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Essential oils from Carapebus sandbank plants as natural controllers against insect pests of importance in Brazilian public health and agriculture

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ABSTRACT: The use of biological controllers of natural origin against pests of agricultural and health importance has been increasingly recommended in recent years due to lower environmental toxicity, in addition to promoting greater safety for human and animal health. At the same time, the development of studies with native and promising plant resources, which are still little studied, means that conservation measures for these species are encouraged. In this context, this review aims to optimize and discuss the use of essential oils from plants that grow in Carapebus sandbanks as controllers of Brazil's most important agricultural pests and disease transmitters. This work was presented as an important tool for promoting plant resources in the fight against these pests in Brazilian territory, aiming to stimulate more eco-friendly and safer-health agents in agronomic practices and for the urban and rural population use. Furthermore, these essential oils, in addition to presenting an interesting potential to be used as organic insecticides, also contribute to the valorization of native species.

1. INTRODUCTION

The need for greater agricultural productivity and vector eradication demand initially led to the use of synthetic pesticides, which are only sometimes used below the limit concentrations allowed by related legislation (Nicopoulou-Stamati et al., 2016). Many of these pesticides are organophosphates, which cause residual effects to the environment and adverse effects on human and animal health, such as methylparathion, phorate, and dimethoate (Edwards & Tchounou, 2005; Montana et al., 2021; Van Scoy et al., 2016). Furthermore, other synthetic pesticides such as carbamates, triazines, pyrethroids, and neonicotinoids can also impact health and the environment (Nicopoulou-Stamati et al., 2016). As well as the organophosphates, carbamates are also acetylcholinesterase inhibitors and are related to neurotoxic events, besides also acting as disrupters of the endocrine/reproductive system (Jamal et al., 2016; Mnif et al., 2011). This effect is also observed with pyrethroids, whereas triazines can induce breast cancer and endocrine-disrupting effects (Kettles et al., 1997; Mnif et al., 2011). In turn, neonicotinoids are considered safer for animals. However, a recent study demonstrated that this pesticide class increases the expression of the enzyme aromatase, which is related to breast cancer and also plays a vital role during developmental stages (Caron-Beaudoin et al., 2016).

Thus, the search for new alternatives in the control of pests of agricultural and health importance has been encouraged so that new methodologies or products can be more sustainable to the environment and less harmful to human and animal health (Nicopoulou-Stamati et al., 2016). The use of organic products as pest controllers, such as essential oils (EOs), has been heavily explored as biological controllers of plant predators and disease transmitters. These products have advantages such as greater selectivity of target organisms and rapid biodegradability, which causes less intense residual effects compared to synthetics, in addition to being less susceptible to the emergence of resistance by pests (Smith & Perfetti, 2020). Particularly, EOs have constituents from the class of monoterpenes, sesquiterpenes, phenylpropanoids, among others, which have insecticidal or biological control activity and are involved in plant defense against predators, having toxic, repellent or hormonal action on target organisms (Ding-Feng, 2010).

Brazil has an important source of plant resources due to its high biodiversity spread over a territory of more than 8 million km^2, which includes six different biomes. Among these biomes is the Atlantic Forest, which has part of its vegetation as a sandbank along the Brazilian coast and has an important preservation unit in Carapebus city, named Restinga de Jurubatiba National Park (Araújo, 1992).

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Table 1
Essential oils from *Carapebus sandbank* plants and affected pests

Plant Species	Plant Family	Brazilian Common Name	Organ	Main compounds	Affected Pest	Effectiveness
Annona acutiflora	Annonaceae	Araticum	Leaves	α-santalene (15.5 %), bicyclogermacrene (12.5 %) and α-zingiberene (8.7 %)	*Aedes aegypti*	LC_{50} and LC_{90} = 21.3 and 37.1 ppm after 48 h
Xylopia ochrantha	Annonaceae	Imbiú-prego	Leaves	Bicyclogermacrene (25.2 %) and germacrene D (20.9 %)	*Aedes aegypti*	LC_{50} and LC_{90} = 217.685 ppm and 459.716 ppm within 48 hours, respectively
Cordia curassavica	Boraginaceae	Erva-baleeira	Leaves	α-pinene (49.0 %) and β-caryophyllene (12.4 %)	*Rhipicephalus microplus*	Larvicidal effect (59.0 % at 25.0 mg/mL after 24 h) and insecticidal action against engorged females (96.9 % at 25.0 mg/mL)
Protium heptaphyllum	Burseraceae	Breu Branco	Resin	p-cimene (27.70 %) and α-pinene (22.31%)	*Aedes aegypti*	LC_{50} = 2.91 and 0.17 ppm, in 24 and 48 h, respectively.
Ocotea notata	Lauraceae	Canela Branca	Leaves	Trans-muurola-4(14),5-diene (15.61 %) and bicyclogermacrene (12.69 %)	*Rhipicephalus microplus*	90% survival reduction after incubation for 15 days; 100% reduction for posture inhibition and reproductive capacity
Ocotea indecora	Lauraceae	Canela-Sassafrás-do-campo	Leaves	Sesquirosefuran (81.4 %)	*Rhipicephalus microplus*	LC_{50} in larval packed tests (24 and 48 h) = 59.68 and 25.59 mg/mL, respectively; LC_{50} and LC_{90} in the immersion test = 4.96 and 17.37 mg/mL; LC_{50} and LC_{90} in the repellence test = 0.04 and 1.24 mg/mL, respectively (after 24 h)
					Aedes aegypti	LC_{50}. 61.4 ppm after 48 h h
				Sesquirosefuran (92 %)	*Dysdercus peruvianus*	LC_{50} = 162,18 μg/mL, after 24 h
Eugenia punicifolia	Myrtaceae	Mirtilo-vermelho	Leaves	Germacrene D (21.34 %), bicyclogermacrene (26.73 %) and β-longipenene (9.42 %) in Goiás and Spathulenol (26.84 %), (Z)-caryophyllene (8.92 %), α-cadinol (6.28 %), γ-cadinene (6.27 %), and caryophyllene oxide (6.02 %)in Minas Gerais	*Aedes aegypti*	LC_{50} = 85.53 - 91.52 μg/mL, after 24 h

Continued on next page

Table 1 continued

Eugenia uniflora	Myrtaceae	Pitanga	Leaves	Curzerene (24.13 %), E-β-ocimene (11.64 %), germacrene B (9.60 %) and germacrone (8.09 %)	*Culex quinquefasciatus*	LC_{50} between 31.52 and 60.08 mg/L, after 24 h
				Selina-1,3,7(11)-trien8-one (25.42 %), Selina-1,3,7(11)-trien8-one epoxide (15.49 %), and germacrone (11.05 %)	*Diaphania hyalinata*	oviposition deterrence (2.98 %) and strong repellence against larvae (15.84 % caterpillars)
Myrciaria floribunda	Myrtaceae	Camboim	Leaves	1,8-cineol (10.4 %), β-selinene (8.4 %), (E)-nerolidol (5.5 %), and β-curcumene (5.2 %).	*Rhodnius prolixus*	LD_{50} = 742.29 μg/insect after 24h
				1,8-cineole (38.4 %)	*Oncopeltus fasciatus*	LD_{50} values (μg/insect) = 112.44 after one day of treatment and 72.18 after 22 days of treatment
					Dysdercus peruvianus	LD_{50} values (μg/insect) = 309.64 after one day of treatment and 94.42 after 22 days of treatment
Pilocarpus spicatus	Rutaceae	Jaborandi-da-Restinga	Leaves	Limonene (46.8 %)	*Rhipicephalus microplus*	98.10 % repellency against the larvae, 50 mg/mL, after 10 hours.
				ND	*Rhodnius prolixus*	90.5 and 91.1% mortality in 24 hours, 0.5 and 1 μL/insect, respectively
Zanthoxylum caribaeum	Rutaceae	Espinho-preto	Leaves	Sylvestrene (11.3 %), muurola-4 (14), 5-trans-diene (8.4 %), isodaucene (8.3 %) and α-pinene (7.6 %)	*Rhodnius prolixus*	80 - 98.9 % mortality with crude EO
					Rhipicephalus microplus	85 % mortality after two days, 5 % concentration
					Dysdercus peruvianus	LC_{50} = to 215 μg/insect, after two days

The species from this locality are still little studied in terms of chemical and pharmacological activity. Those studied have shown interesting activities, considering that the sandbank species are important from the pharmacological point of view, as they produce many secondary metabolites, including EOs (Santos et al., 2009; F.V. Silva et al., 2022).

Among the countries with the highest agricultural production in the world, Brazil produces tons of food of plant origin and a large number of consumers, with a population of over 210 million inhabitants and is one of the main crop producers in the world, providing food for 800 million people around the world (Contini & Aragão, 2020). However, the wide use of pesticides is still a constant reality in Brazilian agribusiness, which often leads to the supply of food that exceeds the safety limits for consumers' health (Disner et al., 2021). On the other hand, Brazil is affected by several tropical diseases, with important transmission vectors such as Aedes aegypti, the transmitter of at least five diseases, including dengue Zika, Chikungunya, Mayaro fever, and yellow fever, so their biological control is important in urban or quickly propagated areas (Clancy et al., 2021). Thus, this review aims to compile and discuss the recent studies carried out with EOs from Carapebus sandbanks species with activity against the main pests that affect the Brazilian territory.

2. METHODOLOGY

The research was carried out using the combination of the name of Carapebus sandbanks species described in the study of Santos et al. (2009) and the recently described species "*Pilocarpus spicatus*" and "*Zanthoxylum caribaeum*" together with the words "essential oil", "insecticidal" and/or "larvicidal" and "activity". Google Scholar and Scopus were used as the research databases. Table 1 summarizes the studies described below.

3. PESTS AND VECTORS AFFECTED BY ESSENTIAL OILS FROM CARAPEBUS SANDBANKS

3.1. *Aedes aegypti*

The insecticidal activity against the mosquito *A. aegypti* was evaluated by several EOs of species from Carapebus sandbanks, among them from the Annonaceae family *Annona acutiflora* and *Xylopia ochrantha*. The nanoemulsionated EO from *A. acutiflora* leaves showed LC_{50} and LC_{90} values after 48 h, respectively, of 21.3 and 37.1 ppm against the 3rd instar larvae of *A. aegypti*. α-santalene (15.5 %), bicyclogermacrene (12.5 %), and α-zingiberene (8.7 %) were the major compounds of the oil (Folly et al., 2021). The EO from *X. ochrantha* leaves presented a low activity with LC_{50} and LC_{90} equal to 217,685 ppm and 459,716 ppm within 48 hours, respectively. The main substances of the oil were bicyclogermacrene (25.2 %) and germacrene D (20.9 %) (Viana et al., 2022). For the EO extracted from the resin of *Protium heptaphyllum*, the larvicidal action showed a potent LC_{50} equal to 2.91 and 0.17 ppm in 24 and 48 h, respectively. p-cymene (27.70 %) and α-pinene (22.31 %) were the main constituents of the EO (Faustino et al., 2020). In turn, the nanoemulsioned EO from *Ocotea indecora* leaves presented LC_{50} values against *A. aegypti* larvae equal to 61.4 ppm after 48 h. Interestingly, sesquirosefuran was the major compound, presenting 81.4 % of EO composition (Machado et al., 2023). Furthermore, EOs from *E. punicifolia* leaves collected from two different regions of Brazil (Goiás and Minas Gerais) presented different levels of action on *A. aegypti* L3 larvae (LC_{50} = 85.53 μg/mL and 91.52 μg/mL, respectively), besides their main chemical compounds (Bicyclogermacrene (26.73 %), Germacrene D (21.34 %) and β-longipenene (9.42 %) in Goiás and Spathulenol (26.84 %), (Z)-caryophyllene (8.92 %), α-cadinol (6.28 %), γ-cadinene (6.27 %), and caryophyllene oxide (6.02 %) in Minas Gerais) (L.S. Silva et al., 2021).

3.2. *Culex quinquefasciatus*

The EO from *Eugenia uniflora* leaves was active against *C. quinquefasciatus*, one of the filariasis's main vectors, so it transmits parasites as *Wuchereria bancrofti* and *Brugia malayi*, which in turn are the etiological agents of the disease. The EOs had LC_{50} values between 31.52 and 60.08 mg/L, considered effective against larvae. Curzerene (24.13 %), E-β-ocimene (11.64 %), germacrene B (9.60 %) and germacrone (8.09 %) were the principal constituents of the oil (Oliveira et al., 2022).

3.3. *Diaphania hyalinata*

The leaves EO from *E. uniflora* was also active against *D. hyalinata*, an important plant predator, presenting robust oviposition deterrence (2.98 %) and strong repellence against larvae (15.84 % caterpillars). In this assay, Selina-1,3,7(11)-trien8-one (25.42 %), Selina-1,3,7(11)-trien8-one epoxide (15.49 %), and germacrone (11.05 %) were the main compounds of the oil (Lobo et al., 2019).

3.4. *Dysdercus peruvianus*

The nanoemulsion containing the EO from *O. indecora* were active on D. peruvianus adult, a Hemiptera cotton pest, presenting a LD_{50} equal to 162.18 μg/mL, with a sesquirosefuran oil concentration of 92 % (Nascimento et al., 2020). The leaves EO from the species *Myrciaria floribunda* was also effective against this pest with LC_{50} values (μg/insect) equal to 309.64 after one day of treatment, and 94.42 after 22 days of treatment. 1,8-cineole (38.4 %) was the main compound of the oil (Tietbohl et al., 2014). Moreover, the oil from *Zanthoxylum caribaeum* leaves is rich in sylvestrene (11.3 %), muurola-4 (14), 5-trans-diene (8.4 %), isodaucene (8.3 %) and α-pinene (7.6 %) showed a LC_{50} equal to 215 μg/insect, besides it interrupted insect metamorphosis and molting, often in a dose-dependent manner. In addition, nymphs with deformed legs, wings and antennae were observed (Pacheco et al., 2020).

3.5. *Oncopeltus fasciatus*

The leaves EO from *Myrciaria floribunda* demonstrated insecticidal activity against *O. fasciatus*, a milkweed bug. The

LD_{50} values (μg/insect) were equal to 112.44 after one day of treatment and 72.18 after 22 days of treatment (Tietbohl et al., 2014).

3.6. *Rhipicephalus microplus*

R. microplus, a tickle that affects cattle productivity, is one of the most evaluated pests for insecticidal activity of sandbank plants. In this context, the EO from *Cordia curassavica* exhibited a larvicidal effect (59.0 % at 25.0 mg/mL) and insecticidal action against engorged females (96.9 % at 25.0 mg/mL). α-pinene (49. 0 %) and β-caryophyllene (12.4 %) were the major compounds of the oil (Carvalho-Castro et al., 2019). *Ocotea notata* was another plant with activity against this pest. The oil from leaves reduced the survival by 90% after incubation for 15 days, and there was 100% reduction in posture inhibition and reproductive capacity. Trans-muurola-4(14),5-diene (15.61 %) and bicyclogermacrene (12.69 %) were the main substances in this study (Moussavou et al., 2019). As observed with *D. peruvianus*, the oil from the species O. elegans also presented insecticidal activity against *R. microplus*. The adult immersion test detected efficacy higher than 90% from the concentration 25 mg/mL upward. In larval-packed tests performed after 48 h, only the 100 mg/mL concentration resulted in mortalities above 70%. On the other hand, the EO caused an average of 95.8% repellency from 0.78 to 100 mg/mL. The LC_{50} for the larval packed tests (24 and 48 h) were 59.68 and 25.59 mg/mL, respectively, whereas LC_{50} and LC_{90} for the immersion test showed 4.96 and 17.37 mg/mL, and in the repellence test, they presented 0.04 and 1.24 mg/mL, respectively (Figueiredo et al., 2018). Furthermore, the EO from *Pilocarpus spicatus* leaves showed 98.10 % repellency against the larvae, when used a concentration equal to 50 mg/mL, after 10 hours. Limonene (46.8 %) was the principal compound of this oil (Nogueira et al., 2020). The EO from *Z. caribaeum* leaves also demonstrated effect against R. microplus, so that 5% concentration caused 65% mortality on the 1^{st} day after treatment, 85% on the 2^{nd} day, and 100% on the 5^{th} day (Nogueira, Vinturelle, et al., 2014).

3.7. *Rhodnius prolixus*

The EO from *M. floribunda* leaves demonstrated insecticidal activity against the 5^{th} instar of *R. prolixus*, an important *Triatomine* species that transmits *Trypanosoma cruzi*, the etiological agent of Chagas Disease, presenting an LD_{50} equal to 742.29 μg/insect, with 24h after the treatment. Interestingly, the oil showed more activity when compared with its major compound, 1,8-cineol (10.4 %), which suggests the synergism effect, taking into count other relevant compounds such as β-selinene (8.4 %), (E)-nerolidol (5.5 %) and β-curcumene (5.2 %). Moreover, disruption of metamorphosis on averaged nymphs and juvenoid-like insects was also observed (Tietbohl et al., 2020). High levels of toxicity and paralysis, together with discrete molting inhibition, were caused by topical application of either 0.5 μL or 1.0 μL per insect of the EO from P. spicatus on nymphae. The mortality rate was 90.5 and 91.1% in 24 hours. Partial fagoinhibition, high molting inhibition, prolonged intermolting period, and a high number of paralyzed insects were observed with oral treatment (5-10 μL oil per ingested blood meal) (Mello et al., 2007). Furthermore, topical treatment with the crude EO of *Z. caribaeum* induced high levels of paralysis (from 18.88 to 33.33 %) and mortality (from 80 to 98.9 %) of nymphae, depending on the dose applied (0.5 to 5.0 μL/insect). Feeding treatment with the crude EO also induced high levels of mortality (from 48.8 to 100 %), but low levels of paralysis (from 2.22 to 7.77 %), depending on the dose applied (0.5 - 5.0 μL/mL of blood). Sylvestrene (11.3 %), muurola-4,5-trans-diene (8.4 %), isodaucene (8.3 %), and α-pinene (7.6 %) were the major constituents of the oil (Nogueira, Mourão, et al., 2014).

4. DISCUSSION

Recent studies with EOs from plants present in the Carapebus sandbank are promising in terms of insecticidal and larvicidal activity, taking into account that EOs are more biodegradable products and, therefore, have less impact on the environment, in addition to being, in general, less toxic to human and animal health (Samada & Tambunam, 2020). Another advantage is the lower rate of emergence of resistance by pests due to the greater chemical diversity presented by natural products (Ding-Feng, 2010). Some EOs have even been studied in nanoemulsion form, which facilitates the dispersion of these substances in the aquatic environment, in addition to promoting greater bioavailability of the active ingredients (Jaiswal et al., 2015). The EOs studied for the insecticide/larvicide evaluations showed mainly hydrocarbon sesquiterpenes and, in second place, monoterpenes among the groups of major substances. Monoterpenes, for example, p-cimene and α-pinene, can disrupt the cellular membrane function due its low polarity characteristic, which disaggregates the lipid structure that makes up the inner layer of the membrane (Salakhutdinov et al., 2017). The effect on insects also includes the fact that they have greater ease of penetration into the respiratory system of target organisms (Langsi et al., 2020). In addition, it is already described in the literature that the monoterpenoid 1,8-cineole, major compound of Myrciaria floribunda EO, inhibit the acetylcholinesterase activity from insects (Abdelgaleil et al., 2009). Limonene, the main substance of *Pilocarpus spicatus* oil, also demonstrated an inhibition effect on ovoposition and egg hatching of insects, besides causing repellency and toxicity (Karr & Coats, 1988). In turn, some EOs rich in sesquiterpenoids showed greater activity, as with *Annona acutiflora* and *Eugenia punicifolia* against *Aedes aegypti*, and *Eugenia uniflora* against *Culex quinquefasciatus*. The first two presented the bicyclogermacrene as the majority, which has already demonstrated intense insecticidal activity against the genus *Anopheles*, *Aedes*, and *Culex* (Govindarajan & Benelli, 2016). On the other side, interesting structures such as curzerene (present in *Eugenia uniflora* against *C. quinquefasciatus*), a furanogermacrenoid, and sesquirosefuran, a furanosesquiterpene present in *Lauraceae* species, also appeared as majorities in oils with higher activity. Curzerene has already proven to be effective against mosquitoes of the *Anopheles*, *Aedes*, and *Culex* genus (Govindarajan et al., 2018), while sesquirosefuran is described as a semiochemical (Petroski et al., 2005). Furthermore, it also presents termiticidal properties (Ozaki, 1999). In this way, these EOs, in addition to presenting an interesting potential to be used as organic insecticides, also contribute to the valorization of native species, which includes taking measures to preserve these species and maintain local biodiversity. Among the most promising EOs, *P. heptaphyllum* can be mentioned, with high potency against *A. aegypti*, while *O. indecora* proved to be quite efficient against R. microplus, presenting a lower LC_{50} value than against *A. aegypti*, which demonstrates selectivity of the oil. The same oil with a higher concentration of sesquirosefuran than the two previously mentioned assays, presented a higher LC_{50} against *D. peruvianus*, which corroborates the selectivity factor. However, studies that aim to elucidate the mechanisms involved in insecticide and larvicide tests should be carried out for a better understanding of how EOs act and whether there is influence of synergism between the components. In addition, field trials must be carried out with the most promising oils, so that the real applicability is measured.

5. CONCLUSION

This review demonstrates the importance of EOs from native species located in the sandbanks of the municipality of Carapebus as an alternative in the fight against agricultural pests and disease transmitters that affect the Brazilian territory, thus being a possible biosustainable resource, in addition to contributing to the preservation of local species. Taking into account the efficiency of the EOs described in this review, the oils from *P. heptaphyllum* and *O. indecora* proved to be promising resources against *A. aegypti* and *R. microplus*, respectively. However, further studies on field efficiency and pharmacological mechanism should be conducted to obtain more relevant information on the use of these resources and a better understanding of their actions against the mentioned pests.

CONFLICTS OF INTEREST

The authors have no conflict of interests.

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AUTHOR CONTRIBUTIONS

Ricardo Diego D.G. de Albuquerque conceptualized, structured and wrote the article. Leandro Rocha wrote, revised and approved the article.

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