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Comparison of the anatomic structure of the wood and flavonoid composition of the extracts of Jiangzhenxiang and *Dalbergia odorifera*

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Abstract

Jiangzhenxiang—the resinous material formed in *Dalbergia pinnata*—exhibits dense texture, attractive grain patterns, and abundant inclusions, frequently being substituted for or combined with *Dalbergia odorifera* as the traditional Chinese medicine “Jiangxiang.” Investigating their physicochemical characteristics and clarifying their distinctions will facilitate optimized material utilization. Comparative anatomical analysis through sectioning revealed three key differences: (1) Jiangzhenxiang exhibits more densely distributed vessels, frequently occluded with reddish-brown gum deposits, whereas such deposits are rarely observed in *D. odorifera*; (2) its wood rays in Jiangzhenxiang are predominantly uniseriate and non-storied, while *D. odorifera* possesses predominantly multiseriate rays accompanied by a distinctly storied arrangement of all axial elements; (3) axial parenchyma in Jiangzhenxiang is primarily vasicentric and paratracheal banded (2–5 cells wide), whereas *D. odorifera* displays aliform, confluent, paratracheal banded, and apotracheal banded configurations. Ultra-high-performance liquid chromatography quadrupole time-of-flight mass spectrometry analysis of wood extracts identified 18 flavonoid compounds and the suggestion of 17 flavonoids in Jiangzhenxiang for the first time, primarily comprising flavonoids, dihydroflavonoids, isoflavones, and chalcones showing compositional congruence with *D. odorifera*. Both species shared dominant constituents including liquiritigenin, formononetin, calycosin, and isoliquiritigenin. Quantitative variations emerged notably in calycosin and isorhamnetin levels (significantly higher in Jiangzhenxiang, contrasted with fisetin, butin, medicarpin, and dalbergin concentrations [markedly lower than *D. odorifera*]). This study delineates microstructural distinctions in vessel pores, wood rays, and axial parenchyma while pioneering the identification of principal flavonoids in Jiangzhenxiang. These findings establish a scientific foundation for its rational application in wood utilization and herbal medicine, particularly regarding its substitutive potential for *D. odorifera*.

Keywords Jiangzhenxiang (the resinous wood from *Dalbergia pinnata*), *Dalbergia odorifera*, Wood anatomy, Flavonoid

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Introduction

Jiangzhenxiang—also referred to as “zitengxiang” or “jiguxiang”—is a resinous composite formed in *Dalbergia pinnata* (Leguminosae) during wound-healing responses, comprising resinous deposits and lignified tissue, exhibiting compositional parallels to agarwood formation processes. Characterized by reddish-brown heartwood with esthetically striking grain patterns, it is crafted into root carvings, ornamental displays, and bracelets. Due to morphological similarities to the premium rosewood species *Dalbergia odorifera* T. Chen (commonly termed Hainan Huanghuali), it is frequently misrepresented as *D. odorifera*, a semi-deciduous tree in the Papilionaceae family, features dense heartwood with intricate figuring and ranks as the most valuable timber among the 29 rosewood species listed in China's National Standard GB/T 18107–2017 [1–4]. Although Jiangzhenxiang heartwood mimics the coloration and grain of *D. odorifera*, its market value remains substantially lower. Accurate differentiation between these species is of critical importance for maintaining stability in the rosewood trade.

Jiangzhenxiang contains abundant extractable compounds, demonstrating medicinal properties such as promoting blood circulation, resolving blood stasis, reducing swelling, alleviating hemorrhage, dispelling rheumatism, and exhibiting antimicrobial and anti-inflammatory effects, with potential applications in cardiovascular disease prevention [5–8]. Historically, it has been utilized as the traditional Chinese medicine “Jiangxiang” [9, 10]. However, standardized pharmacological regulations in the Chinese Pharmacopoeia (2015 Edition) strictly define “Jiangxiang” as the dried heartwood and roots of *D. odorifera*, which possesses well-documented pharmacological actions including blood activation, stasis elimination, Qi regulation, pain alleviation, coronary artery dilation, and antitumor activity, primarily employed in treating coronary heart disease, cardiac conditions, and cerebrovascular disorders [11–15]. Consequently, Jiangzhenxiang is excluded from the official “Jiangxiang” classification. Nevertheless, its heartwood exhibits comparable therapeutic efficacy to *D. odorifera* heartwood, prompting critical questions: What underlies their pharmacological similarities? What distinctions exist in their bioactive profiles? Comprehensive comparative analysis of their extract compositions is essential to address these questions. However, the chemical constituents of Jiangzhenxiang extracts remain uncharacterized, significantly constraining its potential pharmaceutical applications.

To address these research gaps, this study first conducted comparative analyses of Jiangzhenxiang and *D. odorifera* through macroscopic and microscopic examination of wood sections, establishing identification criteria for these species. Subsequently,

ultra-high-performance liquid chromatography quadrupole time-of-flight mass spectrometry (UHPLC-QTOF-MS) was employed to systematically characterize flavonoid constituents in Jiangzhenxiang heartwood extracts, followed by comparative phytochemical profiling against *D. odorifera*. This dual-pronged approach aims to elucidate both anatomical distinctions and phytochemical convergences between the species, thereby providing a scientific foundation for the standardized utilization of “Jiangxiang” in traditional Chinese medicine.

Materials and methods

Plant material and chemical reagent

Wood specimens of *D. odorifera* and Jiangzhenxiang were obtained from the Herbarium of the Forestry College at Guangxi University. Both specimens were collected from Haikou, Hainan Province, and were derived from arborescent (tree-form) individuals. For *D. odorifera*, all experiments were conducted exclusively on heartwood. In contrast, for Jiangzhenxiang, which lacks a distinct heartwood-sapwood boundary, wood blocks were selected from the inner region near the pith. Both microscopic observation and chemical analysis specifically targeted the “resin-rich” areas (a process known as “Jiexiang” [resin deposition] formation), identified by their characteristic dark discoloration.

Methanol and formic acid were obtained from Shanghai Macklin Biochemical Co., Ltd (Shanghai, China). Ultrapure water was prepared using a Milli-Q system (Millipore Corp., Bedford, MA, USA). Medicarpin, formononetin, pinocembrin, butein, isoliquiritigenin, liquiritigenin, butin, dalbergin, eriodictyol, luteolin, naringenin, genistein, glycitein, tectorigenin, calycosin, daidzein, biochanin A, and fisetin were purchased from Shanghai Yuanye Co., Ltd (Shanghai, China).

Observation of microstructural characteristics

The wood surfaces were polished with sandpaper to reveal macroscopic features. Images were acquired using a stereomicroscope (ZOOM 70XL, OPTEM) with a 10× objective lens and a digital camera (EOS R7, Canon). Scale bars are indicated in each image.

The observations were conducted on 20 µm thick transverse sections prepared with a sliding microtome (SM2010R, Leica), which were subsequently stained with safranin, dehydrated through a graded ethanol series, cleared with TO Type Transparent Agent (a turpentine oil-based xylene substitute), and permanently mounted with a synthetic resin for microscopic examination. Images were acquired using a light microscope (Ti2-U, Nikon) equipped with a 40× objective lens (NA 0.95). Scale bars are indicated in each image.

Characterization of flavonoid components

Wood was ground in liquid nitrogen to pass through a 60-mesh sieve. Subsequently, 10.0 mg of the resulting wood powder was weighed and mixed with 1 mL of 80% methanol solution. Extraction was performed at 4 °C for 24 h, with two intermittent rounds of ultrasonication (40 kHz) in an ice-water bath. Finally, the mixture was centrifuged at $17000\times g$ and 4 °C for 15 min, and the supernatant was collected for analysis.

Ultra-high-performance liquid chromatograph quadrupole time-of-flight mass spectrometer (Thermo Fisher Scientific, USA) was used to identify the flavonoid chemical components. The chromatographic column ACQUITY UPLC BEH C18 (2.1 mm $\times$ 50 mm $\times$ 1.7 μ m) was used with the following mobile phase: A=0.1% formic acid in water, B=methanol; the gradient elution conditions were: 0–15.0 min, 5% B, 15.0–18.0 min, 5–80% B, 18.0–18.1 min, 100–5% B, 18.1–21.0 min, 5% A. The flow rate was 0.3 mL min⁻¹. The injection volume was set at 1.0 μ L. The high-resolution mass spectrometry conditions involved the following: an ESI ion source, temperature=300 °C, transmission capillary temperature=320 °C, a sheath gas of the pressure 206 kPa, auxiliary gas flow rate=69 mL/min, spray voltage=3.0 kV in the positive ion mode, a scan mode in full MS and Full MS/dd-MS2, a mass range of 100–1000 Da, and the resolutions of primary and secondary scans were 70,000 and 17,500, respectively. Each mixture was repeatedly analyzed three times.

Results and discussion

Anatomical analysis of Jiangzhenxiang

Macroscopically, the heartwood of Jiangzhenxiang exhibits a distinct color demarcation from the sapwood,

ranging from reddish-brown to deep reddish-brown against the lighter-colored sapwood (Fig. 1A). The heartwood emits a characteristic, complex aroma with notes of coconut, sweetness, and herbs, attributable to abundant resinous deposits. Anatomically, the wood is diffuse-porous. Vessels are solitary, in radial multiples of 2–4, and in occasional clusters. They show considerable variation in diameter, are densely distributed, and have oval to circular outlines (Fig. 1B, C). Many vessels are occluded with reddish-brown gum deposits (Fig. 1C). Axial parenchyma manifests primarily as paratracheal banded patterns (2–5 cells wide) and vasicentric (Fig. 1C). Rays are predominantly uniseriate; multiseriate rays are 2–3 cells wide and 4–15 cells high. The ray tissue is primarily homocellular, though heterocellular rays are occasionally observed. The wood rays are non-storied to locally storied. (Fig. 1D, E).

Anatomical analysis of *D. odorifera* wood

Macroscopically, the heartwood of *D. odorifera* exhibits a distinct color demarcation from the sapwood, ranging from brown to deep reddish-brown against the pale yellow sapwood. A characteristic, persistent “Jiangxiang” (rosewood) aroma is emitted from the heartwood. Anatomically, the wood is transitional from diffuse-porous to semi-ring-porous (Fig. 2B). Vessels are solitary and in radial multiples of 2–3, with oval to circular outlines. Axial parenchyma is abundant and predominantly paratracheal, specifically manifested as vasicentric, aliform, and confluent; additional apotracheal banded parenchyma (3–6 cells wide) is also present (Fig. 2C). Wood rays are composed of large, rounded cells. They are predominantly multiseriate (2–4 cells wide and 4–10 cells high), with fewer uniseriate rays. The ray tissue

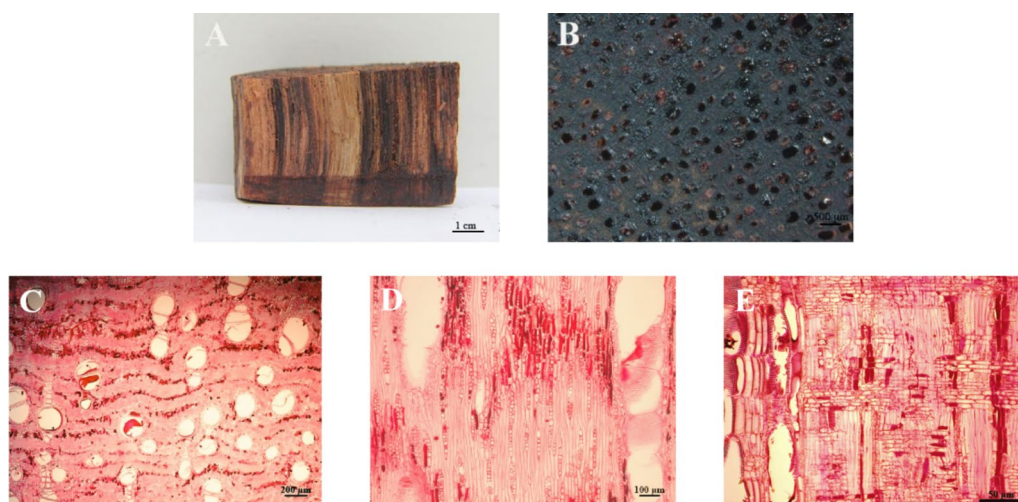


Fig. 1 Macroscopical and microscopic photos of Jiangzhenxiang. **A** and **B** Macroscopical, **C** cross section, **D** tangential section, **E** radial sections

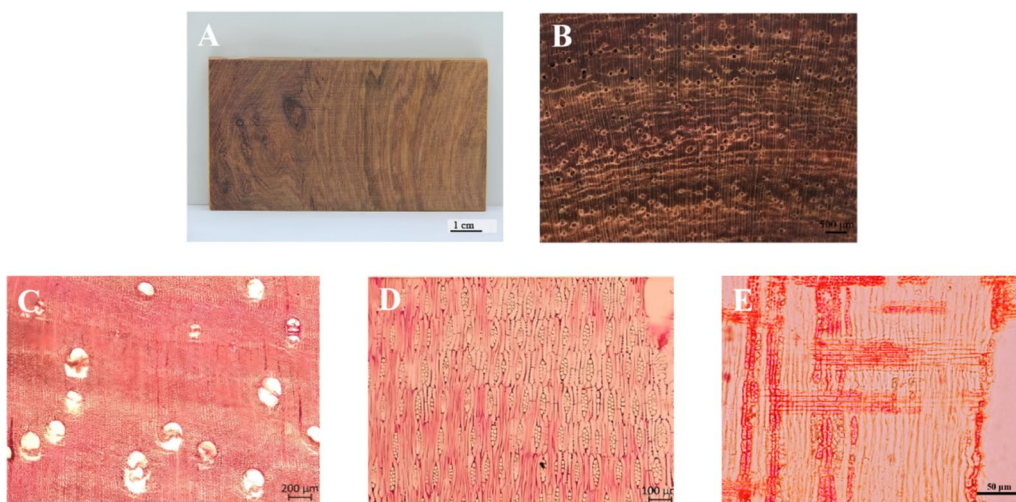


Fig.2 Macroscopic and microscopic photos of *D. odorifera* wood. **A** and **B** Macroscopical, **C** cross section, **D** tangential section, **E** radial sections

is primarily homocellular, though heterocellular rays are occasionally observed (Fig. 2 D, E). A key diagnostic feature is that all axial elements (vessels, fibers, axial parenchyma) and rays demonstrate a distinctly storied arrangement.

The anatomical difference between Jiangzhenxiang and *D. odorifera* wood

Current research on the anatomical distinctions between *D. odorifera* and Jiangzhenxiang remains limited. This study systematically investigated heartwood sections of both species, revealing anatomical differences. Macroscopically, though both exhibit reddish-brown to deep reddish-brown heartwood coloration, with discernible aromatic variations. Microscopically, cross-sections of Jiangzhenxiang show abundant reddish-brown gum deposits within vessels, a feature less prominent in *D. odorifera*. While both species possess predominantly solitary vessels with occasional radial multiples, those in Jiangzhenxiang are more densely distributed. A clear diagnostic difference lies in ray structure. In *D. odorifera*, all axial elements (vessels, fibers, axial parenchyma) and rays exhibit a distinctly storied arrangement. Rays are primarily homocellular, with occasional heterocellular rays, and are predominantly multiseriate. In contrast, rays of Jiangzhenxiang are non-storied to only locally aligned, predominantly uniseriate with rare biseriate formations, and lack storied structure in axial tissue. Axial parenchyma organization further distinguishes the two species: Jiangzhenxiang shows mainly paratracheal banded parenchyma, whereas *D. odorifera* displays more diverse configurations, including aliform, confluent, and broader paratracheal bands. These anatomical divergences provide critical identification markers for species

differentiation and quality control in medicinal and timber applications.

Structure identification of flavonoids in extracts

The chemical composition of wood extracts not only determines chromatic and aromatic properties but also governs pharmacological efficacy through bioactive constituents, particularly flavonoids. Despite Jiangzhenxiang's therapeutic potential, its extract composition remains uncharacterized, significantly limiting application development. To elucidate flavonoid divergences between Jiangzhenxiang and *D. odorifera* heartwoods, we conducted UPLC-QTOF-MS analyses of 80% methanol extracts in positive ion mode. Using the XIC Manager module in Compound Discoverer 3.1 software, we performed automated molecular formula prediction based on precursor ion exact masses. Compound identification was performed using UHPLC-QTOF-MS data. Where available, reference standards were used to confirm identities based on retention time and MS/MS fragmentation (Fig. 3, Fig. S1 and S2). For compounds without standards, tentative identifications were suggested based on accurate mass measurements (mass error < 5 ppm), MS/MS fragmentation patterns, and comparison with spectral databases (mzCloud, MassBank) and published literature. This approach enabled the identification of 18 flavonoid compounds and the suggestion of 17 flavonoids (Fig. 4; Table 1), categorized into flavones, flavonols, dihydroflavones, isoflavones, and chalcones. Notably, all 35 flavonoids represent novel identifications and suggestions in Jiangzhenxiang, marking the first comprehensive phytochemical profile of this species. These findings establish a critical foundation for understanding

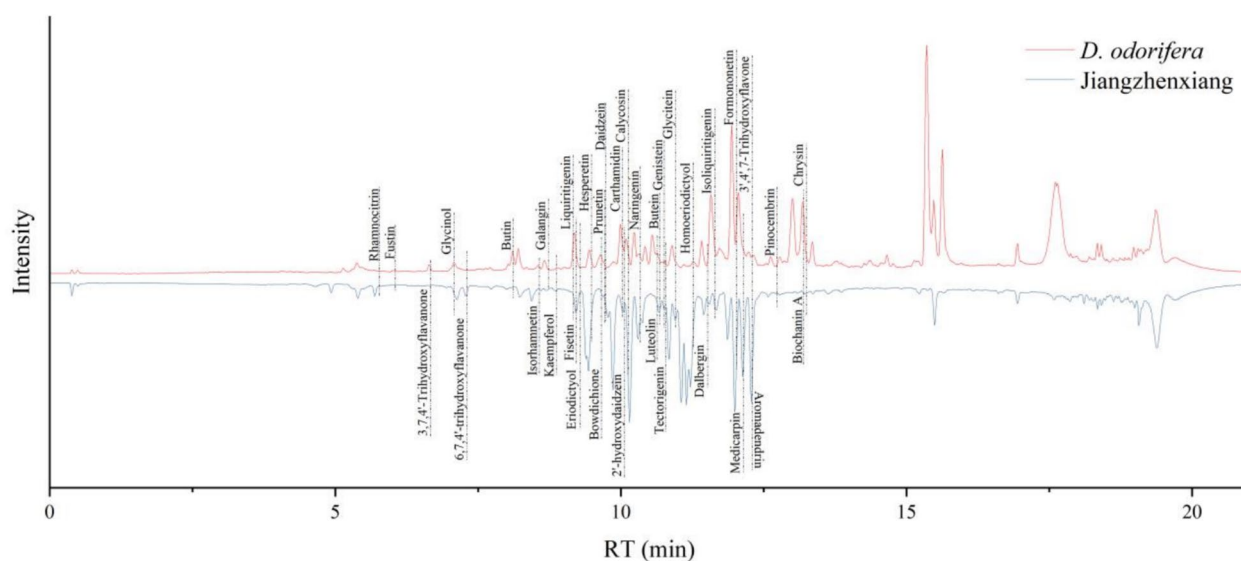


Fig.3 Total ion chromatogram of *D. odorifera* and Jiangzhenxiang

interspecies bioactivity variations and optimizing medicinal applications of Jiangxiang-related materials.

Flavonoids and flavonol compounds

Compound 2 exhibited a precursor ion at m/z 255.0647 $[M+H]^+$. The flavone skeleton's C-ring demonstrated characteristic oxygen loss and underwent retro-Diels-Alder (RDA) cleavage. With RDA-derived diagnostic ions at m/z 153.0180 and m/z 103.0545. Spectral matching with reference databases suggested the identity of this compound as chrysin.

Compounds 8 and 12 were isomers with molecular ion peaks both at m/z 271.0952 $[M+H]^+$, inferred molecular formula $C_{15}H_{10}O_5$, compound 8 suggested to have a hydroxyl substitution at the C_3 position and suggested to be a flavonol compound, and compound 12 suggested to be a flavonoid. The secondary fragmentation letter of compound 8 had m/z 253.0493 $[M+H-H_2O]^+$, m/z 225.0542 $[M+H-H_2O-CO]^+$, m/z 197.0592 $[M+H-H_2O-2CO]^+$, and m/z 169.0645 $[M+H-H_2O-3CO]^+$, which was deduced to be Galangin after mass spectral library. Compound 12 showed secondary characteristic fragments m/z 243.0647 $[M+H-CO]^+$, m/z 197.0594 $[M+H-2CO-H_2O]^+$, and then RDA cleavage supposed to yield fragments m/z 137.0596, which were recommended as 3',4',7- trihydroxyflavone in combination with the literature reports [16].

Compounds 24 and 25 were identified and compound 23 was suggested as isomeric form sharing the molecular formula $C_{15}H_{10}O_6$ with a precursor ion peak at m/z 287.0545 $[M+H]^+$. Compounds 24 and 25 demonstrated chromatographic and spectrometric congruence with

reference standards, enabling their definitive identification as fisetin and luteolin, respectively. Compound 23 exhibited characteristic fragmentation patterns: initial possible elimination of a CO molecule supposed to generate the fragment ion at m/z 259.0963, followed by possible sequential losses of CO and H_2O yielding diagnostic ions at m/z 213.0901. Subsequent possible RDA cleavage produced signature fragments at m/z 153.0181 and 135.0440 $[M+H]^+$. Through comparative analysis with mass spectral databases and fragmentation pathway elucidation, compound 23 was suggested to be kaempferol.

Compound 31 exhibited a molecular ion peak at m/z 301.0708 $[M+H]^+$, with high-resolution mass spectrometry confirming its molecular formula as $C_{16}H_{12}O_6$. Sequential fragmentation analysis revealed characteristic possible dissociation pathways: initial elimination of two CO molecules supposed to generate the fragment ion at m/z 245.0607, followed by possible dehydration H_2O yielding m/z 227.1751. Possible RDA cleavage would produce the diagnostic ion m/z 167.0700 $[A^{1,3}]^+$ (A-ring fragment ion of the flavonoid). Through systematic comparison with mass spectral databases and fragmentation pattern analysis, compound 31 was conclusively suggested to be rhamnocitrin.

Compound 35 displayed a molecular ion peak at m/z 317.0652 $[M+H]^+$, with high-resolution mass spectrometry establishing its molecular formula as $C_{16}H_{12}O_7$. Tandem MS analysis revealed possible sequential fragmentation patterns: initial elimination of a methanol molecule (CH_3OH) generated the fragment ion at m/z 285.0791 $[M+H-CH_3OH]^+$, followed by possible successive CO losses producing

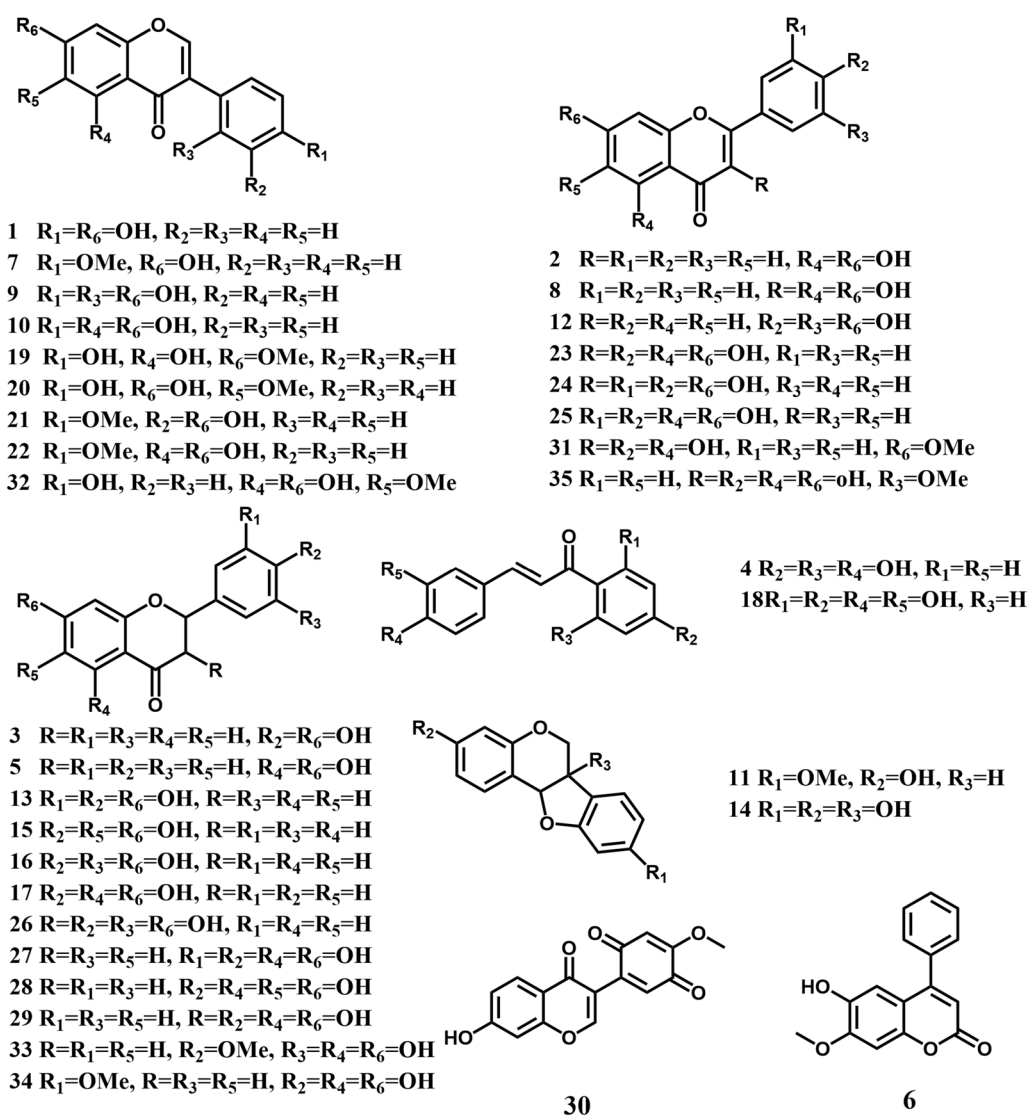


Fig.4 Chemical structures of compositions identified in Jiangzhenxiang extracts

ions at m/z 257.0840 $[M+H-CH_3OH-CO]^+$ and m/z 228.0495 $[M+H-CH_3OH-2CO]^+$. A characteristic RDA cleavage would yield the diagnostic ion m/z 153.0482 $[A^{1,3}]^+$ (A-ring fragment ion of the flavonoid). Through systematic spectral matching and fragmentation pathway analysis against mass spectral databases, compound 35 was unambiguously suggested to be isorhamnetin.

Dihydroflavonoids compounds

Compounds 3, 5, 16, 17, and 27 exhibited retention times and fragmentation patterns identical to reference standards, confirming their identities as liquiritigenin, pinocembrin, butin, naringenin, and eriodictyol, respectively.

Compounds 13 and 15 were suggested to be isomers with the parent ion of m/z 273.0755 $[M+H]^+$, and both were supposed to be cleaved by RDA to produce the characteristic peak of m/z 137.0232 $[A^{1,3}]^+$. Compound 13 had secondary fragments of m/z 245.0804 $[M+H-CO]^+$, m/z 229.0489 $[M+H-CO-O]^+$, m/z 227.1751 $[M+H-CO-H_2O]^+$, which were recommended by reference [17] and mass spectrometry library as 3,7,4'-trihydroxyflavanone. Compound 15 secondary fragments had m/z 255.0647 $[M+H-H_2O]^+$, m/z 227.0698 $[M+H-H_2O-CO]^+$, m/z 199.0751 $[M+H-H_2O-2CO]^+$, m/z 181.0644 $[M+H-2H_2O-2CO]^+$, which was recommended to be 6,7,4'-trihydroxyflavanone by reference [18] and mass spectral library.

Table 1 UPLC-MS/MS data of the compositions identified in the heartwood extracts of Jiangzhenxiang and *D. odorifera*

NO	RT	Identification	Molecular formula	Error/ppm	[M + H] ⁺		Main fragments (m/z)	Peak areas	
					calculated	experimental		<i>D. odorifera</i>	Jiangzhenxiang
1	9.69	Daidzein	C ₁₅ H ₁₀ O ₄	0.22	255.0652	255.0648	227.0700, 237.0538, 199.0753, 181.0645, 137.0232	4.42 × 10 ⁸	1.00 × 10 ⁸
*	9.69	Daidzein	C ₁₅ H ₁₀ O ₄	0.22	255.0652	255.0648	227.0700, 237.0538, 199.0753, 181.0645, 137.0232		
2	13.24	Chrysin	C ₁₅ H ₁₀ O ₄	0.16	255.0652	255.0647	239.1061, 153.0180, 103.0545	1.51 × 10 ⁷	2.29 × 10 ⁵
3	9.22	Liquiritigenin	C ₁₅ H ₁₂ O ₄	−0.24	257.0808	257.0804	239.0696, 211.0751, 137.0232, 119.0492	4.66 × 10 ⁹	2.40 × 10 ⁹
*	9.22	Liquiritigenin	C ₁₅ H ₁₂ O ₄	−0.24	257.0808	257.0804	239.0696, 211.0751, 137.0232, 119.0492		
4	11.66	Isoliquiritigenin	C ₁₅ H ₁₂ O ₄	−0.19	257.0808	257.0804	239.0699, 211.0753, 137.0232, 119.0493	2.53 × 10 ⁹	1.31 × 10 ⁹
*	11.66	Isoliquiritigenin	C ₁₅ H ₁₂ O ₄	−0.19	257.0808	257.0804	239.0699, 211.0753, 137.0232, 119.0493		
5	12.71	Pinocembrin	C ₁₅ H ₁₂ O ₄	−0.37	257.0808	257.0804	153.0181	1.28 × 10 ⁹	8.92 × 10 ⁶
*	12.70	Pinocembrin	C ₁₅ H ₁₂ O ₄	−0.37	257.0808	257.0804	153.0181		
6	11.5	Dalbergin	C ₁₆ H ₁₂ O ₄	−0.83	269.0808	269.0804	254.0566, 253.0492	3.56 × 10 ⁹	2.55 × 10 ⁶
*	11.51	Dalbergin	C ₁₆ H ₁₂ O ₄	−0.83	269.0808	269.0804	254.0566, 253.0492		
7	12.01	Formononetin	C ₁₆ H ₁₂ O ₄	−0.62	269.0808	269.0803	254.0566, 253.0490, 225.0541, 197.0594, 137.0233	9.99 × 10 ⁹	3.07 × 10 ⁹
*	12.01	Formononetin	C ₁₆ H ₁₂ O ₄	−0.62	269.0808	269.0803	254.0566, 253.0490, 225.0541, 197.0594, 137.0233		
8	8.57	Galangin	C ₁₅ H ₁₀ O ₅	0.09	271.0601	271.0592	253.0493, 225.0542, 197.0592, 169.0645	7.03 × 10 ⁸	1.29 × 10 ⁸
9	10.07	2'-hydroxydaidzein	C ₁₅ H ₁₀ O ₅	0.1	271.0601	271.0598	225.0544, 197.0597, 169.0648, 137.0233	2.40 × 10 ⁸	1.56 × 10 ⁷
10	10.74	Genistein	C ₁₅ H ₁₀ O ₅	−0.11	271.0601	271.0598	257.0437, 229.0493, 137.0596	1.59 × 10 ⁸	6.32 × 10 ⁶
*	10.73	Genistein	C ₁₅ H ₁₀ O ₅	−0.11	271.0601	271.0598	257.0437, 229.0493, 137.0596		
11	12.15	Medicarpin	C ₁₆ H ₁₄ O ₄	−0.11	271.0965	271.0959	243.1010, 197.0601, 137.0599	6.75 × 10 ⁹	3.25 × 10 ⁷
*	12.14	Medicarpin	C ₁₆ H ₁₄ O ₄	−0.11	271.0965	271.0959	243.1010, 197.0601, 137.0599		
12	12.29	3',4',7-Trihydroxyflavone	C ₁₅ H ₁₀ O ₅	0.59	271.0601	271.06	243.0647, 197.0594, 137.0596	5.71 × 10 ⁷	2.53 × 10 ⁶
13	6.67	3,7,4'-Trihydroxyflavanone	C ₁₅ H ₁₂ O ₅	−0.21	273.0757	273.0755	245.0804, 229.0489, 227.1751, 137.0599	2.30 × 10 ⁷	1.99 × 10 ⁶
14	7.04	Glycinol	C ₁₅ H ₁₂ O ₅	−0.53	273.0757	273.075	255.0647, 227.0699	4.08 × 10 ⁷	4.57 × 10 ⁸
15	7.21	6,7,4'-trihydroxyflavanone	C ₁₅ H ₁₂ O ₅	−0.48	273.0757	273.0744	255.0647, 227.0698, 199.0751, 181.0644, 137.0232	1.00 × 10 ⁸	2.25 × 10 ⁷
16	8.13	Butin	C ₁₅ H ₁₂ O ₅	−0.26	273.0757	273.0753	255.0647, 237.0540, 227.0700, 163.0421, 137.0232	2.36 × 10 ⁹	4.23 × 10 ⁶
*	8.13	Butin	C ₁₅ H ₁₂ O ₅	−0.26	273.0757	273.0753	255.0647, 237.0540, 227.0700, 163.0421, 137.0232		
17	10.35	Naringenin	C ₁₅ H ₁₂ O ₅	−0.32	273.0757	273.0752	255.0652, 189.0452, 171.0285, 153.0180	5.41 × 10 ⁸	1.57 × 10 ⁷
*	10.37	Naringenin	C ₁₅ H ₁₂ O ₅	−0.32	273.0757	273.0752	255.0652, 189.0452, 171.0285, 153.0180		

Table 1 (continued)

NO	RT	Identification	Molecular formula	Error/ppm	[M + H] ⁺		Main fragments (m/z)	Peak areas	
					calculated	experimental		<i>D. odorifera</i>	<i>Jiangzhenxiang</i>
18	10.69	Butein	C ₁₅ H ₁₂ O ₅	− 0.33	273.0757	273.0752	255.0648, 227.0700, 137.0232, 135.0440	1.51 × 10 ⁹	1.81 × 10 ⁶
*	10.69	Butein	C ₁₅ H ₁₂ O ₅	− 0.33	273.0757	273.0752	255.0648, 227.0700, 137.0232, 135.0440		
19	9.68	Prunetin	C ₁₆ H ₁₂ O ₅	− 0.33	285.0757	285.0748	270.0516, 229.0855, 213.0544	1.48 × 10 ⁹	5.78 × 10 ⁷
20	10.96	Glycitein	C ₁₆ H ₁₂ O ₅	− 0.36	285.0757	285.0754	257.0805, 229.0858, 225.0542, 197.0594	3.97 × 10 ⁹	2.46 × 10 ⁸
*	10.97	Glycitein	C ₁₆ H ₁₂ O ₅	− 0.36	285.0757	285.0754	257.0805, 229.0858, 225.0542, 197.0594		
21	10.15	Calycosin	C ₁₆ H ₁₂ O ₅	− 0.34	285.0757	285.0753	270.0518, 253.0491, 197.0596, 137.0232	3.95 × 10 ⁹	1.16 × 10 ¹⁰
*	10.14	Calycosin	C ₁₆ H ₁₂ O ₅	− 0.34	285.0757	285.0753	270.0518, 253.0491, 197.0596, 137.0232		
22	13.20	Biochanin A	C ₁₆ H ₁₂ O ₅	− 0.23	285.0757	285.0752	270.0616, 269.0435, 241.0492, 213.0542, 153.0182	6.73 × 10 ⁸	7.20 × 10 ⁷
*	13.20	Biochanin A	C ₁₆ H ₁₂ O ₅	− 0.23	285.0757	285.0752	270.0616, 269.0435, 241.0492, 213.0542, 153.0182		
23	8.77	Kaempferol	C ₁₅ H ₁₀ O ₆	0.59	287.055	287.0545	259.0963, 213.0901, 153.0181, 135.0440	7.35 × 10 ⁷	2.67 × 10 ⁶
24	9.14	Fisetin	C ₁₅ H ₁₀ O ₆	0.51	287.055	287.0546	241.0494, 213.0542, 185.0593, 157.0647, 137.0233	3.07 × 10 ⁸	1.58 × 10 ⁶
*	9.14	Fisetin	C ₁₅ H ₁₀ O ₆	0.51	287.055	287.0546	241.0494, 213.0542, 185.0593, 157.0647, 137.0233		
25	10.63	Luteolin	C ₁₅ H ₁₀ O ₆	0.70	287.055	287.0552	137.0596	6.86 × 10 ⁶	3.08 × 10 ⁵
*	10.63	Luteolin	C ₁₅ H ₁₀ O ₆	0.70	287.055	287.0552	137.0596		
26	6.04	Fustin	C ₁₅ H ₁₂ O ₆	− 0.04	289.0707	289.0697	271.0594, 243.0647, 215.0699, 197.0595, 137.0232	1.48 × 10 ⁸	1.89 × 10 ⁶
27	9.28	Eriodictyol	C ₁₅ H ₁₂ O ₆	− 0.59	289.0707	289.0707	271.0602, 153.0181	8.60 × 10 ⁷	2.34 × 10 ⁵
*	9.28	Eriodictyol	C ₁₅ H ₁₂ O ₆	− 0.59	289.0707	289.0707	271.0602, 153.0181		
28	10.03	Carthamidin	C ₁₅ H ₁₂ O ₆	− 0.47	289.0707	289.0703	273.0392, 245.0442, 199.0390, 181.0494	2.07 × 10 ⁸	1.79 × 10 ⁶
29	12.29	Aromadendrin	C ₁₅ H ₁₂ O ₆	− 0.37	289.0707	289.0667	255.0344, 229.0904, 153.0545	3.17 × 10 ⁷	1.41 × 10 ⁶
30	9.62	Bowdichione	C ₁₆ H ₁₀ O ₆	0.06	299.055	299.0553	271.0595, 137.0236	5.00 × 10 ⁷	1.99 × 10 ⁷
31	5.77	Rhamnocitrin	C ₁₆ H ₁₂ O ₆	− 0.21	301.0707	301.0708	245.0607, 227.1751, 167.0700	9.64 × 10 ⁵	6.52 × 10 ⁶
32	10.76	Tectorigenin	C ₁₆ H ₁₂ O ₆	− 0.14	301.0707	301.0703	286.0465, 285.0412	6.43 × 10 ⁸	3.19 × 10 ⁸
*	10.75	Tectorigenin	C ₁₆ H ₁₂ O ₆	− 0.14	301.0707	301.0703	286.0465, 285.0412		
33	9.49	Hesperetin	C ₁₆ H ₁₄ O ₆	− 0.16	303.0863	303.0863	285.0755, 275.0911, 269.0438	2.21 × 10 ⁹	1.18 × 10 ⁸
34	11.28	Homoeriodictyol	C ₁₆ H ₁₄ O ₆	− 0.11	303.0863	303.0864	285.0752, 229.0860, 213.0543, 151.0389	2.59 × 10 ⁷	3.30 × 10 ⁶
35	8.88	Isorhamnetin	C ₁₆ H ₁₂ O ₇	0.34	317.0655	317.0652	285.0791, 257.0840, 228.0495, 153.0482	1.37 × 10 ⁷	2.41 × 10 ⁸

* means authentic standard compounds

Compounds 26, 28, and 29 had parent ions m/z 289.0667 $[M+H]^+$, which were suggested to be isomers. Secondary mass spectral characteristic fragment ions of compound 28 were m/z 273.0392, 245.0442, 199.0390, 181.494, similar to the literature [19], deduced to be carthamidin. Compound 29 underwent possible RDA cleavage to yield m/z 153.0545 characteristic ions, thus the A ring of the compound would be with two hydroxyl groups, and compound 29 was deduced to be aromaden-drin based on the database. Compound 26 was supposed to be cleaved by RDA to yield the m/z 137.0232 characteristic ion, which was recommended by the mass spectral library as fustin.

Compounds 33 and 34 were suggested to be isomers, both with molecular formula $C_{16}H_{14}O_6$ and parent ion peak m/z 303.0864 $[M+H]^+$. Compound 33 was inferred to be possibly hesperetin by database comparison. Compound 34 had major fragments m/z 285.0752 $[M+H-H_2O]^+$, m/z 151.0389 $[A^{1,3}]^+$, which was deduced to be homeriodictyol by reference [16] and mass spectral library.

Isoflavonoid compounds

Compounds 1, 7, 10, 20, 21, 22, and 32 were unambiguously identified through retention time alignment and MS/MS spectral matching with authenticated standards as daidzein, formononetin, genistein, glycitein, calycosin, biochanin A, and tectorigenin, respectively. Notably, formononetin demonstrated potent antioxidant activity [20].

Compound 9 showed molecular ion peak m/z 271.0598 $[M+H]^+$, with possible easy loss of carbonyl and neutral water molecules, generating characteristic fragment ions m/z 225.0544 $[M+H-H_2O-CO]^+$, m/z 197.0597 $[M+H-H_2O-2CO]^+$, m/z 169.0648 $[M+H-H_2O-3CO]^+$, after possible RDA would yield the characteristic ion m/z 137.0233 $[A^{1,3}]^+$, which was deduced to be 2'-hydroxydaidzein by the mass spectral library.

Compound 19 gave molecular ion peak m/z 285.0748 $[M+H]^+$, possibly susceptible to loss of methyl group yielding m/z 270.0516 $[M+H-CH_3]^+$, and possible loss of 1 molecule of O yielding m/z 269.0438 $[M+H-O]^+$, and continuing to possible loss of 2 molecules of CO yielding m/z 213.0544 $[M+H-O-2CO]^+$, was suggested to be prunetin by reference [21] and mass spectral library.

Compound 30 showed molecular ion peak m/z 299.0553 $[M+H]^+$, with a presumed molecular formula of $C_{16}H_{10}O_6$, possibly underwent RDA cleavage to produce the characteristic ion m/z 137.0236 $[A^{1,3}]^+$, which was suggested to be bowdichione by reference [22] and mass spectral library. This substance has significant anti-inflammatory activity [23].

Chalcone compounds

Compounds 4 and 18 were unambiguously identified through retention time alignment and spectral matching with reference standards isoliquiritigenin and butein, respectively. Both compounds exhibited analogous fragmentation pathways.

Isoliquiritigenin has hydroxyl substitutions at the C_2 , C_4 , and C_4' positions and has the molecular formula $C_{15}H_{12}O_4$, with a molecular ion peak of m/z 257.0804 $[M+H]^+$ and a secondary mass spectral fragmentation ion of m/z 137.0232 $[M+H-C_8H_7O]^+$. Butein has the molecular formula $C_{15}H_{12}O_5$ with hydroxyl substitutions at the C_2 , C_3 , C_4 and C_4' positions, with a molecular ion peak of m/z 237.0752 $[M+H]^+$ and secondary mass spectral fragments of m/z 135.0440 and m/z 137.0232. Isoliquiritigenin has anti-inflammatory effects [11], and butein possesses vasodilatory, antioxidant, antitumor, and anti-inflammatory bioactivities [23, 24].

Others

Compounds 6 and 11 were conclusively identified through retention time and fragmentation pattern alignment with reference standards dalbergin and medicarpin, respectively.

Compound 14 exhibited a precursor ion at m/z 273.0750 $[M+H]^+$ ($C_{15}H_{12}O_4$), with characteristic MS/MS fragments including m/z 255.0647 $[M+H-H_2O]^+$ and m/z 227.0699 $[M+H-H_2O-CO]^+$. Spectral database matching suggested its identity as glycinol.

Comparison of flavonoids in extracts

The flavonoid content not only influences wood coloration but also serves as a determining factor for pharmacological activity in traditional Chinese medicine. By utilizing peak areas as quantitative indicators, we compared the principal flavonoid constituents between *D. odorifera* and Jiangzhenxiang. Two primary similarities emerged: (1) chemical congruence, with nearly all components identified in *D. odorifera* being detected in Jiangzhenxiang; (2) quantitative parallels, as both species exhibited elevated levels of liquiritigenin, formononetin, and isoliquiritigenin—compounds demonstrating antibacterial, antioxidant, and anti-inflammatory activities. These compositional similarities suggest shared therapeutic potential. Notable differences were observed in specific bioactive constituents: Jiangzhenxiang contained significantly higher concentrations of calycosin and isorhamnetin compared to *D. odorifera*. However, *D. odorifera* generally surpassed Jiangzhenxiang in overall flavonoid content, particularly fisetin, butin, medicarpin, and dalbergin (Fig. 5). While most flavonoids were less abundant in Jiangzhenxiang, its compositional

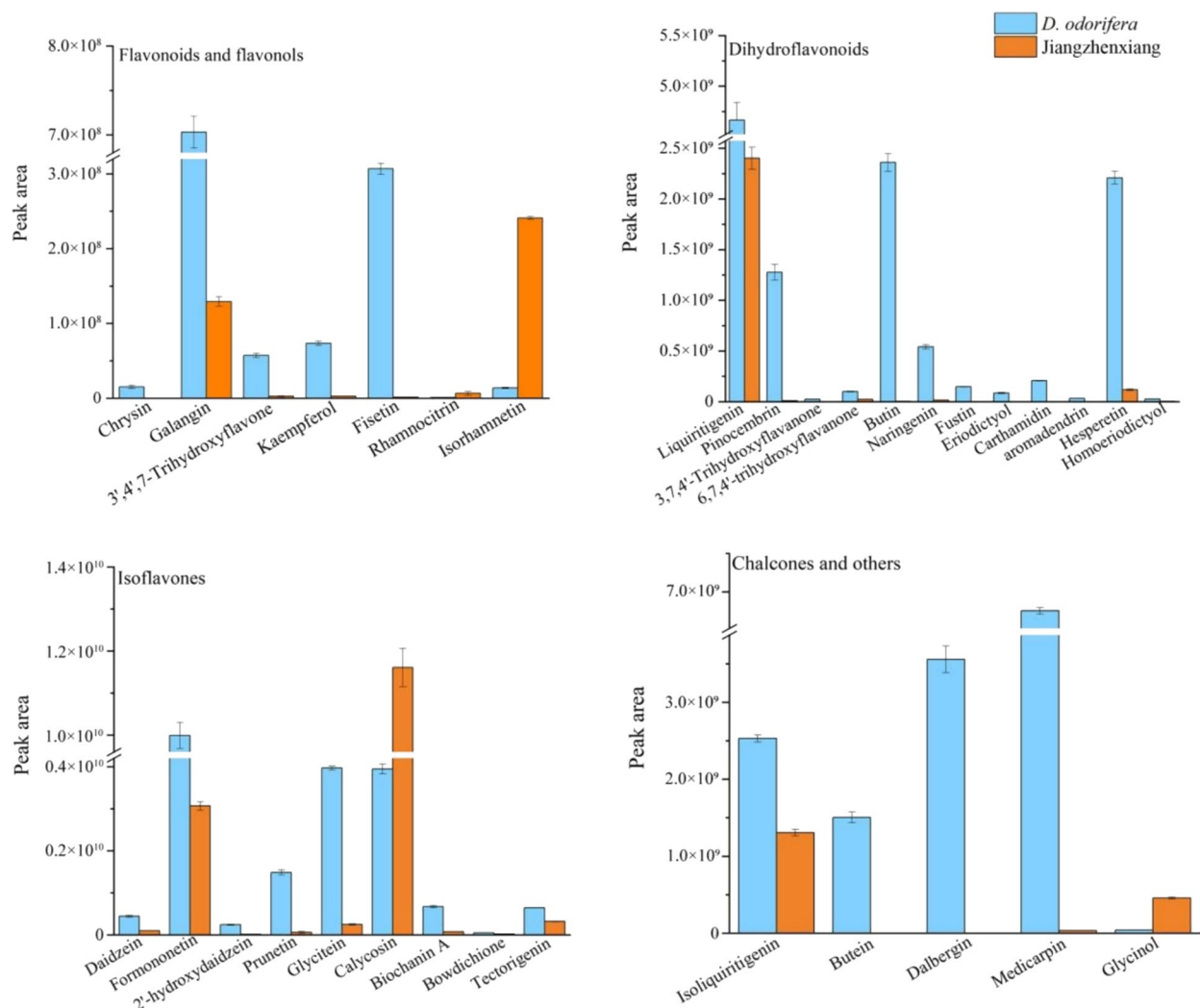


Fig. 5 Flavonoids contents between Jiangzhenxiang and *D. odorifera*

consistency with *D. odorifera* supports its potential as a viable substitute in specific pharmacological applications.

Conclusions

This study investigated the distinctiveness between Jiangzhenxiang and *D. odorifera* through comparative analysis of wood anatomical structures and phytochemical constituents. The results demonstrated discernible differences in wood microstructure between Jiangzhenxiang and *D. odorifera*, primarily manifested in aromatic properties, vessel distribution patterns, ray cellular organization, and axial parenchyma arrangements. Employing UPLC-MS analysis, we identified 18 flavonoid compounds in Jiangzhenxiang for the first time, revealing compositional parallels with *D. odorifera*. Both species contained significant concentrations of liquiritigenin, formononetin, calycosin, and

isoliquiritigenin, suggesting shared pharmacological potentials including vasodilatory effects, antioxidant activity, and anti-inflammatory properties. In conclusion, while Jiangzhenxiang and *D. odorifera* heartwood exhibit substantial structural divergence in wood anatomy, they demonstrate notable similarities in flavonoid profiles and quantitative compositions. These findings provide critical chemotaxonomic evidence for differentiating these two medicinally significant species while highlighting their overlapping bioactive potential.

Abbreviation

UHPLC-QTOF-MS Ultra-high-performance liquid chromatograph quadrupole time-of-flight mass spectrometer

Author contributions

H.L., R.M., and Y.F. conceived the research. R.M., Y.F., and J.H. conducted sample preparations. H.L., J.T., and X.Z. performed microscopic observations. H.L., R.M.,

Y.X., and B.L. conducted chemical analyses. H.L. and R.M. wrote the manuscript. All authors read and contributed to the manuscript.

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Data availability

The datasets used and analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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