Composition Characteristics of Volatile Organic Compounds in Different Tree Species and their Chemical Ecological Functions

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Ancient trees represent a significant ecological niche, constituting a vital habitat for a variety of species. Moreover, they serve as a cultural heritage and are worthy of preservation. The systematic analysis of volatile organic compounds (VOCs) in the wood of 11 species of ancient trees in Sichuan Province was performed using headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME-GC–MS). The results revealed significant compositional variations across different ancient trees species. This finding indicates species-specific chemical defense mechanisms that have evolved in response to environmental adaptation. For instance, *Magnolia sargentiana* exhibited a preference for terpene-based preservation, whereas *Acer grosseri* demonstrated a preference for lipid-derived aldehydes. Terpenoids, which are the dominant constituents (e.g., *α*-cedrene and *β*-cedrene in *Magnolia sargentiana* and hexanal in *Acer grosseri*), demonstrate antimicrobial, insect-repellent and ecological signaling functions. These findings contribute to the advancement of knowledge regarding the role of VOCs in woods in ecological interactions and lay the foundation for the development of natural antimicrobial, flavorant, and medicinal products.

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INTRODUCTION

Volatile organic compounds (VOCs) are important components of secondary metabolites in plants and play a pivotal role in the survival and competitive dynamics of plant species by modulating the 'plant–environment' interaction network. (Hu and Zhang 2022). Research has demonstrated that plant VOCs can mediate a variety of ecological functions. These include antibacterial defence (*e.g.*, *α*-pinene inhibits fungal spore germination), pest repellence (*e.g.*, *β*-caryophyllene deters coleopteran pests), and allelopathic suppression (*e.g.*, methyl jasmonate regulates the growth of neighboring plants) (Rashaduz *et al*. 2024; Tays *et al*. 2025). The ecological functions of these organisms are facilitated by the secretion of bioactive molecules, including terpenes and aldehydes. In recent years, innovations in gas chromatography–mass spectrometry (GC–MS), particularly the synergistic application of static headspace sampling and comprehensive two-dimensional gas chromatography (GC × GC), have significantly enhanced the detection sensitivity and compositional resolution of trace volatile organic compounds (VOCs) (Yu *et al.* 2020). This advancement has furnished substantial technical assistance for research endeavors concerning the mechanisms of chemical interaction in plants (Sotaro and Akiko 2024).

Research has focused predominantly on the functions of VOCs in above-ground plant organs, such as leaves and flowers—for instance, their role in attracting pollinators—while the compositional characteristics and ecological adaptability of wood-derived VOCs have received insufficient attention (Loreto and Schnitzler 2010). Because of prolonged environmental adaptation, the VOCs present in the wood of plants exhibit characteristics such as prolonged release cycles and high compositional stability. They might form unique chemical defense systems through terpenoid metabolites (*e.g.*, cedrene) and phenolic derivatives (*e.g.*, lignin degradation products) (Pichersky and Gershenzon 2002). Notably, while research on VOCs in coniferous species (*e.g.*, *Pinus massoniana* and *Picea asperata*) has been relatively extensive, the VOCs diversity, functional differentiation, and resource potential of broadleaved tree species—particularly rare and endangered ones—remain to be systematically analyzed (Yan *et al.* 2020).

Sichuan Province's abundant rainfall, diverse soil and rock types, and rugged terrain create an ideal environment for a wide variety of plant species (Li *et al*. 2021). Sichuan Province is located within the biodiversity hotspot of Southwest China and is home to national-level protected plants, with *Davidia involucrata* serving as a notable example. Old forests containing ancient trees are essential ecosystems for life on earth (Gilhen-Baker *et al*. 2022). The chemical diversity of VOCs in ancient tree wood might be closely related to its specific ecological adaptability (Meritxell *et al.* 2021). However, owing to limitations in technical approaches and the complexity of research subjects, studies on the VOCs in the wood of broadleaved tree species in this region remain scarce. Specifically, in addition to sporadic reports on *Davidia involucrata* and *Populus koreana*, VOCs of most species (*e.g.*, *Fagus lucida* and *Acer flabellatum*) remain unclear (Shen *et al.* 2024). The extant research in this field has focused primarily on the identification of components, with a paucity of quantitative correlation analyses between terpenoid markers (*e.g.*, *α*-cedrene) and ecological functions (*e.g.*, plant insect resistance) (Turlings and Erb 2018). Conventional steam distillation techniques frequently resulted in the degradation of heat-sensitive components, such as furans. This complicated the precise reflection of wood VOCs (Ninkuu *et al.* 2021).

Based on these findings, the present study investigated the compositional differences of VOCs in the wood of 11 broadleaved tree species. These species, including a national first-class protected plant, were selected from Sichuan Province. This study employed headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS–SPME–GC–MS) to systematically analyze VOCs. The objective of this study was to address the following scientific inquiries: First, the objective was to identify the distinctive components of VOCs in the wood of diverse broadleaved tree species and to elucidate their chemotaxonomic significance. Second, the investigation addressed the ecological functions (*e.g.*, antibacterial and insect-repellent properties) and concentration thresholds of key terpenoid compounds (*e.g.*, cedrene and cedrol). Third, the resource utilization potential of rare VOCs in wood was assessed (*e.g.*, prioritized for developing natural preservatives) (Schreiner *et al.* 2018; Zeng *et al.* 2021).

EXPERIMENTAL

Materials

The experimental samples were collected from 11 types of wood in Sichuan Province. Tree cores with a diameter of 1 cm and a length of 20 cm were drilled at breast height using an increment borer.

The wood samples were sourced from ancient trees. The method of morphological identification was utilized by Professor Hu Chao for species identification. The methods of core sampling, historical documents, and archival records were utilized by Professor Xie Jiulong for tree age determination. These include samples from *Davidia involucrata*, a nationally protected first-class plant (from a 170-year-old tree); *Fagus lucida*, a precious species of Fagaceae (100-year-old tree); *Carpinus fangiana*, a species of Betulaceae (from a 120-year-old tree); *Magnolia sargentiana*, a rare species of Magnoliaceae (160-year-old tree); *Cinnamomum jensenianum*, a common economic plant of Lauraceae (120-year-old tree); *Camellia oleifera*, an oil plant of Theaceae (150-year-old tree); *Enkianthus ruber*, an ornamental plant (110-year-old tree); and *Acer flabellatum*, a common landscaping tree species with a 130-year-old tree. *Sorbus folgneri* (an ornamental Rosaceae plant with a 190-year-old tree), *Lindera limrichtii* (an ornamental Lauraceae plant with a 100-year-old tree), and *Prunus conradinae* (an ornamental Rosaceae plant with a 130-year-old tree) were also analyzed.

Methods

The wood samples were promptly ensconced in hermetically sealed bags, meticulously labeled with the time and location of collection, altitude, and pertinent information, and expeditiously conveyed to the laboratory at a temperature of 4 °C. The samples were placed in a constant-temperature drying oven (DHG-9070A) and dried at 60 °C until they reached a constant weight. This process required approximately 72 h. A plant grinder (RT-34) was subsequently used to grind the dried samples into wood powder, with particle sizes ranging from 80- to 100-mesh. The ambient temperature was maintained at 25 °C, and the relative humidity was maintained at 40% throughout the process. The wood powder samples were subsequently meticulously portioned into brown, wide-mouth bottles, hermetically sealed, and stored in a desiccator for subsequent use.

This study employed HS–SPME–GC–MS to systematically analyze VOCs. Two grams of wood powder were taken from a brown wide-mouth bottle into a headspace vial. The vials were hermetically sealed, subsequently placed in a headspace sampler, and subjected to a heating and equilibration process for a designated period. The headspace gas was subsequently sampled for one min and analyzed by gas chromatography–mass spectrometry (GC–MS).

The chromatographic column utilized was an MI-5STUS (30 m × 0.25 mm × 0.25 μm). The inlet temperature was set to 250 °C. The temperature program was as follows: the initial temperature was held at 40 °C for two min, then increased to 100 °C at a rate of 5 °C per min, and finally increased to 165 °C at a rate of 4 °C per min and held for two min. Helium was utilized as the carrier gas. The column flow rate was set to 0.80 mL/min.

The injection volume was 1 microliters. The septum purge flow rate was 6 milliliters per min (mL/min), and the mass spectrometer (MS) employed an electron ionization (EI) source. The detector voltage was set to 0.90 kV. The ion source temperature was set to 230 °C. The interface temperature was set to 200 °C. The solvent delay time was set to 5.00 min. The detector gain was set to 1.50 kV + 0.40 kV.

The NIST17-1.lib database was utilized to identify volatile components with a match degree of 90% or higher in conjunction with the literature for qualitative analysis. The relative content of each volatile component was calculated using the peak area normalization method. The generation of GC–MS spectra was carried out using Origin Pro 8.1 software.

RESULTS AND DISCUSSION

Compositional Characteristics of the Main Volatile Components in the Wood of Ancient Trees

An analysis of the compositional characteristics of volatile components in the wood of ancient trees revealed significant differences. The MS data of the plant samples are presented in Table 1.

Among the ancient tree samples, those with terpenoid compounds as the dominant volatile components included *Lindera limprichtii* and *Cinnamomum jensenianum*. The analysis of volatile components in the ancient tree samples revealed the predominance of terpene compounds in *Magnolia sargentiana*, *D. involucrata*, and *Acer flabellatum*. The analysis of the ancient tree samples revealed that those containing aldehyde compounds as the primary volatile organic compounds include *Carpinus fangiana*, *Fagus lucida*, *Camellia oleifera*, *Prunus conradinae*, and *Enkianthus ruber*. The volatile components of the ancient tree sample from *Sorbus folgneri* were primarily composed of patchoulane.

Monoterpenes and sesquiterpenes were significant components of the extracts of numerous medicinal plants and demonstrate robust biological activities and pharmacological effects (Kagawa *et al.* 2003; Nakai *et al.* 2003; Umeno *et al.* 2008; Tays *et al.* 2025). In the present study, the terpenoid substances identified in *Lindera limprichtii*, *Cinnamomum jensenianum*, *M. sargentiana*, *D. involucrata*, and *A. flabellatum* were *β*-cedrene, *α*-cedrene, *α*-pinene, (+)-*β*-funebrene, *cis*-Thujopsene, and (+)-cuparene. The bioactive substances cedrol and *cis*-Thujopsene endowed the wood of *Sorbus folgneri* with antibacterial and insect-repellent functions. *M. sargentiana* and *L. limprichtii* were notable for their abundance of terpenoid compounds, including *α*-cedrene and *β*-cedrene, which had antibacterial and anti-inflammatory properties. These compounds might also function as natural preservatives, contributing to the protection of wood from microbial infestation (Xie *et al.* 2022; Rashaduz *et al.* 2024). As demonstrated in the studies by Gao *et al.* (2005) and Dong *et al.* (2021), *Carpinus fangiana*, *Enkianthus ruber*, and *Camellia oleifera* contained high levels of aldehyde compounds, including valeraldehyde and hexanal. These compounds have been shown to release volatile organic compounds, which may contribute to the resistance of plants to herbivorous insects or pathogens (Gao *et al.* 2005; Dong *et al.* 2021). These results suggested that different tree species adapt to their ecological environments by synthesizing and releasing specific volatile compounds, thereby forming diverse ecological defense mechanisms (Peng *et al.* 2002).

Table 1. The Main Constituents of Ancient Trees

Ancient tree	Retention time	Constituent name	CAS	Peak area (%)
Lindera limprichtii	5.021	Acethydrazide	1068-57-1	9.2
	10.407	*α*-Pinene	80-56-8	1.25
	26.907	*α*-cedrene	469-61-4	40.02
	27.168	(+)-*β*-Funebrene	79120-98-2	26.49
	27.519	*cis*-Thujopsene	470-40-6	2.86
	29.868	(+)-Cuparene	16982-00-6	6.16
	32.984	Cedrol	77-53-2	12.93
Cinnamomum jensenianum	5.02	Formic acid vinyl	692-45-5	2.87
	5.053	acetic acid	64-19-7	16.25
	7.019	2,3-Butanediol	123513-85-9	3.96
	26.93	*α*-cedrene	469-61-4	32.45
	27.189	(+)-*β*-Funebrene	79120-98-2	18.11
	27.543	*cis*-Thujopsene	470-40-6	12.91
	29.89	(+)-Cuparene	16982-00-6	13.45
Prunus conradinae	5.019	Ethyl acetate	141-78-6	12.65
	5.079	acetic acid	64-19-7	13.68
	7.035	2,3-Butanediol	123513-85-9	2.77
	7.19	hexanal	66-25-1	51.06
	10.418	*α*-Pinene	80-56-8	3.48
	11.95	2-Pentylfuran	3777-69-3	6.35
	26.935	*α*-cedrene	469-61-4	7.03
	27.155	*β*-cedrene	546-28-1	2.99
Sorbus folgneri	26.942	patchoulane	19078-35-4	50.97
	27.552	*cis*-Thujopsene	470-40-6	5.4
	29.9	Benzene,1-methyl-4-propyl-	1074-55-1	7.15
	33.022	Cedrol	77-53-2	7.47
Carpinus fangiana	5.021	Ethyl acetate	141-78-6	14.33
	10.407	acetic acid	64-19-7	7.41
	26.907	Valeraldehyde	110-62-3	6.55
	27.168	hexanal	66-25-1	57.64
	27.519	*α*-Pinene	80-56-8	3.81
	29.868	2-Pentylfuran	3777-69-3	7.19
	32.984	hexadecane	544-76-3	1.38
Magnolia sargentiana	5.021	Acethydrazide	1068-57-1	9.2
	10.407	*α*-Pinene	80-56-8	1.25
	26.907	*α*-cedrene	469-61-4	40.02
	27.168	(+)-*β*-Funebrene	79120-98-2	26.49
	27.519	*cis*-Thujopsene	470-40-6	2.86

	29.868	(+)-Cuparene	16982-00-6	6.16
	32.984	Cedrol	77-53-2	12.93
Enkianthus ruber	5.278	acetic acid	64-19-7	24.86
	5.405	2-Methylbutanal	96-17-3	5.85
	5.549	1-Methoxy-2-propanol	4984-22-9	13.75
	5.696	Valeraldehyde	110-62-3	7.3
	7.191	hexanal	66-25-1	41.28
	11.954	2-Pentylfuran	3777-69-3	6.96
Camellia oleifera	5.126	acetic acid	64-19-7	29.06
	7.07	2,3-Butanediol	123513-85-9	9.09
	7.188	hexanal	66-25-1	50.21
	11.948	2-Pentylfuran	3777-69-3	11.64
Fagus lucida	5.02	Ethyl acetate	141-78-6	13.8
	5.075	chloroform	8013-54-5	23.39
	5.308	acetic acid	64-19-7	27.48
	5.4	2,2,4,15,17,17-Hexamethyl-7,12-bis(3,5,5-trimethylhexyl)octadecane	55470-97-8	4.7
	7.18	hexanal	66-25-1	14.81
	8.732	o-xylene	95-47-6	2.54
	11.932	2-Pentylfuran	3777-69-3	2.26
	26.321	hexadecane	544-76-3	1.8
	26.915	*α*-cedrene	469-61-4	2.89
	27.17	(+)-*β*-Funebrene	79120-98-2	1.89
	28.298	2,6,10,15-tetramethylheptadecane	54833-48-6	2.12
	29.569	hexadecane	544-76-3	2.32
Davidia involucrata	5.019	Ethyl acetate	141-78-6	15
	7.204	hexanal	66-25-1	14.2
	26.945	*α*-cedrene	469-61-4	39.43
	27.203	(+)-*β*-Funebrene	79120-98-2	24.47
	29.904	(+)-Cuparene	16982-00-6	6.9
Acer flabellatum	5.056	acetic acid	64-19-7	26.61
	5.12	Methylcyclopentane	96-37-7	10.27
	7.177	hexanal	66-25-1	13.39
	26.947	*α*-cedrene	469-61-4	30.97
	27.207	(+)-*β*-Funebrene	79120-98-2	18.76

Analysis of Aroma Constituents in the Wood of Ancient Trees

The aroma properties of the volatile compounds in the wood of 11 ancient tree species were retrieved from the online database PubChem (Table 2). Specifically, a total of six aroma compounds were identified among the volatile organic compounds of both *E. ruber* and *F. lucida*. A total of five aroma compounds were identified among the volatile components of *C. fangiana* and *P. conradinae*. A total of three aroma compounds were identified among the volatile components of *M. sargentiana*, *D. involucrata*, *A. flabellatum*, and *C. oleifera*. The volatile components of both *L. limprichtii* and *C. jensenianum* were found to contain two aroma compounds. A single aroma compound was identified among the volatile components of *S. folgneri*.

In summary, the wood of the ancient tree species *E. ruber*, *F. lucida*, *C. fangiana*, and *P. conradinae* contained a greater number of aroma compounds. Compounds such as ethyl acetate and *α*-cedrene were detected in *D. involucrata* and *C. jensenianum*; these compounds exhibited fruity and woody aroma characteristics. These compounds might attract specific pollinating insects, thereby facilitating plant reproduction (Tak and Isman 2015; Chen *et al.* 2020). The high-content aldehyde compounds presented in *E. ruber* may function as defensive signaling molecules, thereby attracting natural enemies or repelling pests. Concurrently, the fruity aroma characteristics of these plants might also function as a form of attraction for pollinators (Zhu-Salzman *et al.* 2005; Meng *et al.* 2025). The broadening of research in the field has given rise to novel insights into the ecological functions of these volatile aromatic components, thereby offering a novel perspective for studying the interactions between plants and their environment.

Table 2. Odor Descriptions of Aroma Constituents in the Wood of Ancient Trees

Compound	Odor description	Species
Hexanal	Grass, green, fat	*M. sargentiana*, *D. involucrata, A. flabellatum, C. fangiana, F. lucida, C. oleifera, P. conradinae, E. ruber*
Acetic acid	Vinegar-like	*C. Jensenianum*, *A. flabellatum, C. fangiana, F. lucida, C. oleifera, P. conradinae, E. ruber*
α-cedrene	Woody	*L. limprichtii, C. jensenianum, M. sargentiana, D. involucrata, A. flabellatum, F. lucida, P. conradinae*
2-pentylfuran	Buttery, caramel	*C. fangiana*, *F. lucida, C. oleifera*, *P. conradinae, E. ruber*
Ethyl acetate	Weedy, fruity, sweet, green, ethereal	*M. sargentiana*, *D. involucrata*, *C. fangiana*, *F. lucida*, *P. conradinae*
Cedrol	Woody-earthy	*L. limprichtii, S. folgneri*
Valeraldehyde	Fermented, bready, fruity, nutty, berry	*C. fangiana*, E. ruber
1-methoxy-2-propanol	Sweet ether-like odor	*E. ruber*
2-methylbutanal	Malty	*E. ruber*
o-xylene	Aromatic odor	*F. lucida*

Identification of Medicinal Active Constituents in Volatiles from Ancient Tree Wood

Based on the findings reported in the literature, a total of 25 volatile metabolites were identified across 11 ancient tree wood species (Ru *et al.* 2014). These results were derived from the Traditional Chinese Medicine Systems Pharmacology Database (TCMSP). Among these, 16 exhibited active medicinal components. Among the 16 metabolites examined, 15 were found to bind to 589 target proteins, corresponding to 466 diseases (Table 3). These diseases primarily included cancer, tumors, cardiovascular diseases, hypertension, inflammation, diabetes, Alzheimer's disease, and neurological disorders.

Table 3. Identification of the Key Active Ingredients of Traditional Chinese Medicines in Poplar Wood

Metabolites	Related target numbers	Related number of diseases	OB (%)	DL	Species
Hexanal	6	28	55.71	0.01	*M. sargentiana*, *D. involucrata*, *A. flabellatum*, *C. fangiana*, *F. lucida*, *C. oleifera*, *P. conradinae*, *E. ruber*
Acetic acid	504	206	47.87	0.00	*C. Jensenianum*, *A. flabellatum*, *C. fangiana*, *F. lucida*, *C. oleifera*, *P. conradinae*, *E. ruber*
α-cedrene	4	36	50.9	0.10	*L. limprichtii*, *C. jensenianum*, *M. sargentiana*, *D. involucrata*, *A. flabellatum*, *F. lucida*, *P. conradinae*
β-cedrene	8	46	56.53	0.11	*M. sargentiana*, *P. conradinae*
2-pentylfuran	2	3	54.59	0.02	*C. fangiana*, *F. lucida*, *C. oleifera*, *P. conradinae*, *E. ruber*
Ethyl acetate	12	5	45.02	0.00	*M. sargentiana*, *D. involucrata*, *C. fangiana*, *F. lucida*, *P. conradinae*
(+)-Cuparene	28	103	38.26	0.07	*L. limprichtii*, *C. jensenianum*, *M. sargentiana*, *D. involucrata*
Hexadecane	1	1	12.32	0.06	*C. fangiana*, *F. lucida*
cis-Thujopsene	2	11	56.43	0.12	*L. limprichtii*, *C. jensenianum*, *S. folgneri*
Valeraldehyde	1	1	59.53	0.00	*C. fangiana*, *E. ruber*
Cedrol	5	19	16.23	0.12	*L. limprichtii*, *S. folgneri*
Patchoulane	3	4	52.71	0.11	*S. folgneri*
o-xylene	5	1	45.55	0.01	*F. lucida*
Methylcyclopentane	7	2	55.78	0.01	*A. flabellatum*
2,6,10,15-Tetramethylheptadecane	N/A	N/A	13.73	0.13	*F. lucida*
2-methylbutanal	1	N/A	54.16	0.00	*E. ruber*

Note: Oral bioavailability, OB; Drug likeness, DL. These results are derived from the Traditional Chinese Medicine Systems Pharmacology Database (TCMSP).

To identify key bioactive components, screening criteria of oral bioavailability (OB) ≥ 5% and drug-likeness (DL) ≥ 0.11 were applied. Among the 16 metabolites, 2,6,10,15-tetramethylheptadecane, *cis*-Thujopsene, cedrol, patchoulane, and *β*-cedrene meet both oral bioavailability (OB) ≥ 5% and drug-likeness (DL) ≥ 0.11. These results could serve as a reference for future research on the bioactive components (beneficial to human health) of the volatile substances in the wood of *M. sargentiana*, *P. conradinae*, *L. limprichtii*, *C. jensenianum*, *S. folgneri*, and *F. lucida*. The volatile substances of *F. lucida* wood contained 11 active medicinal components, among which 2,6,10,15-tetramethyl heptadecane—a key active component—had no corresponding target proteins or diseases. This finding suggested that 2,6,10,15-tetramethylheptadecane, a volatile compound present in the wood of *F. lucida*, might possess significant health-promoting properties and potential for drug development (Zhang *et al.* 2008). The presence of plant VOCs and negative air ions has been identified as a significant component of forest therapy. Li *et al.* (2011) demonstrated that ancient trees were a critical component of forests. This study contributed to the existing body of research on the key active components in the volatile substances of ancient tree wood that affected human health. The wood of *M. sargentiana*, *P. conradinae*, *L. limprichtii*, *C. jensenianum*, *S. folgneri*, and *F. lucida* was notable for its fresh aroma characteristics and high medicinal component content, which was advantageous for human health. These characteristics positioned the aforementioned tree species as promising candidates for the production of healthcare wood (Sales *et al.* 2020; Kong *et al.* 2022; Li *et al.* 2022; Jiang and Fan 2025).

CONCLUSIONS

1. In this study, HS–SPME–GC–MS was utilized for the systematic analysis of volatile components in the wood of ancient trees. An analysis of ancient tree species revealed the presence of terpenoid compounds, predominantly monoterpenes (*e.g.*, *α*-cedrene and *β*-cedrene) and sesquiterpenes (*e.g.*, (+)-*β*-Funebrene). These secondary metabolites had the potential to increase the stress resilience of trees through mechanisms such as antibacterial activity and insect repellency. *C. fangiana*, *E. ruber*, and *C. oleifera* contain high levels of aldehyde compounds, including valeraldehyde and hexanal. The two compounds have been shown to release volatile organic compounds, which may contribute to the resistance of plants to herbivorous insects or pathogens. Additionally, they played a role in chemical signal transmission within ecosystems.
2. A comprehensive analysis revealed substantial disparities in metabolic characteristics among diverse ancient tree species. *D. involucrata*, *C. oleifera*, and *E. ruber* were found to be particularly abundant in ester compounds, including ethyl acetate, which contributed to their fruity aroma profile and suggests potential for utilization in health care applications. *C. fangiana* and *E. ruber* contained a high proportion of aldehydes (with a peak area of up to 67%), which reflected their lipid oxidation properties and provided biomarkers for evaluating the preservation status of wood. *M. sargentiana* and *L. limprichtii* produced unique secondary metabolites, such as cedrol, which exhibited antibacterial activity and were valuable for the development of fragrance in the pharmaceutical and chemical engineering industries.

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Conflict of Interest

The present study received no third-party financial support from enterprises, companies, or other entities, and no potential conflicts of interest are present.

Use of Generative AI

The authors declare that no generative AI was used in the preparation of this manuscript.

REFERENCES CITED

Chen, Y. C., Li, Z., Zhao, Y. X., Gao, M., Wang, J. Y., Liu, K. W., Wang, X., Wu, L. W., Jiao, Y. L., Xu, Z. L., *et al.* (2020). "The *Litsea* genome and the evolution of the laurel family," *Nat. Commun.* 11(1), 1-14. https://doi.org/10.1038/s41467-020-15493-5

Dong, S. S., Liu, M., Liu, Y., Chen, F., Yang, T., Chen, L., Zhang, X. T., Guo, X., Fang, D. M., Li, L. Z, *et al.* (2021). "The genome of *Magnolia biondii* Pamp. provides insights into the evolution of Magnoliales and biosynthesis of terpenoids," *Hortic. Res*. 8(1), 38. https://doi.org/10.1038/s41438-021-00471-9

Gao, Y., Jin, Y.-J., Li, H.-D. and Chen, H.-J. (2005). "Volatile organic compounds and their roles in bacteriostasis in five conifer species," *J. Integr. Plant Biol.* 47(4), 499-507. https://doi.org/10.1111/j.1744-7909.2005.00081.x

Hu, S. J., and Zhang, R. M. (2022). "Roles of volatile organic compounds in plant adaptation to stress and physiological ecology," *J. Zhejiang Agric. & For. Univ.* 39(6), 1378-1387. https://doi.org/10.11833/j.issn.2095-0756.20220180

Gilhen-Baker, M., Roviello, V., Beresford-Kroeger, D., Roviello, G. N. (2022). "Old growth forests and large old trees as critical organisms connecting ecosystems and human health, A review," *Environ. Chem. Lett.* 20(2), 1529-1538. https://doi.org/10.1007/s10311-021-01372-y

Jiang, M., and Fan, Z. L. (2025). "Determination of bioactive compounds and antioxidant activity of four berries," *China Food Addit.* 36(10), 69-76. https://doi.org/10.19804/j.issn1006-2513.2025.10.009

Kagawa, D., Jokura, H., Ochiai, R., Tokimitsu, I., and Tsubone, H.(2003). "The sedative effects and mechanism of action of cedrol inhalation with behavioral pharmacological evaluation," *Planta. Med.* 69(7), 637-641. https://doi.org/10.1055/s-2003-41114

Kong, Q. B., Jiang, H., Guo, C. Y., Chen, T., Feng, S. L., Ding, C. B., Zhou, L. J. (2022). "Research progress on main chemical constituents and pharmacological activities of *Camellia oleifera*," *J. Chin. Cereals Oils Assoc.* 37(4), 194-202. https://doi.org/10.3969/j.issn.1003-0174.2022.04.029

Li, H. Y., Lv, Q. Y., Liu, A., Wang, J. R., Sun, X. Q., Deng, J., Chen, Q. F., and Wu, Q. (2022). "Comparative metabolomics study of Tartary (*Fagopyrum tataricum* (L.) Gaertn) and common (*Fagopyrum esculentum* Moench) buckwheat seeds," *Food Chem.* 371(1), 131125.1-131125.11. https://doi.org/10.1016/j.foodchem.2021.131125

Li, M. L., Yin, L.C., Zhang, Y., Su, X. K., Liu, G. H., Wang, X. F., Au, Y., and Wu, X. (2021). "Spatio-temporal dynamics of fractional vegetation coverage based on MODIS-EVI and its driving factors in Southwest China," *Acta Ecol. Sin.* 41(3), 1138-1147. https://doi.org/10.5846/stxb201907101451

Li, Q., Otsuka, T., and Kobayashi, M. (2011). "Acute effects of walking in forest environments on cardiovascular and metabolic parameters," *Eur. J. Appl. Physiol.* 111(11), 2845-2853. https://doi.org/10.1007/s00421-011-1918-z

Loreto, F., and Schnitzler, J. P. (2010). "Abiotic stresses and induced BVOCs," *Trends Plant Sci.* 15(3), 154-166. https://doi.org/10.1016/j.tplants.2009.12.006

Meng, L. S., Zheng, T. T., Wang, S. Q., Chen T. J., Nie, Y., and Xu S. (2025). "Characterization and analysis of characteristic aroma compounds of fresh *Dictyophora rubrovalvata* in Guizhou based on gas chromatography-ion mobility spectrometry and gas chromatography-mass spectrometry," *Food and Fermentation Industries* 51(16), 314-323. https://doi.org/10.13995/j.cnki.11-1802/ts.041636

Meritxell, P. H., Miquel, A. V., Sandra, V., Carolina, G., Clara, P., Vicent, A., Jose L. R., Vicente, N. L., Antonio, G., Alberto, U. (2021). "Plant exposure to herbivore-induced plant volatiles: a sustainable approach through eliciting plant defenses," *J. Pest Sci.* 94(4), 1221-1235. https://doi.org/10.1007/s10340-021-01334-x

Nakai, Y., Kido, T., Hashimoto, K., Kase, Y., Sakakibara, I., Higuchi, M., and Sasaki, H. (2003). "Effect of the rhizomes of *Atractylodes lancea* and its constituents on the delay of gastric emptying," *J. Ethnopharmacol.* 84(1), 51-55. https://doi.org/10.1016/s0378-8741(02)00260-x

Ninkuu, V., Zhang, L., Yan, J. P., Fu, Z. C., Yang, T. F., Zeng, H. M. (2021). "Biochemistry of terpenes and recent advances in plant protection," *Int. J. Mol. Sci.* 22(11), 5710. https://doi.org/10.3390/ijms22115710

Peng, S. L., Nan P., and Zhong, Y. (2002). "Terpenoids in higher plants and their roles in ecosystems," *Chin. J. Ecol.* 21(3), 33-38. https://doi.org/10.13292 / j.1000-4890.2002.0050

Pichersky, E., and Gershenzon, J. (2002). "The formation and function of plant volatiles: perfumes for pollinator attraction and defense," *Curr. Opin. Plant Biol.* 5(3), 237-243. https://doi.org/10.1016/s1369-5266(02)00251-0

Rashaduz, Z., Akanksha J., Almuth H., Jonathan G., and Dineshkumar K. (2024). "A rationale for chemical defense mixtures in spruce oleoresin: Most monoterpenes are highly toxic to either bark beetles or to their symbiotic fungi, but not both," *New Phytol.* 1(1), 1-21. https://doi.org/10.21203/rs.3.rs-4919445/v1

Ru, J. L., Li, P., Wang, J. N., Zhou, W., Li, B. H., Huang, C., Li, P. D., Guo, Z. H., Tao, W. Y. Yang, Y. F., *et al.* (2014). "TCMSP: a database of systems pharmacology for drug discovery from herbal medicines," *J. Cheminform.* 6(1), 1-6. https://doi.org/10.1186/1758-2946-6-13

Sales, A., Felipe, O. L., and Bicas, J. L. (2020). "Production, properties, and applications of α-terpineol," *Food Bioproc. Tech.* 13(8), 1261-1279. https://doi.org/10.1007/s11947-020-02461-6

Schreiner, L., Bauer, P., and Buettnerm, A. (2018). "Resolving the smell of wood identification of odour-active compounds in Scots pine (*Pinus sylvestris* L.)," *Sci. Rep.* 8(1), 1-9. https://doi.org/10.1038/s41598-018-26626-8

Shen, L., Chu Y. G., Zhang W. X., Zhang J., Zhang T. Q., Li Z. H., Ding C. J., and Su X. H. (2024). "Comparative analysis of volatile compounds in the wood of *Populus koreana* and *Populus ussuriensis*," *Scientia Silvae Sinicae* 60(01), 103-110. https://doi.org/10.11707/j.1001-7488.LYKX20220443

Sotaro, H., and Akiko, S. (2024). "Theoretical analyses for the evolution of biogenic volatile organic compounds (BVOC) emission strategy," *BMC Ecol. Evol.* 14(7), 1-13. https://doi.org/10.1002/ece3.11548

Tak, J. H., and Isman, M. B. (2015). "Enhanced cuticular penetration as the mechanism for synergy of insecticidal constituents of rosemary essential oil in *Trichoplusia ni*," *Sci. Rep.* 5(1), 12690. https://doi.org/10.1038/srep12690

Tays, G., Arthur A., Larisse P., Julio O., Mathania F., Javanyr J., Robson V. and Isac M. (2025) "Monoterpenes in vascular function: A review of bioactivity and mechanisms

of action," *Int. J. Mol. Sci.* 26(18), 9243. https://doi.org/10.3390/ijms26189243
Turlings, T. C. J., and Erb, M. (2018). "Tritrophic interactions mediated by herbivore induced plant volatiles: Mechanisms, ecological relevance, and application potential," *Annu. Rev. Entomol.* 7(63), 433-452. https://doi.org/10.1146/annurev-ento-020117-043507
Umeno, K., Hori, E., Tsubota, M., Shojaku, H., Miwa, T., Nagashima, Y., Yada, Y., Suzuki, T., Ono, T., and Nishijo, H. (2008). "Effects of direct cedrol inhalation into the lower airway on autonomic nervous activity in totally laryngectomized subjects," *Br. J. Clin. Pharmacol.* 65(2), 188-196. https://doi.org/10.1111/j.1365-2125.2007.02992.x
Xie, D. Z., Ma, H. Y., Lai, W. T., Zhang, H. L., Yuan, F. J., and Qian, Y. L. (2022). "Released characteristics of volatile organic compounds in *Cunninghamia lanceolata*," *Subtrop. Plant Sci.* 51(03), 178-183. https://doi.org/10.3969/j.issn.1009-7791.2022.03.003
Yan, Y. F., Yang, C. J., Shang, X. F., Zhao, Z. M., Liu, Y. Q., Zhou, R., Liu, H., Wu, T. L., Zhao, W. B., Wang, Y. L., *et al.* (2020). "Bioassay- guided isolation of two antifungal compounds from *Magnolia officinalis*, and the mechanism of action of honokiol," *Pestic. Biochem. Physiol.* 170(170), 12-13. https://doi.org/10.1016/j.pestbp.2020.104705
Yu, J. F., He, Q., Zhang, X. T., Yao, L. H., Wang, X. M. (2020). "Sampling and test method of volatile organic compounds (VOCs) from wood drying," *Appl. Chem. Ind.* 49(08), 1941-1945. https://doi.org/10.16581/j.cnki.issn.1671-3206.2020.08.002
Zeng, B., Shen, J., Wang, Q. F., Dong, H. J. (2021). "Analysis of odorants in *Cinnamomum burmannii* wood with different moisture contents," *Sci. Silv. Sin.* 57(4), 133-141. https://doi.org/10. 11707/j.1001-7488.20210414
Zhang, Y. Y., Jia, X. N., Cao, Y. X., and Wang, J. X. (2008). "Studies on the chemical constituents of *Abelmoschus manihot*," *Northwest Pharm. J.* 23(2), 80-82. https://doi.org/10.3969/j.issn.1004-2407.2008.02.010
Zhu-Salzman, K., Bi, J. L., and Liu, T. X. (2005). "Molecular strategies of plant defense and insect counter-defense," *Insect Sci.* 12(1), 3-15. https://doi.org/10.1111/j.1672-9609.2005.00002.x

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