Journal of Agricultural Science; Vol. 13, No. 11; 2021
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Essential Oil Content and Chemical Composition in 14 Selected Species From a Stretch of Restinga in Southern Brazil

Teomar Duarte da Silva[1,2], Michele Trombin de Souza[2], Mireli Trombin de Souza[2], Roger Raupp Cipriano[2], Humberto Ribeiro Bizzo[3] & Cicero Deschamps[2]

[1] Department of Agronomy, Catarinense Federal Institute, Araquari, Brazil

[2] Graduate Program in Agronomy-Plant Production, Federal University of Parana, Curitiba, Brazil

[3] Embrapa Food Technology, Rio de Janeiro, Brazil

Correspondence: Teomar Duarte da Silva, Catarinense Federal Institute, Highway BR 280, km 27, Araquari, Santa Catarina, Brazil. Tel: 55-(41)-3350-5687. E-mail: teomar.duartedasilva@gmail.com

Received: August 1, 2021 Accepted: September 7, 2021 Online Published: October 15, 2021

doi:10.5539/jas.v13n11p23 URL: https://doi.org/10.5539/jas.v13n11p23

Abstract

The restinga is an Atlantic Forest ecosystem characterized by tree, shrub, and herb species that are rich sources of essential oils. In this study, we aim to quantify the essential oil content and determine the chemical constituents of fresh leaves of 14 plant species in a restinga stretch in southern Brazil. Essential oils were obtained by hydrodistillation in a Clevenger-type apparatus and analyzed by gas chromatography coupled to mass spectrometry. *Campomanesia reitziana*, *Cortaderia selloana*, and *Sophora tomentosa* had no essential oils. Total essential oil content ranged from 0.01% (*Mikania involucrata*) to 1.56% (*Varronia curassavica*). In total, 60 chemical constituents were identified, representing between 46.2% and 96.5% of the chemical composition of the essential oils. Limonene was the common constituent in all species in which the essential oils were present. The major constituents were ar-curcumene (15.1%) and cis-chrysanthenol (14.2%) in *Ambrosia elatior*; benzyl benzoate (43.5%) and benzyl salicylate (23.7%) in *Aniba firmula*; caryophyllene oxide (35.7%) and spathulenol (10.6%) in *Austroeupatorium inulaefolium*; spathulenol (19.8%) and caryophyllene oxide (14.0%) in *Baccharis spicata*; caryophyllene oxide (16.3%) in *Eugenia astringens*; curzerene (30.0%), limonene (13.0%), and germacrone (11.9%) in *Eugenia uniflora*; caryophyllene oxide (17.1%) and ledol (11.3%) in *Lantana camara*; caryophyllene oxide (27.7%) and limonene (12.7%) in *M. involucrata*; 1,8-cineole (19.8%) in *Psidium cattleianum*; limonene (10.2%) in *Schinus terebinthifolius*, and allo-aromadendrene (15.2%) in *V. curassavica*. We expect that our results can assist in selecting species of potential interest for herbal, phytotherapeutic, and cosmetic products.

Keywords: bioprospecting, native species, phytochemicals, aromatic plants

1. Introduction

The restinga is an ecosystem type that originated from Quaternary marine deposits and is part of the Atlantic Forest biome. Restingas are characterized by dunes and sandy coastal plains, with vegetation growing in open and/or inaccessible places such as lagoons, lakes, and marshes. These communities include a mosaic of plants with physiognomic and xeromorphic variations that respond to the numerous constraints imposed by nutrient-poor sandy soils, drought, salinity, solar radiation, constant winds, and high air and soil temperatures (Reinert et al., 1997). The unique character of the restinga comes from a plant community with high ecological plasticity. Many restinga species colonize, grow, and survive in inhospitable situations despite their origin in forest environments.

The ecological balance of species in the restinga is largely maintained through the propagation of specific plants, including the abundant aromatic herbs, shrubs, and trees. The botanical families of Asteraceae, Fabaceae, Myrtaceae, and Poaceae are the most representative of this habitat (Melo Junior & Boeger, 2015). Other common families include Anacardiaceae, Boraginaceae, Lauraceae, and Verbenaceae. Species of this ecosystem are characterized by adaptations to its adverse conditions. Plants use various strategies to deal with their difficult environmental conditions (Amorim & Melo Júnior, 2017). These include changes in secondary metabolism, resulting in the production of a wide variety of compounds, including essential oils.

Essential oils are complex mixtures of volatile, lipophilic, generally aromatic, and liquid substances, the characteristics of which change depending on environmental conditions. Researchers have recently devoted considerable attention to their applications in herbal medicine, including antioxidant, antimicrobial, antifungal, antiviral, antinociceptive, and antitumor activities (Ali et al., 2015). Essential oils have been noted for their agricultural uses as acaricides, insecticides, fungicides, and herbicides (Ootani et al., 2013). They are also widely used in cosmetics and perfumes (Sarkic & Stappen, 2018). Despite the wealth of applications, the bioprospecting of essential oil-producing restinga plants has been limited to certain Myrtaceae species (Ramos et al., 2010; Albuquerque et al., 2012). Research into species of other families may uncover the potential of the Brazilian restinga as a source of secondary metabolites of potential interest.

Here, two hypotheses about the prospection of essential oils from native species can then be presented: the hypothesis of 'commercial potential' and the hypothesis of 'species conservation strategy'. The 'commercial potential' hypothesis suggests that the collected species could be commercially inserted, as they resemble existing species on the market. The hypothesis of a 'species conservation strategy' implies that the choice of these species would serve as an alternative for the sustainable management of the Atlantic Forest biome, which is highly degraded and in need of conservation. In this context, given the considerable interest in finding new sources of essential oils, the chemical richness of restinga plants, and the growing demand for phytotherapeutic, phytosanitary and cosmetic products, we selected a variety of herbaceous, shrub, and tree species from a restinga stretch in southern Brazil. This study, which is part of a larger effort to investigate the aromatic flora of the Atlantic Forest systematically, aims to (i) quantify the essential oil content and (ii) determine the chemical constituents of the essential oils in the fresh leaves of 14 plant species.

2. Method

2.1 Plant Material

Leaves of 14 plant species were collected in February 2014 in Penha, Santa Catarina, Brazil (between 26°47′57.9″S, 48°35′39.3″W and 26°48′39.7″S, 48°35′52.4″W). The sampling site is comprised of a restinga ecosystem with herbaceous, shrub, and tree communities. The study area has approximately 3.51 ha of coastline (Figure 1). The region's climate is subtropical, with hot and rainy summers and mostly dry winters. During the collection period, the mean monthly temperature was 26.1 °C, the mean monthly precipitation was 113.0 mm, and the mean monthly relative humidity was 85.0%.

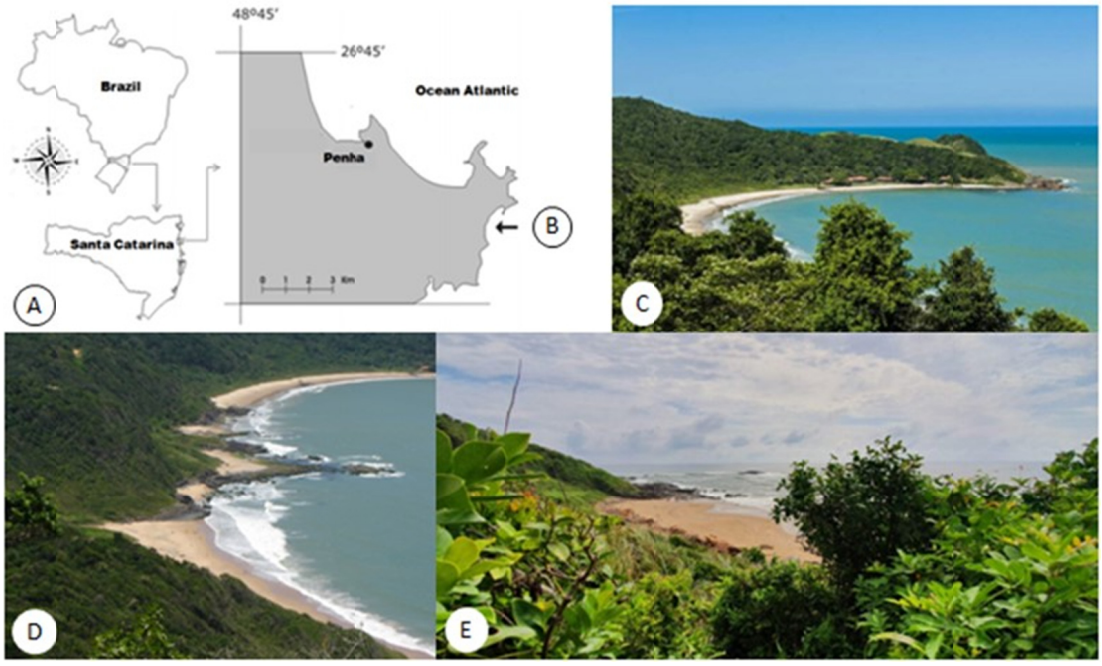

Figure 1. Location of the study area and its vegetation aspects. (A) Location map of the study area. (B) Detail of the collection area (arrow). (C-D). Panoramic views with vegetation formed by a restinga ecosystem covering the communities herbaceous, shrub and tree. (E) Shrub vegetation in the foreground and herbaceous vegetation in the background

The species analyzed were *Ambrosia elatior* L. (Asteraceae), *Aniba firmula* (Nees & Mart.) Mez. (Lauraceae), *Austroeupatorium inulaefolium* (Kunth) R.M.King & H.Rob. (Asteraceae), *Baccharis spicata* (Lam.) Baill. (Asteraceae), *Campomanesia reitziana* D. Legrand (Myrtaceae), *Cortaderia selloana* (Schult. & Schult. f. Asch. & Graebn. (Poaceae), *Eugenia astringens* Cambess. (Myrtaceae), *Eugenia uniflora* L. (Myrtaceae), *Lantana camara* Linn. (Verbenaceae), *Mikania involucrata* Hook. & Arn. (Asteraceae), *Psidium cattleianum* Sabine (Myrtaceae), *Schinus terebinthifolius* Raddi (Anacardiaceae), *Sophora tomentosa* L. (Fabaceae), and *Varronia curassavica* Jacq. (Boraginaceae) (Figure 2).

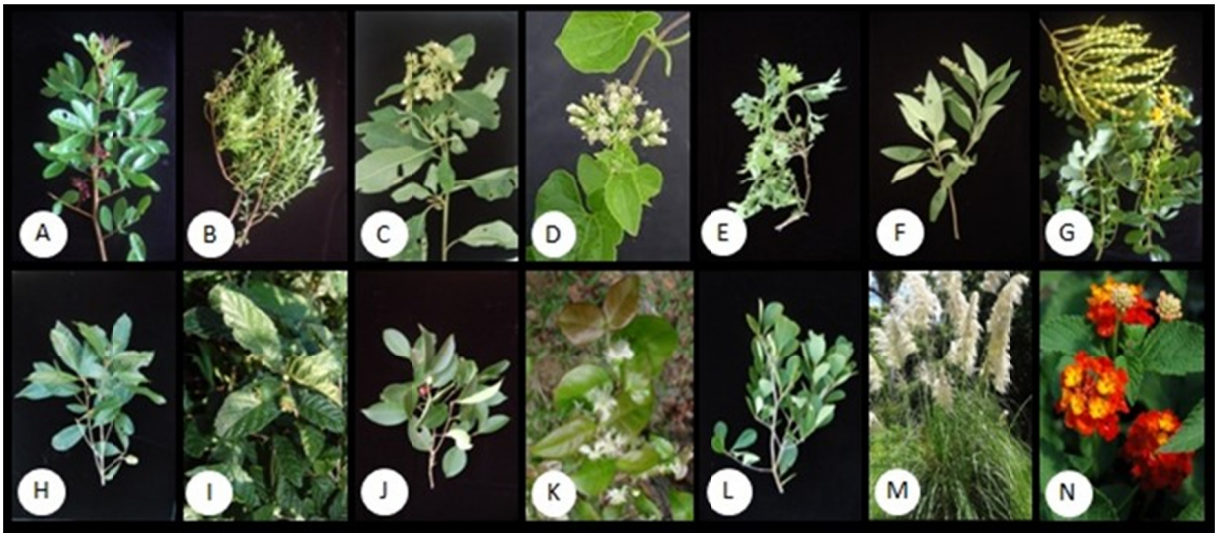

Figure 2. Species collected off the coast of Penha, Santa Catarina, Brazil, for essential oil extraction. *Schinus terebinthifolius* (A); *Baccharis spicata* (B); *Austroeupatorium inulaefolium* (C); *Mikania involucrata* (D); *Ambrosia elatior* (E); *Varronia curassavica* (F); *Sophora tomentosa* (G); *Aniba firmula* (H); *Campomanesia reitziana* (I); *Eugenia astringens* (J); *Eugenia uniflora* (K); *Psidium cattleianum* (L); *Cortaderia selloana* (M); *Lantana camara* (N)

The plants were selected based on their aroma and botanical groups based on aromatic characteristics, as reported in the literature (Trombin-Souza et al., 2017; de Souza et al., 2020; de Souza et al., 2021). Three leaf samples were collected from the terminal portion of a branch of each species during its vegetative period. Samples were collected from at least ten plants per species to provide sufficient quantity for essential oil extraction.

2.2 Extraction and Quantification of Essential Oil Content

Three 100g samples of fresh leaves per species were prepared by cutting the leaves into segments of approximately 2 cm in length. The plant material then underwent hydrodistillation in a Clevenger-type apparatus for 4.5 h. After obtaining the essential oil, it was dried over anhydrous sodium sulfate and then stored at 4°C until analysis was performed. Essential oil yield (%) was calculated as a percentage of dry matter using the following formula:

$$Essential\ oil\ yield\ (\%) = \frac{Mass\ of\ essential\ oil\ obtained\ (g)}{Mass\ of\ dry\ matter\ (g)} \times 100 \quad (1)$$

2.3 Analysis and Quantification of Essential Oils

The analysis of the chemical composition of the essential oils was performed in a gas chromatograph (Agilent 6890) coupled to a mass selective detector (Agilent 5973N). The gas chromatograph was equipped with a fused HP-5MS capillary column (film thickness 30 m × 0.25 mm × 0.25 μm) coated with a stationary phase of 5% phenyl-95% dimethylpolysiloxane. Helium was used as carrier gas at a flow rate of 1.0 mL/min. The temperature programming was set from 60 °C to 240 °C at a rate of 3 °C/min and heated at 240 °C for 10 min. The injector temperature was maintained at 250 °C. The essential oil samples were diluted to 1% in dichloromethane, and 1.0 μL of the solution was injected with a separation ratio of 1:20. The mass detector was operated in electron

ionization mode (70 eV) at a speed of 3.15 scans/min and a scanning range of 40-450 Da. The transfer line was kept at 260 °C, the ion source at 230 °C, and the analyte (in four replicates) at 150 °C.

For quantification, the essential oils were injected into a gas chromatograph (Agilent 7890) equipped with a flame ionization detector operated at 280 °C. Hydrogen was used as a support gas at a flow rate of 1.5 mL/min, using the same column and conditions described above. The quantification of each constituent was estimated by electronic integration of the flame ionization detector with the corresponding peak area, which was determined using the average of three injections.

2.4 Identification of the Chemical Constituents of the Essential Oil

Identification of the chemical constituents of the essential oil was performed by comparing Kovats indices (KIs) obtained from a correlation of the homologous series of alkanes (C_8-C_{26}) and matching their mass spectra with those of libraries, and comparing KIs from the literature (Adams, 2007).

2.5 Statistical Analyses

Essential oil content data were tested for homogeneity using Bartlett's test. An analysis of variance (ANOVA) was performed using ASSISTAT® software, version 7.7 (Silva & Azevedo, 2016), and a Tukey test was used to determine significance at the $p > 0.05$ level.

3. Results and Discussion

The essential oil was obtained through the hydrodistillation process from 11 of the 14 species sampled. Although these species are recorded in other coastal regions of the Atlantic Forest biome (Silva et al., 2021), to our knowledge, there is no information about the chemical compounds of essential oil found in these populations. *Sophora tomentosa*, *Campomanesia reitziana,* and *Cortaderia selloana* did not have essential oil in their leaves (Table 1). Though the plants exhibited presumed aromatic potential at the time of collection, these may be attributed to the presence of other compounds. Many water-soluble substances have odors that can be confused with the presence of essential oils, such as free amino acids, soluble carbohydrates, and aliphatic oxygenated compounds (Eisenreich et al., 1997).

Table 1. Description of essential oil content from collected herbs, shrubs, and trees from a patch of restinga in Penha, Santa Catarina, Brazil

Family	Species	Growth habit	Essential oil content*
Anacardiaceae	*Schinus terebinthifolius* Raddi	Tree	1.04 b**
Asteraceae	*Baccharis spicata* (Lam.) Baill.	Bush	0.48 c
Asteraceae	*Austroeupatorium inulaefolium* (Kunth) R.M.King & H.Rob.	Herbaceous	0.14 e
Asteraceae	*Mikania involucrata* Hook. & Arn.	Herbaceous	0.01 f
Asteraceae	*Ambrosia elatior* L.	Herbaceous	0.14 e
Boraginaceae	*Varronia curassavica* Jacq.	Bush	1.56 a
Fabaceae	*Sophora tomentosa* L.	Tree	-***
Lauraceae	*Aniba firmula* (Nees & Mart.) Mez	Tree	0.33 d
Myrtaceae	*Campomanesia reitziana* D.Legrand	Tree	-***
Myrtaceae	*Eugenia astringens* Cambess.	Bush	0.29 d
Myrtaceae	*Eugenia uniflora* L.	Bush	0.11 e
Myrtaceae	*Psidium cattleianum* Sabine	Tree	0.56 c
Poaceae	*Cortaderia selloana* (Schult. & Schult. f.) Asch. & Graebn.	Herbaceous	-***
Verbenaceae	*Lantana camara* Linn.	Herbaceous	0.08 ef
C.V. (%) = 8.61			

Note. * Content expressed as % of essential oil extracted from fresh leaves by hydrodistillation. ** Means followed by the same letter are not significantly different from each other according to the Tukey test at the 5% probability level. *** No essential oil present in their leaves.

The highest essential oil content was observed in *Varronia curassavica* (1.56%), while essential oil content ranged between 0.01% and 1.04% in the remaining plants (Table 1). Although phytochemical studies have been carried out for the selected species, comparisons of essential oil content are not an easy task due to their heterogeneous profiles. For example, the essential oil content of *Lantana camara* reported in the literature ranges

from 0.004% (Zhu et al., 2013) to 0.09% (Sousa et al., 2010). These differences may be attributed to several reasons, including the duration and method of extraction, population genetics of each species (Nizio et al., 2015), the plant part used (Cole et al., 2014), collection time (Sousa et al., 2010), exposure to sunlight (Feijó et al., 2014), seasonality, temperature, and precipitation (Matias et al., 2016).

A total of 60 chemical constituents were identified in the essential oils extracted, comprising between 46.2% and 96.5% of their chemical compositions (Table 2). Of these constituents, 7.5-18.7% were from the hydrocarbon monoterpene class, 0.3-27.2% oxygenated monoterpenes, 2.5-32.1% hydrocarbon sesquiterpenes, 3.9-69.8% oxygenated sesquiterpenes, 1.4% phenylpropanoids, and 1.8-68.9% were esters. Limonene was the only common constituent in all the species analyzed, with a concentration ranging between 4.9% and 13.0% (Table 2). This similarity may be associated with the role of limonene as a precursor of monoterpene biosynthesis (Trombin-Souza et al., 2017; de Souza et al., 2021).

Table 2. Chemical constituents of essential oils from the fresh leaves of herbs, shrubs, and trees from a stretch of restinga in Penha, Santa Catarina, Brazil

Constituent	KI^{lit}	KI^{cal}	Species										
			S 01	S 02	S 03	S 04	S 05	S 06	S 07	S 08	S 09	S 10	S 11
1. α-pinene	933	932	4.0[1]	-	2.9	1.6	0.2	0.6	0.6	5.3	0.4	1.8	-
2. camphene	949	946	-	-	-	-	-	6.7	0.1	-	-	-	-
3. β-pinene	976	974	1.5	1.9	4.8	2.1	0.3	0.6	0.7	3.7	0.7	0.4	-
4. myrcene	992	988	-	-	-	-	-	0.2	0.2	-	-	2.5	-
5. p-cymene	1024	1025	1.6	-	0.4	0.5	0.4	0.6	0.8	2.2	0.4	1.1	0.9
6. limonene	1028	1029	10.2	5.8	4.9	12.7	6.6	8.3	6.9	7.5	13.0	8.8	7.8
Monoterpene hydrocarbon			17.3	7.7	13.0	16.9	7.5	17.0	9.3	18.7	14.5	14.6	8.7
7. 1,8-cineole	1031	1026	-	-	-	-	-	-	0.3	-	-	19.8	-
8. α-camphonelal	1127	1129	-	-	0.3	-	-	-	-	1.7	-	-	-
9. trans-pinocarveol	1138	1142	-	1.7	1.7	0.7	-	0.3	0.1	2.5	-	0.2	-
10. cis-chrysanthenol	1163	1163	-	-	-	-	14.2	-	-	-	-	-	-
11. borneol	1165	1169	-	-	-	0.2	4.2	-	-	-	-	-	-
12. terpinen-4-ol	1177	1174	4.6	0.9	0.6	0.4	-	-	0.2	1.6	-	0.6	-
13. ρ-cymen-8-ol	1187	1187	-	-	1.6	-	-	-	-	8.2	-	-	-
14. cryptone	1188	1189	5.7	-	-	-	-	-	0.1		-	-	-
15. α-terpineol	1191	1190	4.5	1.7	0.5	0.8	-	-	0.3	4.6	-	2.9	-
16. myrtenol	1197	1198	-	2.7	1.5	0.7	-	-	-	1.5	-	-	-
17. cis-piperitenone epoxide	1253	1254	-	-	-	-	-	-	-	3.5	-	-	-
18. thymol acetate	1344	1355	-	-	-	-	-	-	-	3.6	-	-	-
Oxygenated monoterpene			14.8	7.0	6.2	2.8	18.4	0.3	1.0	27.2	0.0	23.5	0.0
19. α-copaene	1374	1374	-	-	0.4	0.7	-	0.4	0.6	-	-	3.2	1.0
20. β-elemene	1392	1391	0.8	-	0.5	1.5	-	1.2	-	-	2.6	0.1	-
21. (E)-caryophyllene	1418	1417	0.7	-	1.8	6.8	0.8	6.3	0.4	-	-	0.9	4.3
22. aromadendrene	1438	1439	0.6	-	0.6	-	-	0.2	0.3	1.6	-	0.2	3.0
23. α-humulene	1452	1452	0.3	-	0.8	1.6	0.5	2.4	0.1	-	-	0.3	0.4
24. (E)-β-farnesene	1457	1459	1.4[1]	-	-	-	-		0.7	-	-	-	-
25. *allo*-aromadendrene	1459	1461	-	-	-	-	-	15.2	0.8	0.4	-	-	1.7
26. γ-muurolene	1476	1478	2.1	0.6	0.9	1.0	-	-	0.1	-	-	1.5	3.5
27. ar-curcumene	1483	1482	-	0.6	-	-	15.1	-	-	-	-	-	-
28. β-selinene	1484	1486	-	-	0.5	2.9	-	0.8	0.6	-	0.8	2.0	0.3
29. germacrene D	1485	1484	2.5	-	-	-	-	0.2	-	-	-	-	-
30. α-muurolene	1500	1500	1.4	0.8	0.3	-	-	0.3	-	-	-	0.3	0.8
31. γ-cadinene	1514	1513	-	0.8	1.0	-	-	-	0.1	-	-	0.2	2.5
32. trans-calamenene	1523	1525	2.7	1.0	-	-	-	-	0.1	0.5	-	0.6	2.2
33. zonarene	1534	1533	3.7	-	-	-	-	-	-	-	-	5.0	-
34. α-cadinene	1514	1517	-	-	-		-	5.1	-	-	-	-	0.6
35. selina-3,7(11)-diene	1541	1543	1.8	-	-	-	-	-	-	-	-	2.0	-
36. germacrene B	1557	1558	1.2	-	-	-	-	-	-	-	5.0	-	-

Sesquiterpene hydrocarbon			19.2	3.8	6.8	14.5	16.4	32.1	3.8	2.5	8.4	16.3	19.7
37. curzerene	1498	1497	-	-	-	-	-	-	-	-	30.0	-	-
38. (E)-nerolidol	1564	1561	-	-	-	-	-	-	5.9	-	-	0.8	-
39. spathulenol	1576	1576	3.1	19.8	10.6	8.2	-	-	3.7	1.5	1.6		-
40. caryophyllene oxide	1582	1581	4.7	14.0	35.7	27.7	-	4.7	2.5	16.3	-	7.9	17.1
41. globulol	1584	1583	-	-	-	-	-	-	-	-	-	-	2.4
42. viridiflorene	1592	1591	2.3	0.9	0.6	-	-	-	0.2	1.1	3.0	0.6	-
43. ledol	1602	1602	-	2.9	-	1.1	-	2.4	0.4	-	-	0.5	11.3
44. humulene epoxide II	1608	1608	-	4.4	4.4	2.6	-	2.5	0.3	-	-	1.2	0.9
45. 1-epi-cubenol	1628	1627	2.6	2.6	-	5.4	-	-	0.2	-	-	4.0	0.3
46. *epi*-α-muurolol	1641	1640	2.5	10.4	3.2	3.3	-	2.0	-	-	-	-	2.7
47. demethoxyencecaline	1643	1642	-	-	-	-	-	-	-	-	-	4.2	-
48. α-muurolol	1646	1644	0.7	2.8	0.6	0.6	-	0.8	-	-	-	2.5	0.7
49. α-cadinol	1654	1657	2.8	12.0	6.9	4.9	0.6	2.6	-	1.6	4.8	3.0	2.4
50. epi-α-cadinol	1661	1662	-	-	-	-	-	-	0.3	2.0	-	-	-
51. atractilone	1662	1660	-	-	-	-	-	-	-	-	4.0[1]	-	-
52. 14-hydroxy-9-epi-caryophyllene	1671	1662	-	-	-	-	-	-	-	-	-	-	4.0
53. α-bisabolol	1684	1687	-	-	-	-	3.3	-	-	-	-	-	-
54. germacrone	1697	1699	-	-	-	-	-	-	-	-	11.9	-	-
Oxygenated sesquiterpene			18.8	69.8	62.0	53.8	3.9	20.9	13.5	22.5	58.4	24.7	49.6
55. (E)-methyl-isoeugenol	1488	1489	-	-	-	-	-	-	-	-	-	1.4	-
Phenylpropanoid			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
56. α-terpinyl acetate	1349	1347	-	-	-	-	-	-	-	-	-	1.8	-
57. geranyl butyrate	1561	1663	-	-	-	-	-	-	-	5.9	-	-	-
58. benzyl benzoate	1769	1767	-	-	-	-	-	-	43.5	-	-	-	-
59. 2-phenylethyl benzoate	1879	1880	-	-	-	-	-	-	1.7	-	-	-	-
60. benzyl salicylate	1887	1889	-	-	-	-	-	-	23.7	-	-	-	-
Ester			0.0	0.0	0.0	0.0	0.0	0.0	68.9	5.9	0.0	1.8	0.0
Total constituents (%)			70.1	88.3	88.0	88.0	46.2	70.3	96.5	76.8	81.3	82.3	78.0

Note. Species: KI^{it} = Kovats literature index; KI^{cal} = Kovats experimental index; S 01: *Schinus terebinthifolius*; S 02: *Baccharis spicata*; S 03: *Austroeupatorium inulaefolium*; S 04: *Mikania involucrata*; S 05: *Ambrosia elatior*; S 06: *Varronia curassavica*; S 07: *Aniba firmula*; S 08: *Eugenia astringens*; S 09: *Eugenia uniflora*; S 10: *Psidium cattleianum*; S 11: *Lantana camara*. -: trace element < 0.1%. [1]: Content expressed in %.

Limonene was only the most abundant constituent in *Schinus terebinthifolius*, accounting for 10.2% of the essential oil. The presence of 9-epi-(*E*)-caryophyllene (10.1%) and p-cymen-7-ol (22.5%) have been reported in fresh leaves of the species (Silva et al., 2010), as well as germacrene D (23.8%), bicyclogermacrene (15.0%) (Santana et al., 2012), and δ-3-carene (68.78%) (Uliana et al., 2016). However, the concentrations of these constituents measured in this study were lower or absent (Table 2). Quantitative and qualitative variations in the species' essential oil may be related to the metabolic plasticity of *S. terebinthifolius*. The production of secondary metabolites is likely influenced by the peculiarities of each environment, including abiotic and edaphic conditions, as well as herbivores, pollinators, and seed dispersers. Furthermore, alterations in essential oil biosynthesis may also reflect a possible deviation in metabolic pathways to help the plant survive in particular environments.

The most abundant constituents in the Asteraceae species were spathulenol (19.8%), caryophyllene oxide (14.0%), α-cadinol (12.0%), and epi-α-muurolol (10.4%) in *Baccharis spicata*; caryophyllene oxide (35.7%) and spathulenol (10.6%) in *Austroeupatorium inulaefolium*; caryophyllene oxide (27.7%) and limonene (12.7%) in *Mikania involucrate*, and ar-curcumene (15.1%) and cis-chrysanthenol (14.2%) in *Ambrosia elatior* (Table 2). The chemical profiles of these oils indicated a predominance of sesquiterpenes (3.8-69.8%) over monoterpenes (2.8-18.4%). These findings can be interpreted as a competition between two pathways for the same precursor. It is known that the concentrations of monoterpenes and sesquiterpenes are negatively correlated (Ghaffari et al., 2011). Thus, the highest flux of isopentenyl diphosphate (IPP) among the species studied tended to be in the cytosol (the site of sesquiterpene biosynthesis) in the restinga environment. Higher proportions of sesquiterpenes may also indicate the stressful conditions that plants undergo in this ecosystem since high temperatures, strong winds, and solar radiation contribute to the volatilization of smaller molecules such as monoterpenes. In contrast

to our results, the essential oils of other Asteraceae species collected in non-coastal areas of the Atlantic Forest had roughly equal proportions of monoterpenes and sesquiterpenes (Amaral et al., 2017). This suggests that site-specific characteristics (*i.e.*, environmental differences) are determining factors in terpene variation.

The sesquiterpene hydrocarbon allo-aromadendrene was the most common constituent in *V. curassavica* (15.2%; Table 2). The chemical constituents most commonly found in the species' essential oil are trans-caryophyllene (14.4%), caryophyllene oxide (15.8%) (Feijó et al., 2014), α-pinene (16.2%), β-phellandrene (11.0%), sabinene (69.7%), γ-elemene (12.6%), δ-elemene (12.6%), β-caryophyllene (11.5%), γ-caryophyllene (15.6%), and germacrene B (13.8%) (Matias et al., 2016). Variations in essential oil composition have often been associated with plant growth conditions, seasonality (Matias et al, 2016), and solar radiation (Feijó et al., 2014). Recently, sampling from 59 *V. curassavica* accessions showed that the genetic composition of the plants and/or the genotype × environment interaction is probably the most influential factor on the diversity chemical constituents in the essential oil (Nizio et al., 2015). Thus, plants collected in the same locality have been classified into different chemical groups.

In *Aniba firmula*, the main constituents were benzyl benzoate (43.5%) and benzyl salicylate (23.7%; Table 2). The essential oils of Brazilian species of Lauraceae are generally divided into groups of chemotypes based on their main constituents. *Aniba firmula* belongs to the benzoate group. Species in this family can also belong to the linalool and allylbenzene chemotypes, depending on the principal constituents, which remain consistent across each species (Morais et al., 1972). Similarly, *Aniba firmula* exhibited low variation in the main constituents of its essential oil and lower sensitivity to environmental characteristics. These findings are interesting because they reveal that the restinga conditions did not result in significant changes in the essential oil composition.

The main constituents found in species of Myrtaceae were caryophyllene oxide (16.3%) in *Eugenia astringens*; limonene (13.0%), curzerene (30.0%), and germacrone (11.9%) in *Eugenia uniflora*, and 1,8-cineol (19.8%) in *Psidium cattleianum* (Table 2). The chemical constituents of Myrtaceae essential oils belong predominantly to the hydrocarbons (14.5-18.7%), oxygenated monoterpenes (0-27.2%), and oxygenated sesquiterpenes (22.5-58.4%). This finding contrasts with earlier results for Myrtaceae plants in the Atlantic Forest, which showed that sesquiterpenes generally predominated (Nakamura et al., 2010; Albuquerque et al., 2012). In the restinga, an increase in hydrocarbon and oxygenated monoterpenes has been observed (Ramos et al., 2010; Defaveri et al., 2011). Although monoterpenes volatilize easily under conditions of high temperature and solar intensity (Arruda and Victório, 2011), the abundance of these compounds in species of this family can be explained by their thick and wax-covered leaves, especially in plants from the restinga (Donato and Morretes, 2007). Thus, the functional traits of the leaves indicate the existence of mechanisms to reflect incident light and protect against the loss of water and volatile substances.

In *L. camara*, the most abundant constituents were caryophyllene oxide (17.1%) and ledol (11.3%; Table 2). The predominance of sesquiterpenes in this study reveals their importance for the species (Sousa et al., 2010; Medeiros et al., 2012; Zhu et al., 2013). The qualitative and quantitative presence of this class of compounds has been shown to vary in various organs of *L. camara* (Medeiros et al., 2012; Zhu et al., 2013). In leaves, the major essential oil constituents are germacrene D (24.5%), bicyclogermacrene (33.3%), spathulenol (25.0%), eremophilene (20.6%), valencene (33.7%), viridiflorene (19.5%), and 1,10-di-epi-cubenol (21.3%) (Sousa et al., 2010). The variation in the chemical composition is also due to the numerous varieties of the species, such as *L. camara var. aculeata*, *L. camara var. ava*, *L. camara var. hybrida*, *L. camara var. mista*, and *L. camara var. nivea* (Da Silva et al., 1999).

This study reports the chemical diversity present in the essential oils of plant species collected in the restinga ecosystem of southern Brazil. Although *E. uniflora* and *V. curassavica* are commercially exploited, in this work we report that these species have a high content of the substance of economic interest such as curzurene (30.0%) and α-humulene (2.4%), which may represent a potential commercial. Likewise, the selection of matrices with economic value can be subsidized with sustainable use practices of the species, since they are distributed in Biome highly threatened by anthropogenic disturbance (de Souza et al., 2021). This information is critical when selecting species with economic potential for phytotherapeutic products, as well as for the phytosanitary and cosmetic industries.

4. Conclusions

In conclusion, our study reports the yield and chemical composition of essential oils from 14 species distributed on the coast of Santa Catarina, Brazil. The EO content ranges from 0.01% (*M. involucrata*) to 1.56% (*V. curassavica*). The major constituents are ar-curcumene (15.1%) and cis-chrysanthenol (14.2%) in *A.elatior*;

benzyl benzoate (43.5%) and benzyl salicylate (23.7%) in *A. firmula*; caryophyllene oxide (35.7%) and spathulenol (10.6%) in *A. inulaefolium*; spathulenol (19.8%) and caryophyllene oxide (14.0%) in *B. spicata*; caryophyllene oxide (16.3%) in *E. astringens*; curzerene (30.0%), limonene (13.0%), and germacrone (11.9%) in *E. uniflora*; caryophyllene oxide (17.1%) and ledol (11.3%) in *L. camara*; caryophyllene oxide (27.7%) and limonene (12.7%) in *M. involucrata*; 1,8-cineole (19.8%) in *P. cattleianum*; limonene (10.2%) in *S. terebinthifolius*, and allo-aromadendrene (15.2%) in *V. curassavica*.

Acknowledgments

The authors are grateful to José Tadeu Weidlich Motta and Felipe Marinero, specialists from the Botany Department of the Municipal Botanical Museum in Curitiba, Paraná, Brazil, for the identification of the species studied. The authors also thank and CAPES and CNPQ for the scholarships and financial support for the research. Thanks are also due to the Interinstitutional Doctorate Program (Dinter) for making the doctorate-level training of the first author possible. Finally, the authors express their gratitude to the Catarinense Federal Institute, Campus Araquari, Santa Catarina, Brazil, for the technical support and licenses granted during the Ph.D. of the first author.

References

Adams, R. P. (2007). *Identification of Essential Oil Components by Gas Chromatography/Quadrupole Mass Spectroscopy* (p. 469). Allured, Illinois.

Albuquerque, R. D. D. G., Tietbohl, L. A., Fernandes, C. P., Couteiro, P. P., Eiriz, D. N., Santos, M. G., … Rocha, L. (2012). Chemical and biological study of essential oils from *Eugenia pruniformis* Cambess., an endemic species from Brazilian Atlantic Forest. *Latin American Journal of Pharmacy, 31*(6), 830-834.

Ali, B., Al-Wabel, N. A., Shams, S., Ahamad, A., Khan, S. A., & Anwar, F. (2015). Essential oils used in aromatherapy: A systemic review. *Asian Pacific Journal of Tropical Biomedicine, 5*, 601-611. https://doi.org/10.1016/j.apjtb.2015.05.007

Amaral, W. D., Deschamps, C., Bizzo, H. R., Pinto, M. A. S., Biasi, L. A., & Silva, L. E. (2017). Essential oil yield and composition of native tree species from Atlantic forest, South of Brazil. *Journal of Essential Oil Bearing Plants, 20*, 1525-1535. https://doi.org/10.1080/0972060x.2017.1346484

Amorim, M. W., & Melo Júnior, J. C. F. (2017). Functional diversity of restinga shrub species on the coastal plain of southern Brazil. *International Journal of Development Research, 7*, 13189-13201.

Arruda, R. C. O., & Victório, C. P. (2011). Leaf secretory structure and volatile compounds of *Eugenia copacabanensis* Kiaersk. (Myrtaceae). *Journal of Essential Oil Research, 23*, 1-6. https://doi.org/10.1080/10412905.2011.9700472

Cole, E. R., Santos, R. B., Lacerda Júnior, V., Martins, J. D. L., Greco, S. J., & Cunha Neto, A. (2014). Chemical composition of essential oil from ripe fruit of *Schinus terebinthifolius* Raddi and evaluation of its activity against wild strains of hospital origin. *Brazilian Journal of Microbiology, 45*, 821-828. https://doi.org/10.1590/s1517-83822014000300009

Da Silva, M. H. L., Andrade, E. H. A., Zoghbi, M. das G. B., Luz, A. I. R., da Silva, J. D., & Maia, J. G. S. (1999). The essential oils of *Lantana camara* L. occurring in North Brazil. *Flavour and Fragrance Journal, 14*, 208-210. https://doi.org/10.1002/(sici)1099-1026(199907/08)14:4<208::aid-ffj811>3.0.co;2-f

de Souza, M. T., de Souza, M. T., Bernardi, D., Krinski, D., Melo, D. J., Oliveira, D. C., … Zawadneak, M. A. C. (2020). Chemical composition of essential oils of selected species of *Piper* and their insecticidal activity against *Drosophila suzukii* and *Trichopria anastrephae*. *Environmental Science and Pollution Research, 27*, 13056-13065. https://doi.org/10.1007/s11356-020-07871-9

de Souza, M. T., de Souza, M. T., Bernardi, D., Melo, D. J., Zarbin, P. H. G., & Zawadneak, M. A. C. (2021). Insecticidal and oviposition deterrent effects of essential oils of *Baccharis* spp. and histological assessment against *Drosophila suzukii* (Diptera: Drosophilidae). *Scientific Reports, 11*, 3944. https://doi.org/10.1038/s41598-021-83557-7

Defaveri, A. C., Sato, A., Borré, L. B., Aguiar, D. L., San Gil, R. A., Arruda, R. C., & Riehl, C. A. (2011). *Eugenia neonitida* Sobral and *Eugenia rotundifolia* Casar. (Myrtaceae) essential oils: composition, seasonality influence, antioxidant activity and leaf histochemistry. *Journal of the Brazilian Chemical Society, 22*, 1531-1538. https://doi.org/10.1590/S0103-50532011000800018

Donato, A. M., & Morretes, B. L. D. (2007). Anatomia foliar de *Eugenia brasiliensis* Lam. (Myrtaceae) proveniente de áreas de restinga e de floresta. *Revista Brasileira de Farmacognosia, 17*, 426-443. https://doi.org/10.1590/S0102-695X2007000300018

Eisenreich, W., Sagner, S., Zenk, M. H., & Bacher, A. (1997). Monoterpenoid essential oils are not of mevalonoid origin. *Tetrahedron Letters, 38*, 3889-3892. https://doi.org/10.1016/s0040-4039(97)00761-2

Feijó, E. V. R. S., Oliveira, R. A., & Costa, L. C. B. (2014). Light affects *Varronia curassavica* essential oil yield by increasing trichomes frequency. *Revista Brasileira de Farmacognosia, 24*, 516-523. https://doi.org/10.1016/j.bjp.2014.10.005

Ghaffari, Z., Rahimmalek, M., & Sabzalian, M. R. (2019). Variation in the primary and secondary metabolites derived from the isoprenoid pathway in the *Perovskia* species in response to different wavelengths generated by light emitting diodes (LEDs). *Industrial Crops and Products, 140*, 111592. https://doi.org/10.1016/j.indcrop.2019.111592

Matias, E. F. F., Alves, E. F., Silva, M. K. N., Carvalho, V. R. A., Figueredo, F. G., Ferreira, J. V. A., … Costa, J. G. M. (2016). Seasonal variation, chemical composition and biological activity of the essential oil of *Cordia verbenacea* DC (Boraginaceae) and the sabinene. *Industrial Crops and Products, 87*, 45-53. https://doi.org/10.1016/j.indcrop.2016.04.028

Medeiros, L. B. P., Rocha, M. S., Lima, S. G., Sousa Júnior, G. R., Citó, A. M. G. L., Silva, D., … Costa, J. G. M. (2012). Chemical constituents and evaluation of cytotoxic and antifungal activity of *Lantana camara* essential oils. *Revista Brasileira de Farmacognosia, 22*, 1259-1267. https://doi.org/10.1590/s0102-695x2012005000098

Melo Júnior, J. C. F. D., & Boeger, M. R. T. (2015). Riqueza, estrutura e interações edáficas em um gradiente de restinga do Parque Estadual do Acaraí, Estado de Santa Catarina, Brasil. *Hoehnea, 42*, 207-232. https://doi.org/10.1590/2236-8906-40/2014

Morais, A., Rezende, C. A. D., Bülow, M. V., Mourão, J. C., Gottlieb, O. R., Marx, M. C., … Magalhaes, M. T. (1972). Óleos essenciais de espécies do gênero Aniba. *Acta Amazonica, 2*, 41-44. https://doi.org/10.1590/1809-43921972021041

Nakamura, M. J., Monteiro, S. S., Bizarri, C. H. B., Siani, A. C., & Ramos, M. F. S. (2010). Essential oils of four Myrtaceae species from the Brazilian Southeast. *Biochemical Systematics and Ecology, 38*, 1170-1175. https://doi.org/10.1016/j.bse.2010.11.003

Nascimento, A. F., Camara, C. A. G., Moraes, M. M., & Ramos, C. S. (2012). Essential oil composition and acaricidal activity of *Schinus terebinthifolius* from Atlantic forest of Pernambuco, Brazil against *Tetranychus urticae*. *Natural Product Communications, 7*, 129-132. https://doi.org/1934578X1200700141

Nizio, D. A. C., Brito, F. A., Sampaio, T. S., Melo, J. O., Silva, F. L. S., Gagliardi, P. R., … Blank, A. F. (2015). Chemical diversity of native populations of *Varronia curassavica* Jacq. and antifungal activity against *Lasiodoplodia theobromae*. *Industrial Crops and Products, 76*, 437-448. https://doi.org/10.1016/j.indcrop.2015.07.026

Oliveira, J. C. S., Camara, C. A. G., & Schwartz, M. O. E. (2007). Volatile constituents of the stem and leaves of *Cordia* species from mountain forests of Pernambuco (North-eastern Brazil). *Journal of Essential Oil Research, 19*, 444-448. https://doi.org/10.1080/10412905.2007.9699947

Ootani, M. A., Sousa Aguiar, R. W., Ramos, A. C. C., Brito, D. R., Silva, J. B., & Cajazeira, J. P. (2013). Utilização de óleos essenciais na agricultura. *Journal of Biotechnology and Biodiversity, 4*, 162-174. https://doi.org/10.20873/jbb.uft.cemaf.v4n2.ootani

Pilatti, D. M., Fortes, A. M. T., Jorge, T. C. M., & Boiago, N. P. (2018). Comparison of the phytochemical profiles of five native plant species in two different forest formations. *Brazilian Journal of Biology, 79*, 233-242. https://doi.org/10.1590/1519-6984.179526

Ramos, M. F. S., Monteiro, S. da S., da Silva, V. P., Nakamura, M. J., & Siani, A. C. (2010). Essential oils from Myrtaceae species of the Brazilian Southeastern maritime forest (Restinga). *Journal of Essential Oil Research, 22*, 09-113. https://doi.org/10.1080/10412905.2010.9700275

Reinert, F., Roberts, A., Wilson, J. M., Ribas, L., Cardinot, G., & Griffiths, H. (1997). Gradation in nutrient composition and photosynthetic pathways across the restinga vegetation of Brazil. *Botanica Acta, 110*, 135-142. https://doi.org/10.1111/j.1438-8677.1997.tb00620.x

Santana, J. S., Sartorelli, P., Guadagnin, R. C., Matsuo, A. L., Figueiredo, C. R., Soares, M. G., … Lago, J. H. G. (2012). Essential oils from Schinus terebinthifolius leaves-chemical composition and *in vitro* cytotoxicity evaluation. *Pharmaceutical Biology, 50*, 1248-1253. https://doi.org/10.3109/13880209.2012.666880

Sarkic, A., & Stappen, I. (2018). Essential oils and their single compounds in cosmetics—A critical review. *Cosmetics, 5*, 11. https://doi.org/10.3390/cosmetics5010011

Silva, A. B., Silva, T., Franco, E. S., Rabelo, S. A., Lima, E. R., Mota, R. A., … Lima-Filho, J. V. (2010). Antibacterial activity, chemical composition, and cytotoxicity of leaf's essential oil from Brazilian pepper tree (*Schinus terebinthifolius*, Raddi). *Brazilian Journal of Microbiology, 41*, 158-163. https://doi.org/10.1590/s1517-83822010000100023

Silva, F. D. A. E., & Azevedo, C. D. (2016). The Assistat Software Version 7.7 and its use in the analysis of experimental data. *African Journal of Agricultural Research, 11*, 3733-3740. https://doi.org/10.5897/ajar2016.11522

Silva, T. D., Souza, M. T., Souza, M. T., Cipriano, R. R, Bizzo, H. R., & Deschamps, C. (2021). Essential oil variation in Brazilian *Varronia curassavica* Jacq. in response to drying and edaphoclimatic conditions. *Journal of Agricultural Science, 13*, 16-30. https://doi.org/10.5539/jas.v13n8p16

Sousa, E. O., Viana, A. C., Rodrigues, F. F., Campos, A. R., Lima, S. G., & Costa, J. G. M. (2010). Effect of collection time on essential oil composition of *Lantana camara* Linn (Verbenaceae) growing in Brazil Northeastern. *Records of Natural Products, 4*, 31-37.

Souza, M. F., Manganotti, S. A., Souza, P. N. S., Meira, M. R., de Matos, C. D. C., & Martins, E. R. (2011). Influência do horário de coleta, orientação geográfica e dossel na produção de óleo essencial de *Cordia verbenacea* DC. *Biotemas, 24*, 9-14. https://doi.org/10.5007/2175-7925.2011v24n1p9

Trombin-Souza, M., Trombin-Souza, M., Amaral, W., Pascoalino, J. A. L., Oliveira, R. A., Bizzo, H. R., & Deschamps, C. (2017). Chemical composition of the essential oils of *Baccharis* species from Southern Brazil: A comparative study using multivariate statistical analysis. *Journal of Essential Oil Research, 29*, 400-406. https://doi.org/10.1080/10412905.2017.1322007

Uliana, M. P., Fronza, M., da Silva, A. G., Vargas, T. S., de Andrade, T. U., & Scherer, R. (2016). Composition and biological activity of Brazilian rose pepper (*Schinus terebinthifolius* Raddi) leaves. *Industrial Crops and Products, 83*, 235-240. https://doi.org/10.1016/j.indcrop.2015.11.077

Zhu, F., Lu, W. H., Pan, J. H., Huang, M. Z., & Wu, J. S. (2013). Chemical Composition and Antibacterial Activity of Essential Oils from the Leaves, Fruits and Stems of *Lantana camara* L. from the South China. *Advanced Materials Research, 781-784*, 1060-1063. https://doi.org/10.4028/www.scientific.net/amr.781-784.1060

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).