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Exploring fine compounds and biomass potential in *Cabralea canjerana* and *Cordia americana* wood

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Cabralea canjerana and *Cordia americana*, two Brazilian tree species found across various states, serve a range of applications from sawmill products to folk medicine. The extractives, non-structural wood components, are utilized for diverse purposes, including natural dyes, preservatives, and medicinal products. After a comprehensive search of the literature, no publications were found characterizing the chemical composition of *C. canjerana* and *C. americana* wood. This increases the need to research these species and learn more about their potential. The vast diversity of Brazil's tree species sometimes complicates the selection process for extraction purposes, highlighting the importance of anatomical wood identification. This study evaluates the presence of fine molecules with important biological activity or industrial value in the wood extractives of *C. canjerana* and *C. americana*, proposing potential uses for the extracted lignocellulosic biomass and providing anatomical identification support for these species. Characterization methods of the wood included analysis of ash, hemicellulose, cellulose, and lignin content. Extraction techniques employed ethanol, ethanol-toluene, hot water, and 1% soda, followed by gas chromatography-mass spectrometry (GC-MS) for chemical analysis. Anatomical characteristics were determined using histological slides. The results show that Cordia americana displayed a 53.61% holocellulose content in relation to the dry mass, suitable for paper production, while *Cabralea canjerana*, with a 55.92% content, was deemed even more appropriate. GC-MS analysis identified several significant molecules in the extractives, including Phenol, 2,4-bis(1-phenylethyl), which is potentially effective in breast cancer drug development, and Gestrinone, a possible

treatment for endometriosis. The anatomical examination of the *C. canjerana* and *C. americana* samples confirmed their species identity, aligning with the study's objectives.

KEYWORDS

***Cabralea canjerana*, *Cordia americana*, extractives, GC-MS, cellulose, hemicellulose, lignin, histological slides**

1 Introduction

In recent years, intensified research has focused on plant species that remain little explored or unidentified, to serve in different areas in increasingly demanding markets (Coelho et al., 2016; Bhardwaj et al., 2020; Chan et al., 2020; Eller et al., 2020; Hassan et al., 2020; Zhou et al., 2020; Zwingelstein et al., 2020). Although Brazil is a leader in flora diversity, a substantial portion of its plant life remains underutilized or unknown, especially for high-value applications, primarily due to an inadequate understanding of its exploitation potential (Stegmann et al., 2024).

In this context, there are *Cabralea canjerana* (Vell.) Mart. and *Cordia Americana* (L.) Gottschling and J. S. Mill., two Brazilian tree species that are present across the nation, predominantly in the Southeast and South Regions, characterized by predominant tropical and subtropical climates. The wood of both species exhibits remarkable natural durability, while their bark, leaves, and seeds find use in traditional medicine for treating various diseases (Carvalho, 2003). Moreover, the wood serves in constructing sleepers, roof structures, floors, frames, furniture, and skirting boards, showcasing its versatility (Carvalho, 2003; Gonzaga, 2006; Rodrigues et al., 2008; Almeida, 2013). After a comprehensive search in the literature, no publications were found characterizing the chemical composition of *C. canjerana* and *Cordia americana* wood. This increases the need to research these species and learn more about their potential. Especially about the existence of fine molecules with important biological activity or industrial value.

Wood extractives, non-structural components concentrated mainly in the heartwood, enhance wood's natural durability by imparting resistance to biological degradation through their antifungal and insecticidal properties (Kirker et al., 2013; Mbakidi-Ngouaby et al., 2018).

The sustainable extraction process utilizes by-products or waste from the timber industry, such as wood chips, knots, branches, and sawdust, as raw materials, thereby increasing the process's sustainability (Eller et al., 2020). These extractives, ranging from natural dyes to preservatives and medicinal compounds, allow the remaining lignocellulosic biomass to serve other purposes once extracted, thus reducing the environmental impact of forestry activities and offering economic benefits (Wang et al., 2011; Zule et al., 2016; Wen et al., 2019). To maximize extraction yields, the biomass must be ground and the resulting sawdust used for extraction (Kumar et al., 2011). This increases the contact surface with the solvent and thus the efficiency of the process (Mbakidi-Ngouaby et al., 2018; Setiawan et al., 2020).

Chemical characterization of the wood for extractive retrieval is essential for understanding the composition of these raw materials and, consequently, for assessing possible uses for the solid extraction residue (Surup et al., 2020), which is mainly composed of the structural components of the wood, namely, cellulose, hemicellulose, and lignin, constituting a lignocellulosic biomass (Strehmel et al., 2017).

Due to the immense variety of tree species in Brazil (Carvalho, 2003; 2006; 2008; 2010; 2014; Marchiori et al., 2009; Marchiori et al., 2010), mistakes can occur when selecting the wood to be used in extractions, resulting in extractives from an unwanted species. To avoid this risk, anatomical identification of the wood can be carried out, allowing the species to be confirmed based on its characteristics. This can be done using histological slides, which allow the observation of the anatomical characteristics of the wood cells under a microscope (Burger and Richter, 1991).

This work aims to evaluate the presence of fine molecules in the extractives of *C. canjerana* and *C. americana* wood, as well as to suggest possible uses for the extracted lignocellulosic biomass and to provide support material for the anatomical identification of the wood of these two species.

2 Materials and methods

2.1 Characterization of the raw material

For the chemical characterization of *C. canjerana* and *C. americana* wood, the study utilized samples obtained from a sawmill in São Domingos do Sul, Brazil. These samples were ground, and the portion that passed through a 40 mesh sieve was selected for analysis (TAPPI T 264, 2007). The characterization process included determining the ash content (TAPPI T 211, 1993) and measuring the levels of structural components, specifically hemicellulose (Wise et al., 1946), cellulose (Rowell, 1983), and lignin (TAPPI T 222, 1998). The number of samples for each test was five.

2.2 Obtaining extractives

Extractives were obtained from the sawdust of *C. canjerana* and *C. americana* wood using four different solvents and five samples for each assay, as described below:

- Extractives Soluble in Hot Water (TAPPI T 207, 1993): A mixture of sawdust and hot water (100°C) at a solid-to-liquid ratio of 2:100 (w:v) was placed in an Erlenmeyer flask and subjected to reflux for 3 h. Subsequently, the mixture was filtered through a No. 2 porous plate filter, washed with hot water at 60°C, and the extractives were dried in an oven to a constant weight.
- Extractives Soluble in 1% Sodium Hydroxide (TAPPI T 212, 1998): A blend of sawdust and a 1% sodium hydroxide

aqueous solution, at a solid-to-liquid ratio of 2:100 (w:v), was combined in an Erlenmeyer flask. The flask was covered and placed in a thermostatic bath at 100 °C for 1 h. Afterward, it was vacuum filtered using a No. 1 porous plate filter and washed with 100 mL of hot water at 60 °C. Following the collection of the solvent with the extractives, the vacuum was halted, and the fibers were treated with 25 mL of 10% acetic acid for 2 min and the fibers were rinsed again with water to a neutral pH before drying in an oven to a constant weight.

- Extractives Soluble in Ethanol-Toluene (TAPPI T 204, 1997): Using the Soxhlet system, extractives were extracted with ethanol-toluene at a 1:2 (v:v) ratio. The heating temperature was adjusted so that a reflux occurred every 15 min. After 6 h of reflux, the extractives were dried in an oven to a constant weight.
- Ethanol-Soluble Extractives: The sawdust sample underwent maceration at 50°C for 4 h with a solid-liquid ratio of 1:10 (w:v), under magnetic stirring, using ethanol as the solvent, a standard procedure for wood maceration according to Santos et al. (2022). The material was then vacuum filtered using a Kitasato, Buchner funnel, and filter paper. The extractives was concentrated using a rotary evaporator - and dried in an oven at 50°C.

2.3 Gas chromatography-mass spectrometry (GC-MS)

The extractives from *C. canjerana* and *C. americana*, derived through ethanol, ethanol-toluene, hot water, and 1% soda extractions, were analyzed using gas chromatography-mass spectrometry (GC-MS) to determine their components. The samples, dissolved in ethyl acetate and methanol, at an extractive-solvent ratio of 1:1,000 (w:v), were automatically injected into a GC-MS QP-2010 system (Shimadzu, Kyoto, Japan) utilizing helium as the carrier gas through an RTX-5 ms capillary column (30 m × 0.25 mm x 0.25 μm). Following the procedure outlined by Hernández-Ramos et al. (2020), the analysis began at a temperature of 50°C. Subsequently, the temperature increased to 120°C at a rate of 8°C/min and was maintained for 5 min, then elevated to 280°C at the same rate and held for 8 min, followed by an increase to 300°C at 10°C/min, where it remained for 2 min. Mass spectra were acquired in the m/z range of 70–1,000 at a frequency of two scans per second.

2.4 Anatomical identification of wood species

The samples of *C. canjerana* and *C. americana* were identified by their anatomical characteristics, for which histological wood slides were prepared. To soften the wood and facilitate the cutting of histological slides, the wood samples were placed in beakers with water and heated to 100°C. The softening process lasted 24 h for *C. americana* and 80 h for *C. canjerana*. Subsequently, slides were prepared using a microtome (Leica SM 2010R), achieving thicknesses between 14 and 16 μm. These slides were immersed for 8 min in a 0.05 g toluidine blue dye solution (Sigma Aldrich) in 100 mL of water; following the removal of excess dye, they were then immersed in a 0.5 g safranine dye solution (Dinâmica Química Contemporânea) in 100 mL of water for another 8 min. The slides were further treated with ethyl alcohol at concentrations of 30%, 50%, 70%, and 95% for 5 min each and then stored in a Petri dish containing xylene. For mounting, the adhesive Entellan Novo (Merck) was applied to secure the histological slide to the coverslip and glass slide.

The analysis of the optical microscope slides was conducted by Opton TNB-04T-PL, assisted by a 13 Megapixel digital camera attached to a Zeiss Stemi SV11 optical magnifier. The ImageJ software was employed for image processing.

3 Results

3.1 Characterization of the raw material

The percentage of structural components and inorganic material (ashes) present in the wood of the *C. canjerana* and *C. americana* species is shown in Table 1. The values are expressed as a percentage in relation to the dry wood sawdust.

The sum for each wood species does not reach 100% because the remaining fraction corresponds to extractives, which are non-structural components. The wood of *C. canjerana* had cellulose content around 17% higher than the wood of *C. americana*. The ash content of *C. canjerana* was approximately 4.3 times lower than that of *C. americana*. The content of hemicellulose was around 17% higher in *C. americana* than in *C. canjerana*. The lignin content was approximately 29% higher in *C. canjerana* than in *C. americana*.

3.2 Extractives yield

Figure 1 shows the extractive yields of *C. canjerana* and *C. americana* obtained using different techniques and solvents. The yields are based on the initial mass of dry sawdust. Considering the Fisher test at the 95% confidence level, the extraction yields were different for the two species, with *C. americana* showing higher yields for extraction with hot water and ethanol-toluene, while *C. canjerana* showed a higher yield for extraction with soda. The exception was extraction with ethanol, in which the two species showed statistically the same yield. For the ethanol extraction, the average yield of the *C. americana* samples was 10.43% and the standard deviation was 2.94%, while for the *C. canjerana* samples the average yield was 15.07% and the standard deviation was 0.58%, but the Fisher test indicated that there was no statistical difference, as the P-value was 0.0549. For both species, extraction with the soda solution had the highest yield.

3.3 Gas chromatography-mass spectrometry (GC-MS)

Figures 2, 3 present the GC-MS chromatograms of the extractives of *C. canjerana* and *C. americana* wood, obtained from extractions with ethanol, ethanol-toluene, hot water and soda (1%) and dissolved in ethyl acetate and methanol.

TABLE 1 Average wood characterization values.

Test	Wood species	
	C. canjerana	*C. americana*
Ashes (%)	0.33 ± 0,01[a]	1.42 ± 0,17[b]
Cellulose (%)	37.24 ± 0,63[a]	31.77 ± 0,63[b]
Hemicellulose (%)	18.68 ± 0,36[a]	21.84 ± 0,53[b]
Lignin (%)	33.05 ± 0,64[a]	25.59 ± 1,37[b]

The average values are followed by the standard deviation. The letter a on the *C. canjerana* results and the letter b on the *C. americana* results indicate the existence of a statistically significant difference between the two species for each of the parameters analyzed, according to the Fisher test at the 95% confidence level. Different letters above the numbers represent statistically different averages.

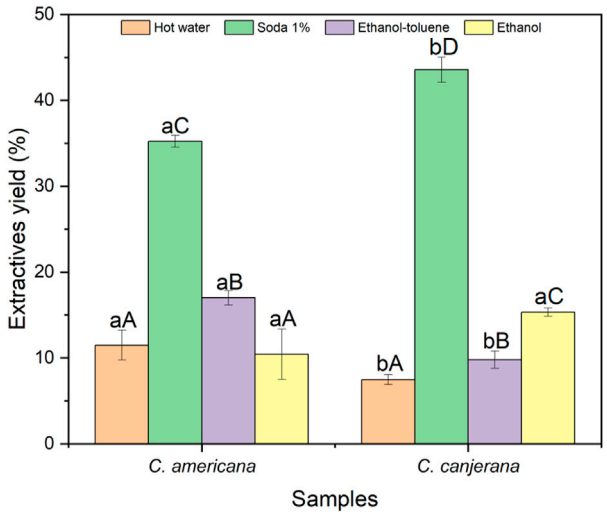

FIGURE 1
Yield of the extractives obtained under different conditions. Different lowercase letters indicate a statistically significant difference between species and different uppercase letters indicate a statistically significant difference between ways of extracting. Note: Vertical lines represent the standard deviation.

Table 2 lists all the molecules present in the chromatograms that coincided with the library of the equipment. Thus, the small peaks present in the chromatograms, which were not listed, did not correspond to the library. The molecules were grouped according to the species of wood used, the solvent used to obtain the extractives and the solvent used in the GC-MS to solubilize the samples.

3.4 Anatomical identification of wood species

3.4.1 *Cabralea canjerana*

Based on slide observations (Figure 4), the cross-section reveals distinct growth rings bordered by marginal parenchyma (Marchiori et al., 2010). The pores display a uniform diffuse distribution, existing as solitary units or in radial multiples of 2 to 3, occasionally more, with an oval to circular cross-section (Rodrigues et al., 2008). Frequently observed in the heartwood are resin-like deposits that sometimes block the vascular cavities (Marchiori et al., 2010). The axial parenchyma exhibits a confluent aliform paratracheal type, creating marginal sinuous bands wider than three cells, characterized as serial and non-stratified (Rodrigues et al., 2008).

In the radial section, vessel-ray and vessel-parenchyma pits appear alternating and rounded (Cury, 2001). The rays are heterogeneous, consisting of procumbent, square, and erect cells (Marchiori et al., 2010). Fibers are septate, featuring simple, semi-bordered, and bordered pits, with fiber wall thickness varying from thin to thick (Cury, 2001).

The tangential section illustrates that vessel elements have simple perforation plates (Rodrigues et al., 2008). Intervessel pits resemble those between vessels and parenchyma but are larger (Cury, 2001). Uniseriate rays, primarily composed of procumbent cells or with a marginal row of square cells, dominate, ranging from 1 to 25 cells in height. Although most multiseriate rays are two cells wide, a few extend to three cells wide; they contain procumbent cells in the multiseriate portion and square, erect cells at the margins, with heights between 5 and 37 cells (Marchiori et al., 2010).

3.4.2 *Cordia americana*

In the cross-section, distinct growth rings are observed (Almeida, 2013), demarcated by thin bands of marginal parenchyma and ray thickening (Figure 5). Besides these bands, the axial parenchyma exhibits types such as vasicentric, confluent vasicentric, aliform, confluent aliform paratracheal, and diffuse in aggregates apotracheal (Richter and Dallwitz, 2019). The pores demonstrate diffuse porosity, featuring solitary pores, radial multiples of 2 to 3 (Machado, 2016), and racemiform multiples. There is a pattern of semi-circular ring porosity, with pores arranged in tangential chains (Richter and Dallwitz, 2019). Oil/resin frequently blocks several pores (Almeida, 2013).

In the radial section, vessel-ray pits appear alternate and bordered. Observed solely on radial walls, the fiber pits are simple or have very small borders. The rays are heterogeneous, primarily consisting of procumbent cells with square and erect cells located in marginal rows (Richter and Dallwitz, 2019).

The tangential section reveals that vessel elements have simple perforation plates. The intervessel pits are alternate and bordered, with the observation of tyloses in the vessel elements' lumen. The rays are identified as multiseriate, with their width spanning from 2 to 5 cells (Richter and Dallwitz, 2019).

4 Discussion

4.1 Characterization of the raw material

For *C. americana*, the combined cellulose and hemicellulose content, or holocellulose, reached 53.61% (Table 1), indicating the biomass's potential for paper production. *Cabralea canjerana* exhibited a holocellulose content of 55.92%, rendering it even more appropriate for paper production post-extractive removal, especially since a holocellulose percentage above 33% suggests suitability for the paper industry. Moreover, the ash contents of 0.33% for *C. canjerana* and 1.42% for *C. americana* are below the

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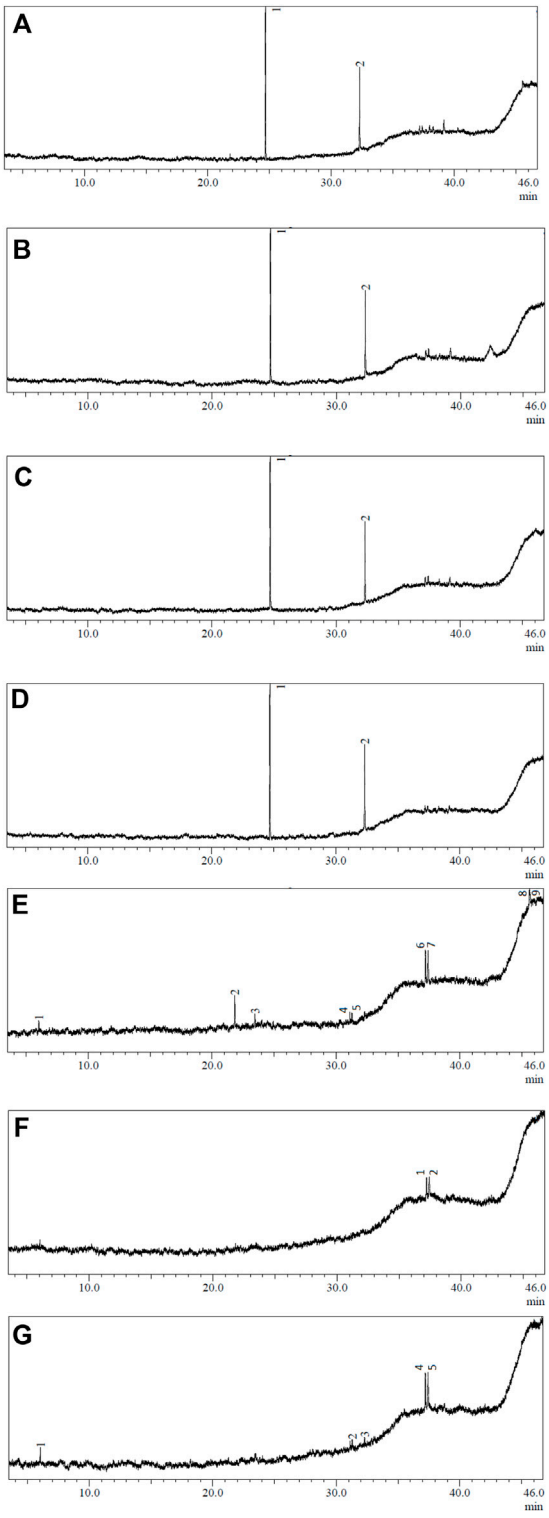

FIGURE 2
GC-MS chromatograms obtained with ethyl acetate dissolution of *C. canjerana* extractives extracted with: **(A)** ethanol-toluene, **(B)** hot water, **(C)** soda (1%) and **(D)** ethanol. GC-MS chromatograms obtained with dissolution in methanol of *C. canjerana* extractives extracted with: **(E)** ethanol-toluene, **(F)** hot water and **(G)** soda (1%). The retention time is expressed in minutes.

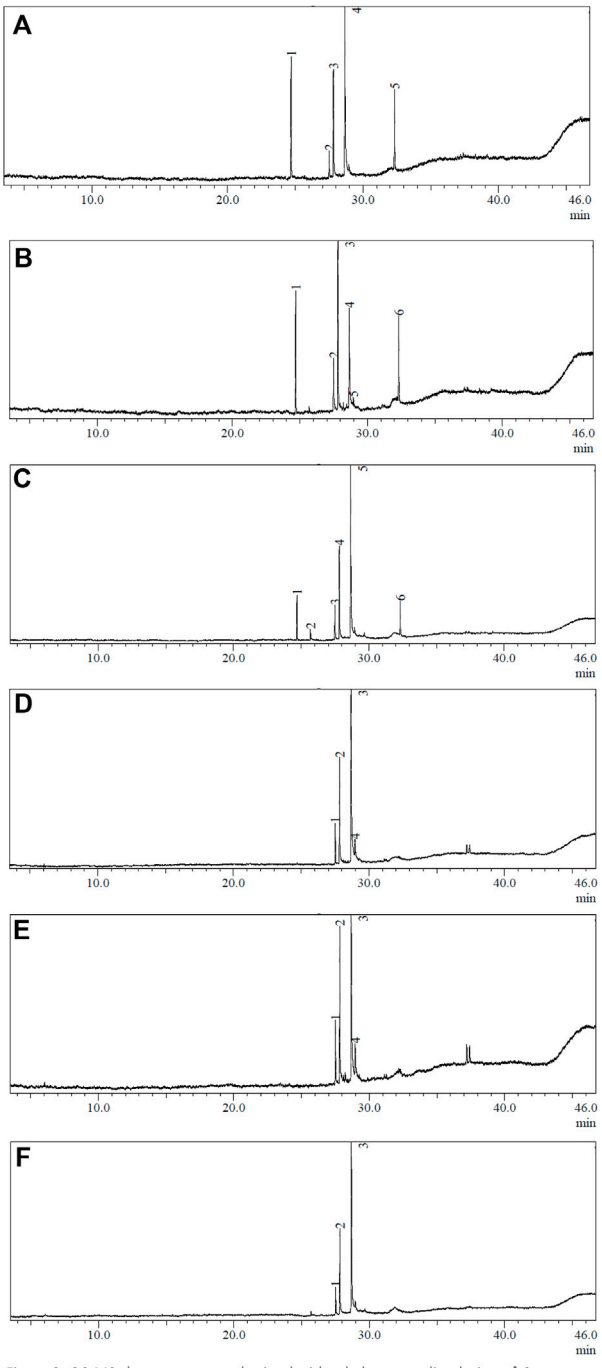

FIGURE 3
GC-MS chromatograms obtained with ethyl acetate dissolution of *C. americana* extractives extracted with: **(A)** ethanol-toluene, **(B)** hot water and **(C)** ethanol. GC-MS chromatograms obtained with dissolution in methanol of *C. americana* extractives extracted with: **(D)** ethanol-toluene, **(E)** hot water and **(F)** ethanol. The retention time is expressed in minutes.

2.87% found in *Eucalyptus grandis*, commonly used in paper production. Lower ash contents facilitate energy and time savings during paper production, as ash removal is necessary

TABLE 2 Molecules identified by GC-MS.

Raw material	Extraction solvent	Solvent for GC-MS	Principal molecules	Retention time (minutes)	Peak height %	Peak area %	Principal uses	References
Cabralea canjerana	Ethanol-toluene (1:2)	Ethyl acetate	Diisobutyl phthalate	24.686	65.20	65.20	Adhesives and sealants, cleaning products, floor coverings, paints, toner, plastic and rubber	Huang et al. (2021)
			Bis(2-ethylhexyl) phthalate	32.318	34.80	34.80	Building materials, electrical products, fabrics, leather products, food packaging, paints and coatings	
	Hot water		Diisobutyl phthalate	24.686	64.45	63.80	Mentioned previously	
			Bis(2-ethylhexyl) phthalate	32.320	35.55	36.20	Mentioned previously	
	Hot water and soda (1%)		Diisobutyl phthalate	24.686	65.57	64.13	Mentioned previously	
			Bis(2-ethylhexyl) phthalate	32.321	34.43	35.87	Mentioned previously	
	Ethanol		Diisobutyl phthalate	24.687	64.81	63.27	Mentioned previously	
			Bis(2-ethylhexyl) phthalate	32.323	35.19	36.73	Mentioned previously	
	Ethanol-toluene (1:2)	Methanol	Undecane	6.019	5.79	3.09	Lubricants, greases, sealants, coatings, paints, toners, perfumes, fragrances, cosmetics and sexual attractants for moths and cockroaches	ECHA (2024); Fisher (2024)
			Naphthalene, 1,6-dimethyl-4-(1-methylethyl)	21.819	17.56	14.30	Biomarker of higher plants, which makes it useful for paleobotanical analysis of rock sediments	Chebi (2017)
			Phenol, 2-(1,1-dimethylethyl)-4-(1-methyl-1-	23.457	7.44	7.34	Plastics, synthetic rubber, mineral oil and fuel additives, pharmaceuticals, cosmetics and printing inks	Nicnas (2020)
			Phenol, 2,4-bis(1-phenylethyl)-	31.119	6.74	4.99	Drugs against breast cancer	Muhammed Ashraf et al. (2020)
				31.280	5.67	4.31		
			Phenol, 2,4,6-tris(1-phenylethyl)-	37.210	19.39	24.42	Additive for natural and synthetic rubber, adhesives, plastics, textile	Brooke et al. (2009)
				37.428	18.09	21.87		

(Continued on following page)

TABLE 2 (*Continued*) Molecules identified by GC-MS.

Raw material	Extraction solvent	Solvent for GC-MS	Principal molecules	Retention time (minutes)	Peak height %	Peak area %	Principal uses	References
							fibers, cable coatings, flooring and natural and synthetic oils	
			Lilac alcohol epoxide	45.619	10.23	15.14	Repel thrips and blowflies	Ilc et al. (2016)
			Silicic acid, diethyl bis(trimethylsilyl) ester	45.650	9.10	4.56	Antibacterial activity	Sharmila Juliet et al. (2018)
	Hot water		Phenol, 2,4,6-tris(1-phenylethyl)-	37.208	47.07	48.41	Mentioned previously	Brooke et al. (2009)
				37.428	52.93	51.59		
	Hot water and soda (1%)		Undecane	6.036	13.96	6.70	Mentioned previously	ECHA (2024); Fisher (2024)
			Methanone, [2-(1-methylethyl)phenyl]phenyl	31.291	9.47	7.90	The molecule was found in the bibliography, but there was no mention of any use for it	Woods et al. (2007); Molnar (1971)
			3-Ethyl-2-methoxy-4-(methylsulfonyl)benzoic acid	32.297	8.19	5.55	Not found	
			Phenol, 2,4,6-tris(1-phenylethyl)-	37.208	34.45	38.79	Mentioned previously	Brooke et al. (2009)
				37.430	33.93	41.06		
	Ethanol		No molecules have been identified					
Cordia americana	Ethanol-toluene (1:2)	Ethyl acetate	Diisobutyl phthalate	24.692	24.24	19.92	Mentioned previously	Huang et al. (2021)
			Carbamic acid, 2,5-dimethoxyphenyl-, allyl ester	27.500	5.35	4.87	Not found	
			Bis(2-ethylhexyl) phthalate	32.325	15.73	12.67	Mentioned previously	Huang et al. (2021)
	Hot water		Diisobutyl phthalate	24.690	23.09	19.25	Mentioned previously	
			N-(2-Fluoro-phenyl)-2-oxo-2-[N'-(3,4,5-trimethoxy-benzylidene)-hydrazino]-acetamide	27.497	9.74	9.63	Not found	
			Bis(2-ethylhexyl) phthalate	32.324	15.89	14.21	Mentioned previously	Huang et al. (2021)
	Ethanol		Diisobutyl phthalate	24.689	11.60	9.25	Mentioned previously	
			Bis(2-ethylhexyl) phthalate	32.322	8.69	7.05	Mentioned previously	
	Ethanol-toluene (1:2)	Methanol	Carbamic acid, 2,5-dimethoxyphenyl-, allyl ester	27.511	12.20	8.66	Not found	
			Cyclopropa [3,4] cyclohepta [1,2-a]	27.834	31.57	25.21	The molecule was found in the	Kan, Strezov and Evans (2017)

(Continued on following page)

TABLE 2 (*Continued*) Molecules identified by GC-MS.

Raw material	Extraction solvent	Solvent for GC-MS	Principal molecules	Retention time (minutes)	Peak height %	Peak area %	Principal uses	References
			naphthalene, 1,1a,1b,2,3,7b,8,9,10,10a-decahydro-5-methoxy-10-methylene-				bibliography, but there was no mention of any use for it	
			Cyclopentane-3′-spiropentacyclo [9.1.0.0(2,4).0(5,7).0(8,10)] dodecane-6′,9′,12′-trisspirocyclopentane, anti,syn,anti-	28.681	51.48	60.77	Not found	
			Tetracyclo [10.2.1.0(2,11).0(4,9)] pentadeca-2 (11),6,13-triene-5,8-dione	28.964	4.75	5.36	The molecule was found in the bibliography, but there was no mention of any use for it	Hashemi-Nasab and Parastar (2020)
	Hot water		N-(2-Fluoro-phenyl)-2-oxo-2-[N'-(3,4,5-trimethoxy-benzylidene)-hydrazino]-acetamide	27.507	15.41	12.34	Not found	
			Cyclopropa [3,4] cycloheptа [1,2-a] naphthalene, 1,1a,1b,2,3,7b,8,9,10,10a-decahydro-5-methoxy-10-methylene-	27.829	38.04	34.38	Mentioned previously	Kan, Strezov and Evans (2017)
			Cyclopentane-3′-spiropentacyclo [9.1.0.0(2,4).0(5,7).0(8,10)] dodecane-6′,9′,12′-trisspirocyclopentane, anti,syn,anti-	28.673	39.78	46.96	Not found	
			Gestrinone	28.960	6.77	6.32	Endometriosis treatment	Lobo et al. (2008)
	Ethanol		N-(2-Fluoro-phenyl)-2-oxo-2-[N'-(3,4,5-trimethoxy-benzylidene)-hydrazino]-acetamide	27.507	9.79	8.24	Not found	

(NagarajaGanesh et al., 2023). Post-extraction, the lignocellulosic biomass from both species also serves as a primary material for Medium Density Fiberboard (MDF) production, leveraging the wood fibers (Esshelf, 2017).

4.2 Extractives yield

Soxhlet extraction yields using ethanol-toluene were 17.01% for *C. americana* and 9.79% for *C. canjerana*, therefore showed higher yields than other species cited in the bibliography using the same extraction method. Such as *Castanea sativa* at 7.4% (D'Auria et al., 2021), *Schizolobium parahyba* at 2%, *Pinus taeda* at 6% (Mattos et al., 2014), and eucalyptus hybrids at 5% (Santos et al., 2011). Section 4.4 will discuss potential reasons for these high yields with ethanol-toluene.

The yield of extraction with 1% sodium hydroxide was 35.23% for *C. americana* and 43.56% for *C. canjerana*. Ali et al. (2019) extracted wood from different species using 1% sodium hydroxide. The authors found yields of 28.29% for *Parthenium argentatum*, 19.17% for *Parthenium tomentosum*, 31.30% for *Asclepias syriaca* and 17.10% for *Acer rubrum*, so there is considerable variation from one species to another. The high yield of extraction with 1% sodium hydroxide is possibly due to the fact that in addition to non-structural extractives, lignin and hemicellulose are also obtained.

4.3 Gas chromatography-mass spectrometry

In a GC-MS chromatogram, the retention time is dependent on the properties of the chemical structure of the substance, the capacity and dimensions of the column, the chemical nature of the mobile and stationary phase and the flow rate of the mobile phase (Moldoveanu and David, 2017). Thus, it is possible to understand that the longer the retention time, the greater the

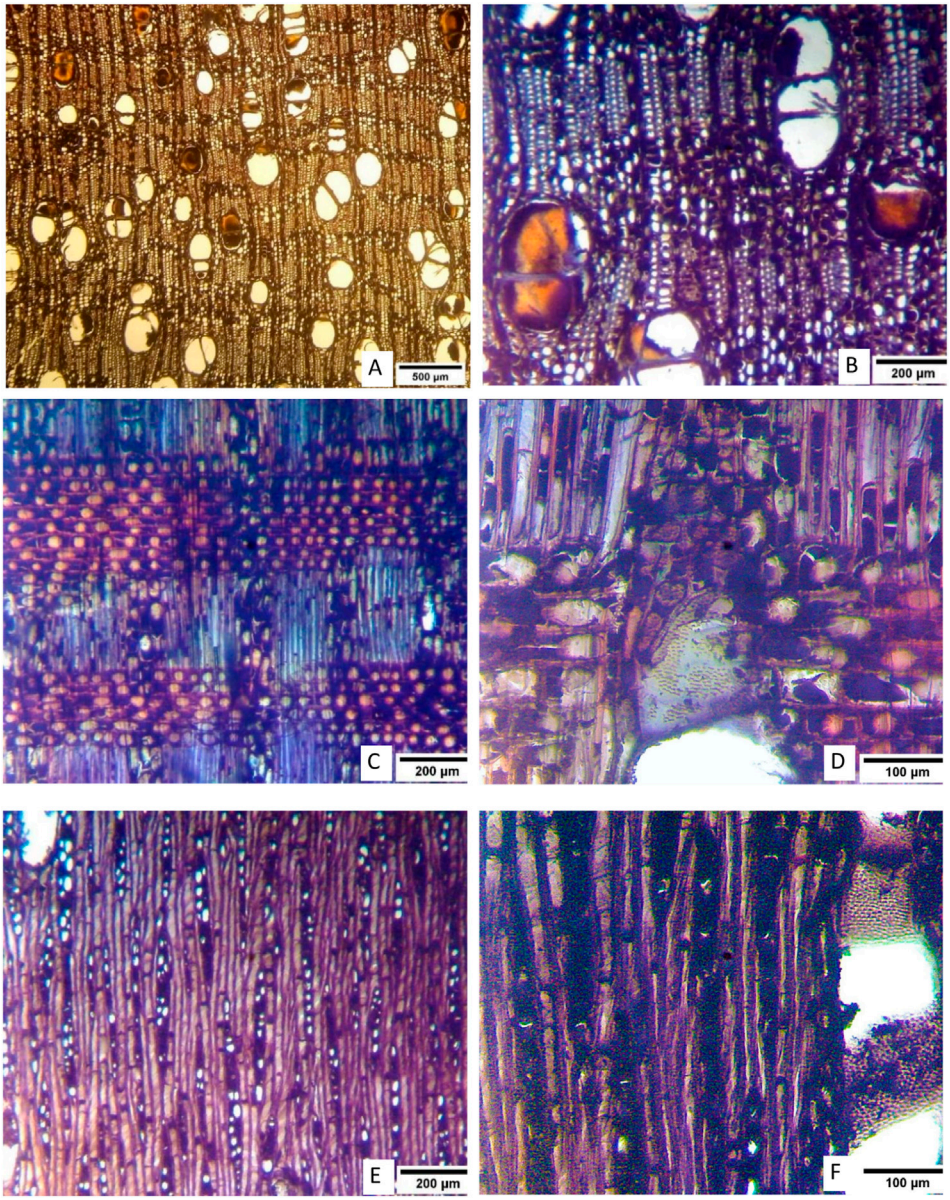

FIGURE 4
Anatomical aspects of *Cabralea canjerana* wood. **(A, B)** Cross section. **(C, D)** Radial longitudinal section. **(E, F)** Tangential longitudinal section. Source: Prepared by the authors.

force of interaction between the substance and the stationary phase (Simomukay et al., 2022). In addition, the peak area and the peak height are proportional to the concentration of the compounds present in the analyte (Laajimi et al., 2022). It was possible to observe that the compounds that remained for longer in the stacionary phase were lilac alcohol epoxide and silicic acid, diethyl bis(trimethylsilyl) ester. Regarding to the concentration, it can be said that diisobutyl phthalate and phenol, 2,4,6-tris(1-phenylethyl)- were more present in the substances studied. In this way, the GC-MS analysis facilitated the identification of various molecules in the extractives from *C. canjerana* and *C. americana*, as detailed in Table 2. Notable among these molecules were Phenol, 2,4-bis(1-phenylethyl), which, according to Muhammed Ashraf et al. (2020), shows potential in the development of breast cancer treatments, and Gestrinone, identified by Lobo et al. (2008) as a candidate for endometriosis therapy. Additionally, Diisobutyl phthalate and Bis(2-ethylhexyl) phthalate, recognized for their wide range of industrial applications (Huang et al., 2021), were found in the extractives of both species in significant quantities, using various solvents, such as ethanol-toluene, hot water, hot water and soda (1%), and ethanol.

4.4 Anatomical identification of wood species

The anatomical features of *C. canjerana* and *C. americana* were examined across three planes in histological slides: cross-sectional, radial, and tangential. These features were then cross-referenced

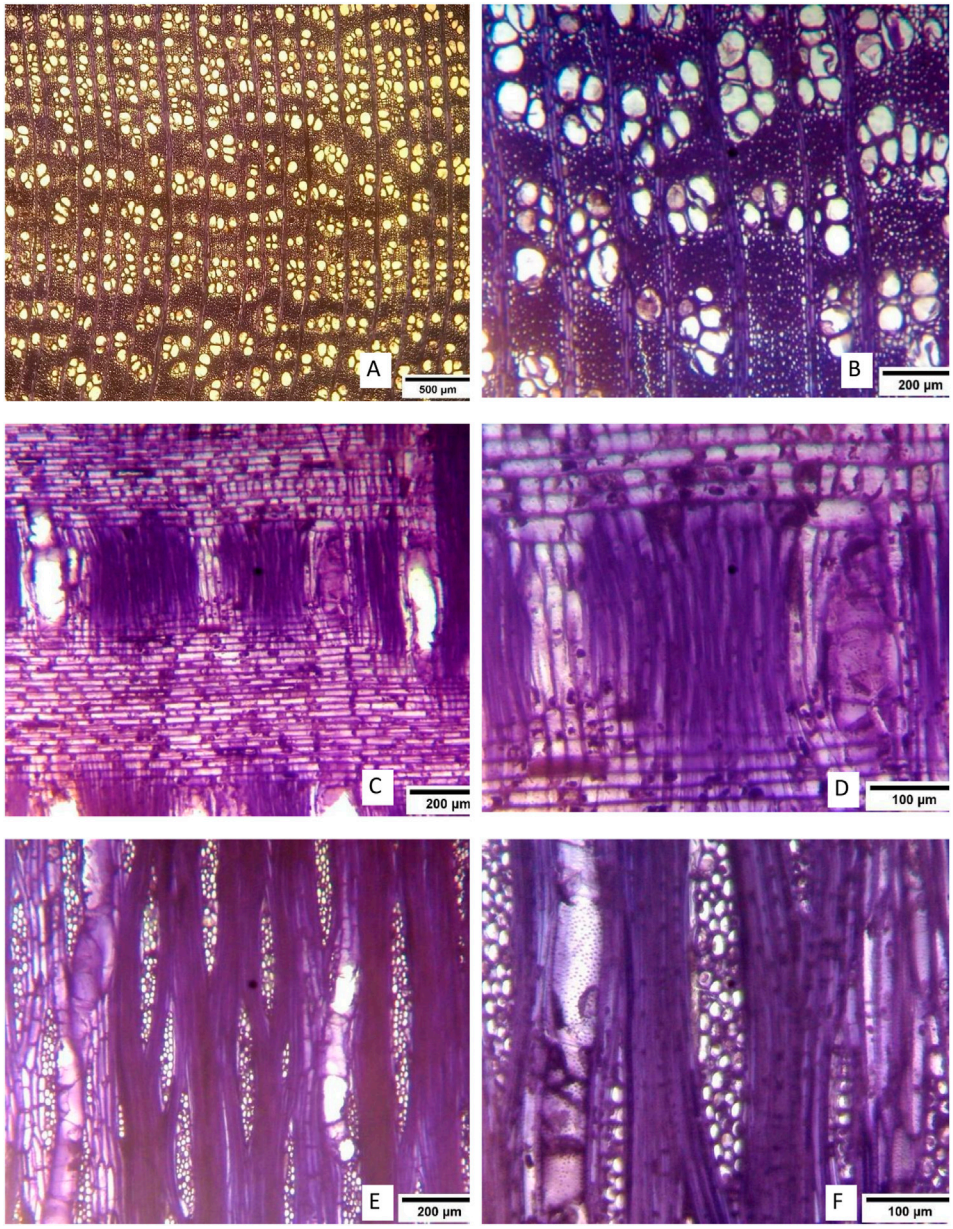

FIGURE 5
Anatomical aspects of *Cordia americana* wood. **(A, B)** Cross section. **(C, D)** Radial longitudinal section. **(E, F)** Tangential longitudinal section. Source: Prepared by the authors.

with the existing literature on these species (Cury, 2001; Rodrigues et al., 2008; Marchiori et al., 2010; Almeida, 2013; Machado, 2016; Richter and Dallwitz, 2019), affirming that the specimens used in this study indeed corresponded to the identified species. The observation of a significant number of parenchymatous cells, encompassing both radial and axial parenchyma, alongside the frequent occurrence of resin-blocked vessel elements in the slides, contributes to understanding the elevated extraction yields (Burger and Richter, 1991; Díaz, 2017). The presence of tyloses in the vessel elements of *Cordia Americana* also contributes to the high yields of extractions of this species, as tyloses are the occlusion of vessels by parenchymatous cells (Florsheim et al., 2020; Acosta et al., 2021).

5 Conclusion

GC-MS analysis facilitated the identification of noteworthy molecules within the extractives of *C. canjerana* and *C. americana*, particularly highlighting Phenol, 2,4-bis(1-phenylethyl), and Gestrinone. These compounds exhibit significant potential for healthcare applications, underscoring the broader implications of our findings in medical and pharmaceutical research.

Further, the chemical characterization of the wood underlines its versatility, proposing two primary applications for the extracted lignocellulosic biomass: the production of paper and Medium

Density Fiberboard (MDF). This suggests that beyond their immediate scientific value, the use of extractives can contribute to sustainable manufacturing practices, offering a dual benefit of environmental conservation and economic efficiency.

Histological analysis played a crucial role in validating the species origin of the wood samples used in this study. The creation of histological slides from *C. canjerana* and *C. americana* provided not only a methodological foundation for species confirmation but also generated visual data to aid other researchers in species identification. The clarity and reliability of these images ensure they can serve as valuable reference material within the scientific community.

Moreover, the examination of wood's anatomical features shed light on the mechanisms behind the high extraction yields obtained. Understanding these anatomical factors is crucial for optimizing extraction processes in future studies. The ability to achieve such high yields is particularly beneficial, as it enhances the efficiency of isolating fine molecules in substantial quantities, thereby facilitating more comprehensive studies on their properties and potential applications.

In conclusion, this research enhances our understanding of the chemical and anatomical properties of *C. canjerana* and *C. americana*, facilitating their potential use in health sciences and materials engineering. The results highlight the critical role of multidisciplinary methods in the investigation of natural resources, providing valuable insights that may contribute to breakthroughs in drug development and the creation of sustainable materials.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MS: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Writing–original draft, Writing–review and editing. EM: Formal Analysis, Writing–review and editing. AL: Data curation, Formal Analysis, Investigation, Writing–original draft. MR: Data curation, Formal Analysis, Investigation, Writing–original draft. PS: Investigation, Methodology, Writing–review and editing, Writing–original draft. SF: Data curation, Formal Analysis, Investigation, Methodology, Writing–original draft, Writing–review and editing. DG: Funding acquisition, Resources, Supervision, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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