

GC-MS analysis and phytochemical profiling of the methanolic extract of *Hyophila involuta* (Hook.) A. Jaeger from Mount Abu, India

Tripti Sharma¹, Afroz Alam^{1*}

¹Banasthali Vidyapith, Department of Bioscience and Biotechnology, Rajasthan, India, 304022

ARTICLE HISTORY

Received: Apr. 23, 2025

Accepted: Mar. 6, 2026

KEYWORDS

Bryophyta,
Bioactive Compounds,
GC-MS Analysis,
Hyophila involuta,
Phytochemical profiling.

Abstract: The present investigation explores the phytochemical composition and bioactive potential of the methanolic extract of *Hyophila involuta*, a commonly occurring moss species in India. Gas Chromatography–Mass Spectrometry (GC-MS) analysis was employed to characterize the volatile constituents of the extract, resulting in the identification of 37 compounds within a retention time range of [4.91–42.52 min]. The phytochemical profile revealed the predominance of terpenoids, phenolic compounds, fatty acids, and alkaloids. Among the identified constituents, [9-Octadecenoic acid (Z)-, methyl Ester and 9-Octadecenoic acid, methyl ester, (E)-] was detected as a major compound based on its relative peak area. Several of the identified compounds were reported in the literature to exhibit antioxidant, antimicrobial, and anti-inflammatory activities, indicating the potential pharmacological relevance of *H. involuta*. The findings provide scientific insight into the medicinal significance of this bryophyte and establish a baseline phytochemical dataset for future quantitative and bioactivity-guided pharmacological investigations of *H. involuta* collected from Mount Abu, India.

INTRODUCTION

Bioactive chemicals found in plants are abundant and essential for the manufacturing of nutraceuticals, pharmaceuticals, and other products like cosmetics, food colors, and flavors, especially in biodiversity rich countries like India (Gomathi *et al.*, 2013). These substances, sometimes referred to as secondary metabolites, are essential to the creation of new drugs. Terpenoids, alkaloids, saponins, tannins, flavonoids, and phenolics have been found in plant extracts using phytochemical screening. These compounds have a variety of biological actions, such as anti-inflammatory, antioxidant, anticancer, and antibacterial qualities (Starlin *et al.*, 2019).

Bryophytes represent an early-diverging lineage of land plants with considerable yet underexplored phytochemical diversity. Despite their ecological significance, less than 10% of bryophyte species have been investigated for their chemical composition (Asakawa, 2004). Recent studies have reported more than 400 bioactive compounds from bryophytes, including terpenoids, phenolics, glycosides, flavonoids, lipids, and diterpenoids (Alam, 2012). While liverworts are particularly rich in terpenoids, mosses remain comparatively less studied, though they are known to produce terpenoids, flavonoids, and bibenzyl derivatives (Asakawa *et al.*,

*Corresponding Author: Afroz ALAM ✉ aafroj@banasthali.in 📠 Banasthali Vidyapith, Faculty of Life Sciences, Department of Bioscience and Biotechnology, Rajasthan, India, 304022

The copyright of the published article belongs to its author under CC BY 4.0 license. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>

e-ISSN: 2148-6905

2013). Terpenoids isolated from bryophytes have demonstrated antimicrobial, antifungal, cytotoxic, and anti-inflammatory activities, highlighting their pharmaceutical potential (Chen *et al.*, 2018; Ludwiczuk & Asakawa, 2019; Whitehead *et al.*, 2018).

Hyophila involuta (Hook.) A. Jaeger is a terrestrial moss belonging to the family Pottiaceae, commonly distributed in tropical and subtropical regions of India, particularly on moist soil, rocks, and walls. The species is known for its ecological adaptability and tolerance to desiccation and environmental stress, suggesting the presence of protective secondary metabolites. Despite its widespread occurrence and ecological importance, phytochemical and pharmacological studies on *H. involuta* are extremely limited, with no comprehensive GC-MS-based profiling reported to date. This lack of chemical characterization underscores the necessity of investigating *H. involuta* to understand its phytochemical composition and potential bioactive properties.

Mosses have a haploid gametophytic dominant vegetative phase, fewer chromosomes, a relatively simple structure, and less morphological variability throughout the course of the growth season (Joshi & Alam, 2023). *Hyophila involuta* is a moss that grows in lawns and has upright stems. The small leaves of *Hyophila involuta* are arranged in rosettes, giving the plant a characteristic star-like appearance. The species is widely distributed across low to high elevations and colonizes a variety of substrates, including soil, rocks, logs, rock fissures, and walls, reflecting its ecological adaptability (Aslanbaba *et al.*, 2017).

In view of its widespread occurrence and limited phytochemical characterization, the present study aimed to evaluate the chemical constituents of the whole-plant methanolic extract of *H. involuta* using Gas Chromatography–Mass Spectrometry (GC-MS). GC-MS is a well-established and reliable analytical technique for profiling secondary metabolites in plant extracts and provides valuable insight into their potential bioactive compounds.

These bioactive compounds find applications in the pharmaceutical, food, and cosmetics industries, among others (Uma *et al.*, 2009). GC-MS combines two analytical techniques: gas chromatography separates the components of the given mixture, and mass spectrometry analyzes each compound separately. It is an important tool nowadays in the phytochemical analysis of plant extracts containing bioactive compounds. Despite increasing recognition of bryophytes as sources of unique secondary metabolites, *Hyophila involuta* remains largely unexplored in terms of its phytochemical composition. Owing to its wide ecological distribution and tolerance to environmental stress, it was hypothesized that *H. involuta* synthesizes a diverse array of secondary metabolites with potential bioactive relevance. However, comprehensive chemical profiling of this species is currently lacking. To address this gap, the present research article reports a detailed GC-MS-based phytochemical analysis of the methanolic extract of *Hyophila involuta* collected from Mount Abu (Rajasthan), India. This study represents the systematic report on the volatile phytochemical constituents of *H. involuta* from this region and establishes a baseline for future quantitative and bioactivity-guided pharmacological investigations.

METHODS

Chemicals

HI Media, Sigma, and SRL provided all of the analytical-grade chemicals and reagents used in this study.

Collection of plant material and identification

In August and September of 2023, plant material of the bryophyte *Hyophila involuta* was gathered from various locations in Mount Abu (District Sirohi, Rajasthan), India. Plant specimens were carefully gathered by selecting only uniform areas devoid of dead and decomposing material because they have a tendency to grow closely together. Terrestrial and corticolous habitats, including tree surfaces, rocks, soil-covered rocks, wet rocks, etc., are always represented among the specimens that are gathered. The plant specimens were identified

and authenticated by the corresponding author himself. Herbarium of the bryophyte, *H. involuta* was prepared and deposited in BURI Herbarium (Herbarium number: BURI-1738/2024).

Preparation of plant extract

Fresh plant material of *Hyophila involuta* was ground using liquid nitrogen and subsequently air-dried at room temperature. The dried material was powdered and stored in an airtight container at 4 °C, pending further utilization. (Mehra & De, 2017). For extraction, 10 g of powdered plant material was subjected to Soxhlet extraction using 150 mL of methanol for 12 h at 40–45 °C, until the solvent in the extraction chamber became colorless. The methanolic extract was then concentrated to dryness, yielding 2.5 g of crude extract, which corresponds to a percentage yield of 25% (w/w) based on the dry weight of the plant material.

Preliminary phytochemical screening

The methanolic extract of *H. involuta* was tested in triplicate for various phytochemicals using previously described procedures (Harborne, 1998; Kumar *et al.*, 2007; Soni & Sosa, 2013).

Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The methanolic extract of *Hyophila involuta* was analyzed using a Thermo Scientific™ TRACE™ 1300 gas chromatograph coupled with a TSQ 8000 Evo triple quadrupole mass spectrometer. The extract prepared using Soxhlet method was dissolved in 1 mL of HPLC-grade methanol and filtered through a 0.22 µm syringe filter before GC-MS analysis. The analysis was performed on a TG-5MS capillary column (30 m × 0.25 mm i.d., 0.25 µm film thickness) with helium as the carrier gas at a constant flow rate of 1.0 mL/min. The sample was injected in splitless mode with an injection volume of 1 µL, and the injector temperature was set at 250 °C. The GC oven temperature was programmed as follows: it was initially held at 60 °C for 2 minutes, then increased at a rate of 10 °C per minute to 200 °C and held for 5 minutes. This was followed by a ramp of 5 °C per minute to 280 °C, with a final hold of 10 minutes. The mass spectrometer operated in electron impact (EI) mode at 70 eV. The ion source temperature was set at 230 °C, the transfer line at 280 °C, and the quadrupole temperature at 150 °C. Mass spectra were acquired in full scan mode over a mass-to-charge (m/z) range of 40–600. Numerous chemicals were identified as a consequence of the GC-MS analysis of the methanolic extract of *H. involuta*. Mass spectrometry in conjunction with GC was used to identify these chemicals. The National Institute of Standards and Technology (NIST) library was used to analyze the resulting mass spectrum. The standard mass spectra of well-known chemicals kept in the NIST collection were compared to the substances identified in the spectrum of the methanolic extract of *H. involuta*.

RESULTS

Preliminary phytochemical screening of the methanolic extract of *H. involuta* revealed the presence of alkaloids, anthraquinones, flavonoids, phenols, saponins, and sterols, whereas cardiac glycosides were absent (Table 1).

Table 1. Phytochemical constituents of methanolic extracts of *Hyophila involuta*.

Phytochemical constituents	Test/ Reagents	Result
Alkaloids	Dragendorff's test	++
Anthraquinones	Borntrager's test	++
Cardiac glycosides	Keller–Killiani	-
Flavonoids	Shinoda test	+++
Phenols	Ellagic acid test	+++
Saponins	Froth formation test	++
Sterols	Liebermann-Burchardt test	++

*Symbols denote Concentration (+) Low, (++) Moderate, (+++) High and (-) Negligible Concentration

The relative abundance of metabolites was evaluated using a semi-quantitative scoring system based on the intensity of color change or reaction, where “+” indicates low, “++” moderate, and “+++” high abundance. Flavonoids and phenols exhibited the highest relative abundance (+++), while alkaloids, anthraquinones, saponins, and sterols were present at moderate levels (++) . Each test was performed in triplicate, and results were consistent across replicates, providing reliability to the observations.

GC-MS Profiling of The Methanolic Extract of *Hyophila involuta*

GC-MS analysis of the methanolic extract of *Hyophila involuta* revealed a diverse array of bioactive compounds. The chromatogram (Figure 1) displayed well-resolved peaks, with retention times ranging from 4.91–42.52 min], indicating the presence of multiple volatile and semi-volatile metabolites. Table 2 summarizes the identified compounds, which were predominantly fatty acids and their methyl esters, including undecanoic acid, 10-methyl-, methyl ester; 17-octadecynoic acid, methyl ester; tetradecanoic acid, 12-methyl-, methyl ester; pentadecanoic acid, methyl ester; oleic acid; γ -linolenic acid; and other long-chain fatty acid derivatives. Alcohols such as 13-heptadecyn-1-ol and 2-hexadecanol, hydrocarbons including octadecane, 3-ethyl-5-(2-ethylbutyl)-, tetradecane, 2,6,10-trimethyl-, and heptacosane, and esters/derivatives like 1,1-bis(dodecyloxy)hexadecane, methyl glycocholate (3TMS derivative), and trinexapac-ethyl (TMS derivative) were also detected. Additionally, bioactive compounds such as astaxanthin and aldehydes (5-octadecenal, 8-octadecenal) were identified. Overall, the chromatogram demonstrated high-intensity peaks corresponding to fatty acids and related esters, suggesting these as the major constituents of the extract. Many of these compounds, including oleic acid, γ -linolenic acid, and astaxanthin, are reported to possess antioxidant, anti-inflammatory, and antimicrobial activities, indicating the pharmacological potential of *H. involuta*.

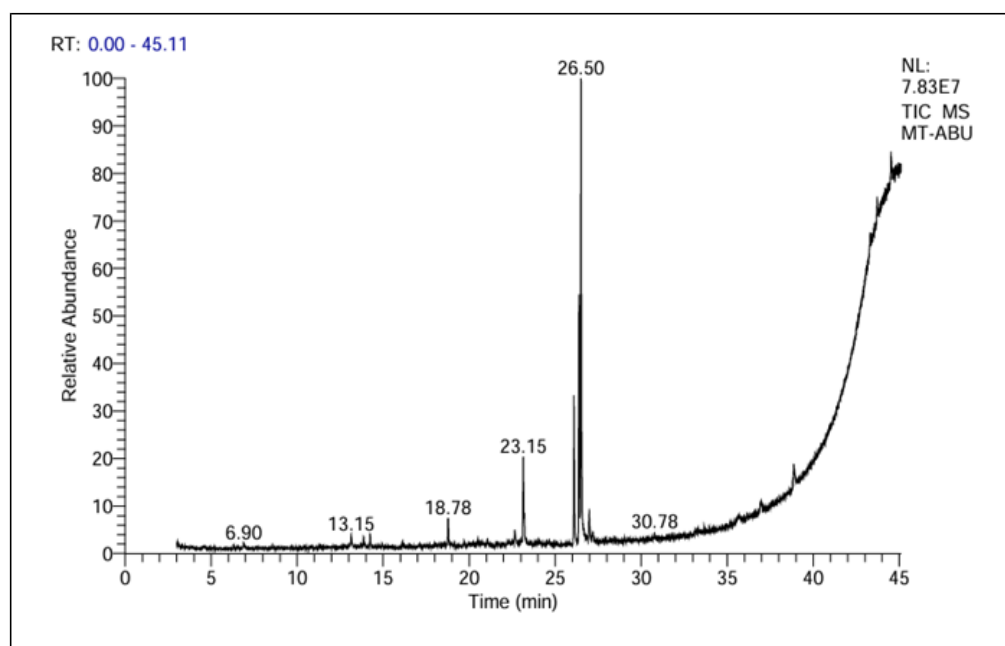
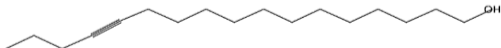
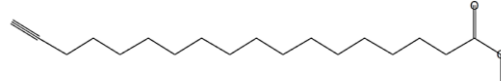
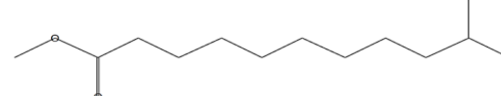
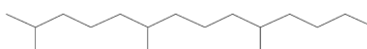
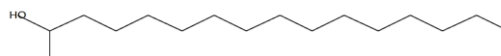
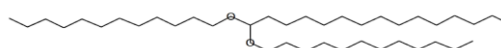
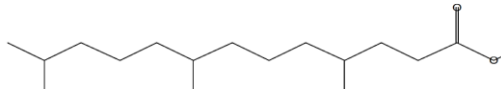
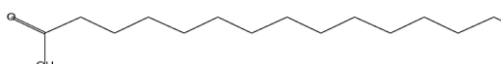
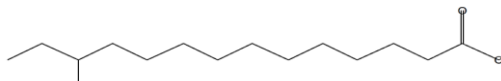
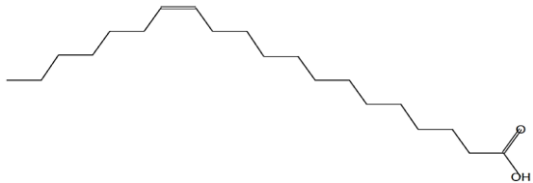
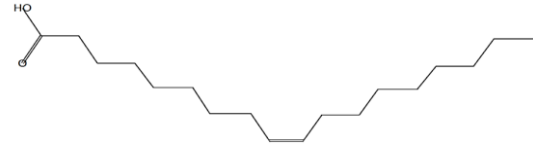
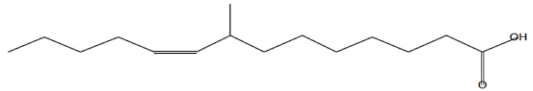
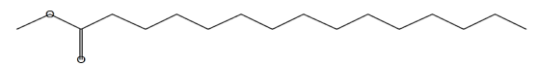
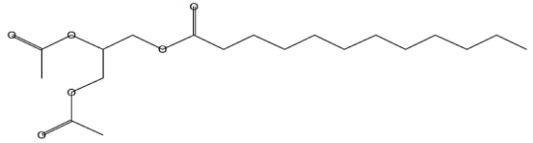
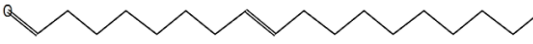
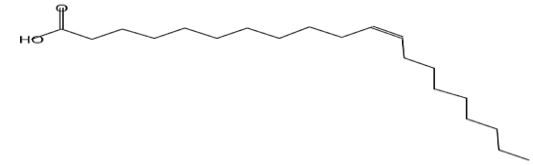
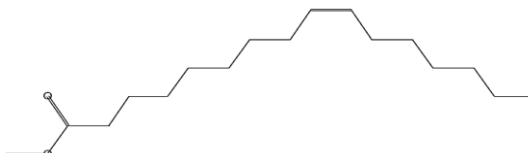
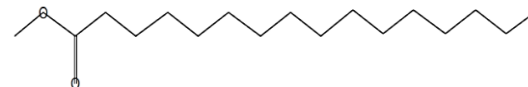
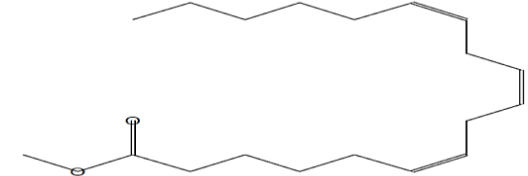
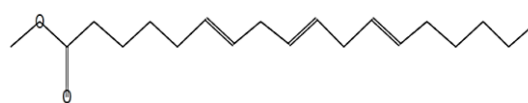
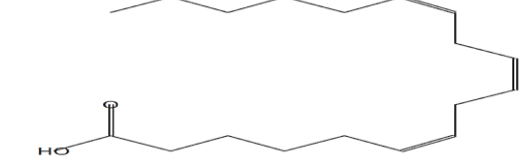
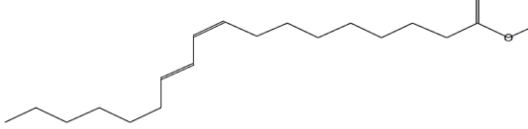
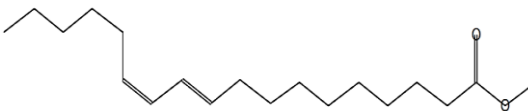


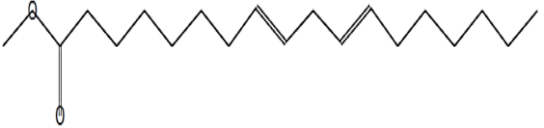
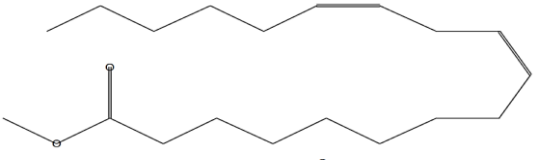
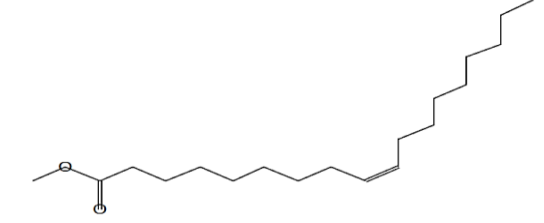
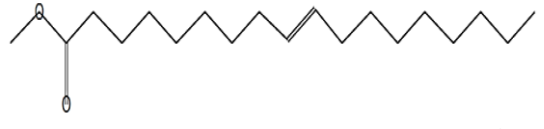
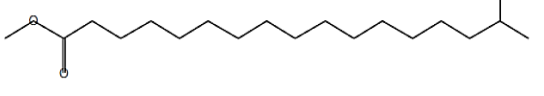
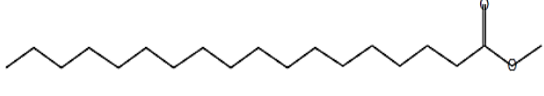
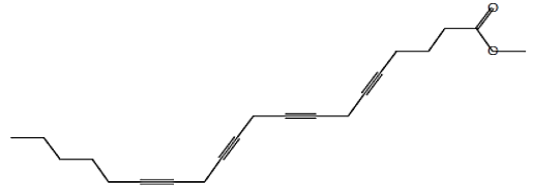
Figure 1. GC-MS chromatogram of methanolic extract of *Hyophila involuta*.

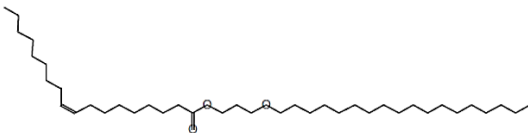
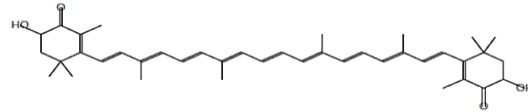
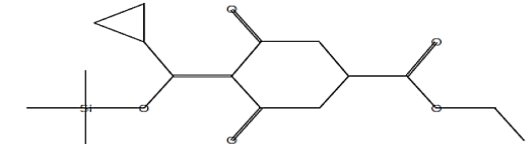
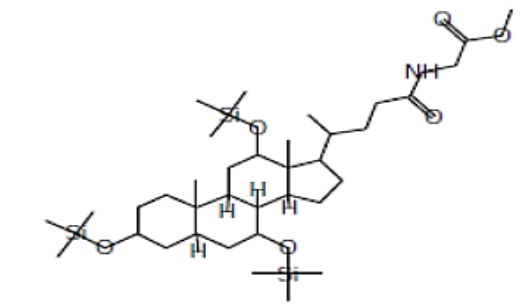
Table 2. Compounds detected in the methanolic extract of *Hyophila involuta* by GC-MS.

S. No.	RT* (min)	Name of the compound	Molecular formula	MW g/mol	Peak Area (%)	Match Quality**	Structures of compounds
1.	6.91	13-Heptadecyn-1-ol	C ₁₇ H ₃₂ O	252.4	0.61	Good	
2.	6.91	17-Octadecynoic acid, methyl ester	C ₁₉ H ₃₄ O ₂	294	0.61	Good	
3.	13.15	Undecanoic acid, 10-methyl-, methyl ester	C ₁₃ H ₂₆ O ₂	214	1.08	Excellent	
4.	13.87	Tetradecane, 2,6,10-trimethyl-	C ₁₇ H ₃₆	240	0.73	Good	
5.	13.87	Heptacosane	C ₂₇ H ₅₆	380	0.73	Excellent	
6.	13.87	Octadecane, 3-ethyl-5-(2ethylbutyl)-	C ₂₆ H ₅₄	366	0.73	Good	
7.	16.12	2-Hexadecanol	C ₁₆ H ₃₄ O	242	0.46	Excellent	
8.	16.12	1,1Bis(dodecyloxy)hexadecane	C ₄₀ H ₈₂ O ₂	594	0.46	Good	
9.	18.78	Tridecanoic acid, 4,8,12-trimethyl-, methyl ester	C ₁₇ H ₃₄ O ₂	270	2.36	Excellent	
10.	18.78	Pentadecanoic acid	C ₁₅ H ₃₀ O ₂	242	2.36	Excellent	
11.	18.78	Tetradecanoic acid, 12-methyl-, methyl ester	C ₁₆ H ₃₂ O ₂	256	2.36	Excellent	

12.	20.52	cis-13-Eicosenoic acid	$C_{20}H_{38}O_2$	310	0.50	Good	
13.	20.52	Oleic Acid	$C_{18}H_{34}O_2$	282	0.50	Excellent	
14.	20.52	Z-8-Methyl-9-tetradecenoic acid	$C_{15}H_{28}O_2$	240	0.50	Good	
15.	21.05	Pentadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	256	0.53	Excellent	
16.	21.05	Dodecanoic acid, 2,3 bis(acetyloxy)propyl ester	$C_{19}H_{34}O_6$	358	0.53	Fair	
17.	22.31	8-Octadecenal	$C_{18}H_{34}O$	266	0.52	Good	
18.	22.31	cis-11-Eicosenoic acid	$C_{20}H_{38}O_2$	310	0.52	Excellent	
19.	22.31	5-Octadecenal	$C_{18}H_{34}O$	266	0.52	Good	

20.	22.66	9-Hexadecenoic acid, methyl ester, (Z)-	$C_{17}H_{32}O_2$	268	1.44	Excellent	
21.	23.14	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	270	7.76	Excellent	
22.	26.09	γ -Linolenic acid	$C_{19}H_{32}O_2$	292	10.89	Excellent	
23.	26.09	6,9,12-Octadecatrienoic acid, methyl Ester	$C_{19}H_{32}O_2$	292	10.89	Excellent	
24.	26.09	Gamolenic acid	$C_{18}H_{30}O_2$	278	10.89	Excellent	
25.	26.39	Methyl 9-cis,11-trans-octadecadienoate	$C_{19}H_{34}O_2$	294	17.37	Excellent	
26.	26.39	Methyl 10-trans,12-cis-octadecadienoate	$C_{19}H_{34}O_2$	294	17.37	Excellent	

27.	26.39	8,11-Octadecadienoic acid, methyl Ester	$C_{19}H_{34}O_2$	294	17.37	Excellent	
28.	26.39	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	$C_{19}H_{34}O_2$	294	17.37	Excellent	
29.	26.50	9-Octadecenoic acid (Z)-, methyl Ester	$C_{19}H_{36}O_2$	296	34.64	Excellent	
30.	26.50	9-Octadecenoic acid, methyl ester, (E)-	$C_{19}H_{36}O_2$	296	34.64	Excellent	
31.	26.98	Heptadecanoic acid, 16-methyl-, methyl ester	$C_{19}H_{38}O_2$	298	2.57	Excellent	
32.	26.98	Methyl stearate	$C_{19}H_{38}O_2$	298	2.57	Excellent	
33.	30.78	5,8,11,14-Eicosatetraynoic acid, methyl ester	$C_{21}H_{26}O_2$	310	0.49	Fair	

34.	30.78	Oleic acid, 3 (octadecyloxy)propyl ester	$C_{39}H_{76}O_3$	592	0.49	Fair	
35.	35.67	Astaxanthin	$C_{40}H_{52}O_4$	596	0.83	Good	
36.	36.62	Trinexapac-ethyl, TMS derivative	$C_{16}H_{24}O_5Si$	324	0.49	Fair	
37.	42.52	Methyl glycocholate, 3TMS derivative	$C_{36}H_{69}NO_6Si_3$	695	0.44	Tentative	

* All compounds with the same RT had identical peak area values; hence, SD = 0

**Match quality was estimated based on compound identity confidence and literature reference spectra.

DISCUSSION

Phytochemical evaluation of the methanolic extract of *H. involuta* revealed the presence of several bioactive phytochemicals, including flavonoids, saponins, sterols, anthraquinones, alkaloids, and phenolic compounds, which collectively explain the antioxidant and related biological activities observed in this moss. Flavonoids, identified in the extract, are among the most efficient free radical scavengers and exert antioxidant activity through free radical neutralization and metal ion chelation (Kumar *et al.*, 2013; Kumar & Pandey, 2013; Saeed *et al.*, 2012). Their presence in *H. involuta* is noteworthy, as flavonoids are comparatively less reported in bryophytes than in higher plants, suggesting a unique chemical adaptation. Similarly, the detection of saponins—phytochemicals known for their antifungal, antimicrobial, antiviral, anti-inflammatory, anticancer, antioxidant, and immunomodulatory activities—adds to the growing evidence that mosses can serve as valuable sources of pharmacologically important secondary metabolites (Biswas & Dwivedi, 2019; Rice-Evans *et al.*, 1995). Saponins are rarely documented in moss species, and their occurrence in *H. involuta* represents a potentially novel contribution to bryophyte phytochemistry.

The presence of sterols in *H. involuta* further supports its therapeutic potential, as plant- and algae-derived sterols have been reported to possess antibacterial, antifungal, anti-inflammatory, anticancer, antidiabetic, and antihypercholesterolemic activities (Sánchez-Machado *et al.*, 2004a). Likewise, anthraquinones identified in the extract are of particular significance, as these compounds exhibit diverse biological activities, including antioxidant, anti-inflammatory, gastroprotective, hepatoprotective, and neuroprotective effects, and have been explored for their role in treating Alzheimer's disease (Park *et al.*, 2009; Rabe & van Staden, 1997; Tan *et al.*, 2011; Xu *et al.*, 2014). Reports of anthraquinones in mosses are limited, indicating that *H. involuta* may represent a previously underexplored source of this class of compounds. Alkaloids detected in the extract are also biologically important, given their well-documented antioxidant, antibacterial, antifungal, antiviral, and anticancer properties (Thawabteh *et al.*, 2019), and their occurrence further underscores the medicinal relevance of this moss species. In addition, the presence of phenolic compounds, known for their antioxidant, anti-inflammatory, antimicrobial, antiproliferative, neuroprotective, and anti-mutagenic activities (Sauceda *et al.*, 2017), provides a biochemical basis for the observed bioactivity of *H. involuta*. Overall, the identification of these phytochemicals—some of which are scarcely reported in mosses—highlights *H. involuta* as a promising and relatively unexplored source of bioactive secondary metabolites with potential pharmaceutical applications (Sánchez-Machado *et al.*, 2004b).

GC–MS analysis of the methanolic extract of *H. involuta* revealed a predominance of fatty acid esters, long-chain alcohols, and hydrocarbons, a profile that is consistent with, yet distinct from, earlier GC–MS studies on bryophytes and lower plants, where terpenoids and simple phenolics are often dominant. Among the identified compounds, 9,12-octadecadienoic acid, methyl ester was detected as a major constituent, suggesting a stronger anti-inflammatory and membrane-stabilizing potential in *H. involuta* compared to moss species reported to contain this compound only in trace amounts (Nishanthini *et al.*, 2014). The occurrence of long-chain fatty alcohols such as 3-heptadecyn-1-ol, reported for their antioxidant properties (El-Naggar *et al.*, 2023), is comparatively less frequent in bryophyte GC–MS profiles, indicating a species-specific metabolic trait of *H. involuta*. Hydrocarbon compounds such as heptacosane and saturated fatty acids like hexadecanoic acid, which exhibit antimicrobial activity (Carev *et al.*, 2023), were present in appreciable proportions, suggesting a stronger antimicrobial defense system when compared with previously studied mosses, where such compounds appear in minor quantities. The detection of 2-hexadecanol, known for its cytotoxic effects on cancer cell lines (Sharifi *et al.*, 2020), further differentiates *H. involuta* from related studies that report limited or no cytotoxic fatty alcohols. In addition, hexadecanoic acid methyl ester and unsaturated fatty acid derivatives, including oleic acid and linoleic acid analogues, were observed at higher relative abundances than those reported in many bryophyte extracts, implying enhanced antibacterial,

antioxidant, and cardioprotective potential (Cook & Samman, 1996; Durgawale *et al.*, 2018; Shaaban *et al.*, 2021; Muzahid *et al.*, 2023). Overall, the dominance of fatty acid-based bioactive compounds in *H. involuta* distinguishes its chemical profile from similar moss studies and supports its potential as a novel source of biologically active lipophilic metabolites.

The compounds identified in *H. involuta*, including phytol and other terpenoid derivatives, are consistent with those reported in related bryophyte studies (Motti *et al.*, 2023; Petkova *et al.*, 2023), suggesting broadly comparable chemical profiles and potential bioactivities. However, it should be noted that these interpretations remain preliminary, as the present study is based solely on GC–MS identification using NIST library spectral matching without confirmation by complementary analytical techniques such as NMR or LC–MS/MS. In addition, no *in vitro* or *in vivo* bioassays were conducted to directly validate the predicted antioxidant, antimicrobial, or anti-inflammatory activities of the identified compounds. Therefore, while the GC–MS profile provides valuable insight into the secondary metabolite composition of *H. involuta*, further quantitative analyses and biological assays are necessary to confirm the functional relevance and pharmacological potential of these compounds.

CONCLUSION

The GC-MS analysis of the methanolic extract of *Hyophila involuta* revealed the occurrence of several phytochemicals known to have pharmacologically relevant properties, including antioxidant, antibacterial, anti-inflammatory, and anticancer activities, based on literature reports. Although no direct bioassays were performed in this study, the identified compounds suggest the potential of *H. involuta* as a source of therapeutic agents. This phytochemical profiling provides the groundwork for future studies focused on the isolation and functional characterization of individual bioactive constituents.

Acknowledgments

The authors extend their heartfelt appreciation to Prof. Ina Aditya Shastri, Vice-Chancellor of Banasthali Vidyapith, Rajasthan, for her invaluable support and motivation. We are also grateful to DBT for providing funding for the Bioinformatics Centre at Banasthali Vidyapith, as well as to the Department of Bioscience and Biotechnology, Banasthali, for their contributions. Additionally, we acknowledge the assistance of the DST through the FIST program, which facilitated networking opportunities.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Authorship Contribution Statement

A.A.: Contributed to the research concept and design; participated in data collection and assembly, data analysis and interpretation; drafted the manuscript; provided critical revisions; and approved the final version of the article. **T.S.:** Participated in data collection and assembly, data analysis and interpretation; drafted the manuscript; and approved the final version of the article.

Data Availability Statement

Research data is available and can be sent via email upon request.

Orcid

Tripti Sharma  <https://orcid.org/0000-0002-6568-8913>

Afroz Alam  <https://orcid.org/0000-0001-8575-4677>

REFERENCES

- Alam, A. (2012). Some Indian Bryophytes Known for Their Biologically Active Compounds. *International Journal of Applied Biology and Pharmaceutical Technology*, 3(2), 239-246.
- Asakawa, Y., Ludwiczuk, A., & Nagashima, F. (2013). *Chemical Constituents of Bryophytes: Bio- and chemical diversity, biological activity, and chemosystematics*. In: Kinghorn, A.D., Falk, H., Kobayashi, J. (Eds.), *Progress in the Chemistry of Organic Natural Products*, vol 95 Springer-Verlag, Vienna, 1-796. https://doi.org/10.1007/978-3-7091-1084-3_1

- Asakawa, Y. (2004). Chemosystematics of the Hepaticae. *Phytochemistry*, 65, 623-669. <https://doi.org/10.1016/j.phytochem.2004.01.003>
- Aslanbaba, B., Yilmaz, S., Tonguz Yayinta, O., Ozyurt, D., & Ozyurt, B.D. (2017). Total phenol content and antioxidant activity of mosses from Yenice forest (Ida Mountain). *Journal of Scientific Perspectives*, 1(1), 1-12. <https://doi.org/0.26900/jsp.2017.0>
- Biswas, T., & Dwivedi, U.N. (2019). Plant triterpenoid saponins: biosynthesis, in vitro production, and pharmacological relevance. *Protoplasma*, 256, 1463–1486. <https://doi.org/10.1007/s00709-019-01411-0>
- Carev, I., Gelemanović, A., Glumac, M., Tutek, K., Dželalija, M., Paiardini, A., & Prosseda, G. (2023). *Centaurea triumfettii* essential oil chemical composition, comparative analysis, and antimicrobial activity of selected compounds. *Scientific Reports*, 13, 7475. <https://doi.org/10.1038/s41598-023-34058-2>
- Chen, F., Ludwiczuk, A., Wei, G., Chen, X., Crandall-Stotler, B., & Bowman, J.L. (2018). Terpenoid secondary metabolites in bryophytes: Chemical diversity, biosynthesis, and biological functions. *Critical Reviews in Plant Sciences*, 37 (2-3), 210-231. <https://doi.org/10.1080/07352689.2018.1482397>
- Cook, N.C., & Samman, S. (1996). Review: flavonoids-chemistry, metabolism, cardioprotective effects and dietary sources. *Journal of Nutritional Biochemistry*, 7(2), 66-76. [https://doi.org/10.1016/S0955-2863\(95\)00168-9](https://doi.org/10.1016/S0955-2863(95)00168-9)
- Durgawale, T.P., Khanwelkar, C.C., & Durgawale P.P. (2018). Phytochemical screening using GC-MS and study of anti-oxidant activity of two species of *Portulaca*. *Research Journal of Pharmacy and Technology*, 11(12), 5534-5540. <https://doi.org/10.5958/0974-360X.2018.01007.7>
- El-Naggar, H.M., Shehata, A.M. & Morsi, M.A.A. (2023). Micropropagation and GC–MS analysis of bioactive compounds in bulbs and callus of white squill. *In Vitro Cellular and Developmental Biology-Plant*, 59, 154–166. <https://doi.org/10.21203/rs.3.rs-1382918/v1>
- Gomathi, D., Kalaiselvi, M., Ravikumar, G., Devaki, K., & Uma, C. (2013). GC-MS Analysis of bioactive compounds from the whole plant ethanolic extract of *Evolvulus alsinoides* (L.) L. *Journal of Food Science and Technology*, 52, 1212-1217. <https://doi.org/10.1007/s13197-013-1105-9>
- Harborne, J.B. (1998). *Phytochemical methods: a guide to modern technique of plant analysis*, Vol. 3; Champman and Hall, pp. 60–66.
- Joshi, S., & Alam, A. (2023). Bryomonitoring of atmospheric elements in *Sphagnum* sp. commonly growing bryophyte in the Indian Himalayan region of Uttarakhand. *Nova Geodesia*, 3(2), 127–127. <https://doi.org/10.55779/ng32127>
- Kumar, G.S., Jayaveera, K.N., Kumar, C.K., Sanjay, U.P., Swamy, B.M., & Kumar, D.V. (2007). antimicrobial effects of Indian medicinal plants against acne-inducing bacteria. *Tropical Journal of Pharmaceutical Research*, 6, 717-23.
- Kumar, S., & Pandey, A.K. (2013). Phenolic content, reducing power and membrane protective activities of *Solanum xanthocarpum* root extracts. *Vegetos*, 26, 301-307. <http://dx.doi.org/10.5958/j.2229-4473.26.1.043>
- Kumar, S., Mishra, A., & Pandey, A.K. (2013). Antioxidant mediated protective effect of *Parthenium hysterophorus* against oxidative damage using in vitro models. *BMC Complementary and Alternative Medicine*, 13, 120. <https://doi.org/10.1186/1472-6882-13-120>
- Ludwiczuk, A., & Asakawa Y. (2019). Bryophytes as a source of bioactive volatile terpenoids – A review. *Food and Chemical Toxicology*, 132, 1-11. <https://doi.org/10.1016/j.fct.2019.110649>
- Mehra, Y.K., & De, K. (2017). Determination of phytochemical, total flavonoids and antioxidant activity of methanolic extract of *Pisum sativum*. *International Journal of Innovative Pharmaceutical Sciences and Research*, 5(8), 1-12.
- Motti, R., Palma, A.D., & de Falco, B. (2023). Bryophytes used in folk medicine: an ethnobotanical overview. *Horticulturae*, 9(2), 137. <https://doi.org/10.3390/horticulturae9020137>
- Muzahid, A.A., Sharmin, S., Hossain, M.S., Ahamed, K.U., Ahmed, N., Yeasmin, M.S., Ahmed, N.U., Saha, B.K., Rana, G.M.M., Maitra, B., & Bhuiyan, M.N.H. (2023). Analysis of bioactive compounds present in different crude extracts of *Benincasa hispida* and *Cucurbita moschata* seeds by gas chromatography-mass spectrometry. *Heliyon*, 9(1), e12702. <https://doi.org/10.1016/j.heliyon.2022.e12702>
- Nishanthini, A., Mohan, V.R., & Jeeva, S. (2014). Phytochemical, FT-IR, and GC-MS analysis of stem and leaf of *Tiliacora acuminata* (Lan.) Hook f and Thomas (Menispermaceae). *International Journal*

- of *Pharmaceutical Science and Research*, 5(9), 3977–3986. [https://doi.org/10.13040/IJPSR.0975-8232.5\(9\).3977-86](https://doi.org/10.13040/IJPSR.0975-8232.5(9).3977-86)
- Park, M.Y., Kwon, H.J., & Sung, M.K. (2009). Evaluation of aloin and aloe-emodin as anti-inflammatory agents in aloe by using murine macrophages. *Bioscience, Biotechnology and Biochemistry*, 73, 828–832. <https://doi.org/10.1271/bbb.80714>
- Petkova, Z., Teneva, O., Antova, G., Angelova-Romova, M., Gecheva, G., & Dimitrova-Dyulgerova, I. (2023). Chemical composition, lipid-soluble bioactive compounds and potential health benefits of the moss *Hypnum cupressiforme* hedw. *Plants*, 12(24), 4190. <https://doi.org/10.3390/plants12244190>
- Rabe, T., & van Staden, J. (1997). Antibacterial activity of South African plants used for medicinal purposes. *Journal of Ethnopharmacology*, 56, 81–87. [https://doi.org/10.1016/s0378-8741\(96\)01515-2](https://doi.org/10.1016/s0378-8741(96)01515-2)
- Rice-Evans, C.A., Miller, N.J., Bolwell, P.G., Broomley, P.M., & Pridham, J.B. (1995). The relative antioxidant activities of plant-derived polyphenolic flavonoids. *Free Radical Research*, 22(4), 375–383. <https://doi.org/10.3109/10715769509145649>
- Saeed, N., Khan, M.R., & Shabbir, M. (2012). Antioxidant activity, total phenolic and total flavonoid contents of whole plant extracts *Torilis leptophylla* L. *BMC Complementary and Alternative Medicine*, 12(1), 221–232. <https://doi.org/10.1186/1472-6882-12-221>
- Sánchez-Machado, D.I., López-Cervantes, J., López-Hernández, J., & Paseiro-Losada, P. (2004a). Fatty acids, total lipid, protein and ash contents of processed edible seaweeds. *Food Chemistry*, 85, 439–444. <https://doi.org/10.1016/j.foodchem.2003.08.001>
- Sánchez-Machado, D.I., López-Cervantes, J., López-Hernández, J., & Paseiro-Losada, P. (2004b). An HPLC method for the quantification of sterols in edible seaweeds. *Biomedical Chromatography*, 18, 183–190. <https://doi.org/10.1002/bmc.316>
- Sauceda, A.E.Q., Sáyago-Ayerdi, S.G., Ayala-Zavala, J.F., Wall-Medrano, A., de la Rosa, L.A., González-Aguilar, G. A., & Álvarez-Parrilla, E. (2017). Biological Actions of Phenolic Compounds. Fruit and Vegetable Phytochemicals. *Chemistry and Human Health*, 1(2), 25-138. <http://dx.doi.org/10.1002/9781119158042.ch6>
- Shaaban, M.T., Ghaly, M.F., & Fahmi S.M. (2021). Antibacterial activities of hexadecanoic acid methyl ester and green-synthesized silver nanoparticles against multidrug-resistant bacteria. *Journal of Basic Microbiology*, 61(6), 557-568. <https://doi.org/10.1002/jobm.202100061>
- Sharifi, S., Mostafavi, P.G., Tarasi, R., Moradi, A.M., Givianrad, M.H., Farimani, M.M., Ebrahimi, S.N., Hamburger, M., & Niknejad, H. (2020). Purified compounds from marine organism sea pen induce apoptosis in human breast cancer cell MDA-MB-231 and cervical cancer cell Hela. *European Journal of Pharmacology*, 877, 173075. <https://doi.org/10.1016/j.ejphar.2020.173075>
- Soni, A., & Sosa, S. (2013). Phytochemical analysis and free radical scavenging potential of herbal and medicinal plant extracts. *Journal of Pharmacognosy and Phytochemistry*, 2(4), 22–24.
- Starlin, T., Prabha, P.S., Thayakumar, B.K.A., & Gopalakrishnan, V.K. (2019). Screening and GC-MS profiling of ethanolic extract of *Tylophora pauciflora*. *Bioinformation*, 15(6), 425-429. <https://doi.org/10.6026/97320630015425>
- Tan, Z.J., Li, F.F., & Xing, J.M. (2011). Separation and purification of aloe anthraquinones using PEG/Salt aqueous two-phase system. *Separation Science and Technology*, 46, 1503–1510. <http://dx.doi.org/10.1080/01496395.2011.563766>
- Thawabteh A., Juma S., Bader M., Karaman D., Scrano L., Bufo S.A., & Karaman R. (2019). The biological activity of natural alkaloids against herbivores, cancerous cells and pathogens. *Toxins*, 11, 656, 1-28.
- Uma, B., Prabhakar, K., Rajendran, S., & Sarayu, L.Y. (2009): Studies on GC/MS Spectroscopic analysis of some bioactive antimicrobial compounds from *Cinnamomum zeylanicum*. *Journal of Medicinal Plants*, 8(31), 125-131.
- Whitehead, J., Wittemann, M., & Cronberg, N. (2018). Allelopathy in Bryophytes-A Review. *Lindbergia*, 41(1). <https://doi.org/10.25227/linbg.01097>
- Xu, K., Wang, P., Wang, L., Liu, C., Xu, S., Cheng, Y., Wang, Y., Li, Q., & Lei, H. (2014): Quinone derivatives from the genus *Rubia* and their bioactivities. *Chemical Biodiversity*, 11, 341–363. <https://doi.org/10.1002/cbdv.201200173>