta biodiversidade, ainda é pouco conhecida e explorada, possuindo um enorme potencial para o desenvolvimento de produtos ecologicamente corretos, ambientalmente seguros e de baixo custo.

**Palavras-chave:** *Aedes aegypti*; Arboviroses; Larvicidas; Flora brasileira; Óleos essenciais.

## Resumen

Las arbovirosis Dengue, Chikungunya y Zika virus están presentes en varias regiones tropicales y son transmitidos por el mosquito *Aedes aegypti*. La contención de estas enfermedades se realiza combatiendo el vector, generalmente con insecticidas químicos, como los organofosforados y los organoclorados. Estos provocan la resistencia del transmisor, tienen una alta tasa de acumulación en el cuerpo de las poblaciones no objetivo y promueven la contaminación de los ecosistemas. La aplicación de materiales de origen natural con actividad larvicida, como los aceites esenciales, es una alternativa prometedora para sustituir el uso de insecticidas químicos. En esta revisión sistemática, buscamos presentar las propiedades larvicidas de los aceites esenciales de especies botánicas de la flora brasileña contra *Ae. aegypti*. La búsqueda dio como resultado 36 artículos seleccionados como artículos de interés. Las 65 plantas descritas en los artículos seleccionados mostraron una actividad larvicida en su mayoría excelente (27 fueron clasificadas como fuertemente activas) o satisfactoria (13 fueron moderadamente activas y 24 fueron eficaces), mientras que sólo una fue inactiva. Las especies que mostraron la mayor actividad larvicida fueron: *Anacardium occidentale* L. (0,01 ppm); *Copaifera langsdorffii* Desf. (0,04 ppm); *Carapa guianensis* Aubl. (0,06 ppm); *Cymbopogon winterianus* Jowitt. (0,10 ppm); *Ageratum conyzoides* L. (0,15 ppm); *Tagetes minuta* L. (0,21 - 0,25 ppm); y *Siparuna guianensis* Aubl. (1,76, 0,98 y 2,46 ppm). Los estudios sobre los aceites esenciales de las plantas brasileñas son de gran relevancia en la lucha contra las arbovirosis. La flora brasileña, a pesar de su enorme biodiversidad, es todavía poco conocida y explorada, y posee un enorme potencial para el desarrollo de productos ecológicamente correctos, ambientalmente seguros y de bajo coste.

**Palabras clave:** *Aedes aegypti*; Arbovirosis; Larvicidas; Flora brasileña; Aceites esenciales.

## 1. Introduction

Dengue, Chikungunya and Zika viruses are the main arboviruses present in tropical countries, transmitted by the *Aedes aegypti* mosquito. Due to its great epidemiological relevance, efforts have been made by the government to promote the control of the transmission agent. The usual forms of mosquito control occur through chemical insecticides, such as organochlorines and organophosphates (Moreira et al., 2012). Due to the high environmental persistence, the tendency to accumulate in organisms, the high degree of toxicity to animals and the emergence of resistance in insects (Sucen, 2001), organochlorines have had their use reduced or even discontinued in many countries. Organophosphates have a higher acute toxicity for mammals, are chemically unstable and biodegradable, have a short persistence in soil, and need to be replaced periodically (Nascimento & Melnyk, 2016), and have been widely used in the health area.

Given the need to develop alternative ways to combat the vector, the use of plant extracts and essential oils with larvicidal properties has shown promise because it is an easy method to obtain, low production cost and low residual effect. Cavalcanti et al. (2004) proved the larvicidal activity of nine Brazilian species against *Ae. aegypti*, such as *Alpinia zerumbet* and *Hyptis suaveolens*. Essential oils are complex natural mixtures that contain about 20-60 components in different concentrations (Bakkali et al., 2008), being composed predominantly of terpenic hydrocarbons and terpenoids. They are characterized by two or three main components in reasonably high concentration (20% - 70%) compared to other components present in trace amounts (Koul et al., 2008). Essential oils can be produced in all parts of the plant, such as in barks, stems, flowers, leaves, fruits, branches, roots, seeds (Bizzo et al., 2009), and are stored in secretory cells, cavities, channels, epidermal cells or glandular trichomes (Carréra, 2016).

The Brazilian flora is characterized by its vast biodiversity. Of a total of more than 46,000 species, 14,776 are in the Amazon Forest, 5,865 in the Caatinga, 13,566 in the Cerrado domain, 1,588 in the Pantanal biome, 2,096 in the Pampa and 20,174 in the Atlantic Forest (Guatimosim, 2020). Of these, 43% are endemic to the national territory, placing Brazil as the country with the highest plant richness in the world (Jacques, 2016), being identified annually, on average, 250 species (Fioravanti, 2016). Despite its richness and potential, Brazilian biodiversity is still little known, and its use has been greatly neglected (Coradin et al., 2018). Therefore, it is essential to intensify the investment in research in the search for a better use of this natural heritage (Coradin et al., 2011). In this review, we sought to gather articles proving the larvicidal potential of the essential oil of botanical species verified in the national territory against *Ae. aegypti*.

## 2. Methodology

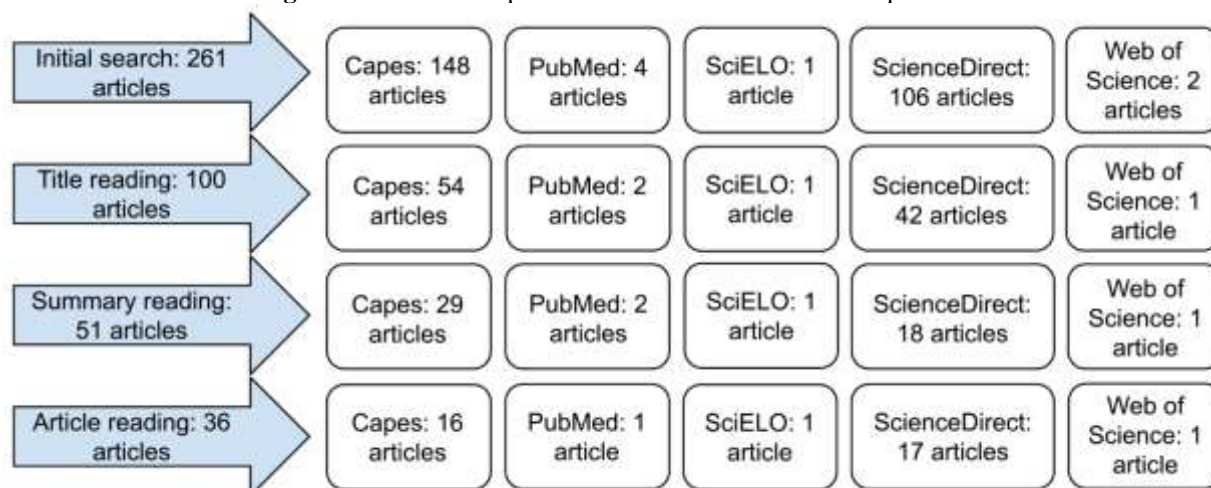
This systematic review article addressed the topic: "Larvicidal properties of essential oils from plants occurring in Brazil against *Ae. aegypti*", seeking to answer the following question: "Is there evidence of the effectiveness of using essential oils from plants occurring in Brazil to combat *Ae. aegypti*? The search was conducted in the following databases: Portal de Periódicos CAPES/MEC; PubMed.gov; SciELO.org; ScienceDirect (Elsevier); and Web of Science – Core Collection (Clarivate Analytics), using the descriptors: *Aedes aegypti*; Brazil; Brazilian plants; essential oil; larvicidal. These were selected based on the terms suggested by the descriptor locator in Health Sciences DeCS/MeSH Finder for the theme addressed. The values of the median lethal concentration (LC<sub>50</sub>) – the dose of the substance needed to kill 50% of the test population – were observed, as well as the larval instar (L1 to L4), botanical material collected, and exposure time.

The inclusion criteria used to select the articles were: articles on Brazilian plants (or with occurrence in Brazil) used as larvicide to combat *Ae. aegypti*; articles in English, Portuguese, or Spanish; full text available. The reading order for the choice of articles was title, abstract and content. The temporal inclusion criterion for the articles comprised the publication date between 2000 and 2020. We did not consider articles about seaweed used as larvicide; articles that use plant extract instead of essential oil, or the mixture of essential oils from different plants, or the association of essential oil with chemical insecticides; articles whose results did not demonstrate the efficacy of the essential oil; and review articles. The analysis and data collection were carried out by three fixed evaluators, and when there was disagreement, a fourth evaluator was recruited. This systematic review was based on the article published by Marmitt et al. (2015).

## 3. Results

The search resulted in the identification of 395 publications that, after checking eligibility following the inclusion criteria, 134 were discarded for not meeting the criteria 'full article', 'year of publication' and 'language'. After reading the sections 'title', 'abstract' and 'full article' (Figure 1), 36 papers were selected as 'articles of interest'. The main characteristics of the articles discarded in the reading stage corresponded to research conducted using seaweed, essential oil mixtures, isolated oil compounds, plant extracts, nanoemulsions, nanosuspensions and oleoresins. Following these criteria, there was disagreement among the evaluators in the selection of articles regarding the inclusion of the latter three, which was resolved through the opinion of an external evaluator, who recommended their exclusion.

**Figure 1.** Schematic representation of the article selection process.



Source: Authors.

In Figure 1, the ScienceDirect (17) and Capes (16) databases had the most articles selected, while the PubMed (1), SciELO (1), and Web of Science (1) databases had only one article selected.

The relevant information from each research was summarized in Table 1, which presents the median lethal concentration (LC<sub>50</sub>) values obtained in the analyzed articles, highlighting the major constituents present in the chemical composition of the essential oil of each species. The lethality data were converted to the same unit of measurement, enabling comparison of their efficacy against *Ae. aegypti* larvae. It was considered that 1 mg/l = 1 µg/mL is approximately equivalent to 1 ppm.

**Table 1.** Median lethal concentration (LC<sub>50</sub>) values obtained.

SPECIES	LARVAL INSTAR	BOTANICAL MATERIAL	TIME (h)	MAIN CONSTITUENTS	LC <sub>50</sub> (ppm)	REFERENCE
<i>Siparuna guianensis</i> Aubl.	L4	stem	24	β-myrcene (79.71%) and 2-undecanone (14.58%)	1,76	Aguiar et al. (2015)
		leaves		β-myrcene (26.91%) and δ-elemene (20.92%)	0,98	
		fruits		2-tridecanone (38.75%) 2-undecanone (26.5%)	2,46	
<i>Piper aduncum</i> L.	L4	aerial parts	24 48	Dilapiol (86.9%)	54,50 44,50	Almeida et al. (2009)
<i>Citrus sinensis</i> (L.) Osbeck	L3	fruits	24	Limonene (91.88%)	11,92 - 16,30	Araujo et al. (2016)
<i>Syzygium aromaticum</i> (L.) Merr					flower buds	
<i>Piper marginatum</i> Jacq.	L4	leaves	48	(Z) and (E)-asarone (4.5 - 30.4% and 6.4 - 32.6%) and patchouli alcohol (16.0 - 25.7%)	23,80	Autran et al. (2009)
		stem			19,90	
		inflorescence			19,90	
<i>Baccharis reticularia</i> DC.	L4	leaves	24 48	D-limonene (25.7%)	221,27 144,69	Botas et al. (2017)
<i>Croton Tetradenius</i> Baill.	L3 and L4	leaves	24	Camphor (25,49%)	152,00	Carvalho et al. (2016)
<i>Alpinia zerumbet</i> (Pers.) Burt & Smith						
<i>Citrus limonia</i> Osbeck	L3	fruit peel	24	Limonene (82%)	519,00	
<i>Citrus sinensis</i> (L.) Osbeck			Limonene (98%)	538,00		
<i>Cymbopogon citratus</i> Stapf.				Geraniol (60.3%)	69,00	
<i>Hyptis suaveolens</i> Poit.				1,8-Cineol (44.2%)	261,00	Cavalcanti et al. (2004)
<i>Lippia sidoides</i> Cham.	L3	aerial parts	24	Thymol (80.8%)	63,00	
<i>Ocimum americanum</i> L.						
<i>Ocimum gratissimum</i> L.				Eugenol (43.7%)	60,00	
<i>Syzygium jambolana</i> DC.				Z-ocimene (27.2%) and E-ocimene (12.2%)	433,00	
<i>Hyptis martiusii</i> Benth.				1,8-Cineol (24.3%) and δ-3-Carene (22.5%)	18,20	
<i>Lippia sidoides</i> Cham.	L3	leaves	24	Thymol (43.5%)	19,50	Costa et al. (2005)
<i>Syzygium aromaticum</i> (L.)		flower buds				

SPECIES	LARVAL INSTAR	BOTANICAL MATERIAL	TIME (h)	MAIN CONSTITUENTS	LC <sub>50</sub> (ppm)	REFERENCE
Merr. & Perry <i>Eugenia piauhiensis</i> Vellaff.				$\gamma$ -elemene (17.48%) and E- $\beta$ -caryophyllene (16.46%)	230,00	
<i>Lippia gracilis</i> Schauer.				1,8-Cineol (56.16%)	282,00	
<i>Myrcia erythroxylon</i> O. Berg	L3	leaves	24	Germacrene D (26.79%)	> 1000	Dias et al. (2015)
<i>Psidium myrsinites</i> DC.				E- $\beta$ -Caryophyllene (26.05%) and $\alpha$ -humulene (23.92%)	292,00	
<i>Siparuna camporum</i> (Tul.) A. DC.				$\gamma$ -patchoulene (28.63%)	251,00	
<i>Citrus sinensis</i> (L.) Osbeck	L3	fruits	24	R-limonene (96.3%)	21,50	Galvão et al. (2015)
<i>Tagetes minuta</i> L.	L3	leaves	24	-	0,21 - 0,25	Lima et al. (2009)
<i>Mentha x villosa</i> Huds.	L3	leaves	24	Piperitenone oxide (70.96%)	45,00	Lima et al. (2013)
<i>Mesosphaerum suaveolens</i> (L.) Kuntze	L3	aerial parts	24	1,8-Cineol (30,15 - 64,44%)	90,9 - 135,20	Luz et al. (2020)
<i>Thymus vulgaris</i> L.	L1 and L3	-	24	Thymol (53.2%)	43,43	Maia et al. (2019)
<i>Lippia origanoides</i> Kunth.	L3	leaves	24 48 72	Carvacrol (48.31%)	187,30 138,60 112,00	Mar et al. (2018)
<i>Psidium guajava</i> L.	L4	leaves	24	E-Caryophyllene (7.6 - 26.6%) and caryophyllene oxide (3.2 - 16.6%)	39,48 - 64,25	Mendes et al. (2017)
<i>Ageratum conyzoides</i> L.		-			0,15	
<i>Anacardium occidentale</i> L.		chestnut			0,01	
<i>Carapa guianensis</i> Aubl.	L4		48	-	0,06	Mendonça et al. (2005)
<i>Copaifera langsdorffii</i> Desf.		-			0,04	
<i>Cymbopogon winterianus</i> Jowitt.					0,10	
<i>Piper gaudichaudianum</i> Kunth.				Viridiflorol (27.5%) and aromadendrene (15.55%)	121,00	
<i>Piper hostmannianum</i> (Miq.) C. DC	L3	leaves	24	Asaricin (27.37%) and myristicin (20.26%)	54,00	Morais et al. (2007)
<i>Piper humaytanum</i> Yunck.				Caryophyllene oxide (16.63%) and $\beta$ -selinene (15.77%)	156,00	
<i>Piper permucronatum</i> Yunck.				Dilapiol (54.7%) and myristicin (25.61%)	36,00	
<i>Lippia rigida</i> Schauer.	-	leaves	-	$\alpha$ -humulene (42.3%) and $\beta$ -caryophyllene (13.0%)	138,90	Oliveira et al. (2016)
<i>Anacardium humile</i> Saint Hill.	L4	leaves	24	-	20,90	Porto et al. (2008)
<i>Schinus terebinthifolia</i> Raddi.	L3	fruits and seeds	24 48	$\delta$ -3-carene (55.36%), $\alpha$ -pinene (15.62%), and	476,23 419,97	Pratti et al. (2015)



SPECIES	LARVAL INSTAR	BOTANICAL MATERIAL	TIME (h)	MAIN CONSTITUENTS	LC <sub>50</sub> (ppm)	REFERENCE
<i>Carapa guianensis</i> Aublet	L3 and L4	-	72	sylvesthrene (10.69%)	366,92	Prophiro et al. (2011)
<i>Copaifera</i> sp.			24	-	136 - 141	
<i>Mentha piperita</i> L.	L3	leaves	48	Linalool (51.8%) and epoxyocimene (19.3%)	47 - 48	Ramos et al. (2017)
<i>Helicteres velutina</i> K. Schum.	L4	roots, stems, bark and leaves	48	-	138,90	Santos et al. (2011)
<i>Scoparia dulcis</i> L.					83,43	
<i>Alpinia purpurata</i> (Viell.) K. Schum. (Pink variant)	L4	flowers	24 e 48	$\alpha$ -pinene (13.86%), $\beta$ -pinene (26.56%) and $\beta$ -caryophyllene (15.58%)	71,50	Santos et al. (2012)
<i>Alpinia purpurata</i> (Viell.) K. Schum. (Red variant)				$\alpha$ -pinene (6.28%), $\beta$ -pinene (13.93%) and $\beta$ -caryophyllene (18.26%)	80,70	
<i>Syagrus coronata</i> (Mart.) Becc.	L4	seeds	48	Octanoic acid (40.55%) and dodecanoic acid (40.48%)	21,07	Santos et al. (2017)
<i>Pogostemon cablin</i> (Blanco) Benth.	L3	leaves	24	Patchouli Alcohol (33.25%) and Seychelene (6.12%)	28,43	Santos et al. (2019)
<i>Syzygium aromaticum</i> (L.) Merr. & Perry	L3 and L4	flower buds	24	Eugenol (71.92%)	40,74	Santos et al. (2020)
<i>Hyptis fruticosa</i> Salzm.						
<i>Hyptis pectinata</i> Poit.	L3 and L4	leaves	24	1,8-Cineol (15.79%) and spatulenol (10.23%) $\beta$ -Caryophyllene (40.90%) and caryophyllene oxide (38.05%)	502,00	Silva et al. (2007)
<i>Lippia gracilis</i> Schauer.				Carvacrol (44.43%)	366,00	
<i>Schinus terebinthifolia</i> Raddi.	L3	fruits	24	$\delta$ -3-carene (55.43%) and $\alpha$ -pinene (16.25%)	98,00	Silva et al. (2010)
<i>Commiphora leptophloeos</i> Leat.	L4	leaves	48	$\alpha$ -Felandrene (26.3%), (E)-caryophyllene (18.0%) and $\beta$ -Felandrene (12.9%)	172,44 - 344,88	
<i>Piper corcovadensis</i> (Miq.) C. DC	L4	leaves	24 e 48	1-Butyl-3,4-methylenedioxy benzene (30.62%)	99,40	Silva et al. (2015)
<i>Vitex gardneriana</i> Schauer.	L3	leaves	24	6,9-guaiadiene (10.13 - 30.15%) and calamenene <cis> (21.29 - 35.62%)	30,52	Silva et al. (2016)
<i>Bauhinia cheilantha</i> (Bong.) Steud.	L3	leaves	24	(E)-caryophyllene (21.65%) and $\alpha$ -pinene (11.75%)	28,0 - 84,3	
<i>Copaifera multijuga</i> Hayne.	L3 and L4	oil-resin, bark, and leaves	24 e 48	$\beta$ -Caryophyllene (57.1%) and $\alpha$ -humulene (10.2%)	40,84	Silva et al. (2020)
<i>Illicium verum</i> Hook. f.		fruits		(E)-anethole (90.1%)	18,00	
<i>Myristica fragrans</i> Houtt.	L3	seeds	24	Sabinene (52.1%) $\alpha$ -pinene (12.8%)	39,80	Trindade et al. (2013)
<i>Pimenta dioica</i> (L.) Merr.		fruits		Methyl eugenol (55.0%) and eugenol (36.3%)	28,20	
					104,40	Voris et al. (2018)

Source: Authors.

In Table 1, the components 1,8-cyrenol (9.23%), limonene (7.69%) and eugenol (7.69%) had the highest frequency of appearance as major constituents of the essential oil. The species *Ageratum conyzoides* L., *Anacardium occidentale* L., *Carapa guianensis* Aubl., *Copaifera langsdorffii* Desf., *Cymbopogon winterianus* Jowitt., *Siparuna guianensis* Aubl. and *Tagetes minuta* L. showed the lowest LC<sub>50</sub> values (0.01 – 2.46 ppm), while the species *Myrcia erythroxyton* O. Berg presented the highest LC<sub>50</sub> value (LC<sub>50</sub> > 1000 ppm). The trials used mainly L3 (47.22%), L4 (33.33%) and L3/L4 (13.89%) instar larvae.

#### 4. Discussion

Terpenes represent the largest class of secondary metabolites, with recognized antimicrobial activity (De Martino et al., 2015; Lutfi & Roque, 2014). Chemically, they present a carbon-carbon double bond being characterized as an unsaturated hydrocarbon (McMurry, 2011). On the other hand, if a terpene contains oxygen, it is called a terpenoid, and may have different chemical functions, including acids, alcohols, aldehydes, ketones, ethers, phenols or terpenic epoxides (Felipe et al., 2016). Terpenes/terpenoids are basically structured in isoprene (C<sub>5</sub>H<sub>8</sub>) blocks, usually linked together in the "head-to-tail" order (bond 1-4) (Loomis et al., 2014; Eschenmoser et al., 2005), except for "irregular terpenes" ("tail-to-tail" bond (bond 4-4)) and cyclic terpenes ("cross-links"). Monoterpenes (two isoprene blocks) are the main constituents of volatile oils, acting in attracting pollinators, while sesquiterpenes (three isoprene blocks) protect plants against fungi and bacteria (Gershenzon et al., 2007). Thus, the relationship between the structural form of the molecules and their biological properties becomes evident (Strub et al., 2014).

The analysis of the chemical composition of the essential oils presented in Table 1 shows the majority presence of the secondary metabolites monoterpenes, sesquiterpenes and phenylpropenes, such as limonene and 1,8-cineole, (E) and (β)-caryophyllene, and eugenol, respectively. The terpenes 1,8-cyrenol (9.23%) and limonene (7.69%) and the phenylpropene eugenol (7.69%) had the highest frequency of appearance in the papers as major constituents of the essential oil. Limonene is the main constituent of the essential oil of the peels of citrus fruits (genus *Citrus*), such as lemons (*C. limonia* Osbeck) and oranges (*C. sinensis* (L.) Osbeck) and is responsible for the characteristic odor that these fruits present. The 1,8-cineol or eucalyptol is found in the essential oil of the leaves of botanical species of the genus *Eucalyptus*, being also reported to occur in plants of the genus *Hyptis*, as in *H. fruticosa* Salzm. (Silva et al., 2007), *H. martiusii* Benth. (Costa et al., 2005) and *H. suaveolens* Poit. (Cavalcanti et al., 2004). The caryophyllene is present in the composition of many essential oils used as spices, especially in clove, rosemary, and black pepper. Eugenol is the predominant component of the essential oil of clove (*Syzygium aromaticum* (L.) Merr. & Perry), as reported by Araujo et al. (2016), Costa et al. (2005), and Santos et al. (2020).

To classify the larvicidal potential of essential oils, the literature provides different criteria, and there are no standardized median lethal concentration values for determining the efficiency of the analyzed substances. According to Kiran et al. (2016), the larvicidal effect is considered significant in essential oils with LC<sub>50</sub> less than 100 ppm under 24h of exposure. Another methodology is proposed by Komalamisra et al. (2005), according to which substances that present LC<sub>50</sub> less than 50 ppm are considered strongly active, LC<sub>50</sub> between 50 and 100 ppm, moderately active, and LC<sub>50</sub> between 100 and 750 ppm, effective, while those with LC<sub>50</sub> values higher than 750 ppm are considered inactive, under 48h of exposure. Table 2 shows the classification of the studied plants adopting the second specification presented. For items that present different larvicidal potentials for the same plant, depending on the botanical material used, place of larval collection, and time of exposure to the essential oil, the lethality considered corresponds to the arithmetic mean of the LC<sub>50</sub> values.

**Table 2.** Classification of larvicidal potential according to Komalamisra et al. (2005).

LC <sub>50</sub> (ppm)	Classification	Species
< 50	highly active	27
50 – 100	moderately active	13
100 – 750	effective	24
>750	inactive	1

Source: Authors.

In Table 2, of the 65 plants described, 27 are classified as strongly active (41.54%), 13 are moderately active (20.00%), 24 are effective (36.92%), and only 1 is inactive (1.54%).

The species *Carapa guianensis* Aublet, *Citrus sinensis* (L.) Osbeck, *Lippia gracilis* Schauer., *Lippia sidoides* Cham., *Schinus terebinthifolia* Raddi. and *Syzygium aromaticum* (L.) Merr. have been studied in more than one article, being assigned different classifications according to the larvicidal potential obtained. For example, Araujo et al. (2016), Costa et al. (2005) and Santos et al. (2020) analyzed the larvicidal activity of the essential oil of *S. aromaticum* floral buds, against larvae (L3, L3 and L3/L4, respectively) of *Ae. aegypti*, during a 24h exposure period. The analysis of the chemical composition of the essential oil identified eugenol as the main constituent (65.99%, 80.80% and 71.92%, respectively). As for larvicidal activity, *S. aromaticum* was classified as strongly active considering the articles by Costa et al. (2005) and Santos et al. (2020), while it was shown to be moderately active/effective considering the article by Araujo et al. (2016) (LC<sub>50</sub> of 40.74, 21.40 and 92.97 – 106.90 ppm, respectively). A possible explanation for the lower lethality of the essential oil in the study by Araujo et al. (2016) may be attributed to the lower percentage of eugenol in the chemical composition of the oil, as well as the use of resistant populations of *Ae. aegypti* in the experiment.

The species that stood out as promising plants for having greater larvicidal potential were: *Anacardium occidentale* L. (0.01 ppm), *Copaifera langsdorffii* Desf. (0.04 ppm), *Carapa guianensis* Aubl. (0.06 ppm), *Cymbopogon winterianus* Jowitt. (0.10 ppm) and *Ageratum conyzoides* L. (0.15 ppm), in the study by Mendonça et al. (2005); *Tagetes minuta* L. (0.21 – 0.25 ppm), in the study by Lima et al. (2009); and *Siparuna guianensis* Aubl. (1.76, 0.98 and 2.46 ppm), in the study by Aguiar et al. (2015).

Of the species mentioned above, the identification of the chemical composition of the essential oil was performed only for *S. guianensis*. The main components were dependent on the botanical material used for essential oil extraction, being β-myrcene (79.71%) for stems, β-myrcene (26.91%) for leaves, and 2-tridecanone (38.75%) for fruits. This fact was not observed in the study of Autran et al. (2009), where the essential oil of *Piper marginatum* Jacq. showed the same composition ((Z) and (E)-asarone and patchouli alcohol) when extracted from leaves, stem, and inflorescences, varying only the percentage with respect to the total composition. The chemical composition of volatile oils varies between parts of the same plant and, when extracted from the same organ of the same plant species, can vary significantly according to age and stage of development, season and time of collection, weather and soil conditions, and their properties depend on the extraction technique used (Burt, 2004; Morais, 2009).

The only species that showed inactivity against *Ae. aegypti* larvae was *Myrcia erythroxylon* O. Berg with LC<sub>50</sub> > 1000 ppm, reported by Dias et al. (2015). The majority constituents identified in the essential oil of the plant were the sesquiterpenes germacrene D (26.79%), bicyclogermacrene (13.26%) and (E)-β-caryophyllene (10.55%). In the articles analyzed, germacrene D and bicyclogermacrene did not appear as majority constituents for any of the other species, which may be an indication of the inefficacy of these compounds as larvicide against *Ae. aegypti*. The (E)-β-caryophyllene was identified in the chemical composition of the species *Eugenia piauiensis* Vellaff. and *Psidium myrsinites* DC. (E)-caryophyllene was found in *Psidium guajava* L., *Commiphora leptophloeos* Leat and *Bauhinia cheilantha* (Bong.) Steud., while β-caryophyllene was detected in



*Lippia rigida* Schauer., *Alpinia purpurata* (Viell.) K. Schum., *Hyptis pectinata* Poit. and *Copaifera multijuga* Hayne. The approach of a possible explanation for the high LC<sub>50</sub> value obtained was not presented by the authors. Also, no new research regarding the larvicidal activity of *M. erythroxylon* essential oil was found in the literature.

Among the species studied, the presence of species endemic to Brazil stands out, such as *Baccharis reticularia* DC., *Croton tetradenius* Baill., *Helicteres velutina* K. Schum., *Hyptis fruticosa* Salzm., *Hyptis martiusii* Benth., *Lippia gracilis* Schauer, *Lippia sidoides* Cham., *Psidium myrsinites* DC., *Syagrus coronata* (Mart.) Becc. and *Vitex gardneriana* Schauer. Note that such species correspond to a small percentage (17.86%) in relation to the total number of species analyzed, which shows the lack of knowledge of the existing native flora, although Brazil is a country of great biodiversity.

The occurrence of species exclusive to the Northeast region of Brazil and the Caatinga biome is also observed. *Croton tetradenius* Baill. is endemic to the Caatinga biome and is frequently found in most states of the Northeast region of Brazil (Carvalho et al., 2016). *Lippia gracilis* Schauer is endemic to Northeast Brazil and is widely distributed in the Caatinga (Gomes et al., 2011). *Vitex gardneriana* Schauer is a native and endemic species of Brazil, having its distribution restricted only to the Northeast region (Soares, 2017).

## 5. Conclusion

Unlike chemical insecticides, which are harmful to the environment and, when unstable, require periodic application to the soil, essential oils are an eco-friendly and economically viable alternative in combating arboviruses transmitted by *Ae. aegypti*. Brazil has a vast natural wealth, with about 46 thousand plant species in the most diverse biomes, 43% of which are endemic to the national territory. The essential oils from different botanical species of Brazilian flora proved to be efficient in fighting the larvae of the *Ae. aegypti* mosquito. Of the 65 plants evidenced in the research, the species *Anacardium occidentale* L. (0.01 ppm), *Copaifera langsdorffii* Desf. (0.04 ppm) and *Carapa guianensis* Aubl. (0.06 ppm) were the most effective among the 27 strongly active species, besides the occurrence of 13 moderately active species, 24 effective, and only one inactive, according to the classification proposed by Komalamisra et al. (2005). Thus, it was proven the ability to use plants grown in the national territory as an alternative in combating *Ae. aegypti*. Therefore, studies on the essential oils of Brazilian plants are of great relevance, not only to combat arboviruses, but also due to their potential for medicinal applications, showing other relevant properties.

As suggestions for future work, we recommend the analysis of the larvicidal activity of essential oils from Brazilian plants against *Ae. aegypti* with different approaches, prioritizing the species that occur exclusively in the Northeast region and the Caatinga biome, to explore the vast biodiversity and the enormous potential existing in the native flora of this region.

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