Chapter

Plant-Based Essential Oils in The Treatment of Microbial Infections

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Abstract

There is a growing demand for bioactive compounds from the great diversity of native plants, which have biological activities that are important for their application in the development of drugs and in the biomedical field. Among these bioactive compounds, essential oils have received great interest from researchers because they have numerous important biological properties for application in the pharmaceutical area, with an emphasis on antimicrobial activity. Due to the great biodiversity, the native Brazilian flora consists of thousands of species rich in these volatile compounds with self-added value. Therefore, this chapter will give an overview of the essential oils and their main compounds obtained from species of native Brazilian flora in terms of their antimicrobial activity, which can be useful in the future as new sources of bioactive compounds for developing innovative drugs in the treatment of microbial diseases.

Keywords: Terpenes, Brazilian plants, Bioactive compounds, Volatile oil, Infectious diseases.

Introduction

Researches around the world starting, just a few decades ago, to unveil in the deepest way, the huge possibilities of native flora for providing a sustainable source of bioactive compounds to develop new drugs and herbal medicines. In this context, Brazil possesses the status of the greatest and more diverse flora around the world, representing 20% of the total flora, with more than 40,000 of different species (Oliveira et al. 2012). However, despite the

great potential of Brazilian native flora, most plants remain commercially underexploited considering their exquisite phytochemical and biological profile (Fraga et al. 2020).

Thinking globally, the actual trend in the industrial field is signaling for natural compounds capable of reducing or even replacing synthetic chemical compounds (Almeida et al. 2018). In this way, ingredients and active compounds based on plants have been intensively searching for application in several fields, such as cosmetic, food and pharmaceutical industries. Additionally, several plant-based drugs are already included in the national health care in many countries, mainly due to their interesting aspects, namely lower cost, higher tolerance and fewer side effects compared to traditional synthetic drugs (Jardim et al. 2015, Uttra et al. 2018).

The most plants used for developing new products present a complex chemical composition composed mainly by secondary metabolites, which exerts a fundamental role in plant survival, protecting them against infectious diseases, acting also as insecticidal or even promoting the healing after damage caused by external factors (Sharifi-Rad et al. 2017, Silva et al. 2020, Tariq et al. 2019). In the range of secondary metabolites produced by plants, the essential oils configure in one of the most important and effectively used groups of compounds in many different fields.

Essential oils (EO) are liquids that present a complex mixture of volatile compounds, with characteristic odor, color that varies between colorless and slightly yellow, lower density than water and solubility in organic solvents. In general, the chemical composition of the essential oil can be influenced by many factors such as part of the plant, method performed to extract the essential oil, external factors as environmental conditions, soil type, altitude, period of the day that plant was collected, seasonality and genetic varieties (Veras et al. 2017, Sciarrone et al, 2017). The EO is commonly extracted from plants by hydrodistillation and in this process different parts of plants can be used, such as leaves, flowers, seeds, trunks and roots (Mancarz et al. 2019, Meroni et al. 2020).

These natural compounds have in their composition a complex mixture of several molecules, which have low molecular weight and concentrations that vary due to the influence of numerous factors, as previously mentioned. The main compounds present in EO are monoterpenes, sesquiterpenes and their oxygenated derivatives, and can present diterpenes, phenylpropanoids, and isothiocyanates. Generally few of these molecules represent the highest percentage of compounds present in EO (major compounds), with the others being present in low concentrations. The major compounds, alone or in combination with the other components,

are responsible for the biological properties attributed to the EO (De Souza et al. 2017, Sharifi-Rad et al. 2017).

Essential oils are used in several applications, whether in the cosmetic (in perfumes and soaps) and food (as flavorings and additives) industry, or as pesticide and insecticide agents in the agro-industrial sector (Yu et al. 2020). In addition to these applications, lately EOs have received a great highlight for their pharmacological properties, which has increased their application in the medical field and in the development of alternative treatments for numerous diseases. The bioactive compounds present in its composition can act as antioxidant and anti-inflammatory agents, as well as antimicrobial agents, due to their lipophilic nature, which facilitates the interaction with microbial cells resulting in their destruction. Due to the intensive use of antimicrobial drugs, an increase in the number of resistant strains has been observed in recent years, which calls attention to the development of new natural and effective antimicrobial compounds, such as essential oils (Mancarz et al. 2019, Ragno et al. 2020).

Antimicrobial activity of Brazilian native plants essential oils

Brazil has a large distribution of potential therapeutic compounds in this native flora, that plays a fundamental role in traditional medicine. The use of medicinal plants by Brazilian population for the treatment of different diseases is a long tradition and has been increased in the last years, arousing the interest of researchers and pharmaceutical companies to increase knowledge about the biological activities from natural compounds of native medicinal plants (Duarte et al. 2007, Jardim et al. 2015, Dutra et al. 2016).

Among these natural compounds obtained from plants, essential oils stand out for having several biological activities due to their bioactive compounds, as previously described. As Brazil has the highest total biodiversity in the world, its native plants are important sources for obtaining essential oils (Dutra et al. 2016). Considering the above, in this chapter we will discuss the main studies related to the antimicrobial activity of essential oils obtained from native Brazilian plants belonging to the genus *Lippia*, *Cordia*, *Croton*, *Copaífera*, *Eugenia*, *Baccharis*, *Hedyosmum*, *Schinus*, and *Aniba*.

Lippia

The genus *Lippia* belongs to the family Verbenaceae and includes a large number of species distributed throughout tropical Africa, Central, and South America. The vast majority of known species are present in the Brazilian territory and are widely used in food and drinks,

in addition to their use in traditional medicine for having a wide range of biological properties (Funari et al. 2012, De Melo et al. 2020). Among the native Brazilian species, *Lippia sidoides*, *Lippia origanoides*, *Lippia grandis*, *Lippia thymoides*, and *Lippia lasiocalycina* are rich in aromatic essential oils that present important biological activities, with emphasis on antimicrobial activity.

Lippia sidoides Cham., whose popular name is "*alecrim-pimenta*", is a perennial bushy plant native to *Caatinga* and widely cultivated in Northeast Brazil (Cavalcanti et al. 2010, Medeiros et al. 2011). The aromatic stem and leaves of this plant are used in therapeutic treatments and the extracted essential oil is used to treat skin lesions, as an oral antiseptic, and in the treatment of oral and vaginal infections (Medeiros et al. 2011, De Farias et al., 2012). Regarding the chemical composition, *L. sidoides* EO contains major constituent thymol (2-Isopropyl-5-methylphenol), a monoterpene phenolic which is responsible for potent antibacterial and antifungal activities, in addition to other biological activities such as larvicidal action, antioxidant, anti-inflammatory, and analgesic (Veras et al. 2013, Saraiva et al. 2020). Lobo et al. (2014) reported the potential activity of *L. sidoides* EO against *Streptococcus mutans*, a Gram positive bacteria from saliva of children with cavities, corroborating with results obtained in the study by Veras et al. (2017), who evaluated the antibacterial activity of *L. sidoides* EO against *S. mutans* and other Gram-positive and Gram- negative bacteria (**Table 1**). In both studies, thymol and carvacrol (a structural molecular isomer of thymol) were considered the major compound, corresponding to approximately 90% of EO chemical composition, which explains the antimicrobial activity shown by the EO under study.

Lippia origanoides Kunt., popularly known as "*alecrim-pimenta*", "*alecrim-do-nordeste*" or "*estrepa-cavalo*" (Queiroz et al. 2014), is a synonym of *L. sidoides* and has several uses, either in food (as seasoning), or as a medicinal plant where leaf infusion is used to treat gastrointestinal (stomach pain, flatulence, and indigestions) and respiratory diseases (Vicuña et al. 2010, Teles et. al. 2014). Its essential oil has thymol, carvacrol, and p-cymene as major compounds, which are also responsible for their biological activities, as observed in the study by Oliveira et al. (2007) that showed the potential antimicrobial activity of EO from *L. origanoides* against bacteria (Gram-negative and Gram-positive) and yeast (**Table 1**).

Table 1. Antimicrobial activity of essential oils from plants of the genus *Lippia*, *Cordia*, *Croton*, *Copaífera*, *Eugenia*, *Baccharis*, *Hedyosmum*, *Schinus*, and *Aniba*.

Genus	Specie/part of the plant	Yield (% EO) / Major compounds	Methodology for AM activity determination	Antimicrobial activity		Reference
				Antibacterial	Antifungal	
Lippia	*Lippia sidoides* (leaves)	Yield: NM Thymol/carvacrol (93.36%) Caryophyllene (3.59%)	Essential oil was incorporated in toothpaste, gel and mouthwash; *In vivo* test (microbiological analysis of saliva)	Toothpaste promoted lower levels of salivarius *Streptococcus mutans* than chlorhexidine	NT	Lobo et al. (2014)
		Yield: 1.06% Thymol (84.9%) Ethyl-methyl-carvacrol (5.33%) p-cymene (3.01%)	Microdilution assay (MIC)	*Staphylococcus aureus* (128 μg/mL) *S. mutans* (256 μg/mL) *Enterococcus faecalis* (512 μg/mL) *Escherichia coli* (512 μg/mL) *Enterobacter cloacae* (256 μg/mL) *Klebsiella pneumoniae* (256 μg/mL) *Pseudomonas aeruginosa* (512 μg/mL) *Providencia rettgeri* (256 μg/mL)	NT	Veras et al. (2017)
	Lippia origanoides (leaves)	Yield: 1.0% (v/w) Oxygenated monoterpenes (66%) Carvacrol (38.6%) Thymol (18.5%)	Drop agar diffusion (inhibition halo diameter)	*S. aureus* (25 mm) *Staphylococcus aureus* MRSA (25 mm) *S. mutans* (26 mm)	*Candida albicans* Serotype B ATCC 36802 (25 mm) *C. albicans* (27 mm) *Candida guilliermondii* (40 mm) *Candida parapsilosis* (35 mm) *Cryptococcus neoformans* (24 mm) *Trichophytum rubrum* (30 mm)	Oliveira et al. (2007)
	Lippia grandis (leaves)	Yield: 2.7% Carvacrol (37.12%) p-cymene (11.64%) Thymol (7.8%)	-Disk diffusion assay (inhibition halo diameter) -Microdilution assay (MIC)	*S. aureus* ATCC 25923 (33.9 mm; 1.15 mg/mL) *E. faecalis* ATCC 51299 (24.5mm; 0.57 mg/mL) *E. faecalis* ATCC 29212 (13.0 mm; 0.57 mg/mL) *E. coli* ATCC 35218 (29.3 mm; 1.15 mg/mL) *E. coli*ATCC 25922 (22.7 mm; 1.15 mg/mL) *K. pneumoniae* ATCC 700603 (9.8 mm; 1.15 mg/mL)	NA	Sarrazin et. (2012)
	Lippia thymoides (leaves)	Yield: 1.63% Thymol (88.56%)	Disk diffusion assay (inhibition halo diameter)	*S. aureus* (11 mm)	*C. albicans* (10 mm) *Candida tropicalis* (8 mm)	Silva et al. (2020)
	Lippia lasiocalycina (leaves)	Yield: ranged from 0.40 to 0.52% Piperitenone oxide (57.55%), limonene (20.69%)	Microdilution assay (MIC)	NA	*C. albicans* ATCC 10231 (512 μg/mL)	Almeida et al. (2018)

Cordia	*Cordia verbenacea* (aerial parts and leaves)	Yield: 0.19% (aerial parts) and 0.23% (leaves) α-pinene (29.69%), *Trans*-caryophyllene (25.27%), alloaromadendrene (9.99%)	Disk diffusion assay (inhibition halo diameter)	*Bacillus cereus* (23 mm) *Bacillus subtilis* (24 mm) *S. aureus 5051* (48 mm) *S. aureus 5164* (41 mm) *S. aureus* ATCC 13150 (27 mm) *S. aureus* ATCC 6534 (21 mm) *Staphylococcus epidermidis* (31 mm) *S. epidermidis* ATCC 27626 (39 mm) *Proteus mirabilis* 1821 (15 mm) *Proteus vulgaris* ATCC 13315 (22 mm)	*C. albicans* 4241 (48 mm) *C. albicans* 14 (22mm) *C. albicans* 14.1 (15mm) *C. albicans* ICB11(48 mm) *C. albicans* ICB58 (29 mm) *Candida dublinenesis* 558 (48 mm) *Candida glabrata* (48 mm) *C. guilliermondii* 158 (37 mm) *Candida lusitaniae* (48 mm) *C. parapsilosis* 006 (48 mm) *C. stellatoidea* 10C (36 mm) *C. tropicalis* ATCC 13803 (17 mm) *Candida tropicalis* 75 (20 mm) *Cryptococcus* sp. 202 (48 mm)	de Carvalho Jret al. (2004)
		Yield: 0.37% NT	Rat periodontitis model-topical application of essential oil (detection of microorganisms by PCR)	Significant decline in *Porphyromonas gingivalis*	Reduction of *Actinobacillus actinomycetemcomitans*	Pimentel et al. (2012)
		Yield: ranged from 0.166% to 0.366% Sabinene (15.69-69.68%), α-pinene (5.57-16.16%), β-phellandrene (2.95-11.02%), γ-elemene (6.49-12.57%), δ-elemene (3.3-12.65%), β-caryophyllene (5.58-11.49%), γ-caryophyllene (5.03-15.65%), Germacrene B (2.89-13.85%)	Microdilution assay (MIC)	-EO combinated with antibiotics: a potential modulator (synergistic effect), reducing the MIC of the antibiotic tested against all bacterial strains	NT	Matias et al. (2016)
Croton	*Croton cajucara* Benth (leaves)	Yield: NM Linalool*	-Microdilution assay (MIC) -Antimicrobial assays in artificial biofilms	-MIC: *Lactobacillus casei* ATCC 4646 (22.3 μg/mL) *Streptococcus sobrinus* ATCC 27609 (13.8 μg/mL) *S. mutans* ATCC 25175 (40.1 μg/mL) *P. gingivalis* ATCC 43146 (31.2 μg/mL) *S. aureus* ATCC 49456 (33.4 μg/mL) -EO inhibited all the microorganisms tested (artificial biofilms)	*C. albicans* ATCC 51501 (13.4 μg/mL)	Alviano et al. (2005)

		Yield: 0.65% (average) α-Pinene (EO1: 7.5%; EO2: 24.7%; EO3: 0.1%; EO4: 0.5%; EO5: less than 0.1%), linalool (EO1: 6.3%; EO2: 11.6%; EO3: 11.0%; EO4: 9.9%; EO5: 13.2%), 7-Hydroxycalamenene (EO1: 37.5%; EO2: ND; EO3: 28.4%; EO4: 30.9%; EO5: 32.9%), β-Caryophyllene (EO1: 4.1%; EO2: 5.7%; EO3: 2.8%; EO4: 4.0%; EO5: 2.6%)	-Drop agar diffusion method (inhibition zones); -Microdilution assay (MIC)	-Inhibition zones (mm): *S. aureus* (MRSA-BMB9393) (EO1: 7; EO2: 5; EO3: 7; EO4: 13; EO5: 38) *E. faecalis* (EO1: 10; EO2: 6; EO3: 8; EO4: 6; EO5: 9) *S. epidermidis* (EO1: 6; EO2: 9; EO3: 7; EO4: 8; EO5: 20) *L. casei* (EO1: 6; EO2: 9; EO3: 7; EO4: 8; EO5: 20) *Mycobacterium smegmatis* (00061) (EO1: 10; EO2: 24; EO3: 12; EO4: 18; EO5: 18) -MIC (μg/mL): *M. smegmatis* (EO1: 39.06; EO2: 5000; EO3: 78.12; EO4: 156.25; EO5: 156.25); *Mycobacterium tuberculosis* H37Rv ATCC 27294 (all EO samples: 4.88); *S. aureus* MRSA (EO1: 0.019; EO2: NA; EO3: 0.019; EO4: 0.004; EO5: 0.001).	-Inhibition zones (mm): *C. albicans* ATCC 24433 (EO1: 6; EO2: 10; EO3: 7; EO4: 8; EO5: 8) *Aspergillus fumigatus* ATCC 16913 ATCC 24433 (EO1: 4.8; EO2: 3.2; EO3: 4.5; EO4: 4.6; EO5: 5) *Aspergillus niger* (EO1: 5.7; EO2: 3.4; EO3: 5.6; EO4: 5.9; EO5: 6) *Aspergillus ochraceus* ATCC 22947 (EO1: 4.5; EO2: 3.1; EO3: 4.5; EO4: 4.7; EO5: 5) *Mucor circinelloides* LIKA0066 (EO1: 8; EO2: 15; EO3: 6; EO4: 10; EO5: 10) *Rhizopus oryzae* UCP1506 (EO1: 6; EO2: 12; EO3: 5; EO4: 8; EO5: 10); *T. rubrum* (T544) (EO1: 5.8; EO2: 0; EO3: 5.5; EO4: 5.7; EO5: 6); *Fusarium solani* (EO1: 3.1; EO2: 2.2; EO3: 3.4; EO4: 3.5; EO5: 3.5); *Microsporum gypseum* (EO1: 14; EO2: 3; EO3: 13; EO4: 14; EO5: 14). -MIC (μg/mL): *C. albicans* (EO1: 1.22; EO2: 1250; EO3: 156.25; EO4: 0.001; EO5: 0.038); *M. circinelloides* (EO1: NT; EO2: NT; EO3: NT; EO4: NT; EO5: 3.63×10^{-8}); *R. oryzae* (EO1: NT; EO2: NT; EO3: NT; EO4: NT; EO5: 0.152).	Azevedo et al. (2013)
	Croton campestris (leaves; branches)	Yield: 0.04% (leaves) and 0.02% (branches) -Leaves: β-caryophyllene (17%), bicyclogermacrene (16.2%) -Branches: Bicyclogermacrene (11.3%), spathulenol (14.7%), β-caryophyllene (8.2%)	Microdilution assay (MIC)	*S. aureus* ATCC 12624 (leaves: ≥512 μg/mL; branches: ≥128 μg/mL) *B. cereus* ATCC 33018 (leaves: NA; branches: ≥256 μg/mL) *E. coli* ATCC 25922 (leaves and branches: ≥512 μg/mL) *P. aeruginosa* ATCC 15442 (leaves: NA; branches: ≥512 μg/mL)	NT	de Almeida et al. (2013)

	Croton heliotropiifolius (leaves; steams)	Yield: 0.60% (winter), 0.24% (spring), 0.36% (summer), 0.16% (autumn) β-caryophyllene (28.61-46.99%), bicyclogermacrene (8.47-22.60%), germacrene-D (3.06-7.80%), limonene (1.76-9.56%) 1,8-cineole (1.12-8.66%)	Microdilution assay (MIC)	-MIC (μg/mL): *B. cereus* ATCC 11778 (winter: NA; spring: NA; summer: 500; autumn: NA) *E. faecalis* ATCC 19433 (winter: 500; spring: 500; summer: 62.5; autumn: 125) *E. coli* ATCC 25922 (winter: 500; spring: 500; summer: 500; autumn: NA) *Salmonella enterica* ATCC 10708 (winter: NA; spring: 500; summer: 500; autumn: NA) *Serratia marcescens* ATCC 13880 (winter: 500; spring: 500; summer: 500; autumn: 500) *Shigella flexneri* ATCC 12022 (winter: NA; spring: NA; summer: 500; autumn: 500)	NT	de Alencar Filho et al. (2017)
		Yield: 0.17% (E)-caryophyllene (23.85%), γ-muurolene (10.52%), viridiflorene (8.08%)	Microdilution assay (MIC)	*S. aureus* ATCC 6538 (500.0 μg/mL) *B. subtilis* ATCC 6833 (62.5 μg/mL)	NT	Araújo et al. (2017)
Copaifera	*Copaifera multijuga* Hayne (oilsresin from trunk)	Yield: 75% β-cariophylene (57.29%), cariophylene oxide (10.34%), α-humuleno (9.11%), trans-α-bergamotene (5.31%), α-copaene (3.29%), γ-muurolene (1.63%), β-bisabolene (1.08%)	-Adapted disk diffusion assay (inhibition halo diameter) -Microdilution assay (MIC)	NT	*Aspergillus flavus* (IOC-3974) (19.5 mm; 0.08 mg/mL) *A. niger* (IOC-200) (9.5 mm; 0.1 mg/mL) *Aspergillus tamarii* (IOC-186) (9.0 mm; 0.5 mg/mL) *A. tamarii* (IOC-187) (12.5 mm; 0.3 mg/mL) *Aspergillus terreus* (IOC-217) (11.5 mm; 0.3 mg/mL[1]) *Candida guilliermondii* (IOC-2889) (9.5 mm; 0.1 mg/mL) *C. tropicalis* (IOC-3610) (10.0; 0.5 mg/mL) *C. parapsilosis* (IOC-2882) (16.0 mm; 0.1 mg/mL)	Deus et al. (2011)
	Copaifera langsdorffii (oilsresin from trunk)	Yield: 36.4% β-Bisabolene (32.0%), trans-α-Bergamotene (15.1%), β-Caryophyllene (9.7%), β-Famesene (3.9%), α-Bisabolene	Microdilution assay (MIC)	*S. aureus* ATCC 6538 (125 μg/mL) *P. aeruginosa* ATCC 15442 (500 μg/mL) *S. choleraesuis* ATCC 10708 (250 μg/mL)	*C. albicans* ATCC 10231 (250 μg/mL) *C. tropicalis* ATCC 750 (15.6 μg/mL) *Candida krusei* ATCC 6258 (62.5 μg/mL)	Ribeiro et al. (2018)

		(3.3%), caryophyllene oxide (3.0%), β-Sesquiphellandrene (2.8%)				
		Yield: NM Cis-thujopsene (46.96%), seychellene (8.04%), α-copaene (7.75), β-sesquiphellandrene (7.34%), caryophyllene (6.71%)	Clinical study: Evaluation of the evolution of surface affected with acne from ten volunteers (photographs)	After 21 days of treatment, there was a highly significant decrease in the extent of area affected by acne (*Propionibacterium acnes*) in the region treated with the active gel (containing *Copaifera langsdorffii* EO)	NT	Gomes da Silva et al. (2012)
Eugenia	*Eugenia uniflora* (leaves)	Yield: NM Selina-1,3,7(11)-trien-8-one (36.37%), selina-1,3,7(11)-trien-8-one epoxide (27.32%)	Microdilution assay with spectrophotometric readings (IC_{50})	NT	*C. albicans* INCQS 40006 (1892.47 μg/mL) *C. tropicalis* INCQS 40042 (4511.82 μg/mL) *C. krusei* INCQS 40095 (12491.80 μg/mL)	dos Santos et al. (2018)
		Yield: 1.08% Isoflurane-germacrene (65.80%), germacra 3,7,9-trien-6-one (16.19%), β-elemenone (4.47%), γ-elemene (3.97%), germacrene B (2.19%)	Microdilution assay (MIC)	*S. aureus* 99 ATCC 25923 and *S. aureus* SA 358 (surgical wound) (> 256 μg/ml)	NT	Pereira et al. (2017)
		Yield: NM Germacrene B (21.2%), seline-1,3,7-(11)-trien-8-one oxide (19.3%), β-caryophyllene (12.6%), germacrene A (11.6%), germacrene C (11.4%), seline-1,3,7-(11)-trien-8-one (9.7%), curzerene (3.9%)	-Agar diffusion method (inhibition halo diameter) -Microdilution assay (MIC)	*L. monocytogenes* 138 ATCC 19117 (18 mm) *S. aureus* 139 ATCC 27664 (26 mm)	*C. albicans* (208.3 μg/mL) *C. parapsilosis* (208.3 μg/mL) *C. guilliermondii* (109.4 μg/mL) *Candida globose* (187.5 μg/mL) *Candida lipolytica* (93.7 μg/mL) *Cryptococcus laurentii* (208.3 μg/mL) *Trichosporon asahii* (312.5 μg/mL)	Victoria et al. (2012)

Baccharis	*Baccharis dracunculifolia* D.C. (leaves)	Yield: 0.31% (fresh) and 0.43% (dried) Germacrene D (18.4%) (E)-nerolidol (14.0%), spathulenol (11%) β-Pinene (9.5%)	Microdilution assay (MIC)	*S. aureus* ATCC 25923 (102 µg/mL) -Resistant to antibiotics: *S. aureus* SA10 (512 µg/mL) *P. aeruginosa* PA24 (813 µg/mL)	NT	Salazar et al. (2018)
Hedyosmum	*Hedyosmum brasiliense* (leaves; flowers)	Yield: 0.5% (v/w) α-terpineol (10.2%), curzerene (8.9%), pinocarvone (8.4%), β-thujene (7.1%)	Agar dilution method (MIC)	MIC: % (vol/vol) *B. subtilis* ATCC 23858 (0.312) S. aureus ATCC 25923 (0.312) *Staphylococcus saprophyticus* ATCC 35552 (0.312)	MIC: % (vol/vol) *C. albicans* ATCC 10231 (0.312) *C. parapsilosis* ATCC 22019 (0.312) *Microsporum canis* C112 (0.125) *M. gypseum* C115 (0.312) *Trichophyton mentagrophytes* ATCC 9972 (0.312) *T. rubrum* C137 (0.125)	Kirchner et al. (2010)
		Yield: 0.24 % (male flowers) and 0.38% (female flowers) -Leaves: Sabinene (16%), β-pinene (5%), 1,8-cineole (3–7%), methyl eugenol (2–5%), curzerene (17–18%), carotol (6%) -Flowers: Sabinene (8–10%), α-phellandrene (1–8%), 1,8-cineole (2–7%), germacrene D (4–6%), curzerene (11%), carotol (9%)	Adapted Bioautography (evaluation of clear inhibition zones on pre-coated Thin Layer Chromatography - TLC - plates sprayed with a suspension containing fungus spores)	NT	Female flowers EO: presented the strongest activity against *Cladosporium cladosporioides* CCIBt 140 and *Cladosporium sphaerospermum* Penz CCIBt 491) in all tested concentrations. Other oils: weaker inhibition against both fungi tested.	Murakami et al. (2017)
Schinus	*Schinus mole* (leaves; fruits)	Yield: 1.2% (w/w) β-pinene (25.23%), Epi-α-cadinol (21.29%), α-pinene (18.72%), Myrcene (11.54%), Sabinene (5.02%)	Microdilution assay (MIC)	*P. aeruginosa* ATCC 27853 (>5000 µg/mL) *E. coli*ATCC 43895 (>5000 µg/mL) *Acinetobacter baumannii* ATCC 19600 (5000 µg/mL) *S. aureus* (MRSA) ATCC 33591 (5000 µg/mL) *E. faecalis* ATCC 10100 (2500 µg/mL)	*C. neoformans* ATCC 90012 (625 µg/mL) *Paracoccidioides brasiliensis* (strain T17LM2) (39.06 µg/mL) *Trichophyton quinckeanum* ATCC 11480 (625 µg/mL)	do Prado et al. (2018)

		Yield: NM Sabinene (34.77%), germacrene-D (7.06%), terpinen-4-ol (5.50%), α-pinene (5.32%), β-pinene (4.50%)	-Diffusion in cylindrical agar cavities (Inhibition halo); -Macrodilution broth assay (MIC)	*S. aureus* ATCC 25923 (38.2 mm; 2.81 mg/mL) *E. coli* ATCC 25922 (22.0 mm; 11.25 mg/mL) *P. aeruginosa* ATCC 27853 (16.0 mm; 11.25 mg/mL)	NT	Rocha et al. (2012)
		Yield: 1.09 ± 0.22% (leaf) and 0.91 ± 0.09% (fruit) -Leaf: α-phellandrene (25.9%), limonene (11.7%), β-myrcene (11.1%), β-phellandrene (10.5%) -Fruit: β-myrcene (51.3%), limonene (14.1%), α-phellandrene (14.0%), β-phellandrene (11.0%)	- Agar diffusion method (inhibition halo diameter); - Macrodilution broth assay (MIC)	-Inhibition growth zone (mm): *S. epidermidis* ATCC 12228 (leaf: 11.3; fruit: 6.7) *S. aureus* ATCC 29213 (leaf: 9.7; fruit: 10.0) *E. coli* ATCC 25922 (leaf: 7.7; fruit: 6.3) *P. aeruginosa* ATCC 27853 (leaf: 6.3; fruit: 6.3) *E. faecalis* (leaf: 9.7; fruit: 8.3) *P. mirabilis* (leaf: 7.3; fruit: 6.3) *S. enteritidis* (leaf: 7.7; fruit: 6.3) *Salmonella entiritidis serovar Typhimurium* (leaf: 6.3; fruit: 6.3) -MIC (μg/ mL): *S. epidermidis* ATCC 12228 (leaf: 66; fruit: 125) *S. aureus* ATCC 29213 (leaf: 125; fruit: 500) *E. coli* ATCC 25922 (leaf: 1000; fruit: 1000) *P. aeruginosa* ATCC 27853 (leaf: >1000; fruit: >1000) *E. faecalis* (leaf: 500; fruit: 1000) *P. mirabilis* (leaf: 1000; fruit: >1000) *S. enteritidis* (leaf: 750; fruit: 1000) *S. entiritidis serovar Typhimurium* (leaf: >1000; fruit: >1000)	- Inhibition growth zone (mm): *A. niger* (leaf: 6.3; fruit: 6.3) *Aspergillus japonicus* (leaf: 7.3; fruit: 9.3) *Aspergillus oryzae* (leaf: 7.3; fruit: 6.7) *Fusarium oxysporum* (leaf: 6.3; fruit: 6.3) *R. oryzae* (leaf: 7.7; fruit: NA) *Rhizopus stolonifer* (leaf: 8.7; fruit: NA) - MIC (μg/ mL): *A. niger* (leaf: 1000; fruit: 750) *A. japonicus* (leaf: 750; fruit: 250) *A. oryzae* (leaf: >1000; fruit: >1000) *F. oxysporum* (leaf:>1000; fruit: >1000) *R. oryzae* (leaf: 750) *R. stolonifera* (leaf: 500)	Martins et al. (2014)
Aniba	*Aniba rosaeodora* Ducke (aerial parts - leaves and thin stems)	Yield: 1.0% Linalool (88.6%)	-Disk diffusion assay (inhibition halo diameter in mm) -Microdilution assay (MIC in μL/mL)	*E. coli* ATCC 35218 (13.2; >10) *K. pneumoniae* ATCC 13883 (11.6; >10) *S. aureus* ATCC 25923 (26.7; 1.3) *E. faecalis* ATCC 29212 (8.80; 5) *S. pyogenes* ATCC 19615 (38.4; 5) *S. epidermidis* ATCC 12228 (> 40; 1.3)	NT	Sarrazin et al. (2016)

NM: not mentioned; NT: not tested; NA: no activity; ND: not detected; MIC: minimum inhibitory concentration; MBC: minimum bactericidal concentration; *percentage not mentioned.

Lippia grandis Schauer, commonly known as "*erva-do-marajó*", is an aromatic shrub whose leaves and branches are widely used in food (giving flavor) and in the production of medicinal teas for the treatment of stomach and liver diseases (Damasceno et al. 2011). Sarrazin et al. (2012) evaluated EO activity obtained from *L. grandis* against Gram-positive, Gram-negative bacteria and against *C. albicans* recovered from clinical samples. It was observed that EO showed potential activity against most of the tested microorganisms and this antimicrobial activity seems to be related to phenolic compounds as carvacrol and thymol, acting synergistically with p-cymene and other minority compounds present in EO composition. These compounds have shown activity against *Candida* species related to envelope damage causing depletion of biofilm formation (Braga et al. 2008).

Lippia thymoides Mart. & Schauer, also known as ''*alecrim-do-mato*'' or ''*alecrim-do-campo*'', is a shrub popularly used in religious rituals and on popular medicine in respiratory problems (bronchitis), in the treatment of rheumatism, as well as headaches and weakness (Silva et al. 2016). The analysis of the chemical composition of the essential oil extracted from *L. thymoides* carried out by Silva et al. (2019) demonstrated that thymol is the main compound present in EO extracted from flowers, leaves and branches (19.34-66.33%), which corroborates with the results obtained by Silva et al. (2020). The authors obtained thymol (88.56%) as the major EO compound of *L. thymoides*. In addition, they evaluated antimicrobial activity of EO that showed activity against Gram-positive bacteria (*S. aureus*) and yeasts (*C. albicans* and *C. tropicalis*) (**Table 1**), however, it showed no activity against Gram-negative bacteria (*E. coli*). In this study, thymol (88.56%) was also the major compound present in the EO.

In the research carried out by Almeida et al. (2018), the EO of *Lippia lasiocalycina* Cham. was evaluated for its antimicrobial activity against bacteria (Gram-negative, Gram-positive) and fungus (*C. albicans*) (**Table 1**). The analysis of the EO chemical composition of this species was carried out by Santos et al. (2020), who found as main components β-myrcene (31.17%), (E)-ocimenone (24.10%), p-cymene (7.17%) and (Z)-ocimenone (6.51%), differing from the results obtained by Almeida et al. (2018), who identified piperitenone oxide (57.55%) and limonene (20.69%) as major compounds in the EO of *L. lasiocalycina*. Despite the great interest in research on the biological properties of natural compounds obtained from the genus *Lippia*, studies related to the species *L. lasiocalycina* are still scarce, which emphasizes the search for more in-depth studies related to the antimicrobial activity of this EO.

In view of the studies carried out to evaluate the essential oil of *Lippia* spp., it is observed that the major phenolic compounds (thymol and carvacrol) show antimicrobial activity against a vast number of microorganisms important for human health. The mechanism

of action of these monoterpenes is related to the direct interaction of these hydrophobic compounds and the cell membrane, causing loss of integrity or even disintegration, which releases lipopolysaccharides (LPS) altering the selective permeability of cell membrane with escaping of internal vital components (Helander et al. 1998, Chorianopoulos et al. 2004, Sarrazin et al. 2012).

Cordia

The genus *Cordia* belongs to the family Boraginaceae and is distributed in tropical and subtropical regions (Matias et al. 2010). The species *Cordia verbenacea* D.C. (synonym *Varronia curassavica* Jacq.) is popularly known as "*erva-baleeira*", "*baleeira*", "*maria-milagrosa*" or "*erva-preta*" and has leaves with a strong and characteristic odor. This plant has traditionally been used in popular medicine to treat rheumatism, inflammation and ulcers, since they have numerous biological activities, including anti-inflammatory, anti-allergic, antioxidant and antiulcerogenic (Nizio et al. 2015, Sciarrone et al. 2017). The EO from this plant is commonly extracted from the aerial part and leaves, presenting a low yield that varies from 0.17% to 0.37% according to data obtained in studies described in the literature (**Table 1**).

Regarding the chemical compounds present in the EO of *C. verbenacea*, it was observed that α-pirene (~30%), sabinene (15.69-69.68%), and β-caryophyllene (5.58-11.49%) are the major compounds (**Table 1**). Pimentel et al. (2012) showed a promising application of essential oil of *C. verbenacea* in periodontitis, using a topical application in rat model the authors showed the significant reduction of *P. gingivalis* and *A. actinomycetemcomitans*, which are important putative periodontopathogens. In another study by de Carvalho et al. (2004), *C. verbenacea* EO showed strong antimicrobial activity against Gram-positive bacteria and yeast, however, most Gram-negative bacteria were resistant to the action of EO. The analysis of the antimicrobial activity of the EO of *C. verbenacea* performed in the study by Rodrigues et al. (2012) showed a strong and similar activity against Gram-positive bacteria (*S. aureus* ATCC 12692 and *B. cereus*) and Gram-negative bacteria (multi-drug resistant *E. coli* 27), presenting MICs of 64 μg/mL. In addition, this study obtained as major compounds present in the EO the sesquiterpenes (83.66%), as ß-caryophyllene (25.4%), bicyclogermacrene (11.3%) d δ-cadinene (9.4%) and the monoterpene α-pinene (9.5%). In addition, the *C. verbenace* EO also acts synergistically with antibiotics, decreasing the MIC values obtained by the antibiotics used alone, as shown in the study by Matias et al. (2016).

The excellent antimicrobial activities of EO of *Cordia* genus are directly related to the major compounds, especially α-pinene, ß-phellandrene, ß-caryophyllene and germacrene B. Numerous studies have shown the effects of these compounds against microorganisms, as in the study by Nissen et al. (2010), who found the excellent activity of α-pirene against Gram-positive and Gram-negative bacteria, as well as yeast species. It was observed that this compound was found in significant amounts in most EO obtained from *C. verbancea*, thus being one of the main compounds responsible for the antimicrobial activity of the EO, synergistically with the other major compounds. In the study by Stojković et al. (2010) α-pirene showed high activity against three tested strains of *Actinomadura madurae* (MICs of 5 μg/mL), demonstrating the excellent antimicrobial activity of this compound, whose mechanism of action is related to its oxidation by microorganism, which results in the formation of acyclic metabolites and consequently death of microbial cells.

Croton

Considered one of the main genus of the Euphorbiaceae family, the genus *Croton* is widely distributed in the Northeast region of Brazil. Many species of this genus have tremendous economic prominence due to the great natural compounds diversity, with several pharmacological properties, emphasizing on anti-inflammatory, gastroportiva, antiulcerogenic, antioxidant and antimicrobial activities, which justifies the wide use in traditional medicine by local population. Most species of this genus, such as *Croton cajucara, Croton campestris* and *Croton heliotropiifolius,* are rich in essential oils with complex chemical composition formed by monoterpenes, sesquiterpenes and phenylpropanoids (Da Costa et al. 2013, Martins et al. 2017).

The species *Croton cajucara* Benth. is commonly known as "*sacaca*" or "*cajuçara*" and grows mainly in the Amazon and the Northeast region of Brazil. Leaf tea is used in traditional medicine to treat diarrhea, diabetes, gastrointestinal disorders, as well as fever, liver problems and malaria (Da Silva et al. 2012, Freires et al. 2015). In addition, the leaves of *C. cajucara* are rich in essential oil, which presents as major compounds the linalool (~11% average) and 7-hydroxycalamenene (~30%) (**Table 1**). Alviano et al. (2005) reported the antimicrobial activity of *C. cajucara* EO against *C. albicans, Lactobacillus casei, S. aureus, S. sobrinus, Porphyromonas gingivalis* and *S. mutans* cell suspensions, that are associated with oral cavity infections. The results show excellent antimicrobial and antifungal activity of EO, with MICs ranging from 13.4 - 40.1 μg/mL (**Table 1**). These results were confirmed by the

analysis of the antimicrobial activities of the chemical compounds present in the EO (previously separated by chromatography), which show linalool as responsible for the activity against *C. albicans* and other polar compounds present in the composition of EO was responsible for antibacterial activity. In the study by Azevedo et al. (2013), 5 samples of EO obtained from leaves of the red morphotype *C. cajucara* were analyzed, and an excellent antimicrobial activity against pathogenic microorganisms was observed, both by the inhibition of growth (inhibition halos) and by the evaluation of the MICs. It was observed that the EO showed significant activities against methicillin resistant *S. aureus* (MRSA), *Enterococcus faecalis*, *Mycobacterium tuberculosis*, *M. smegmatis*, *Mucor circinelloides* and *Rhizopus oryzae* (**Table 1**). In this case, in addition to linalool, EO samples showed large amounts of 7-hydroxyicalamenene (28.4% -37.5%), which was analyzed in isolation and demonstrated activity on a wide spectrum of microorganisms, thus being responsible for antimicrobial activity synergistically with linalool.

In another study by Liu et al. (2020), linalool alone showed strong antibacterial activity against *P. aeruginosa* (MIC = 431 μg/mL), and it was observed through scanning electron microscopy (SEM) that the mechanism of action of this compound is related to the permeability and integrity of cell membrane, resulting in lysis of the bacterial cell wall.

Croton campestris A. St.-Hil, which is known commonly as "*velame do campo*", is a native plant from Brazil, mainly from the Southeast and Northeast regions and is traditionally used in folk medicine to treat many disorders, such as general pain, constipation, bronchitis, intestinal problems, among others. In relation the biological activities, antimicrobial, antiulcerogenic and antiinflammatory activities are the ones that stand out. Regarding the chemical composition of the EO obtained from this plant, it was observed that β-caryophyllene is presented as a major compound, with the biological activities attributed to this sesquiterpene (De Morais et al. 2018, Monteiro et al., 2019). In the antibacterial activity evaluation of the of *C. campestris* EO, de Almeida et al. (2013) reported that the EO extracted from the leaves showed activity against Gram-positive and Gram-negative strains (*S. aureus* and *E. coli* with MICs = 512 μg/mL) and the EO extracted from the branches was active against all bacterial strains (the best MIC was 128 μg/mL against *S. aureus*) (**Table 1**). Babili et al. (2009) showed that the EO obtained from the leaves also showed antifungal activity, with a MIC of 6.25 μg/mL for *C. albicans*. In this case, the caryophyllene oxide (29.9%) was found as the major compound and the β-caryophyllene presented 1.6% of the composition of the analyzed EO.

Another species from this genus is *Croton heliotropiifolius* Kunth., that is popularly known as "*velame-preto*" and is widely distributed in the Northeast region of Brazil, mainly in

the *Caatinga* vegetation. The infusion of the roots of this species is popularly used in the treatment of pain in general, inflammation, as well as in the treatment of influenza infection and dermatitis. *C. heliotropiifolius* is considered a medicinal plant of great economic interest, since it is rich in bioactive compounds that confer numerous activities, such as antimicrobial, antioxidant, among others (Angélico et al. 2014, Saraiva et al. 2015, De Sousa et al., 2020).

In the literature it was found that the major compounds present in EO extracted from leaves and stems were β-caryophyllene (maximum found was 46.99%), in addition to γ-muurolene and germacrene-D (**Table 1**). As for antimicrobial activity, de Alencar Filho et al. (2017) evaluated EO samples obtained in different seasons and observed that the samples showed weak to moderate activity (most had MICs = 500 μg/ml) for Gram-positive and Gram-negative bacteria. EO obtained in the summer showed the best activity compared with the ones obtained from other seasons, with activity against all bacteria tested and lower MIC against *E. faecalis* (62.5 μg/ml). In the study reported by Araujo et al. (2017) activity against Gram-positive bacteria was also observed, for the species *B. subtilis* (MIC = 62.5 $\mu g.mL^{-1}$) and *S. aureus* (MIC = 500.0 $\mu g.mL^{-1}$) (**Table 1**). This result was similar to the observed by Angélico et al. (2014), where the *C. heliotropiifolius* EO showed inhibitory activity for the multiresistant lineage of *S. aureus* (MR 358) with MIC of 512 μg/mL. In this case, the major compounds found in the EO were eucalyptol (16.9%), β-caryophyllene (15.9%) and germacrene-D (14.5%).

Copaifera

Belonging to the Leguminosae Juss. family (Fabaceae) and subfamily Caesalpinoideae Kunth, the genus *Copaifera* L. is widely distributed in the tropical regions of Latin America, and can also be found in Asia and Africa. However, it is in Brazil that the largest number of species of this genus occurs, mainly in the central regions and in the Amazon area (Junior et al. 2007, Furtado et al. 2018, Da Trindade et al. 2018). Plants of this genus are commonly called "*copaíba*", "*copaibeira*" or "*pau-de-óleo*" (Arruda et al. 2019) and are traditionally used in popular medicine, mainly by the Amazonian people, in the treatment of cystitis, urinary incontinence, some respiratory diseases (bronchitis, pneumonia, sinusitis), in the treatment of skin and mucosal wounds, among others (Da Trindade et al. 2018). These uses are related to oil extracted from tree trunks, which are called oil-resin due the composition formed by resin acids (resin fraction) in diterpenes and sesquiterpenes (volatile fraction, which corresponds to most of the oil-resin mass). These oils have numerous biological activities, including

antimicrobial, anti-inflammatory, analgesic activities, among others responsible for their application in various treatments, as mentioned earlier (Kobayashi et al. 2011, Santos et al. 2012, Diefenbach et al. 2018).

Among the copaifera species native to Brazil, *Copaifera multijuga* Hayne has received great prominence for the antimicrobial activity derived from its oil. This species is found mainly in the Western Amazon, in the south of Roraima and in the north of Mato Grosso (Mendonça et al. 2009). In the study by Deus et al. (2011), the antifungal activity of the fraction of essential oil present in the oil-resin extracted from *C. multijuga* trunk was analyzed and it was observed that EO inhibited the growth of all species of *Aspergillus* and *Candida* tested, in addition to showing MIC values ranging from 0.08 to 0.5 $mg.mL^{-1}$ (**Table 1**), indicating its potential antifungal activity. In this case, the volatile fraction of the oil-resin present as major compounds the β-caryophyllene (57.29%), caryophyllene oxide (10.34%) and α-humulene (9.11%), which are related to the observed antimicrobial activity.

Copaifera langsdorffii Desf. is another species of the genus *Copaifera* that has great commercial potential and is commonly used in traditional medicine, due to the biological properties present in the extracts of the leaves and in the oil-resin extracted from the trunks, including antimicrobial, leishmanicidal and antimalarial activity (Lemos et al. 2015). Ribeiro et al. (2018) showed that the essential oil extracted from the oil-resin of *C. langsdorffii* presented β-bisabolene (32.0%) as a major compound and a small amount of β-caryophyllene (9.7%). Activity was observed against *S. aureus*, *P. aeruginosa* and *S. choleraesuis* (MICs between 125 and 500 μg/mL), in addition to antifungal activity against *Candida* species, with the greatest activity against *C. tropicalis* (MIC = 15.6 μg/mL) (**Table 1**). Gomes da Silva et al. (2012) conducted a clinical study with formulations containing *C. langsdorffii* EO for the treatment of acne and reported a significant decrease in the surface affected with acne (*Propionibacterium acnes*) after application of the formulation, with cis-thujopsene (46.96%) as the major compound, and also the presence of caryophyllene (6.71%) (**Table 1**).

As can be seen, β-caryophyllene is a chemical compound present in essential oils of various plant species and numerous studies have reported its potent antimicrobial activity against different species of microorganisms, as this compound is capable of interfering in the metabolism of microbial cells (Sharma et al. 2016). In the study by Yoo & Jwa (2018), it was observed that β-caryophyllene penetrates very well into exopolysaccharide (EPS) of *S. mutans* biofilm, resulting in decreased microbial growth. These results demonstrate that this compound has a great potential to become a strong ally against infectious microorganisms important for human health.

Eugenia

Considered one of the broadest genera of the Myrtaceae family, the genus *Eugenia* has hundreds of species distributed mainly in South America. *Eugenia uniflora* L., popularly known as "*pitanga* cherry" or "*pitangueira*", consists of a fruit species found throughout the Brazilian territory and is one of the main representative species of this genus, attracting important economic interest because of its health benefits. Infusions of *E. uniflora* leaves have been reported to be widely used in folk medicine to treat inflammatory problems, as hypoglycemiant and in intestinal pain. This species contains numerous components with biological activity, such as essential oils rich in monoterpenes, which gives anti-inflammatory, antimicrobial and antioxidant properties, among others (Ogunwande et al. 2005; Amorim et al. 2009, De Araújo et al. 2019).

Victoria et al. (2012) reported, as the major compounds of EO of *E. uniflora*, seline-1,3,7-(11)-trien-8-one oxide (19.3%), β-caryophyllene (12.6%), germacrene (A, B and C) (11.4-21.2%) and seline-1,3,7-(11)-trien-8-one (9.7%) (**Table 1**). In accordance with the previous results, Santos et al. (2018) showed the predominance of seline-1,3,7(11)-trien-8-one (36.37%) and seline-1,3,7(11)-trien-8-one epoxide (27.32%). In relation the biological activity, both studies observed the EO present activity against *Candida* species (**Table 1**), however, some variations in the results were observed since they used different methodologies to evaluate the antimicrobial activity. In addition, the EO showed excellent activity against *L. monocytogenes* and *S. aureus*, with growth inhibition halos of 18 ± 3.2 mm and 26 ± 7.0 mm respectively (Victoria et al. 2012). These results corroborate with the study by Pereira et al. (2017), who evaluated the antibacterial activity *E. uniflora* EO against two strains of *S. aureus*, obtaining MIC >256 μg/mL. In the latter case, the EO presented isoflurane-germacrene (65.80%) as a major compound (**Table 1**). Considering the results, it is possible to observe once again that the influence of the EO chemical composition on antimicrobial activity of EO. According to Sousa et al. (2015), oxygenated compounds, such as seline-1,3,7-(11)-trien-8-one oxide, give EO more pronounced antimicrobial activities in relation to non-oxygenated compounds, which may explain the results obtained.

Baccharis

The genus *Baccharis* L. belongs to the Asteraceae family and has numerous species distributed throughout South America that are commonly used in popular medicine to treat headaches, skin wounds, liver problems, among others. Native to Brazil, the *Baccharis*

dracunculifolia D.C. species, commonly known as "*vassourinha*" or "*alecrim do campo*", has received great prominence due to its biological properties attributed to the presence of active compounds, such as the extracted essential oil from the leaves (diterpene and triterpene) and flavonoids, responsible for the anti-inflammatory, anti-carcinogenic, antimicrobial and immunostimulatory activities (Sobrinho et al. 2016, Bonin et al. 2020).

Salazar et al. (2018) evaluated the antibacterial activity of EO extracted from the leaves of *B. dracunculifolia* and a potential activity was observed against Gram-negative bacteria *P. aeruginosa* (MIC = 813 μg/mL), however, it showed more effective activity against Gram-positive bacteria *S. aureus*, presenting MIC for standard and multi-resistant strains of 102 μg/mL and 512 μg/mL, respectively (**Table 1**). In this case, germacrene D (18.4%), (E)-nerolidol (14.0%), spathulenol (11%) and β-pinene (9.5%) were obtained as major compounds, which have a mechanism of action against microorganisms associated with destructuring of microbial membranes and their functions, since they penetrate cells due to their lipophilic character and results in their destruction.

Hedyosmum

Hedyosmum brasiliense is included in one of 48 species of the genus *Hedyosmum* (Chloranthaceae) spread in American countries, such as Brazil (Radice et al. 2019). In folk medicine, this plant is used in treatment of migraine, stomach pain, rheumatism, ovarian dysfunction and other conditions due to its analgesic indications. Popularly known as "chá de bugre", "cidrão" or "cidreira", *H. brasiliense* presents essential oil from male and female leaves and flowers with low yield, both not exceeding 0.5% (Kirchner et al. 2010, Murakami et al., 2017). Monoterpenes, sesquiterpenes and phenylpropanoids are the major compounds of this EO. Regarding antimicrobial activity, it was found that the activity was limited against Gram-positive bacteria (*S. aureus*, *S. saprophyticus* and *B. subtilis*). And fungal dermatophytes, opportunistic fungi responsible for onychomycosis, probably caused by α-terpineol (Kirchner et al. 2010).

Schinus

Schinus molle belongs to the genus *Schinus* L., from the Anacardiaceae family, which is native of South America (Barbosa et al. 2007). It is a species popularly known as "*aroeira-periquita*" which occurs in Brazilian region from Pernambuco to Rio Grande do Sul (Dos Santos et al. 2010). *S. molle* has been used in treatment of different conditions including

respiratory and urinary infections. This plant provides essential oil from leaves and fruits, both with low yield (1.09 ± 0.22% and 0.91 ± 0.09%, respectively). *S. molle* EO is composed of monoterpenes and sesquiterpenes. Leaf EO and fruit EOs have a large spectrum of antibacterial activity, in particular important activity against Gram-positive bacteria (do Rosário Martins et al., 2014). It was suggested that monoterpenes, such as pinenes and sabinene, act synergistically in Gram-positive strain (Rocha et al. 2012). *S. molle* EO has a promising application due to activity against *Paracoccidioides brasiliensis*, the etiologic agent of paracoccidioidomycosis (Do Prado et al. 2018). Nonetheless, *S. molle* EO showed cytotoxicity in lymphocytes and macrophages, probably in function of the major compound α-pinene because of oxidative stress, but the mechanism of cytotoxicity of α-pinene remains unclear (Türkez & Aydin 2016, Duarte et al. 2018).

Aniba

The species *Aniba rosaeodora* Ducke, popularly known as "*pau-rosa"* (rosewood), is considered one of the main representatives of the genus *Aniba* (Lauraceae) and is distributed mainly in the Amazon region. This plant has an essential oil rich in linalool which is widely used in the cosmetic industry (perfumery) and in popular medicine, as it has numerous pharmacological properties with emphasis on its analgesic, antidepressant and anticonvulsant effect, and is also used in tissue regeneration (Simić et al. 2004, May & Barata 2004, Sarrazin et al. 2016). Another important biological property attributed to the EO of *A. rosaeodora* is antimicrobial activity, which was evaluated in the study by Sarrazin et al. (2016). The EO showed activity against Gram-positive and Gram-negative bacterias, with the highest activity observed against *S. pyogenes* (inhibition zone >40 mm and MIC of 1.3 μL/mL) (**Table 1**). In the study by Donaldson et al. (2005), in addition to antibacterial activity, EO showed antifungal activity of *A. rosaeodora* against *C. albicans* (inhibition zone of 20 mm). The antimicrobial activity is directly related with the presence of linalool in the oil composition, whose mechanism of action has been discussed previously.

Promising plants and research gaps

Despite the increase in research related to the evaluation of the biological activities of essential oils extracted from native Brazilian plants, there are still an uncountable number of EO plants that have not been studied in terms of the antimicrobial activity. Thus, there are many research possibilities to explore the huge diversity of the Brazilian flora using sustainable

approach, which will allow in the future, the discovery of new potent drugs to treat infectious diseases.

The EO from some species, that are already commonly used in popular medicine, have shown interesting profile regarding their antimicrobial activity, with emphasis on the species *Annoa foetida* ("*araticum caatinga*"), *Annona muricata* Lin., *Hypericum* spp. (the species *H. brasiliense* being the most common in Brazil), *Rhaphiodon echinus* (Nees & Mart.) Schauer ("*betônica*") and *Vanillosmopsis arborea* Barker ("*candeeiro*") (Costa et al. 2009, França et al. 2009, Kuete et al. 2016, Costa et al. 2017, Rodrigues et al. 2018). The few studies on these species showed the unexploited potential antimicrobial activity of their bioactive compounds. In this point of view, further investigation of their EO must be carried out in order to obtain new sources of natural compounds for application in various industrial sectors, including pharmaceutical fields.

Conclusion

The chemical composition of essential oils from species of the genus *Lippia, Cordia*, *Croton*, *Copaífera*, *Eugenia*, *Baccharis*, *Hedyosmum*, *Schinus*, and *Aniba* is represented mainly by an aromatic class of compounds, namely terpenes. Many of the essential oils from plants showed a broad spectrum of action against important pathogens for human health, including multi-drug resistant strains of *S. aureus* and fungus such as *Paracoccidioides brasiliensis,* although their activity are, in general, stronger against Gram positive bacteria. However, despite the great antimicrobial potential of essential oils from Brazilian native flora, it is evident the huge necessity to conjugate the efforts from research centers, universities and industries aiming to develop efficient, low cost and sustainable new natural antimicrobial drugs.

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