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Traditional Production and GC–MS Characterization of Conifer-Derived Tar from the Western Mediterranean

Batı Akdeniz Bölgesinde Konifer Katranlarının Geleneksel Üretimi ve GC–MS ile Kimyasal Karakterizasyonu

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ABSTRACT

This study investigates the traditional production processes and chemical composition of tar obtained from three conifer species, *Pinus brutia*, *Pinus nigra*, and *Cedrus libani*, in the Western Mediterranean region of Türkiye. Tar samples produced using traditional earthen kilns were analyzed by Gas Chromatography–Mass Spectrometry (GC–MS) to reveal species-specific chemical profiles. The results demonstrated clear compositional differences among the species. *P. nigra* tar was dominated by monoterpenes, particularly α-pinene (10.52%), limonene (12.92%), and alloocimene (10.84%). *P. brutia* exhibited a similar monoterpene-rich profile, with α-pinene (9.81%), limonene (13.01%), and alloocimene (9.72%) as the predominant constituents. In contrast, *C. libani* tar displayed a sesquiterpene-oriented composition characterized by high proportions of α-himachalene (15.06%), β-himachalene (24.71%), and longifolene-(V4) (10.78%). These findings indicate that pine-derived tars are rich in monoterpene hydrocarbons, whereas cedar tar is characterized by high levels of himachalene derivatives. Overall, this study provides scientific documentation of traditional tar production and highlights interspecific chemical differences with implications for the sustainable utilization and valorization of conifer-derived tar.

Keywords- Cedrus libani, Pinus brutia, Pinus nigra, tar, GC–MS, traditional production, Western Mediterranean region

Highlights

- The traditional production and chemical composition of tar obtained from three conifer species (*P. brutia*, *P. nigra* and *C. libani*) in the Western Mediterranean region were investigated.
- Tar samples were analyzed by GC–MS to reveal species-specific chemical profiles.
- The tars of *P. nigra* and *P. brutia* were found to be rich in monoterpenes (α-pinene, limonene, and alloocimene).
- The tar of *C. libani* exhibited a sesquiterpene-dominated composition and was distinguished by high levels of himachalene derivatives.
- The chemical differences among species were shown to be important for the sustainable use and value-added utilization of tar.

Batı Akdeniz Bölgesinde Konifer Katranlarının Geleneksel Üretimi ve GC–MS ile Kimyasal Karakterizasyonu

ÖZ

Bu çalışma, Türkiye'nin Batı Akdeniz Bölgesi'nde *Pinus brutia*, *Pinus nigra* ve *Cedrus libani* olmak üzere üç iğne yapraklı türden elde edilen katranın geleneksel üretim süreçlerini ve kimyasal bileşimini araştırmaktadır. Geleneksel toprak fırınlarda üretilen katran örnekleri, türe özgü kimyasal profilleri ortaya koymak amacıyla Gaz Kromatografisi–Kütle Spektrometrisi (GC–MS) yöntemi ile analiz edilmiştir. Elde edilen sonuçlar, türler arasında belirgin bileşim farklılıkları bulunduğunu göstermiştir. *P. nigra* katranı başlıca α-pinen (%10.52), limonen (%12.92) ve alloosimen (%10.84) bileşikleriyle karakterize edilen monoterpen ağırlıklı bir yapı sergilemiştir. Benzer şekilde, *P. brutia* katranında da α-pinen (%9.81), limonen (%13.01) ve alloosimen (%9.72) baskın bileşenler olarak belirlenmiş ve monoterpen bakımından zengin bir profil ortaya konmuştur. Buna karşılık, *C. libani* katranı α-himachalene (%15.06), β-himachalene (%24.71) ve longifolene-(V4) (%10.78) bileşiklerinin yüksek oranlarıyla karakterize edilen seskiterpen ağırlıklı bir kompozisyon göstermiştir. Bu bulgular, çam türlerinden elde edilen katranların monoterpen hidrokarbonlar bakımından zengin olduğunu, sedir katranının ise yüksek düzeyde himachalene türevleri içerdiğini ortaya koymaktadır. Sonuç olarak bu çalışma, geleneksel katran üretimine ilişkin bilimsel bir dokümantasyon sunmakta ve iğne yapraklı türlerden elde edilen katranların sürdürülebilir kullanımı ve değerlendirilmesi açısından türler arası kimyasal farklılıkları vurgulamaktadır.

Anahtar Kelimeler- Cedrus libani, Pinus brutia, Pinus nigra, katran, GC–MS, Geleneksel Üretim, Batı Akdeniz Bölgesi

Öne Çıkanlar

- Batı Akdeniz bölgesinde üç konifer türünden (*Pinus brutia, Pinus nigra, Cedrus libani*) elde edilen katranların geleneksel üretimi ve kimyasal bileşimleri incelenmiştir.
- Katran örnekleri GC–MS yöntemiyle analiz edilerek türlere özgü kimyasal profiller ortaya konmuştur.
- *P. nigra* ve *P. brutia* katranlarının monoterpenler açısından zengin olduğu belirlenmiştir (α-pinene, limonene, alloocimene).
- *C. libani* katranının seskiterpen ağırlıklı bir bileşim gösterdiği ve himachalene türevleri bakımından ayırt edici olduğu saptanmıştır.
- Türler arası kimyasal farklılıkların, katranın sürdürülebilir kullanımı ve katma değerinin artırılması açısından önemli olduğu gösterilmiştir.

I. INTRODUCTION

Forest ecosystems are essential for maintaining biodiversity, regulating carbon cycles, and providing critical ecosystem services. Products derived from resinous trees, including turpentine and tar, have long-standing significance in both traditional practices and modern applications due to their medicinal, ethnobotanical, and industrial value [1]. In particular, tar obtained from Turkish red pine (*Pinus brutia* Ten.), black pine (*Pinus nigra* J.F. Arnold), and Taurus cedar (*Cedrus libani* A. Rich.) represents a culturally and economically important natural product.

Tar is a dark, viscous extract obtained through the thermal decomposition of resinous tree trunks using traditional earthen kiln distillation techniques. Black pine tar is traditionally produced in various regions of Türkiye, particularly in the Western Mediterranean region, and is extensively used by local communities for both human and veterinary medicinal purposes [1,2].

In traditional medicine, tar is recognized for its wound-healing properties. Local communities apply it to treat various ailments, including internal wounds, digestive infections, and parasitic infestations. Topical application involves spreading a thin layer of tar on cuts or abrasions, thereby promoting tissue repair and accelerating healing [2].

Cedar tar, primarily obtained from Taurus cedar, has historically played a central role in Anatolian traditional medicine. Produced through oxygen-limited distillation, cedar tar exhibits antiseptic and wound-healing activities. Experimental studies have demonstrated that essential oils derived from cedar and other Pinaceae species promote wound repair and possess anti-inflammatory, antioxidant, and antibacterial properties [2,3]. Furthermore, resins obtained from the roots and stems of Taurus cedar have shown notable antimicrobial activity, supporting the pharmacological potential of cedar-derived products [4].

Studies on tar obtained from *P. brutia* and *C. libani* have also demonstrated antimicrobial and cytotoxic activities, highlighting their broader pharmacological potential. Historically, red pine bark has been used to stop bleeding, treat inflammatory conditions, alleviate cough, relieve dental pain, and support wound healing [5].

This study aims to systematically investigate the traditional production methods of tar in the Western Mediterranean region of Türkiye and to characterize its chemical composition. Tar samples obtained from *C. libani*, *P. brutia*, and *P. nigra* were prepared using traditional techniques, and the effects of these methods on tar yield and chemical quality were evaluated. Chemical profiling was performed using Gas Chromatography–Mass Spectrometry (GC–MS), providing insights into the scientific, ethnobotanical, and economic value of these tar products. The findings contribute to the documentation of traditional knowledge, elucidation of species-specific chemical profiles, and development of sustainable utilization strategies for conifer-derived tar.

II. MATERIALS

Wood materials required for tar production were collected from the Western Mediterranean region of Türkiye. The selected tree species for this study included Taurus cedar (*C. libani*), Turkish red pine (*P. brutia*), and black pine (*P. nigra*).

The sampling study was conducted within the boundaries of the Gazipaşa Forest Management Directorate in Antalya Province, Türkiye. Taurus cedar (*Cedrus libani* A. Rich.) samples were collected at 36.273941° N, 32.396679° E; Turkish red pine (*Pinus brutia* Ten.) samples at 36.284388° N, 32.399266° E; and black pine (*Pinus nigra* J.F. Arnold) samples at 36.286255° N, 32.390098° E.

The sampled individuals were approximately 45 years old for *C. libani*, 50 years old for *P. nigra*, and 55 years old for *P. brutia*. Resin-rich heartwood (fatwood) samples were collected in August. The elevations of the sampling sites were 331 m for *C. libani*, 485 m for *P. nigra*, and 490 m for *P. brutia*, respectively.

III. METHODS

A. Preparation of Tar Feedstock

The tar feedstock was derived from wood of *C. libani*, *P. brutia*, and *P. nigra*. Roots were excavated from the soil and manually and mechanically processed into smaller wood pieces using a hand drill, axe, and sledgehammer. The resulting fragments were further split into thin shavings using a chisel.

B. Tar Production Process

Prepared shavings were placed into a metal barrel, which was sealed to prevent oxygen ingress. Metal pipes were connected to the barrel's upper and lower outlets, and the barrel was positioned on a slightly inclined surface. The barrel was surrounded by wood fuel, which was ignited to initiate pyrolysis. Separate batches were prepared for each tree species.

Approximately one hour after the onset of thermal treatment, tar began to flow through the metal pipes through distillation (Figure 1). The production process lasted approximately six hours, yielding ~1 L of tar from 10 kg of high-resin shavings.

C. Chemical Characterization by GC–MS

Tar samples were collected in opaque containers and transported to the Laboratory of Forest Botany, Faculty of Forestry, Isparta University of Applied Sciences, avoiding direct sunlight exposure.

Volatile components were analyzed using Headspace Solid-Phase Microextraction (HS-SPME) combined with Gas Chromatography–Mass Spectrometry (GC–MS). For HS-SPME, 2 g of sample was placed in a 10 mL vial and heated at 60°C for 30 min. Volatile compounds were adsorbed from the headspace using a 75 µm Carboxen/Polydimethylsiloxane (CAR/PDMS) coated fiber and injected into a HS-SPME-compatible GC–MS system (Shimadzu 2010 PLUS) equipped with a Restek Rx-5 Sil MS capillary column (30 m × 0.25 mm, 0.25 µm). For the extraction of volatile compounds, a 75 µm Carboxen/Polydimethylsiloxane (CAR/PDMS)–coated fiber was selected due to its high affinity for low-molecular-weight volatile compounds.

The oven temperature was initially held at 40°C for 2 min and ramped at 4°C/min to 250°C. Injector and detector temperatures were set to 250°C. Electron ionization (EI, 70 eV) was used, and helium was employed as the carrier gas at 1.61 mL/min. Compound identification was performed using Wiley, NIST, and FFNSC spectral libraries. Linear Retention Indices (LRIs) were calculated using saturated n-alkane standards (C7–C30, Sigma-Aldrich Chemical Co., USA).

Figure 1. Traditional tar production stages.

IV. RESULTS

The chemical analysis of tar samples revealed distinct volatile compound profiles among black pine (*P. nigra*), Turkish red pine (*P. brutia*), and cedar (*C. libani*). In black pine tar, the dominant monoterpenes were identified as α-pinene (10.52%), limonene (12.92%), and alloocimene (10.84%). Similarly, Turkish red pine exhibited a monoterpene-rich profile, with α-pinene (9.81%), limonene (13.01%), and alloocimene (9.72%) as the primary constituents. In contrast, cedar tar displayed a markedly different composition, characterized by high levels of α-himachalene (15.06%) and β-himachalene (24.71%), with longifolene-(V4) (10.78%) identified as another major cedar-specific compound (Table 1).

Table 1. Volatile compound composition of conifer-derived tar samples

R.Time	Name	*P. nigra*	*P. brutia*	*C. libani*	Category
1.460	Formic acid	0.27	0.19	0.17	OC
1.504	Methyl acetate	-	-	0.13	OC
1.983	Acetic acid	1.26	-	0.88	OC
2.269	Acetol	0.40	0.39	0.19	OC
3.811	Toluene	-	0.16	0.40	AH

Table 1. (Continues)

R.Time	Name	*P. nigra*	*P. brutia*	*C. libani*	Category
4.478	4-Methyl-3-penten-2-one	-	-	0.18	OC
5.451	2-Furancarboxaldehyde & Furfural	1.75	1.76	1.54	OC
6.137	Furfuryl alcohol	0.40	0.12	-	OC
6.524	m-Xylene	-	0.46	0.15	AH
7.855	1,5,5,6-Tetramethyl-1,3-cyclohexadiene	-	-	0.20	MH
7.864	2(5H)-Furanone	0.24	0.26	-	OC
8.034	3,3,6,6-Tetramethylcyclohexa-1,4diene	0.65	1.06	-	MH
8.297	Tricyclene	-	0.11	-	MH
8.804	α-Pinene	10.52	9.81	-	MH
9.293	Camphene	1.26	1.39	-	MH
9.374	5,5-Dimethyl-2-propyl-1,3 cyclopentadiene	0.44	0.76	-	OC
9.588	5,5-Dimethyl-1-propyl-1,3cyclopentadiene	0.18	0.41	-	OC
9.755	5-Methylfurfural	0.62	0.61	0.45	OC
9.814	o-Ethyltoluene	-	-	0.49	AH
10.327	β-Pinene	0.44	2.00	-	MH
10.531	1,3,5,5-Tetramethyl-1,3-cyclohexadiene	1.04	1.91	-	MH
10.872	Myrcene	0.46	1.70	-	MH
11.047	1,2,6,6-Tetramethyl-1-3-cyclohexadiene	-	0.36	-	MH
11.173	Propenylbenzene	-	-	0.23	AH
11.557	*Δ*-3-Carene	0.60	9.76	-	MH
11.885	α-Terpinene	0.42	0.83	-	MH
12.022	1,3,5-Trimethylbenzene	-	0.35	-	MH
12.208	p-Cymene	0.73	1.67	0.34	AH
12.511	Limonene	12.92	13.01	0.50	MH
12.695	cis-Ocimene	0.30	0.24	-	MH
13.507	γ-Terpinene	0.20	0.50	-	MH
14.402	4-Methylphenol	-	-	0.56	AA
14.587	α-Terpinolen	1.72	2.84	-	MH
14.758	4-Isopropenyl-1-methylbenzene	0.85	0.81	1.26	AH
16.396	1-(4-Methyl-3-cyclohexen-1-yl)ethanone			1.97	OM
16.410	Alloocimene	10.84	9.72	-	MH
16.786	Neoalloocimene	2.87	3.90	-	MH
16.953	Camphor	0.16	0.23	-	OM
17.089	β-Terpineol	0.29	-	-	OM
17.951	Borneol	0.31	-	-	OM
18.045	Isoborneol	0.36	-	-	OM
18.051	1-Isopropyl-2,3dimethyl-1cyclopentene	-	0.15	-	OC
18.261	4-Terpineol	0.74	1.18	-	OM
18.405	m-Methylacetophenone	0.14	0.14	0.91	OC
18.591	2-Methoxy-5-methylphenol	0.96	1.43	1.84	OC
18.910	α-Terpineol	3.38	2.49	-	OM
20.020	Bornyl formate	0.22	0.08	-	OM
20.925	1,3-Dimethyl-1H-indene	-	-	0.25	AH
21.701	p-Ethylguaiacol	0.66	0.74	1.05	OC
21.882	1,1,3-Trimethyl-1H-indene	-	-	0.13	AH
22.073	Bornyl acetate	0.18	-	-	OM
22.406	1-Methylnaphthalene	-	-	0.14	AH

Table 1. (Continues)

R.Time	Name	*P. nigra*	*P. brutia*	*C. libani*	Category
23.016	Guaiacol	0.40	0.33	1.19	OC
23.880	Cis-Caryophyllene	-	0.28	-	SH
24.246	1,1,6-Trimethyl-1,2,3,4 tetrahydronaphthalene	-	-	0.13	AH
24.287	α-Cubebene	0.19	-	-	SH
24.384	α-Longipinene	-	0.48	0.14	SH
24.476	m-Eugenol	0.24	0.20	0.15	SH
24.825	Eugenol	0.22	0.31	0.31	SH
25.072	Ylangene	0.91	0.14	-	SH
25.209	Longicyclene	-	0.27	0.96	SH
25.305	α-Copaene	1.99	-	-	SH
25.348	4-Phenyl-4-methtlpentane-2-one	-	-	0.42	OC
25.926	4,4-Dimethyl-3-(3-methyl-3-buten-lyliden)	-	-	0.73	MH
26.236	(Z)-Eugenol	0.19	-	-	AA
26.275	α-Chamigrene	0.16	-	-	SH
26.298	Isocaryophyllene	--	0.77	-	SH
26.344	4-Hydroxy-4-(4,6-dimethylcyclohex-3 enyl)butan-2-one	-	-	0.68	OM
26.440	Junipene	2.06	3.35	1.30	SH
26.762	trans-Caryophyllene	1.00	7.27	0.48	SH
26.947	Himachala-2,4-diene	-	-	1.94	SH
27.094	β-Cubebene	0.38	-	-	SH
27.095	Bergamotol	-	-	1.05	OM
27.199	Cyclopentane	-	-	1.05	OC
27.729	1-Methyl-6-7-oxabicyclo	-	-	2.70	OM
27.735	cis-Isoeugenol	1.74	-	-	AA
27.793	α-Himachalene	-	2.63	15.06	SH
27.930	α-Humulene	0.21	1.99	-	SH
28.083	Cadinene	0.29	-	-	SH
28.382	α-Curcumene	-	-	1.16	SH
28.336	β-Cadinene	0.17	-	-	SH
28.501	Cadina-1(6),4-diene	0.60	-	-	SH
28.697	γ-Muurolene	6.98	-	-	SH
28.731	Longifolene-(V4)	-	1.41	10.78	SH
28.772	α-Amorphene	0.93	-	-	SH
28.860	Cedr-8-e	-	0.24	2.39	SH
29.057	β-Selinene	0.22	-	-	SH
29.192	α-Amorphene	1.65	-	-	SH
29.415	α-Muurolene	4.01	-	-	SH
29.473	β-Himachalene	-	3.83	24.71	SH
29.527	Cubebene	0.65	-	-	SH
29.681	(R)-Cuparene	0.30	0.65	-	SH
29.892	γ-Cadinene	3.79	-	-	SH
29.928	Isolongifolene	-	-	3.10	SH
30.122	*Δ*-Cadinene	8.49	-	-	SH
30.460	Cadina-1,4-diene	0.84	-	-	SH
30.465	Cycloisolongifolene	-	1.30	5.33	SH
30.593	Cis- α-Bisabolene	-	-	2.06	SH
30.593	α-Cadinene	0.85	-	-	SH

Table 1. (Continues)

R.Time	Name	*P. nigra*	*P. brutia*	*C. libani*	Category
30.723	α-Calacorene	0.87	-	-	SH
32.230	Dihydro-ar-turmerone	0.21	0.28	0.64	OM
34.161	β-Acorenol	-	-	0.54	OM
34.352	Ar-tumerone	-	0.20	0.43	OM
34.404	Artemisia ketone	-	-	2.78	OM
35.040	Turmerone	-	0.10	1.14	OM
35.330	Deodarone	0.26	0.46	-	OM
37.551	α-Atlantone	-	-	1.69	OM
42.113	Sandaracopimaradiene	0.21	-	-	SH
47.428	Verticillol	0.17	-	-	OM
	Total	100	100	100	
	Number of component	68	58	52	
	AA: Aromatic alcohols	1.93	0	0.56	
	AH: Aromatic hydrocarbons	1.58	3.10	3.52	
	MH: Monoterpene hydrocarbons	44.24	59.49	1.43	
	OM: Oxygenated monoterpenes	6.28	5.02	13.62	
	SH: Sesquiterpene hydrocarbons	38.21	25.12	68.87	
	OC: Other components	7.72	7.29	10.00	

Analysis of the distribution of volatile compound classes highlighted notable interspecific differences (Table 2, Figure 2). In *P. brutia*, monoterpene hydrocarbons (MH, 59.49%) dominated the volatile fraction, representing the most characteristic component class of the species. Conversely, *C. libani* showed a profile heavily concentrated in sesquiterpene hydrocarbons (SH, 68.87%), indicating that cedar is particularly rich in high-molecular-weight terpenoids. Black pine displayed a more balanced distribution, with MH and SH contributing 44.24% and 38.21%, respectively, reflecting a characteristic equilibrium between monoterpene hydrocarbons and sesquiterpene hydrocarbons in its chemical composition. Other compound classes, including oxygenated monoterpenes (OM), aromatic hydrocarbons (AH), aromatic alcohols (AA), and miscellaneous components (OC), were present at varying levels across all species (Table 2, Figure 2).

Table 2. Relative distribution of volatile compound classes in conifer-derived tar samples

Plant Species	**Best Represented Chemical Group**	**Percentage (%)**
P. brutia	Monoterpene hydrocarbon (MH)	59,49
C.libani	Sesquiterpene hydrocarbon (SH)	68,87
P. nigra	Balance between (MH) and (SH)	MH: 44,24 SH: 38,21

These compositional patterns provide clear evidence of species-specific chemical signatures in conifer-derived tars. Pine-derived tars are predominantly monoterpene-based, whereas cedar tar is distinguished by its high content of sesquiterpene hydrocarbons, suggesting potential implications for industrial applications, pharmacological activity, and chemotaxonomic differentiation.

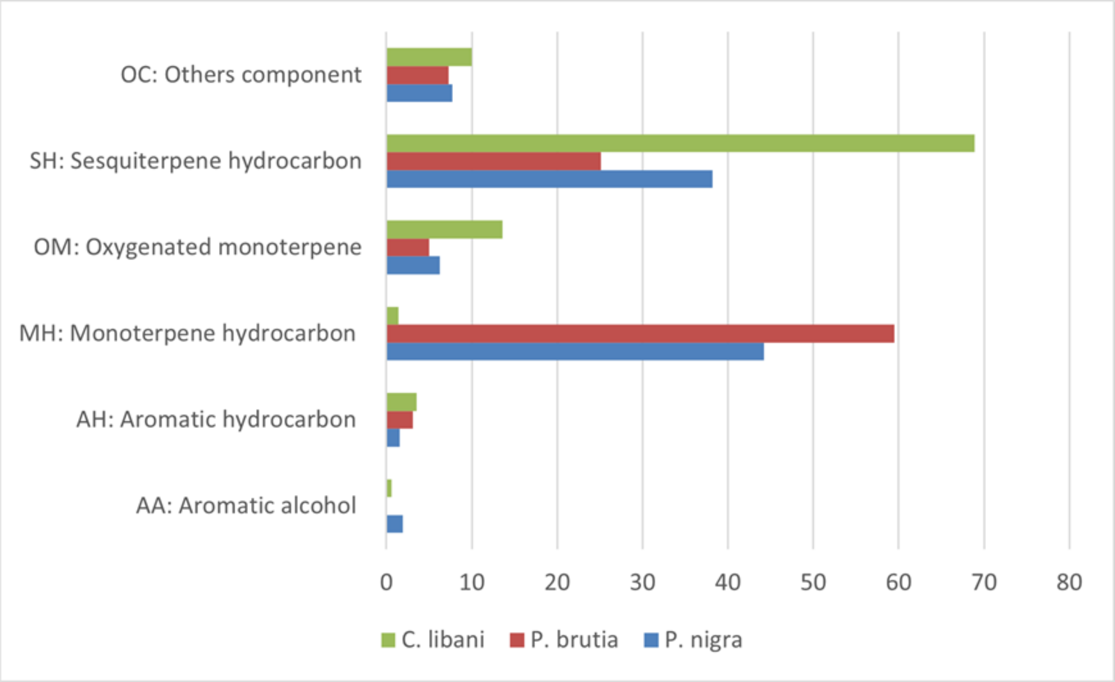

Figure 2. Relative Distribution of Volatile Compound Classes Across Conifer Species

V. DISCUSSION AND CONCLUSION

This study systematically characterized the chemical profiles of tar obtained from Turkish red pine (*P. brutia*), black pine (*P. nigra*), and cedar (*C. libani*) produced using traditional methods in the Western Mediterranean region of Türkiye. The GC–MS analyses revealed clear interspecific differences in volatile compound composition.

Turkish red pine tar was dominated by monoterpenes, particularly α-pinene (9.81%), limonene (13.01%), and alloocimene (9.72%). These findings are consistent with prior analyses of *P. brutia* leaves, which reported high α-terpineol (66.16%), 3-carene (4.90%), carveol (4.55%), and cis-verbenol (3.22%) levels [6]. Black pine tar also exhibited a monoterpene-rich profile, with α-pinene (10.52%), limonene (12.92%), and alloocimene (10.84%) as the major constituents, aligning well with previously reported α-pinene ranges of 24.40–44.16% in *P. nigra* [7].

Cedar tar showed a contrasting chemical profile, dominated by sesquiterpene hydrocarbons, including α-himachalene (15.06%) and β-himachalene (24.71%), with longifolene-(V4) (10.78%) as another major component. These results are consistent with prior studies demonstrating that oils derived from *Cedrus* wood and heartwood are enriched in himachalene derivatives and other sesquiterpenes [8,9]. The observed differences between needle and foliage oils and wood-derived oils are in line with literature reports indicating that monoterpene compounds predominate in foliage oils, whereas sesquiterpenes are enriched in wood and tar derivatives [10–12].

The present findings highlight that pine-derived tars are monoterpene-dominant, while cedar tar is characterized by high sesquiterpene content, particularly himachalene derivatives. Quantitative variations in major compounds such as α-pinene and himachalene are likely attributable to differences in raw material type (wood/tar vs. needles), production method (traditional tar distillation vs. hydrodistillation), geographic and climatic factors, and analytical conditions.

Overall, this study provides comprehensive chemical documentation of traditional tar production, contributing valuable insights to ethnobotanical knowledge and natural product chemistry. The high sesquiterpene content in cedar tar suggests strong potential for biological activities, including antimicrobial, insecticidal, and wound-healing effects.

Future studies should focus on comparative analyses between traditionally produced tars and laboratory hydrodistilled oils. Additional research should also investigate chemical variations among different plant tissues, including wood, roots, needles, and resin, as well as seasonal and provenance-related variability. Moreover, biological assays are needed to validate the pharmacological potential of major constituents such as β-himachalene and longifolene.

In conclusion, traditional tar production not only preserves cultural heritage but also yields chemically distinct products with potential industrial and pharmacological applications. These findings emphasize the importance of sustainable utilization strategies for conifer-derived natural products.

Future research should further explore the relationship between the compounds identified by GC–MS analyses and their potential biological activities. In particular, the antimicrobial, antioxidant, and anti-inflammatory properties of major chemical groups, including phenolic compounds, diterpenes, and aromatic hydrocarbons, should be validated through in vitro assays such as disk diffusion, minimum inhibitory concentration (MIC), and DPPH/ABTS analyses, as well as appropriate in vivo studies. Furthermore, identifying potential chemical markers associated with biological activity, such as guaiacol derivatives, phenanthrene-like structures, or specific diterpenes, may contribute to the standardization of the functional properties of tar.

In addition, systematic evaluation of the effects of raw material variability, including species, age, growth conditions, production temperature, and differences in traditional production methods, on both GC–MS profiles and biological activities would enable a more reliable assessment of the biological potential of tar.

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