RESEARCH PAPER

Phytochemical characterization of Jasminum mesnyi Hance fractions by GC–MS, UPLC-QTOF/MS and UHPLC-DAD: antioxidant, anti-inflammatory and potential hepatoprotective relevance based on identified Phytoconstituents

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ABSTRACT

This study aimed to perform comprehensive phytochemical profiling of solvent fractions obtained from the aerial parts of Jasminum mesnyi Hance and to explore their antioxidant and anti-inflammatory potential. The crude ethanolic extract was fractionated into chloroform, ethyl acetate, and n-butanol fractions. Preliminary GC–MS analysis was followed by detailed characterization using UPLC-QTOF/MS, leading to the tentative identification of 82 phytoconstituents, predominantly flavonoids, along with phenolic acids, fatty acids, terpenoids, quinones, and alkaloids. Quantitative UHPLC-DAD analysis confirmed the presence of caffeic acid in ethyl acetate and butanol fractions. Biological evaluation revealed that the ethyl acetate fraction exhibited the highest antioxidant activity (IC_{50} = 6.00 ± 0.35 µg/mL) in the DPPH assay and comparatively better nitric oxide scavenging activity (IC_{50} = 69.9 ± 1.51 µg/mL), with ascorbic acid used as the standard. The presence of diverse bioactive compounds, particularly flavonoids and phenolic acids, suggests potential pharmacological relevance, including possible hepatoprotective effects; however, further experimental validation is required. Overall, the findings highlight Jasminum mesnyi as a promising source of natural antioxidants with moderate anti-inflammatory potential.

Keywords: Jasminum mesnyi Hance; GC–MS; UPLC-Q-TOF/MS; UHPLC-DAD; phytochemical analysis; caffeic acid.

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phytochemical analysis; caffeic acid

1. Introduction

Jasminum mesnyi Hance, a member of the Oleaceae family, is native to China and widely distributed in India and Nepal. It is commonly known as Primrose jasmine and is locally referred to as *Pahari butti*, *Sansonae*, and *Peeli chameli* in Himachal Pradesh, India [32]. It is an evergreen shrub that grows up to 2.5 m in height and exhibits a climbing or sprawling habit. In the absence of support, it forms dense foliage with a spread of approximately 5–10 feet [5,32]. The leaves are trifoliate, elliptic, and oppositely arranged on quadrangular branches, while yellow flowers typically appear during March–April.

Medicinal plants are rich sources of bioactive compounds such as flavonoids, phenolic acids, terpenoids, and fatty acids, which are known to exhibit significant pharmacological activities, including hepatoprotective, anti-inflammatory, and antioxidant effects. However, despite its traditional relevance, the detailed phytochemical composition of *Jasminum mesnyi* Hance and its correlation with biological activities remain inadequately explored.

In the present study, fresh aerial parts of *Jasminum mesnyi* Hance were collected from Nalagarh, Himachal Pradesh, India. The plant material was air-dried, coarsely powdered, and defatted with petroleum ether (60–80 °C), followed by extraction with 90% ethanol using a Soxhlet apparatus. The obtained crude extract was dissolved in distilled water and successively fractionated using chloroform, ethyl acetate, and n-butanol, yielding respective fractions along with the aqueous fraction [28,4].

Preliminary phytochemical profiling of the chloroform fraction using GC–MS revealed the presence of several bioactive compounds, including nonadecane, tetradecane, hexadecane, methyl stearate, and heptadecanoic acid methyl ester, which have been reported to exhibit antioxidant activity. Compounds such as 2,4-di-tert-butylphenol and octadecane are known for their antioxidant and anti-inflammatory properties, while pentadecane has been associated with anti-inflammatory and antimicrobial activities. Additionally, hexadecanoic acid methyl ester has been reported to possess hepatoprotective and anti-inflammatory effects (Table 1).

Similarly, GC–MS analysis of the ethyl acetate fraction identified compounds such as stannane and benzene derivatives, which have been reported to

exhibit anti-inflammatory activity. Other detected constituents, including tetracosane, tetradecane, hexadecane, methyl stearate, and heptadecanoic acid methyl ester, are associated with antioxidant properties. Furthermore, compounds such as hexadecanoic acid methyl ester and thymoquinone have been reported to possess hepatoprotective, anti-inflammatory, and antioxidant activities (Table 2).

Further characterization of chloroform (JMH-Chl), ethyl acetate (JMH-EA), and butanol (JMH-But) fractions was carried out using UPLC-QTOF/MS for the tentative identification of phytoconstituents. A total of fourteen, twenty-four, and fourteen compounds were identified in chloroform, ethyl acetate, and butanol fractions, respectively, comprising diverse classes of bioactive molecules with reported antioxidant, anti-inflammatory, and hepatoprotective relevance (Table 3).

Moreover, UHPLC-DAD-based quantitative analysis confirmed the presence of caffeic acid in both ethyl acetate and butanol fractions. The concentration of caffeic acid was found to be 23.577 ppm in JMH-EA and 29.209 ppm in JMH-But, indicating its higher affinity toward relatively polar fractions. The UHPLC chromatograms exhibited peaks at retention times of 9.147 min and 9.150 min for JMH-EA and JMH-But, respectively, closely matching the retention time of the standard caffeic acid, thereby confirming its presence. Caffeic acid has been widely reported for its antioxidant activity [39].

Furthermore, the antioxidant and anti-inflammatory activities of *Jasminum mesnyi* fractions were evaluated using DPPH and nitric oxide scavenging assays, respectively, employing ascorbic acid as the standard reference. Among the tested fractions, the ethyl acetate fraction demonstrated the most pronounced activity, indicating its potential role in mitigating oxidative stress and inflammation.

Overall, these findings suggest that *Jasminum mesnyi* Hance fractions are rich in diverse bioactive phytoconstituents, particularly polyphenolic compounds, which may contribute to their antioxidant and anti-inflammatory potential, while also indicating possible hepatoprotective relevance that warrants further experimental validation.

2. Materials and Methods

2.1. Materials and chemicals

Ethanol, formic acid, acetonitrile, petroleum ether, chloroform, ethyl acetate, *n*-butanol, methanol, 1,1-diphenyl-2-picrylhydrazyl (DPPH), Methanol (analytical grade), Ascorbic acid (standard antioxidant), Sodium nitroprusside, Phosphate buffer saline (PBS, pH 7.4), Sulphanilamide and Naphthyl ethylenediamine dihydrochloride (NED) were used in the present study. All solvents and chemicals were of analytical or HPLC grade and were procured from standard commercial suppliers. The test samples included chloroform (JMH-Chl), ethyl acetate (JMH-EA), and *n*-butanol (JMH-But) fractions of *Jasminum mesnyi* Hance.

2.2. Collection and identification of plant material

Fresh and healthy aerial parts of *Jasminum mesnyi* Hance were collected from Nalagarh, Himachal Pradesh, India. The collected plant material was thoroughly washed with double-distilled water (DDW) and shade-dried at room temperature. The dried material was coarsely powdered and stored in an airtight container at 4 °C until further use. The plant was authenticated at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, India, and a voucher specimen was deposited under herbarium number **UHF-Herbarium No. 14136**.

2.3. Extraction and fractionation

The air-dried aerial parts of *Jasminum mesnyi* Hance were coarsely powdered to facilitate extraction. Approximately 120 g of powdered plant material was defatted with petroleum ether (60–80 °C) and subsequently extracted with 90% ethanol using a Soxhlet apparatus for approximately 40 h or until the solvent in the siphon tube became colorless. The obtained ethanolic extract was concentrated under reduced pressure using a rotary evaporator to obtain a dried crude extract. The percentage yield was calculated as % (w/w) with respect to the total weight of the dried plant material used for extraction [42]. The dried ethanolic extract was then dissolved in distilled water and subjected to successive liquid–liquid fractionation using chloroform, ethyl acetate, and *n*-butanol to obtain respective solvent fractions, along with the remaining aqueous fraction [28,4].

Figure 1. A Picture of *Jasminum mesnyi* Hance

2.4. GC–MS analysis

The GC–MS analysis of chloroform and ethyl acetate fractions of *Jasminum mesnyi* Hance was performed using a Thermo Fisher Scientific GC–MS system equipped with a TG-5MS capillary column (40 m × 0.15 mm × 0.15 µm). The initial oven temperature was set at 70 °C and maintained for 1 min, followed by a temperature ramp to 270 °C at a rate of 7 °C/min, and held at 270 °C for 20 min. The injector temperature was maintained at 270 °C, and a 1 µL sample was injected in **splitless mode**. The solvent delay time was set to 4 min. Helium (99.99% purity) was used as the carrier gas at a constant flow rate of 0.7 mL/min. The total run time for the analysis was 45 min. Mass spectrometric detection was carried out in electron ionization (EI) mode at 70 eV. The ion source temperature and transfer line temperature were maintained at 250 °C and 270 °C, respectively. Mass spectra were acquired in the scan range of 35–450 m/z. The identification of chemical constituents was performed by comparing the obtained mass spectra with the NIST library (version 2.2) and further confirmed through available literature [9]. The relative abundance of each component was calculated based on the percentage peak area normalization method.

2.5 UPLC-Q-TOF/MS Analysis

Ultra-performance liquid chromatography coupled with quadrupole time-of-flight mass spectrometry (UPLC-Q-TOF/MS) analysis was performed using an ACQUITY UPLC H-Class system (Waters, USA) equipped with a quaternary solvent manager, an online degasser, an autosampler, and a thermostatically controlled column compartment. Chromatographic separation was achieved on an ACQUITY UPLC BEH C18 column (100 × 2.1 mm, 1.7 µm particle size). Data acquisition and processing were carried out using MassLynx software (version 4.2). The mobile phase consisted of solvent A (0.1% formic acid in LC-MS grade water) and solvent B (0.1% formic acid in acetonitrile). The analysis was performed under gradient elution at a constant flow rate of 0.2 mL/min, with an injection volume of 5 µL. The gradient program was optimized as follows: 0–5 min, 5% B; 5–30 min, linear increase to 90% B; 30–35 min, held at 90% B; 35–36 min, returned to initial conditions (5% B); followed by re-equilibration until 55 min. The column temperature was maintained at 45 °C, while the autosampler temperature was set at 4 °C. Mass spectrometric detection was performed using a Synapt G2-Si Q-TOF mass spectrometer (Waters) equipped with an electrospray ionization (ESI) source operated in both positive and negative ion modes. The MS conditions were set as follows: capillary voltage 2.59 kV (ESI+) and 3.22 kV (ESI−), cone voltage 40 V, desolvation temperature 550 °C, and source temperature 120 °C. Nitrogen was used as both desolvation gas (950 L/h) and cone gas (50 L/h). Low-energy collision was set at 4 eV, while high-energy ramp was applied from 15 to 25 eV. The mass range was acquired from m/z 50 to 1200.

2.6 Construction of UNIFI Theoretical Library on chemical constituents of *Jasminum mesnyi* Hance

A number of internet resources, such as SciFinder, PubMed, PubChem, and Reaxys, were used to build a list of the compounds mentioned in the JMH literature. The terms "Jasminum mesnyi Hance" were used to search published material until April 2026. The process of identifying chemical structures in complex natural goods is made easier by combining UPLC-Q-TOF/MS data with the UNIFI information management platform and its integrated Traditional Medicine Library. In the end, the structures of compounds from the Jasminum mesnyi Hance species were collected and kept in a SDF file as a theoretical library. The QA-TE MS data was imported into the UNIFI platform for rapid matching screening with the theoretical library data of Jasminum mesnyi Hance compounds.

2.7 UHPLC-DAD Quantitative Analysis of Main Components

2.7.1 Development of UHPLC-DAD Analytical Method

Quantitative analysis of major phenolic compounds in different fractions of *Jasminum mesnyi* Hance was performed using an UHPLC-DAD system. Caffeic acid was quantified in chloroform and ethyl acetate fractions, Chromatographic analysis was carried out using a Thermo Scientific Ultimate 3000 UHPLC system (Thermo Fisher Scientific, Milan, Italy) equipped with a diode array detector (DAD). Samples (0.1 mg/mL) were prepared in methanol, sonicated for 45 min at 45 °C, and filtered through a 0.45 µm syringe filter prior to injection. Separation was achieved on a Merck Lichrospher RP-18 column (100 × 2.1 mm, 2 µm particle size) maintained at 25 °C. The mobile phase consisted of solvent A (water adjusted to pH 3.5 with orthophosphoric acid) and solvent B (acetonitrile). The gradient elution was programmed as 15–30% B over 5 min, followed by 30–50% B over 10 min. The total run time was 20 min, including a 4 min re-equilibration period. The flow rate was maintained at 0.8 mL/min. Detection was performed at 260 nm for phenolic and flavonoid compounds using the built-in DAD system. The method was validated in accordance with ICH guidelines to ensure analytical reliability.

2.8 Evaluation of free radical scavenging activity

2.8.1 DPPH (1-1 Diphenyl-2-picrylhydrazyl) radical scavenging assay

The free radical scavenging activity of the prepared samples was evaluated based on the ability of the extract to bleach stable DPPH radicals. To perform the assay, 0.2 ml of DPPH solution was added to 0.2 ml aliquots of standard or test solutions at various concentrations: 2000, 4000, 6000, 8000, 10000, 12000, 14000, 16000, 18000, and 20000 ng/ml. Control tubes contained 0.2 ml of methanol and 0.2 ml of DPPH. After incubating the mixtures in the dark at 37 °C for 30 minutes, the absorbance was measured at 517 nm [47] & [48]. Ascorbic acid was used as the standard antioxidant.

The percentage of radical scavenging by the test samples at each concentration was calculated using the following formula:

$$\text{Scavenging DPPH (\%)} = \frac{\text{Abs control} - \text{Abs sample}}{\text{Abs control}} \times 100$$

IC_{50} represents the concentration at which 50% of the radicals are scavenged by the test or standard sample.

2.8.2 Nitric oxide scavenging assay

An inhibition of nitric oxide radicals was estimated using the Griess reaction method. The Griess reagent was prepared by mixing equal volumes of 1% sulphanilamide in 5% phosphoric acid (v/v) and 0.01% naphthylethylenediamine in distilled water. A 5 mM sodium nitroprusside solution in standard phosphate buffer (0.025 M, pH 7.4) was prepared and incubated with different concentrations of the standard and test samples (10, 20, 40, 60, 80, and 100 µg/ml) at 37 °C for 5 hours. Methanol was used as the control.

After incubation, 0.2 ml of the solution was mixed with 0.2 ml of Griess reagent. The absorbance of the resulting chromophore, formed by the reaction of nitrite with sulphanilamide and subsequent coupling with naphthylethylenediamine, was measured at 546 nm. Ascorbic acid served as the standard antioxidant [49] & [50].

The percentage scavenging by the test fractions at each concentration was calculated using the following formula:

$$\text{Scavenging NO (\%)} = \frac{\text{Abs control} - \text{Abs sample}}{\text{Abs control}} \times 100$$

IC_{50} represents the concentration at which 50% of the radicals are scavenged by the test or standard sample.

3. Results

3.1. Percentage Yield of Extraction and fractions

The *Jasminum mesnyi* Hance ethanolic extract yielded 10%. Further solvent–solvent fractionation produced and percentage yield of chloroform 11.89%, ethyl acetate 4.1%, butanol 33.80% and aqueous 50.21%.

3.2. Gas chromatography–mass spectrometry (GC-MS) of plant fraction

GC–MS analysis of chloroform fraction revealed the presence of twelve bioactive compounds as show in Table 1 and Fig. 2. The compounds with a higher peak area were Nonadecane (1.14%), Hexadecane (1.14%), Tetradecane (1.14%), Octadecane (1.14%), Pentadecane (1.14%), 2,4-Di-tert-butylphenol (1.98%), Benzene, 1,2,4,5-tetrakis(1-methylethyl)- (4.83%), 2,4,6-Tri-isopropylacetophenone (4.83%), Hexadecanoic acid, methyl ester (14.59%), Methyl stearate (7.15%), Heptadecanoic acid, 16-methyl-,methyl ester (7.15%) and Eleven bioactive compound reported in **Table 1** as a **Antioxidant, anti-inflammatory and hepatoprotective activity**.

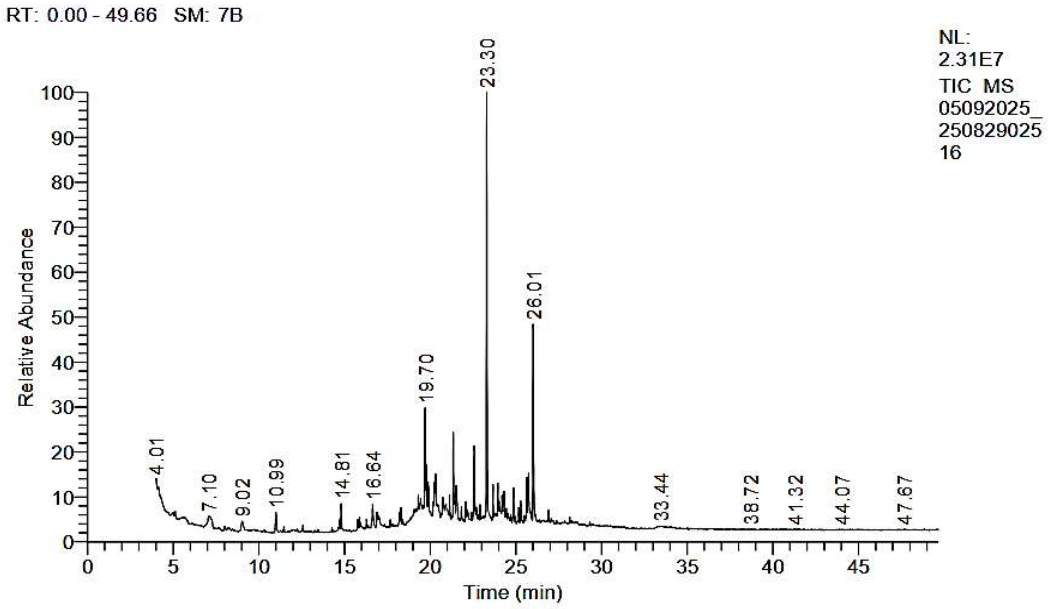
GC–MS analysis of ethyl acetate fraction revealed the presence of twenty two bioactive compounds as show in Table 2 and Fig. 3. The compounds with a higher peak area were Stannane, triethyl(phenylmethyl)- (7.08%), Tetracosane (7.08%), E-2-Methyl-3-tetradecen-1-ol acetate (7.08%), Stannane, diethylbis(phenylmethyl)- (7.08%), Pentanoic acid, 2-ethylhexyl ester (3.16%), Benzene, 1-methyl-4-(4-morpholyl)ethenylsul fonyl- (3.16%), 2(2'-Hydroxymethyl butyl)-1,2,3,5,6,11b-hexahydro-11-h-indolo-(3,2-g)-pyrrocoline (3.16%), 1H-Azepin-

1-amine, hexahydro- (3.16%), Butanoic acid, 3-methyl-, octyl ester (3.16%), Tetradecane (3.50), Hexadecane (2.52%), 2-Propenoic acid, 3-(3-hydroxy-2,6,6-trimethyl-1-cycl ohexen-1-yl)-, methyl ester, (E)- (8.61%),4-(2,3-Dimethyl-2-butenyl)-5-methoxy-2(5H)-furanone (8.61%), Methyl 3-formyl-4,6-dihydroxy-2,5-dimethylbenzoate (8.61%), Thymoquinone (8.61%), Acenaphthylene, dodecahydro- (8.61%), Hexadecanoic acid, methyl ester (22.54%), Heptadecanoic acid, 16-methyl-,methyl ester (11.63%), Methyl stearate (11.63%) and Nineteen bioactive compound reported in **Table 2** as a **Antioxidant, anti-inflammatory and hepatoprotective activity**.

In the present study, various phytochemical components were observed when the chloroform and ethyl acetate fractions of *Jasminum mesnyi* Hance were subjected to GC-MS analysis. Analysis of peak area, retention time, and molecular formula confirmed the presence of these phytochemicals.

Figures 2 and 3 explain the results of the present study.

Figure 2: GC-MS chromatogram of Chloroform fraction of the aerial part of *Jasminum mesnyi Hance*



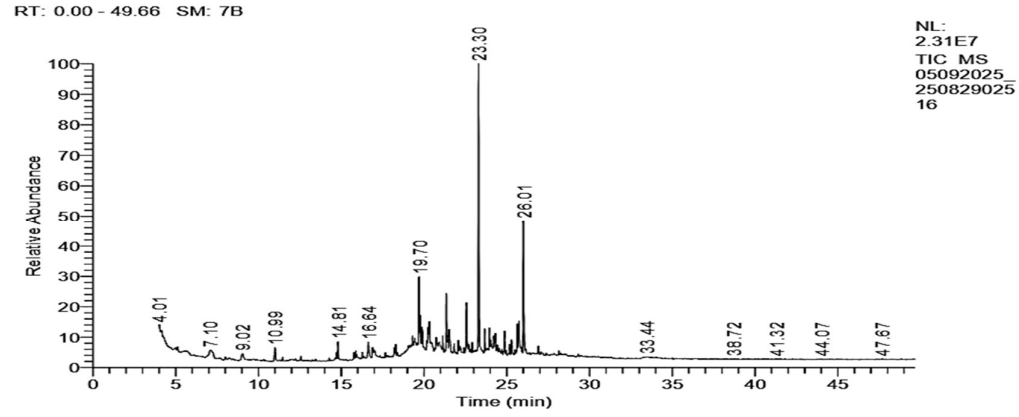
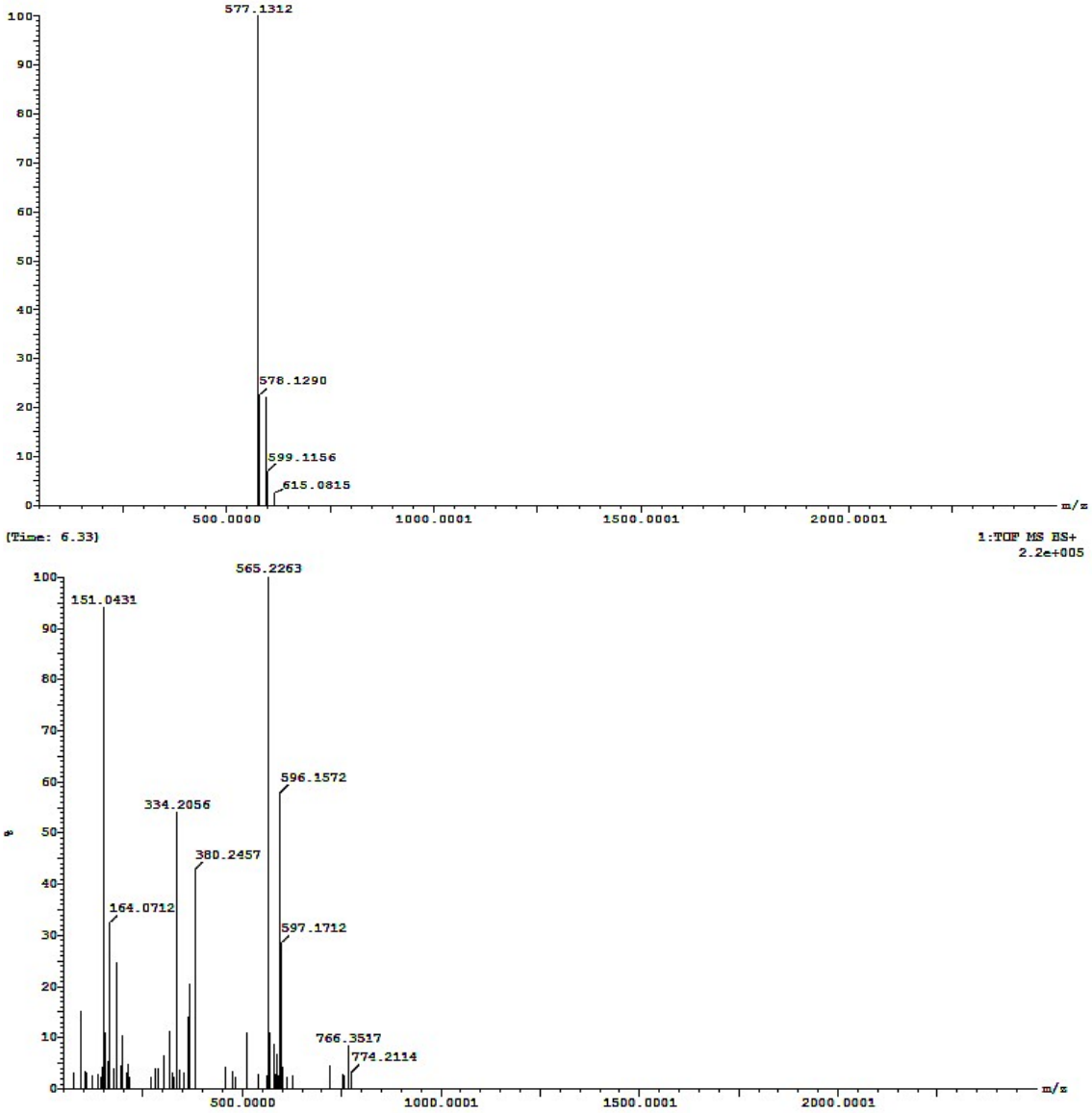


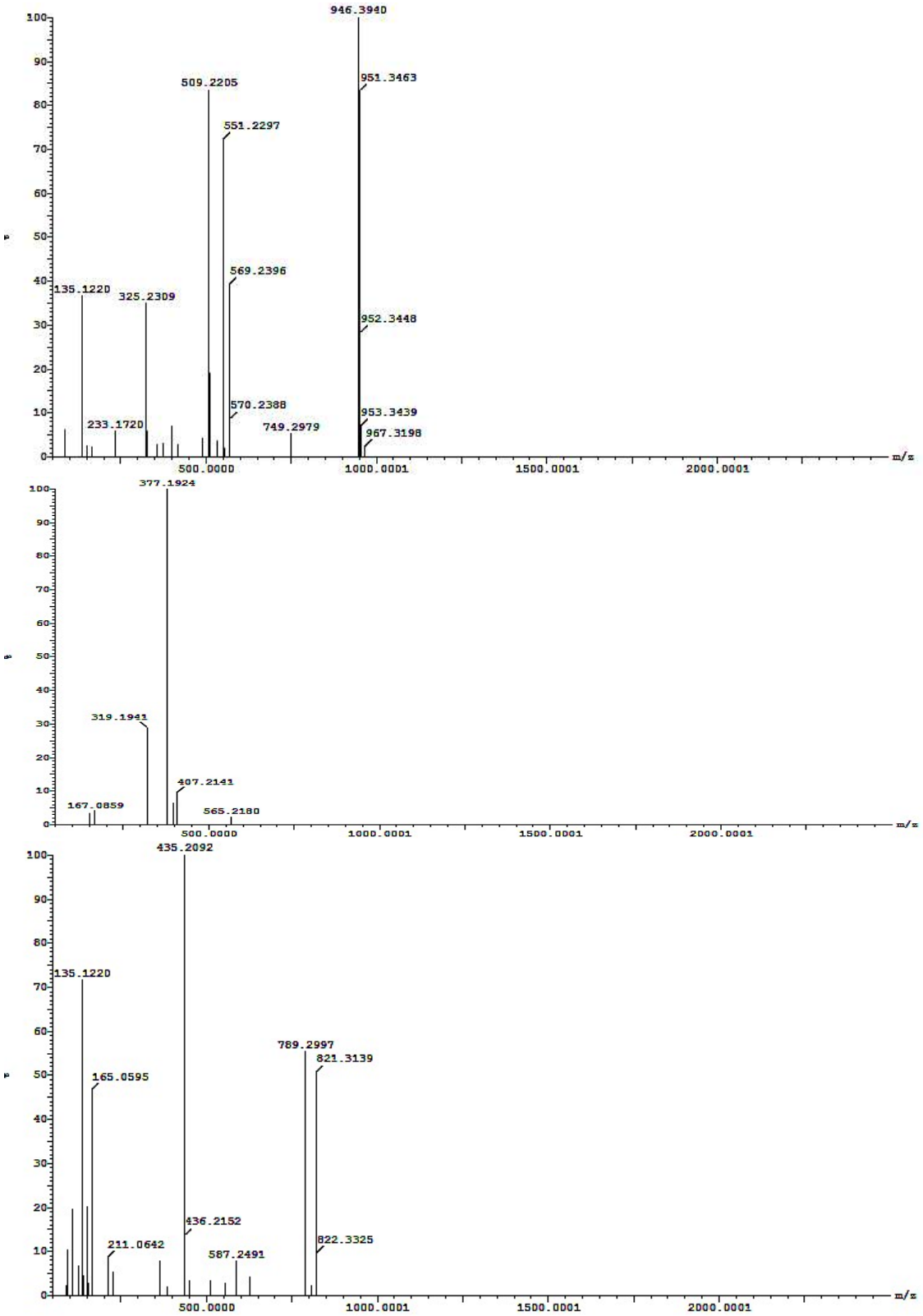
Figure 3: GC-MS chromatogram of Ethyl Acetate fraction of aerial part of *Jasminum mesnyi* Hance

3.3 Identification of Bioactive Compounds by UPLC-Q-TOF/MS

The fractions of *Jasminum mesnyi* Hance were analyzed using UPLC-Q-TOF/MS under optimized chromatographic and mass spectrometric conditions. A rapid and efficient analytical method was established for the identification of major chemical constituents in different fractions. The main bioactive compounds in chloroform, ethyl acetate, and n-butanol fractions were identified and are summarized in Table 3. The base peak

ion (BPI) chromatograms of these fractions (Fig. 4) provided comprehensive metabolite profiling, serving as analytical fingerprints for the characterization of *Jasminum mesnyi* Hance.

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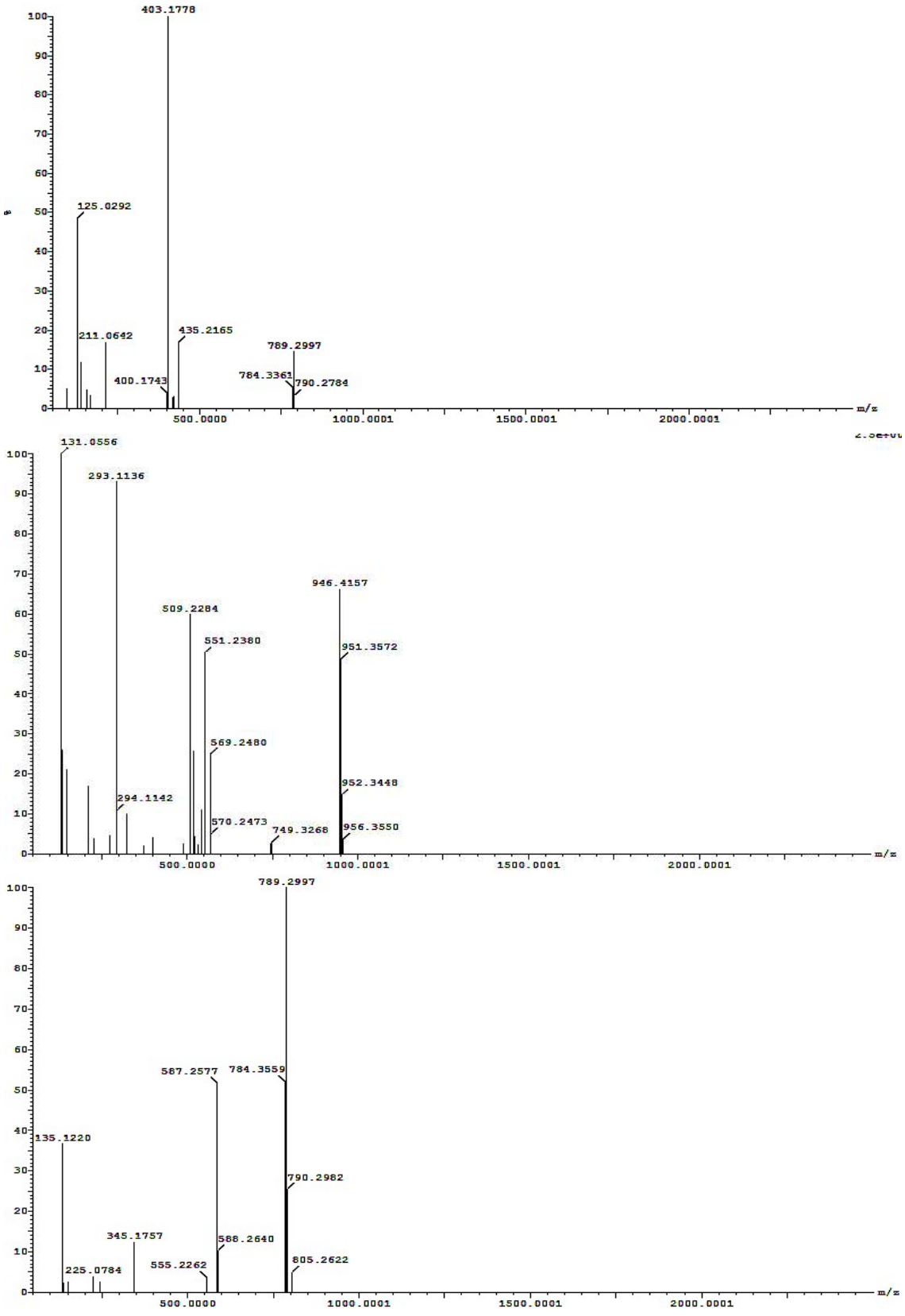
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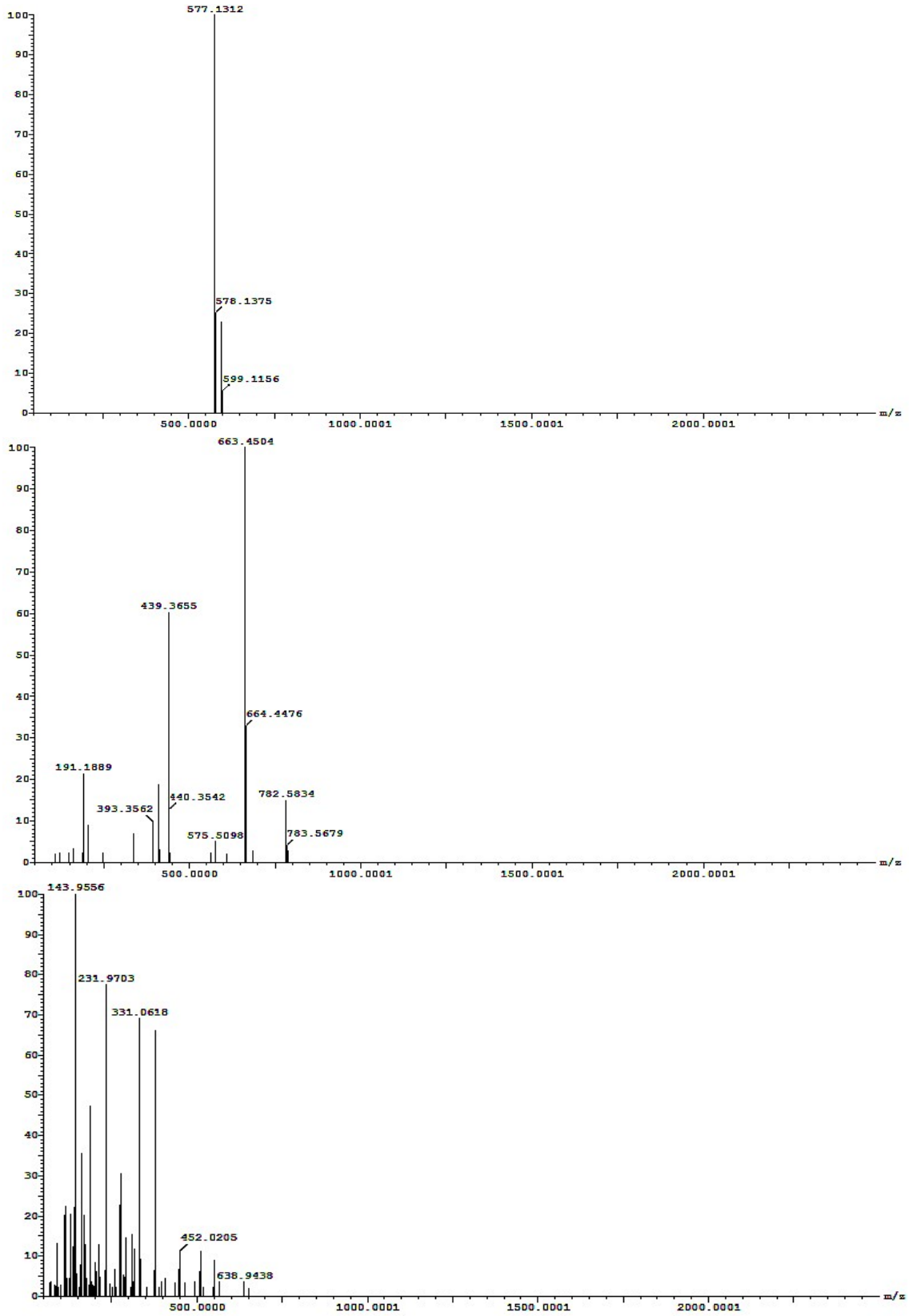
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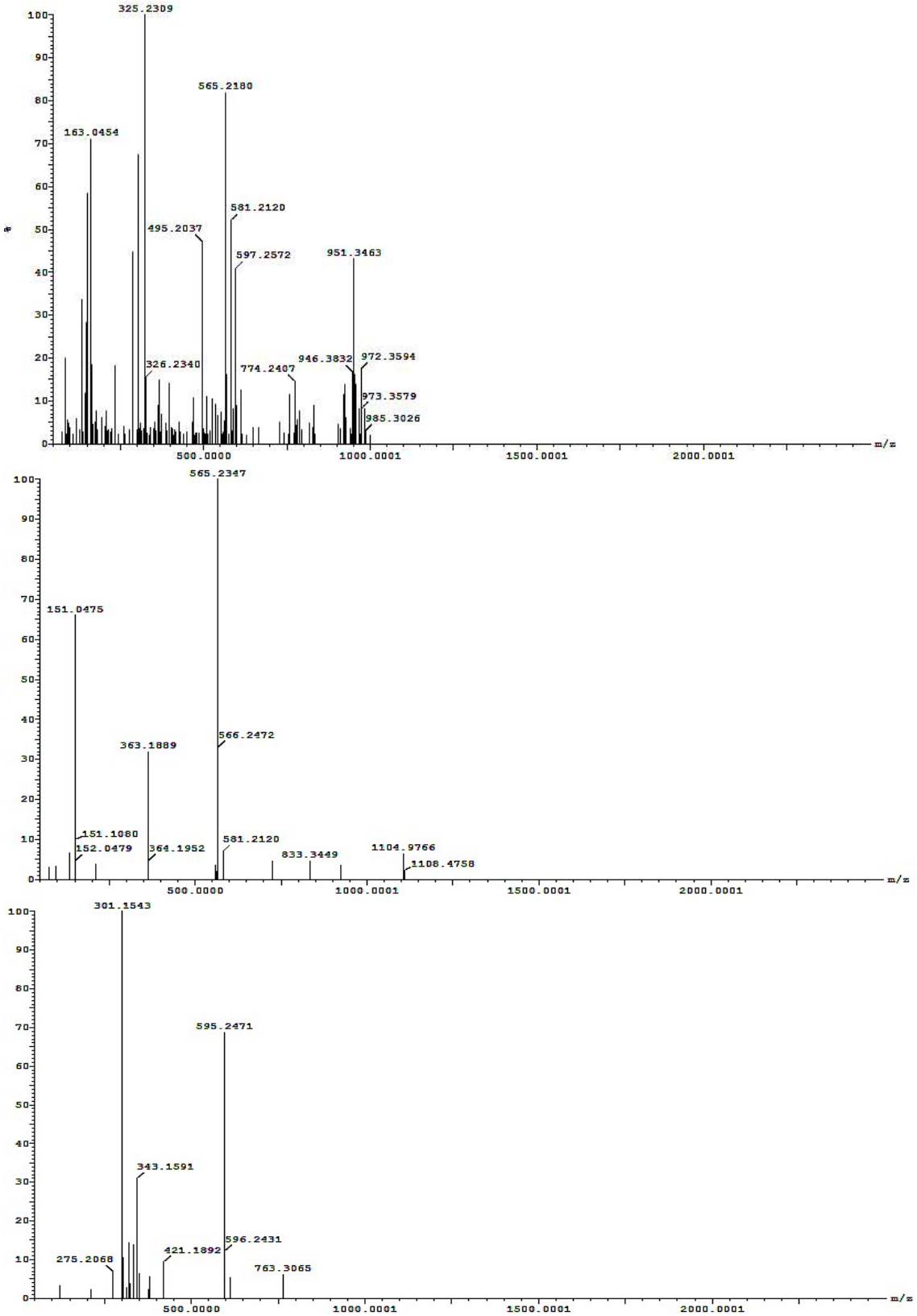
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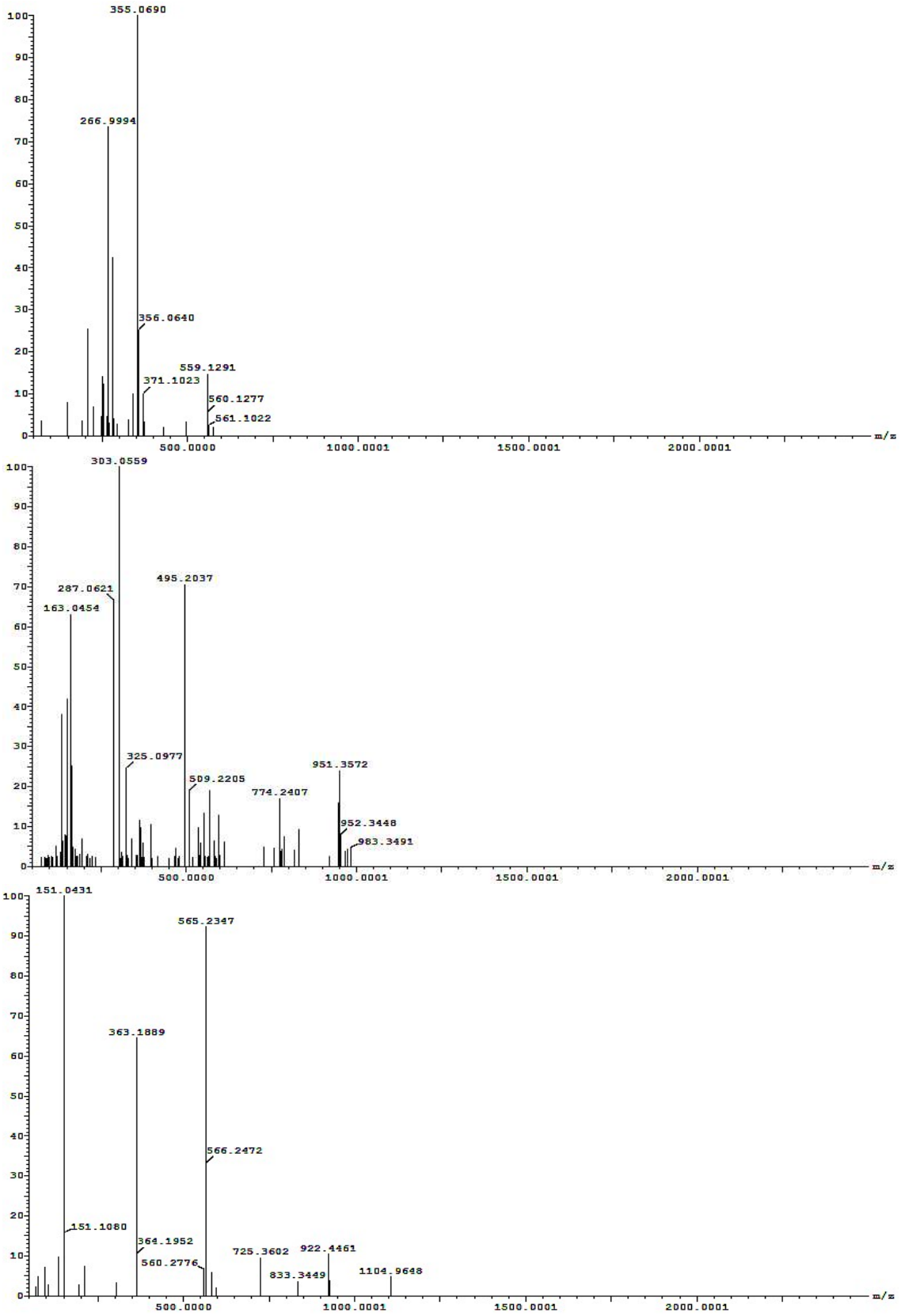
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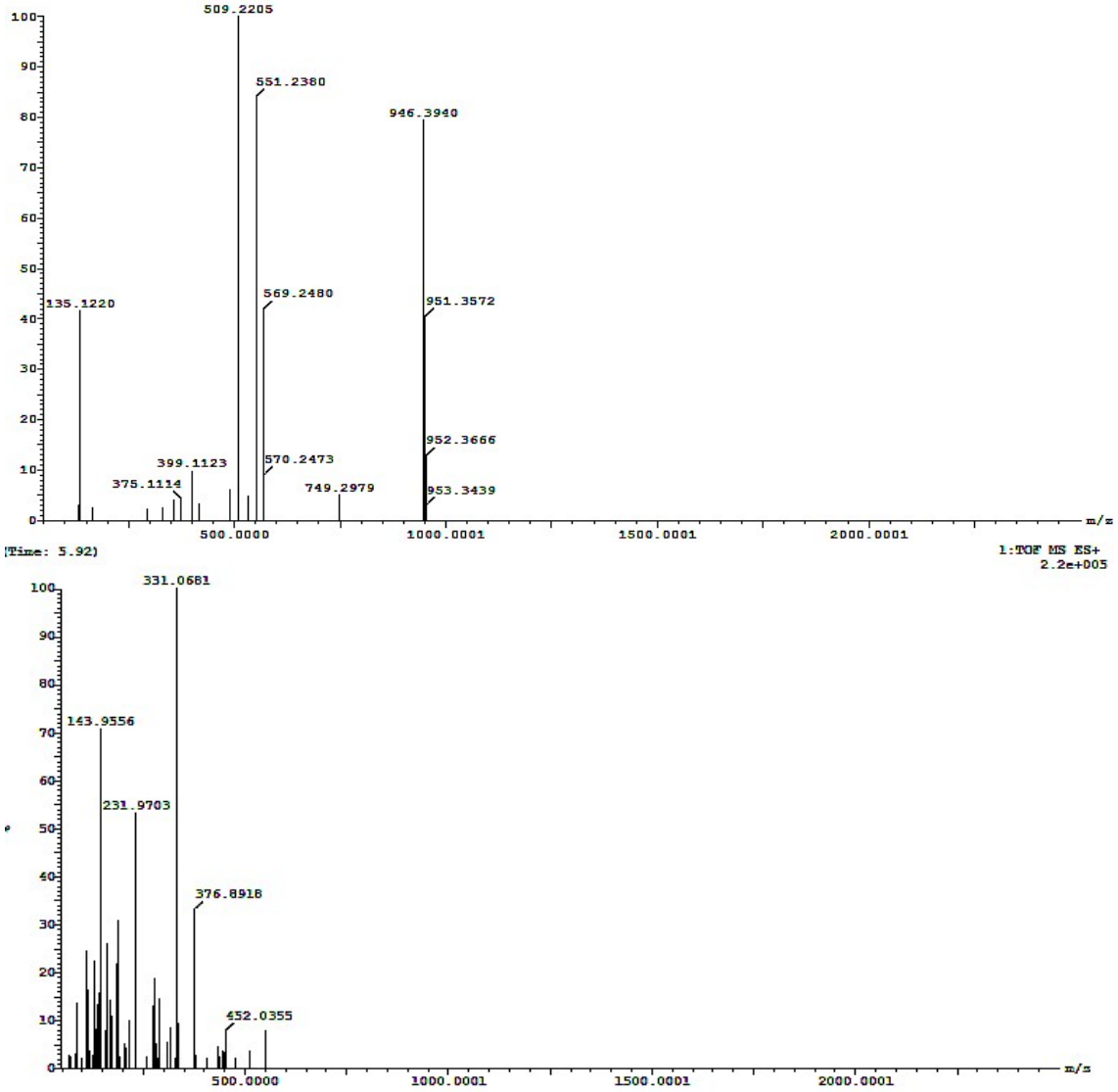


Figure 4: UPLC-Q-TOF/MS chromatogram of chloroform fraction, ethyl acetate fraction and Butanol fraction of berries of *Jasminum mesnyi* Hance.

3.4 Quantitative Analysis by UHPLC-DAD

UHPLC-DAD analysis of *Jasminum mesnyi* Hance fractions confirmed the presence of caffeic acid in both ethyl acetate (JMH-EA) and n-butanol (JMH-BUT) fractions. The compound was identified by comparison of its retention time with that of the standard (RT ≈ 9.15 min). Quantitative determination based on the calibration curve (Y = 0.3547x + 0.2829) revealed a higher concentration of caffeic acid in the JMH-EA fraction (29.209 ppm) compared to the JMH-BUT fraction (23.577 ppm), as shown in Table 4. The identity of caffeic acid was further confirmed by UV–Visible spectral analysis at the corresponding retention time, showing characteristic absorption maxima at 254 nm and 352 nm, consistent with reported spectral data.

Figure 5: Calibration graph of Caffeic acid

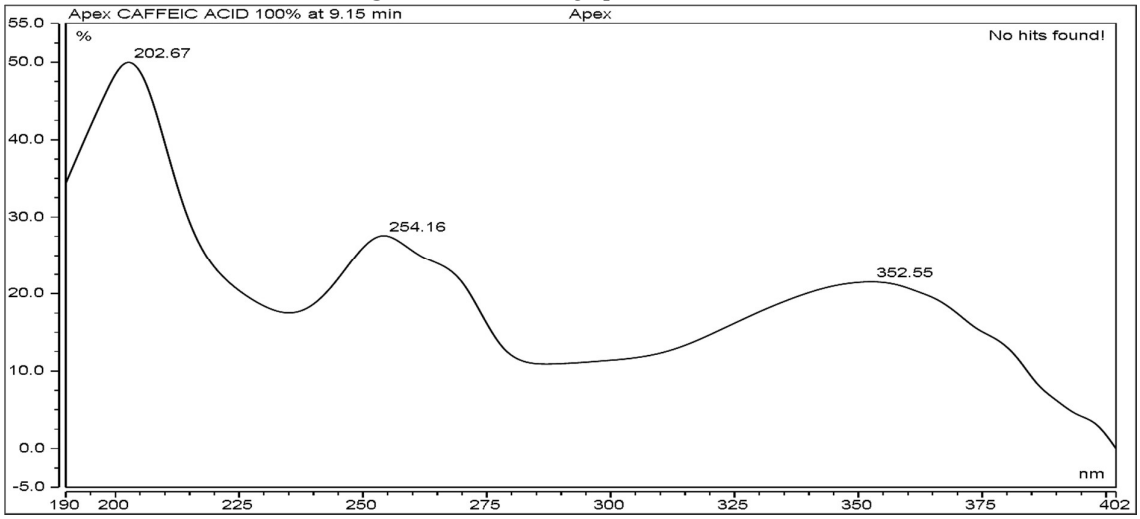


Figure 6: UV–Vis spectrum of caffeic acid identified in *Jasminum mesnyi* Hance fraction (RT ≈ 9.15 min), exhibiting characteristic λmax at 254 nm and 352 nm, confirming its presence.

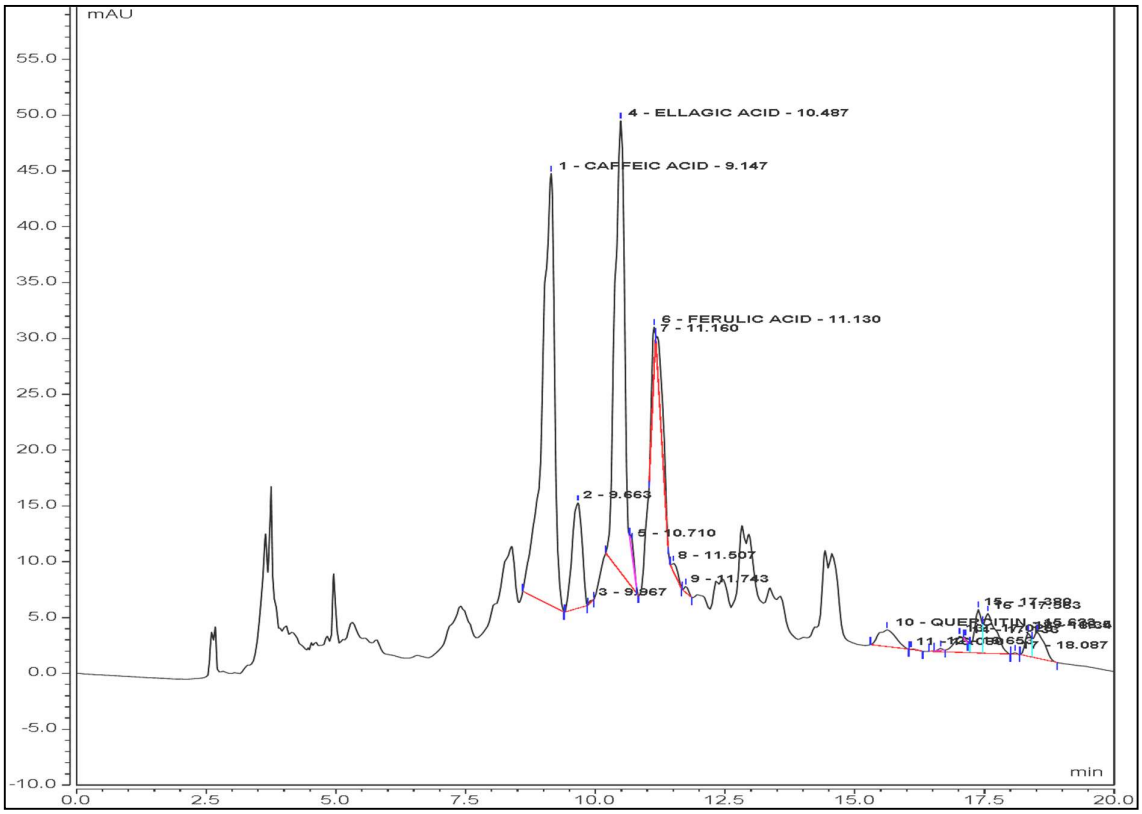


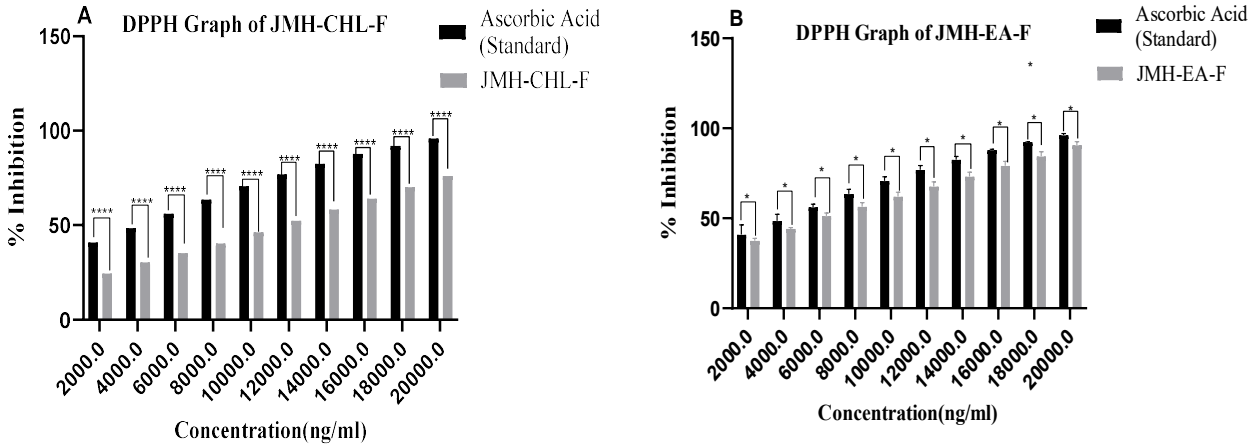
Figure 7: Representative UHPLC-DAD chromatogram of *Jasminum mesnyi Hance* fractions indicating the presence of caffeic acid, identified at retention times of 9.147 min (JMH-EA) and 9.150 min (JMH-BUT).

3.5 Biological activities of plant fractions

The biological potential of *Jasminum mesnyi* Hance fractions was evaluated through antioxidant and anti-inflammatory assays.

3.5.1 Antioxidant activity (DPPH assay)

The antioxidant activity was determined using the DPPH radical scavenging assay and expressed as IC_{50} values. Among the fractions, JMH-EA-F exhibited the strongest activity (6.00 ± 0.35 µg/mL), followed by JMH-BUT-F (9.13 ± 0.32 µg/mL) and JMH-CHL-F (11.02 ± 1.06 µg/mL). Ascorbic acid, used as the standard, showed the highest activity (3.64 ± 0.88 µg/mL). The results indicate significant free radical scavenging potential, particularly for the ethyl acetate fraction.



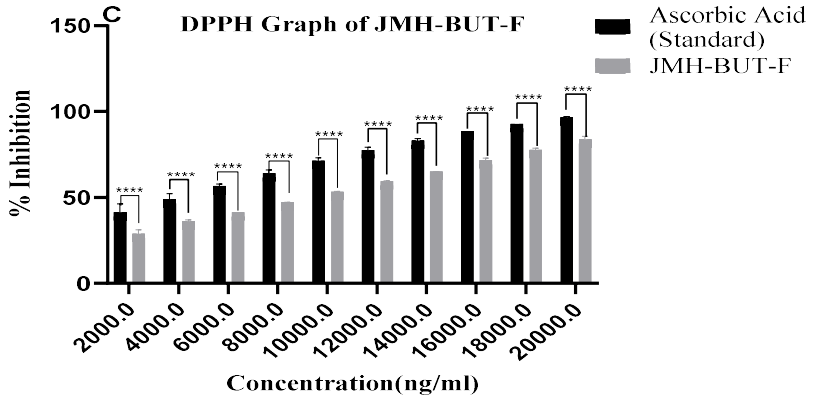


Figure 8: DPPH radical scavenging activity of different fractions of Jasminum mesnyi Hance: (A) chloroform fraction (JMH-CHL-F), (B) ethyl acetate fraction (JMH-EA-F), and (C) n-butanol fraction (JMH-BUT-F), compared with ascorbic acid as standard across concentrations ranging from 2000–20000 ng/ml; all fractions exhibited a concentration-dependent increase in % inhibition, with ethyl acetate and n-butanol fractions demonstrating relatively higher antioxidant activity than the chloroform fraction. Data are presented as mean ± SD (n = 3). Statistical analysis was performed using one-way ANOVA followed by Tukey's test, and significance is indicated as $p < 0.05$, *$p < 0.001$, ****$p < 0.0001$.

3.5.2 Anti-inflammatory activity (Nitric oxide assay)

The anti-inflammatory activity was evaluated via nitric oxide scavenging assay. The IC_{50} values were found to be 59.5 ± 3.05 µg/mL for ascorbic acid (used as the standard), 69.9 ± 1.51 µg/mL for JMH-EA-F, 76.9 ± 1.71 µg/mL for JMH-BUT-F, and 91.1 ± 1.35 µg/mL for JMH-CHL-F. The results suggest moderate nitric oxide inhibitory activity, with JMH-EA-F showing comparatively better potential among the tested fractions.

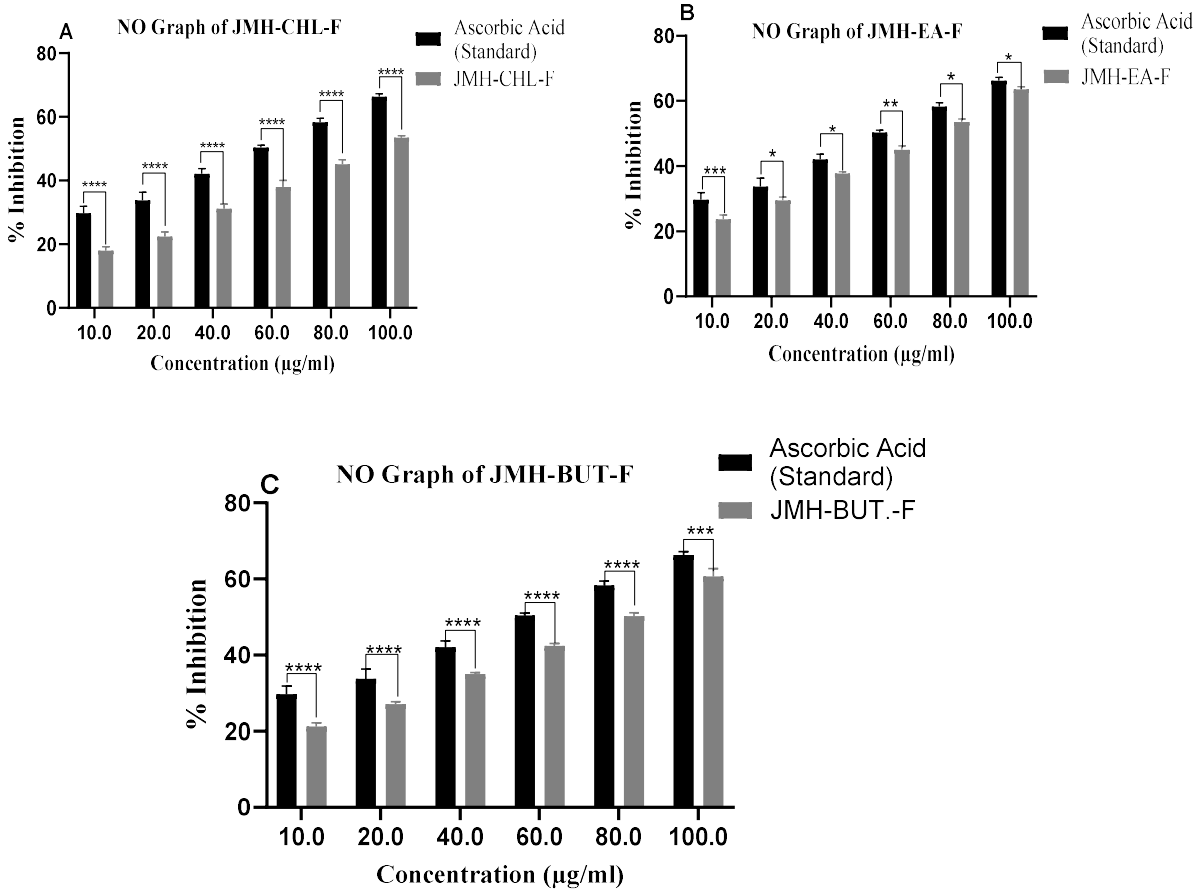


Figure 9: Nitric oxide (NO) inhibitory activity of different fractions of Jasminum mesnyi Hance: (A) chloroform fraction (JMH-CHL-F), (B) ethyl acetate fraction (JMH-EA-F), and (C) n-butanol fraction (JMH-BUT-F), compared with ascorbic acid as standard across concentrations ranging from 10–100 µg/ml; all fractions exhibited a concentration-dependent increase in % inhibition, with ethyl acetate and n-butanol fractions showing comparatively higher inhibitory activity than the chloroform fraction. Data are presented as mean ± SD (n = 3). Statistical analysis was performed using one-way ANOVA followed by Tukey's test, and significance is indicated as $p < 0.05$, $^{**}p < 0.01$, $^{*}p < 0.001$, $^{****}p < 0.0001$.

4. Discussion

4.1 Extraction Yield and Fractionation

The ethanolic extract of *Jasminum mesnyi* Hance yielded 10%, indicating the effectiveness of ethanol as a broad-spectrum solvent for extracting both polar and moderately non-polar phytoconstituents. Subsequent solvent–solvent partitioning resulted in differential distribution of compounds across fractions. The aqueous fraction exhibited the highest yield (50.21%), followed by the n-butanol fraction (33.80%), whereas comparatively lower yields were obtained for the chloroform (11.89%) and ethyl acetate (4.10%) fractions. This variation in yield reflects the polarity-dependent solubility of phytoconstituents.

4.2 GC–MS Analysis of Chloroform Fraction

GC–MS analysis of the chloroform fraction of *Jasminum mesnyi* Hance revealed several bioactive compounds with reported pharmacological activities. Nonadecane has been reported to possess antioxidant activity [20]. Hexadecane exhibits antioxidant and antimicrobial properties [20], while tetradecane has also been associated with antioxidant activity [20]. Octadecane has been reported to show antioxidant, anti-inflammatory, and antifungal activities [33], whereas pentadecane is known for its anti-inflammatory and antimicrobial effects [7].

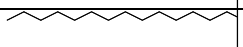
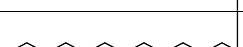
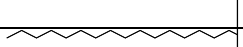
The phenolic compound 2,4-di-tert-butylphenol has been widely reported for its antioxidant and anti-inflammatory activities [36]. Fatty acid esters such as hexadecanoic acid methyl ester have demonstrated hepatoprotective and anti-inflammatory properties [11], while heptadecanoic acid, 16-methyl-, methyl ester and methyl stearate have been associated with antioxidant activity [38].

4.3 GC–MS Analysis of Ethyl Acetate Fraction

GC–MS analysis of the ethyl acetate fraction of *Jasminum mesnyi* Hance revealed the presence of several biologically active compounds. Stannane derivatives, including triethyl(phenylmethyl)- and diethylbis(phenylmethyl)-, have been reported to exhibit anti-inflammatory and anticancer activities [34]. Tetracosane has been associated with antioxidant activity [35], while benzene derivatives such as 1-methyl-4-(4-morpholyl) ethenylsulfonyl- have shown anti-inflammatory properties [19].

Thymoquinone is a well-known bioactive compound with antioxidant, hepatoprotective, and anti-inflammatory activities [22]. Alkanes such as tetradecane and hexadecane have also been reported for antioxidant and antimicrobial properties [20]. Additionally, fatty acid esters including hexadecanoic acid methyl ester, heptadecanoic acid, 16-methyl-, methyl ester, and methyl stearate have demonstrated hepatoprotective and antioxidant activities [11] & [38].

Table 1: Phytochemical reported compounds identified in the Chloroform fraction of Aerial part of *Jasminum mesnyi* Hance

S. N.	RT	Compound Name	Area %	Molecular Weight	Molecular Formula	Molecular Structure	Bioactivity	Ref.
1.	14.81	Nonadecane	1.14	268	$C_{19}H_{40}$		Antioxidant	[20]
2.	14.81	Hexadecane	1.14	226	$C_{16}H_{34}$		Antioxidant, antimicrobial	[20]
3.	14.81	Tetradecane	1.14	198	$C_{14}H_{30}$		Antioxidant, preservative	[20]
4.	14.81	Octadecane	1.14	254	$C_{18}H_{38}$		Antifungal, Antioxidant, Anti-inflammatory	[33]
5.	14.81	Pentadecane	1.14	212	$C_{15}H_{32}$		Antimicrobial & Anti-inflammatory activity	[7]

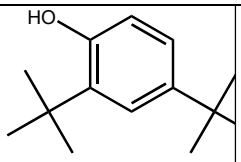
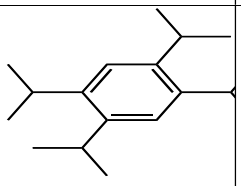
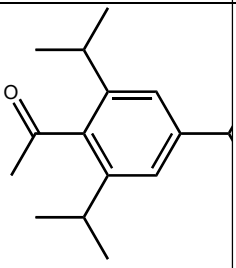
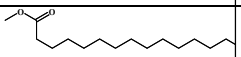
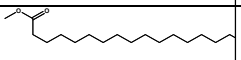
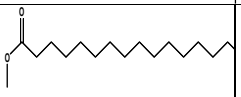
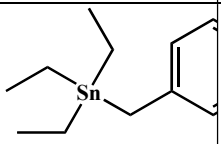
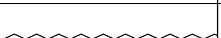
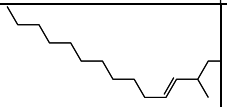
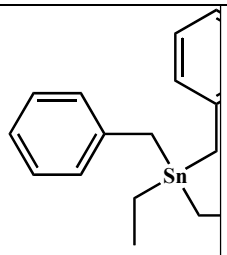
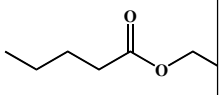
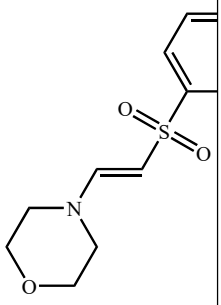
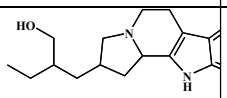
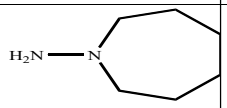
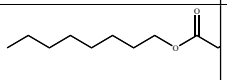
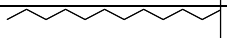
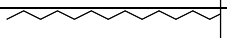
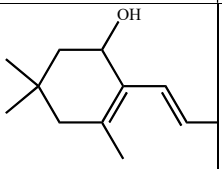
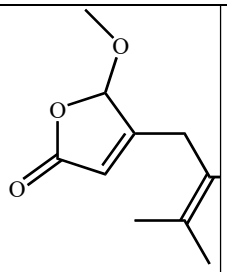
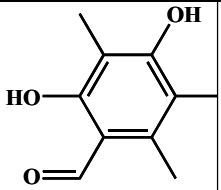
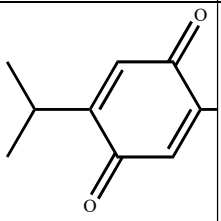
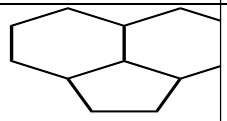
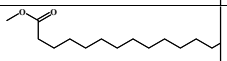
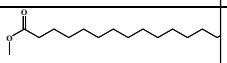
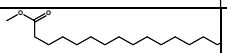
6.	16.64	2,4-Di-tert-butylphenol	1.98	206	$C_{14}H_{22}O$		Antioxidant & Anti-inflammatory	[36]
7.	19.70	Benzene, 1,2,4,5-tetrakis(1-methylethyl)-	4.83	246	$C_{18}H_{30}$		Not reported	
8.	19.70	2,4,6-Tri-isopropylacetophenone	4.83	246	$C_{17}H_{26}O$		Not reported	
9.	23.30	Hexadecanoic acid, methyl ester	14.59	270	$C_{17}H_{34}O_2$		Hepatoprotective Activity & Anti-inflammatory	[11]
10.	26.01	Methyl stearate	7.15	298	$C_{19}H_{38}O_2$		Antioxidant	[38]
11.	26.01	Heptadecanoic acid, 16-methyl-, methyl ester	7.15	298	$C_{19}H_{38}O_2$		Antioxidant	[38]

Table 2: Phytochemical reported compounds identified in the Ethyl Acetate fraction of aerial part of *Jasminum mesnyi* Hance

S. N.	**RT**	**Compound Name**	**Area %**	**Molecular Weight**	**Molecular Formula**	**Molecular Structure**	**Bioactivity**	**Ref.**
1.	7.12	Stannane, triethyl(phenylmethyl)-	7.08	298	$C_{13}H_{22}Sn$		Anticancer & Anti-inflammatory agent	[34]
2.	7.12	Tetracosane	7.08	338	$C_{24}H_{50}$		Antioxidant	[35]
3.	7.12	E-2-Methyl-3-tetradecen-1-ol acetate	7.08	268	$C_{17}H_{32}O_2$		Not reported	

4.	7.12	Stannane, diethylbis(phenylmethyl)-	7.08	360	$C_{18}H_{24}Sn$		Anticancer & Anti-inflammatory agent	[34]
5.	9.03	Pentanoic acid, 2-ethylhexyl ester	3.16	214	$C_{13}H_{26}O_2$		Not reported	
6.	9.03	Benzene, 1-methyl-4-(4-morpholyl)ethenylsul fonyl-	3.16	267	$C_{13}H_{17}NO_3S$		anti-inflammatory agent	[19]
7.	9.03	2(2'-Hydroxymethyl butyl)-1,2,3,5,6,11b-hexahydro-11-h-indolo-(3,2-g)-pyrrocoline	3.16	298	$C_{19}H_{26}N_2O$		Not reported	
8.	9.03	1H-Azepin-1-amine, hexahydro-	3.16	114	$C_6H_{14}N_2$		Not reported	
9.	9.03	Butanoic acid, 3-methyl-, octyl ester	3.16	214	$C_{13}H_{26}O_2$		Not reported	
10.	11.00	Tetradecane	3.50	198	$C_{14}H_{30}$		Antioxidant, preservative	[20]
11.	14.81	Hexadecane	2.52	226	$C_{16}H_{34}$		Antioxidant, antimicrobial	[20]
12.	21.50	2-Propenoic acid, 3-(3-hydroxy-2,6,6-trimethyl-1-cycl ohexen-1-yl)-, methyl ester, (E)-	8.61	224	$C_{13}H_{20}O_3$		Not reported	

13.	21.50	4-(2,3-Dimethyl-2-butenyl)-5-methoxy-2(5H)-furanone	8.61	196	$C_{11}H_{16}O_3$		Not reported	
14.	21.50	Methyl 3-formyl-4,6-dihydroxy-2,5-dimethylbenzoate	8.61	224	$C_{11}H_{12}O_5$		Not reported	
15.	21.50	Thymoquinone	8.61	164	$C_{10}H_{12}O_2$		Hepatoprotective, Anti-inflammatory & Antioxidant	[22]
16.	21.50	Acenaphthylene, dodecahydro-	8.61	164	$C_{12}H_{20}$		Not reported	
17.	23.30	Hexadecanoic acid, methyl ester	22.54	270	$C_{17}H_{34}O_2$		Hepatoprotective Activity & Anti-inflammatory	[11]
18.	26.01	Heptadecanoic acid, 16-methyl-, methyl ester	11.63	298	$C_{19}H_{38}O_2$		Antioxidant	[38]
19.	26.01	Methyl stearate	11.63	298	$C_{19}H_{38}O_2$		Antioxidant	[38]

4.4 Tentatively Identified Bioactive Compounds by UPLC-Q-TOF/MS

UPLC-Q-TOF/MS analysis of different fractions of *Jasminum mesnyi* Hance enabled the tentative identification of several bioactive compounds under optimized chromatographic and mass spectrometric conditions. A total of fourteen compounds were tentatively identified in the chloroform fraction, twenty-four compounds in the ethyl acetate fraction, and fourteen compounds in the n-butanol fraction (Table 3). These identified phytoconstituents predominantly belong to classes such as phenolics, flavonoids, fatty acid derivatives, and terpenoid-related compounds, which have been widely reported to exhibit antioxidant, anti-inflammatory, and hepatoprotective activities. The presence of these compounds supports the pharmacological potential of *Jasminum mesnyi* Hance and correlates well with the results obtained from GC–MS analysis.

Table 3: Tentatively identified bioactive compounds in chloroform, ethyl acetate, and n-butanol fractions of the aerial parts of *Jasminum mesnyi* Hance by UPLC-Q-TOF/MS.

No.	Component Name	JMH Fractions	Observed RT (Min)	Formula	Observed neutral mass (Da)	m/z	Mass Error (mDa)	Adducts	Bioactivity	Reference
1.	Nhatrangin A	JMH-	9.04	$C_{21}H_{32}$	412.20	377.1	0.3	M+H	Not	

		Chl		O_8	60	924		-2H2O	reported	
2.	Pyrogallol	JMH-Chl	27.47	$C_6H_6O_3$	126.0367	149.0265	-0.2	M+Na	Antioxidant & anti-inflammatory activities	[2]
3.	Ligraminol D	JMH-Chl	9.04	$C_{21}H_{28}O_6$	376.1848	377.1924	0.3	M+H	Not reported	
4.	Quercetin	JMH-Chl	31.46	$C_{15}H_{10}O_7$	302.1617	301.1543	-0.1	M-H	Antioxidant and anti-inflammatory activities	[45][25]
5.	Glaucogenin D	JMH-Chl	9.04	$C_{21}H_{28}O_6$	376.1848	377.1924	0.3	M+H	Antiviral Activity	
6.	Norcaesalpinin E	JMH-Chl	9.04	$C_{21}H_{28}O_6$	376.1849	377.1924	0.2	M+H	Antimalarial	
7.	3-O-Methylgallic acid	JMH-Chl	27.47	$C_8H_8O_4$	184.0401	149.0265	0.3	M+H-2H2O	Antioxidant activities	[8]
8.	Naseseazine A	JMH-Chl	27.47	$C_{30}H_{30}N_6O_4$	538.1670	577.1312	0.5	M+K	Not reported	
9.	Hydroxydecenoic acid (HDA)	JMH-Chl	6.33	$C_{10}H_{18}O_3$	186.057	151.0431	0	M+H-2H2O	hepatoprotective activity	[41]
10.	Phloroglucinol	JMH-Chl	27.47	$C_6H_6O_3$	126.0367	149.0265	-0.2	M+Na	Antioxidant & anti-inflammatory activities	[23]
11.	Burmanicumolide A	JMH-Chl	11.79	$C_{23}H_{30}O_8$	434.2015	435.2092	0.4	M+H	Not reported	
12.	4-O-Methylgallic acid	JMH-Chl	27.47	$C_8H_8O_5$	184.0401	149.0265	0.3	M+H-2H2O	anti-inflammatory activities	[29]
13.	Arzanol	JMH-Chl	12.46	$C_{22}H_{26}O_7$	402.1701	403.1778	0.4	M+H	Anti-inflammatory activities	[3]
14.	Gmelinol	JMH-Chl	12.46	$C_{22}H_{26}O_7$	402.1703	403.1778	0.2	M+H	Not reported	
15.	Myristinin A	JMH-EA	12.85	$C_{33}H_{40}O_7$	548.294	587.2577	0	M+K	Not Reported	
16.	Ellagic Acid	JMH-EA	10.28	$C_{14}H_6O_8$	302.1614	301.1543	0.2	M-H	Antioxidant, anti-inflammatory Activity and Hepatoprotective activity	[10]
17.	Citriquinone A	JMH-EA	10.28	$C_{18}H_{24}O_6$	336.1680	301.1543	0.2	M+H-2H2O	Not Reported	
18.	Polyacetylenic fatty acid	JMH-EA	10.28	$C_{18}H_{20}O_4$	300.148	301.1543	0	M+H	anti-Inflammatory	[37]
19.	Oleanane triterpenoid	JMH-EA	42.71	$C_{30}H_{50}O_4$	474.3791	439.3655	0.3	M+H-2H2O	Antioxidant, anti-Inflammatory and	[14]

									hepatoprotective activity	
20.	Ursolic acid	JMH-EA	42.71	$C_{30}H_{48}O_3$	456.392	439.3655	0	M+NH3	Antioxidant, anti-Inflammatory and hepatoprotective activity	[26]
21.	Lupane triterpenoid	JMH-EA	42.71	$C_{30}H_{46}O_2$	438.3579	439.3655	0.3	M+H	Antioxidant & anti-Inflammatory	[21]
22.	Taraxerane triterpenoid	JMH-EA	42.71	$C_{30}H_{46}O_2$	438.3579	439.3655	0.3	M+H	Antioxidant & anti-Inflammatory	[18]
23.	Ursolic-type triterpenoid	JMH-EA	42.71	$C_{30}H_{46}O_2$	438.3579	439.3655	0.3	M+H	Not Reported	
24.	Flavonoid dimer	JMH-EA	27.47	$C_{34}H_{24}O_9$	576.1235	577.1312	0.4	M+H	Antioxidant & anti-Inflammatory	[30]
25.	Guajadial	JMH-EA	42.71	$C_{30}H_{34}O_5$	474.3791	439.3655	0.3	M+H-2H2O	Not Reported	
26.	Psidial A	JMH-EA	42.71	$C_{30}H_{34}O_5$	474.3792	439.3655	0.2	M+H-2H2O	Not Reported	
27	Caffeic Acid	JMH-EA	5.86	$C_9H_8O_4$	208.9805	231.9703	-0.2	M+Na	Antioxidant activity	[39]
28.	Psiguadial A	JMH-EA	42.71	$C_{30}H_{34}O_5$	474.3790	439.3655	0.4	M+H-2H2O	Not Reported	
29.	Mallotophilippen C	JMH-EA	42.71	$C_{30}H_{34}O_5$	474.3792	439.3655	0.2	M+H-2H2O	Not Reported	
30.	Dodecalactone	JMH-EA	4.52	$C_{12}H_{22}O_2$	198.0590	163.0454	0.3	M+H-2H2O	Not Reported	
31.	Secoisolariciresinol	JMH-EA	6.59	$C_{20}H_{26}O_6$	362.1812	363.1889	0.4	M+H	Antioxidant, anti-Inflammatory and liver necrosis	[16]
32.	Gomisin N	JMH-EA	42.71	$C_{23}H_{28}O_6$	400.4015	439.3655	0.3	M+K	anti-Inflammatory and hepatoprotective activity	[17]
33.	Monspelioside	JMH-EA	8.59	$C_{15}H_{20}O_8$	328.1270	293.1136	0.5	M+H-2H2O	Not Reported	
34.	Demethoxylpinoresinol	JMH-EA	8.59	$C_{19}H_{20}O_5$	328.1272	293.1136	0.3	M+H-2H2O	Not Reported	

35.	Dalbergiphenol	JMH-EA	8.59	$C_{17}H_{18}O_3$	270.1232	293.1136	0.4	M+Na	Not Reported	
36.	Phenolic glycoside	JMH-EA	8.59	$C_{15}H_{20}O_8$	328.1270	293.1136	0.5	M+H-2H2O	Antioxidant & anti-Inflammatory	[1]
37.	Iridoid glycoside	JMH-EA	10.28	$C_{25}H_{38}O_{16}$	594.2395	595.2471	0.3	M+H	anti-Inflammatory and hepatoprotective activity	[43]
38.	Phenylethanoid glycoside	JMH-EA		$C_{25}H_{38}O_{16}$	594.2390	595.2471	0.5	M+H	Not Reported	
39.	Coumarin derivative	JMH-But	8.39	$C_{31}H_{34}O_5$	486.2359	509.2262	0.3	M+Na	Antioxidant & anti-Inflammatory	[12]
40.	Chromene (benzopyran) derivative	JMH-But	37.20	$C_{19}H_{24}O_4$	316.0649	355.0690	0.4	M+K	Antioxidant & anti-Inflammatory	[31]
41.	Furanone derivative	JMH-But	6.47	$C_{32}H_{34}N_2O_6$	542.2444	565.2347	0.3	M+Na	anti-Inflammatory	[15]
42.	Prenylated flavonoid (pyranochromene)	JMH-But	4.52	$C_{30}H_{32}O_5$	472.2034	495.2037	0.1	M+Na	Antioxidant & anti-Inflammatory	[40]
43.	Caffeic Acid	JMH-But	5.92	$C_9H_8O_4$	208.9805	231.9703	-0.2	M+Na	Antioxidant activity	[39]
44.	Terpenoid-substituted phenolic acid	JMH-But	4.52	$C_{27}H_{36}O_6$	472.2032	495.2037	0.3	M+K	Antioxidant & anti-Inflammatory	[44]
45.	Prenylated coumarin derivative	JMH-But	4.52	$C_{27}H_{36}O_6$	472.2032	495.2037	0.3	M+K	Antioxidant & anti-Inflammatory	[12]
46.	Isochromenone (lactone) derivative	JMH-But	4.52	$C_{27}H_{36}O_6$	472.2032	495.2037	0.3	M+K	Antioxidant & anti-Inflammatory	[46]
47.	coumarin derivative	JMH-But	4.52	$C_{18}H_{22}O_4$	302.0547	303.0559	0.3	M+H	Antioxidant & anti-Inflammatory	[12]
48.	Terpenoid ester	JMH-But	4.52	$C_{16}H_{24}O_4$	280.0655	303.0559	0.4	M+Na	Antioxidant & anti-Inflammatory	[27]
49.	secoisolariciresinol	JMH-But	6.47	$C_{20}H_{26}O_6$	362.1814	363.1889	0.2	M+H	Antioxidant, anti-Inflammatory and liver necrosis	[16]
50.	Lanostane-type triterpenoid	JMH-But	8.39	$C_{34}H_{50}O_8$	586.2515	551.2380	0.4	M+H-2H20	Antioxidant and hepatoprote	[13]

									ctive activity	
51.	Oleanane-type triterpenoid	JMH-But	8.39	$C_{32}H_{48}O_6$	528.248	551.2380	0	M+Na	Antioxidant, anti-Inflammatory and hepatoprotective activity	[14]
52.	Deoxyvasicinone	JMH-But	6.47	$C_{11}H_{10}N_2O$	186.057	151.0431	0	M+H-2H20	Anti-Inflammatory	[24]

4.5 Quantitative Analysis

The UHPLC-DAD-based quantitative analysis of *Jasminum mesnyi* Hance fractions demonstrated variation in the distribution of phenolic compounds across different solvent systems. Caffeic acid was quantified in both ethyl acetate (JMH-EA) and n-butanol (JMH-BUT) fractions, with a comparatively higher concentration observed in the ethyl acetate fraction (29.209 ppm) than in the n-butanol fraction (23.577 ppm). This distribution suggests a preferential affinity of caffeic acid towards moderately polar solvents. The UHPLC chromatograms (Fig. 7) exhibited well-defined peaks at retention times of 9.147 min (JMH-EA) and 9.150 min (JMH-BUT), which are in close agreement with the standard retention time of caffeic acid, confirming its presence in both fractions. Further confirmation was obtained through UV–Visible spectral analysis at the corresponding retention time (≈9.15 min), showing characteristic absorption maxima at 254 nm and 352 nm, consistent with reported spectral data. Caffeic acid is a well-known phenolic compound with significant antioxidant activity, which may contribute to the overall pharmacological potential of *Jasminum mesnyi* Hance [39].

Table 4: Quantification of caffeic acid in ethyl acetate and n-butanol fractions of *Jasminum mesnyi* Hance by UHPLC-DAD.

***Jasminum mesnyi* Hance fraction**	**Compounds Name**	**Regression Equation**	**Retention Time (Min.)**	**Area (mAU*min)**	**Height (mAU)**	**Amount PPM**	**Relative Area %**
JMH-EA	Caffeic Acid	Y=0.3547x+0.2829	9.147	10.644	38.718	29.209	39.98
JMH-BUT.	Caffeic Acid	Y=0.3547x+0.2829	9.150	8.646	48.212	23.577	18.67

4.6 Antioxidant Activity of JMH Fractions (DPPH Assay)

The DPPH assay showed that all fractions have antioxidant activity, with JMH-EA-F exhibiting the strongest effect, likely due to higher phenolic and flavonoid content. JMH-BUT-F and JMH-CHL-F showed moderate activity. Ascorbic acid, used as the standard, showed the highest activity; however, the ethyl acetate fraction demonstrated comparable and significant scavenging potential, indicating its importance in reducing oxidative stress.

4.7 Anti-inflammatory Activity of JMH Fractions (NO Assay)

The nitric oxide scavenging assay showed that all fractions possess moderate anti-inflammatory activity. Among them, JMH-EA-F exhibited the highest activity, followed by JMH-BUT-F and JMH-CHL-F, indicating a polarity-based distribution of active compounds. Ascorbic acid, used as the standard, showed the highest activity, while the ethyl acetate fraction demonstrated comparatively closer efficacy. This activity may be attributed to phenolic and flavonoid compounds, suggesting its potential role in managing nitric oxide-mediated inflammation.

Table 5: Free radical scavenging activity of *Jasminum mesnyi* Hance plant fractions

Plant Fraction	**IC_{50}/DPPH (µg/ml)**	**IC_{50}/NO (µg/ml)**
Ascorbic Acid	3.64 ± 0.88	59.5 ± 3.05
JMH (CHL-F)	11.02 ± 1.06	91.14 ± 1.35
JMH (EA-F)	6.00 ± 0.32	69.8 ± 1.51
JMH (But.-F)	9.13 ± 0.32	76.86 ± 1.71

Table 6: Percentage DPPH radical scavenging inhibition of *Jasminum mesnyi* Hance plant fractions at different concentration

Conc. (ng/ml)	**Ascorbic Acid (% Inhibition)**	**JMH (CHL-F) (% Inhibition)**	**JMH (EA-F) (% Inhibition)**	**JMH (But.-F) (% Inhibition)**

2000	40.9 ± 5.3	24.4 ±5.58	35.5 ± 1.23	28.2 ± 2.78
4000	48.5 ± 3.6	30.4 ± 6.71	40.1 ± 0.69	35.5 ± 1.33
6000	56.2± 1.6	35.3 ± 4.31	46.3 ± 1.62	40.8 ± 0.14
8000	63.5 ± 2.5	40.4 ± 3.56	56.3 ± 2.32	46.6 ± 0.53
10000	70.7 ± 2.4	46.3 ± 3.01	62.1 ± 2.28	52.7 ± 0.83
12000	76.9 ± 2.4	52.4 ± 2.72	67.6 ± 2.50	58.8 ± 0.83
14000	82.5 ± 1.8	58.3 ± 1.66	73.1 ± 2.39	64.3 ± 0.69
16000	87.9 ± 0.4	64.2 ± 1.21	79.2 ± 2.29	71.2 ± 1.60
18000	92.2 ± 0.1	70.3 ± 0.99	83.4 ± 2.51	77.2 ± 1.53
20000	96.1 ±1.0	76.2 ± 1.21	88.6 ± 1.92	83.4± 2.15

Table 5: Percentage nitric oxide radical scavenging inhibition of *Jasminum mesnyi* Hance plant fractions at different concentration

Conc. (µg/ml)	Ascorbic Acid (% Inhibition)	JMH (CHL-F) (% Inhibition)	JMH (EA-F) (% Inhibition)	JMH (But.-F) (% Inhibition)
10	24.72 ± 3.19	9.93 ± 1.53	19.22 ± 3.10	13.29 ± 1.18
20	30.79 ± 3.76	16.63 ± 0.78	25.29 ± 3.96	20.27 ± 0.59
40	39.51 ± 3.19	24.67 ± 1.56	33.17 ± 3.12	28.75 ± 0.29
60	48.24 ± 3.85	32.47 ± 1.56	42.21 ± 3.34	37.09 ± 0.88
80	56.69 ± 4.36	40.28 ± 2.70	50.33 ± 3.32	45.38 ± 1.84
100	64.96 ± 3.62	48.96 ± 2.62	57.66 ± 2.84	52.65 ± 1.56

5. Conclusions

In conclusion, the present study provides comprehensive phytochemical profiling of solvent fractions of *Jasminum mesnyi* Hance, revealing a diverse array of bioactive constituents, predominantly flavonoids and phenolic compounds. Among the tested fractions, the ethyl acetate (JMH-EA-F), n-butanol (JMH-BUT-F), and chloroform (JMH-CHL-F) fractions exhibited notable biological activities, with the ethyl acetate fraction showing the most pronounced antioxidant activity and comparatively better nitric oxide scavenging potential when evaluated against ascorbic acid as the standard, indicating a polarity-dependent distribution of active metabolites. Importantly, UHPLC-DAD analysis confirmed the presence of caffeic acid in the ethyl acetate and butanol fractions, further supporting their antioxidant potential and contributing to the observed bioactivities. These findings collectively highlight *Jasminum mesnyi* Hance as a promising source of natural antioxidants with moderate anti-inflammatory potential. Moreover, the presence of phytoconstituents previously reported for hepatoprotective effects suggests possible therapeutic relevance. However, further in vivo studies are warranted to validate these biological activities, elucidate the underlying mechanisms, and establish their safety and efficacy.

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