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Microwave-Assisted Extraction of *Ludwigia adscendens* Volatile Compounds and their Antioxidant, Antibacterial and Anti-α-glucosidase Activities

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Ludwigia adscendens is widely used in traditional medicine to treat various inflammatory and intestinal diseases. However, its volatile chemical profile and associated biological properties remain rarely investigated. In this study, microwave-assisted extraction (MAE) was employed to efficiently isolate the volatile compounds from *L. adscendens* collected in Dak Lak, Vietnam. The chemical composition of the extract was comprehensively analysed using gas chromatography-mass spectrometry (GC-MS). Biological potentials were evaluated through DPPH free radical scavenging assay, agar disc diffusion and spectrophotometric methods. GC-MS analysis identified 54 compounds, accounting for 95.68% of the total volatile extract. The major constituents were β-caryophyllene (23.52%), methyleugenol (16.54%), α-terpinene (11.20%), (-)-α-thujene (9.49%), D-limonene (8.04%) and β-myrcene (5.97%). The volatile extract exhibited moderate antioxidant and antibacterial activities, with an IC_{50} value of 2.46 mg/mL and an *Escherichia coli* inhibition rate of 86.94% (at 2.00 mg/mL), respectively. Moreover, the extract showed weak anti-α-glucosidase activity with an IC_{50} value of 4.81 mg/mL. These findings demonstrate the application of MAE in recovering bioactive molecules and underscore the potential of *L. adscendens* volatile compounds as a natural source for pharmaceutical and therapeutic applications.

Keywords: *Ludwigia adscendens*, Volatile compounds, Microwave-assisted extraction, Antioxidant, Antibacterial, α-Glucosidase.

INTRODUCTION

Ludwigia adscendens (L.) Hara is a flowering plant belonging to the Onagraceae family, which currently comprises approximately 83 species worldwide, commonly found in tropical and subtropical climates [1]. In Vietnam, six species have been recorded (*Ludwigia adscendens*, *Ludwigia octovalvis*, *Ludwigia hyssopifolia*, *Ludwigia epilobioides*, *Ludwigia perennis* and *Ludwigia prostrata*) [2,3]. Among them, *L. adscendens* is a widely distributed species, growing wild in ponds, lakes, or wet swamps in Vietnam and other tropical areas [2,4]. This creeping plant floats on the water's surface thanks to its spongy, egg-shaped floats, which are white and usually grow in clumps. The stem is cylindrical, soft and has root-bearing nodes [5,6]. The leaves are egg-shaped and slightly elongated, while the flowers are white and solitary. The fruit is a long, cylindrical capsule covered with fine hairs, which splits into five segments when opened. The plant is harvested year-round, washed to remove mud, cut into short pieces and then air-dried or machine-dried for subsequent use [7,8].

According to traditional medicine, *L. adscendens* has numerous therapeutic applications, including the treatment of scabies, fever, cystitis, skin abscesses, breast abscesses, parotitis, dermatitis, coughs and measles [9]. Furthermore, previous studies have demonstrated that the solvent extracts of this plant contain major chemical components belonging to various groups such as flavonoids, triterpenoids and phenolic derivatives specifically: flavone vitexin, isovitexin, orientin, ellagic acid, isoorientin, saponin, oleanane, oleanolic acid, betulinic acid, piperine, isocoumarin and steroids. These extractable compounds exhibit remarkable anti-inflammatory, anticancer, antibacterial and analgesic effects [8,10-12]. This highlights

the significant pharmacological potential of *L. adscendens* and its applicability in developing natural therapeutic preparations.

Despite the extensive research on solvent extracts, the volatile compounds of *L. adscendens* remain sparsely investigated. Volatile constituents are well-known for their broad spectrum of biological properties including strong antioxidant and antimicrobial effects [13,14]. Conventionally, these volatile compounds are extracted using steam distillation or hydrodistillation [15]. However, these traditional methods are often time-consuming, energy-intensive and involve prolonged thermal exposure, which can lead to the degradation, hydrolysis or transformation of thermo-labile volatile compounds [16,17].

In recent years, microwave-assisted extraction (MAE) has emerged as a promising green technology for the isolation of natural products [18]. By utilizing microwave energy to rapidly penetrate plant matrices and rupture glandular structures, MAE significantly reduces extraction time and energy consumption while enhancing the yield and preserving the structural integrity of sensitive volatile compounds [19,20]. Despite extensive research on the solvent extracts of *L. adscendens*, its volatile constituents remain rarely investigated. Furthermore, the application of green extraction techniques such as MAE, to isolate these volatile compounds has not been previously reported for this species. Therefore, to bridge the current gap in the literature and to explore greener extraction alternatives, this study aimed to apply MAE to isolate the volatile compounds from *L. adscendens* collected in Dak Lak, Vietnam. Furthermore, the chemical composition of the obtained volatiles was comprehensively profiled using gas chromatography-mass spectrometry (GC-MS) and their biological potentials were systematically evaluated through antioxidant (DPPH assay), antibacterial (against *Escherichia coli*) and anti-α-glucosidase assays, thereby providing a deeper scientific rationale for its traditional therapeutic uses.

EXPERIMENTAL

All the chemicals and solvents, butylated hydroxytoluene (BHT), C7-C30 straight-chain hydrocarbons, reference chemicals for identification, Tween 80 and DPPH were purchased from Sigma-Aldrich Chemical Co., USA). Other analytical-grade chemicals, culture media and standard antibiotic discs were obtained from Merck, Germany and Oxoid Ltd., U.K.).

Plant material: Whole plant of *Ludwigia adscendens* were collected in November 2025 from Ea Kao Commune (12º38′54.7′′N, 108º01′45.1′′E), Dak Lak Province, Vietnam. A voucher specimen (No. DN-02) was deposited at Faculty of Natural Sciences and Technology, Tay Nguyen University, Buon Ma Thuot, to serve as a botanical reference.

Microwave-assisted extraction of volatile compounds: The whole plant *L. adscendens* were cleaned, chopped into small pieces and subjected to MAE. To conduct the extraction, the prepared plant material was placed into a 2 L round bottom flask containing distilled water at a water-to-raw material ratio of 6:1 (v/w). The flask was connected to a Clevenger-type apparatus and placed inside a modified domestic microwave oven. Based on established protocols for optimizing volatile compound recovery, the extraction was carried out using a constant microwave power of 440 W for 42 min. Upon completion, the resulting volatile extract was collected, dehydrated over anhydrous sodium sulphate and stored in a sealed vial at 10 ºC in the dark prior to further GC-MS and biological analyses [21,22].

Analysis of volatile compounds by GC-MS: The volatile profile of *L. adscendens* was analysed using an Agilent 8890 gas chromatograph (GC) coupled to an Agilent 7010C mass spectrometer (Agilent Technologies, USA) and data interpretation was performed using Agilent MassHunter software. Separation was carried out on an Agilent HP-5ms Ultra Inert capillary column (15 m × 0.25 mm i.d., 0.25 μm film thickness). GC operating conditions included an injector temperature of 250 ºC, detector temperature of 260 ºC and an oven temperature program ranging from 60 ºC to 260 ºC at a rate of 4 ºC/min. Helium was used as the carrier gas at a flow rate of 1.0 mL/min. A 1 μL sample was injected in split mode with a split ratio of 1:10. The mass spectrometer was operated in electron ionisation (EI) mode under the following conditions: ionisation energy of 70 eV, interface temperature of 280 ºC, ion source temperature of 230 ºC, quadrupole temperature of 200 ºC and a scan range of 35-650 amu. Retention indices (RI) of the volatile constituents were determined using the Agilent HP-5ms column and C7-C30 straight-chain hydrocarbon standards (Sigma-Aldrich, USA). Compound identification was based on a comparison of mass spectra and retention indices with those in GC-MS libraries (NIST 08 and Wiley 09) and/or published literature. The relative percentages of identified compounds were calculated from GC peak areas without applying correction factors [23-25].

Antioxidant assay: The antioxidant capacity of the *L. adscendens* volatile compounds was evaluated based on their DPPH free radical scavenging activity, following a modified method by Nguyen & Eun [26]. Briefly, 1 mL of the volatile extract sample was transferred into a test tube, followed by the addition of 5 mL of DPPH solution. The mixture was shaken thoroughly and kept in the dark at room temperature for 30 min. Absorbance was then measured at 517 nm using a UV-VIS spectrophotometer (Janway 6305, U.K.). A control sample containing methanol was prepared in parallel. The antioxidant activity was calculated using eqn. 1:

$$\text{Antioxidant} = \frac{AB - AA}{AB} \times 100\% \quad (1)$$

where AB and AA are the absorbance of the control sample (containing only methanol) and the absorbance of the reaction solution containing the volatile extract, respectively. The antioxidant activity of the volatile compounds was determined by the half-maximal inhibitory concentration (IC_{50}).

Antimicrobial activity: In the antimicrobial activity assay, *E. coli* (ATCC 25922) was selected as the test organism due to its clinical relevance in gastrointestinal infections [26,27]. This agar disc diffusion assay was designed as an initial screening step to evaluate the preliminary susceptibility of the bacteria to the volatile extract. It provides baseline data prior to conducting more comprehensive and resource-intensive evaluations such as determining the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) across a broader panel of Gram-positive and Gram-

negative strains. The antibacterial activity of the *L. adscendens* volatile compounds was evaluated using the disc diffusion method. The volatile extract was prepared at various concentrations (2.00, 1.75, 1.50, 1.25, 1.00, 0.75 and 0.50 mg/mL) and 50 µL of each concentration was loaded onto sterile 6 mm diameter paper discs. The discs were then dried and used for testing. A total of 100 µL of bacterial culture (10^6 CFU/mL) was spread evenly on tryptic soy agar (TSA) medium supplemented with 2% NaCl using a sterile triangular spreader. After drying for 3-5 min, the impregnated discs were placed onto the agar surface and incubated at 28 ºC for 24 h. Discs impregnated with ciprofloxacin (1 mg/mL) served as the positive control. The experiment was performed in triplicate. The antibacterial activity was assessed by measuring the inhibition zone diameters (IZDs) after 24 h of incubation.

Inhibition of α-glucosidase assay: The anti-α-glucosidase activity of the *L. adscendens* volatile compounds was evaluated following the method described by Sihvonen *et al.* [27]. The volatile extract solution (50 µL) was prepared in 0.1 M phosphate buffer (pH 6.8) at various concentrations (10, 5, 2.5, 1.25 and 0.625 mg/mL) was mixed with 30 µL of α-glucosidase solution (2 U/mL) and incubated at 37 ºC for 10 min. Subsequently, 50 µL of 2.5 mM *p*-nitrophenyl-α-D-glucopyranoside (*p*NPG) solution in 0.1 M phosphate buffer (pH 6.8) was added and the mixture was further incubated at 37 ºC for 30 min. After incubation, the absorbance was measured at 405 nm using an ELISA microplate reader (BIO-RAD iMark). A control sample containing only 50 µL of solvent (without the volatile extract) was used for comparison. The percentage of α-glucosidase inhibition was calculated using eqn. 2:

$$\text{Inhibition } (\%) = \frac{A_0 - A_1}{A_0} \times 100 \quad (2)$$

where A_0 is the absorbance of the control sample (containing only solvent) at the initial time and A_1 is the absorbance of the test sample.

Statistical analysis: All experiments were carried out in triplicate. Analysis of variance (ANOVA) and Statistica 5.5 software (StatSoft Inc., USA) were utilised to analyze the results. The results are presented as the mean ± standard deviation (SD).

RESULTS AND DISCUSSION

Chemical composition of *Ludwigia adscendens* volatile compounds: The extraction of volatile compounds from *L. adscendens* using MAE at 440 W for 42 min yielded 0.64% (w/w) based on the fresh weight. The chemical composition of the volatile extract was comprehensively profiled using GC-MS. A total of 54 compounds were identified, accounting for 95.68% of the total extract (Fig. 1). The extract was predominantly characterised by three major chemical classes *viz.* monoterpene hydrocarbons (5 compounds, 38.37%), sesquiterpene hydrocarbons (4 compounds, 25.46%) and benzenoid derivatives (15 compounds, 20.83%). The major individual constituents determining the chemical profile were β-caryophyllene (23.52%), methyleugenol (16.54%), α-terpinene (11.20%), (-)-α-thujene (9.49%), D-limonene (8.04%) and β-myrcene (5.97%). Oxygenated terpenes are present in significantly lower amounts, with oxygenated monoterpenes and oxygenated sesquiterpenes accounting for 6.86% and 0.04%, respectively (Table-1).

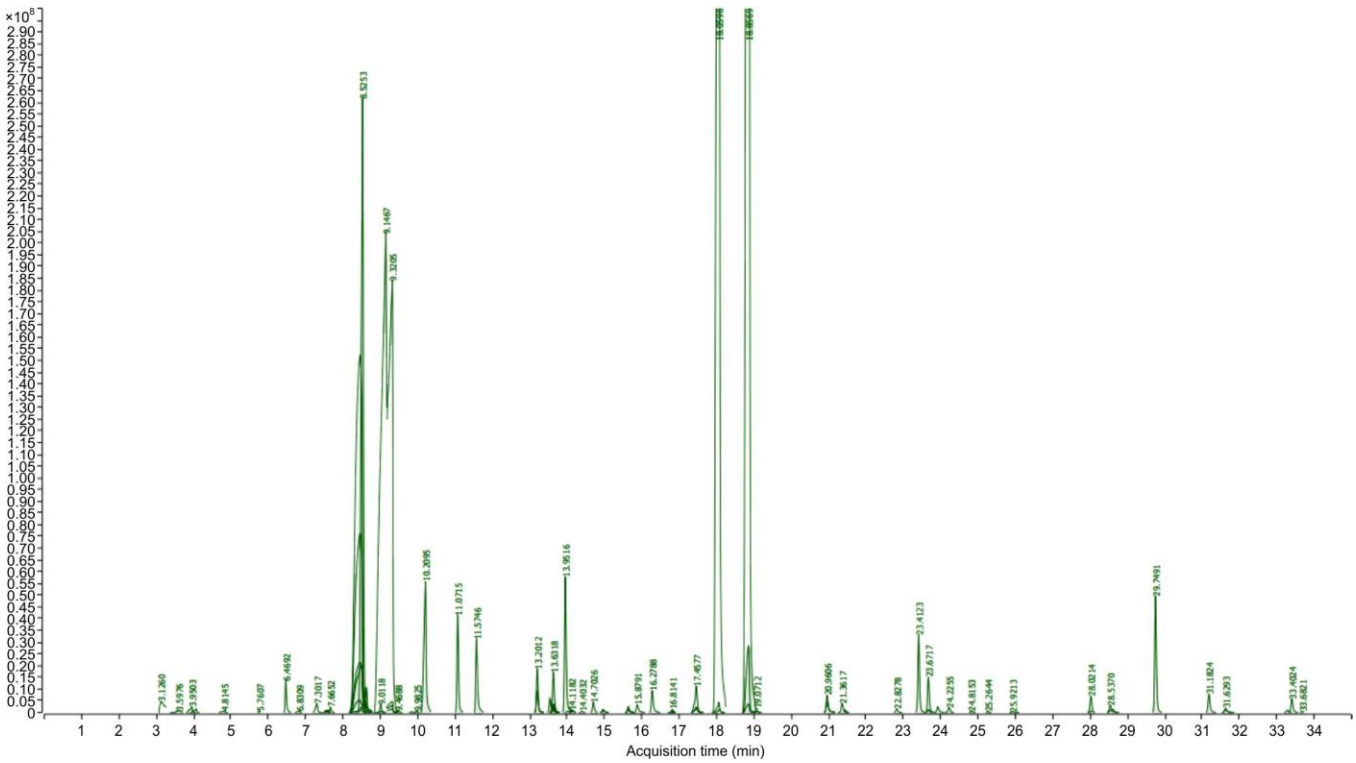
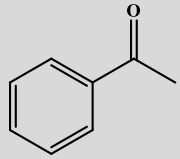
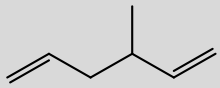
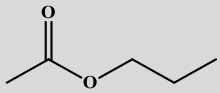
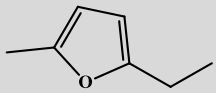
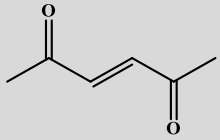
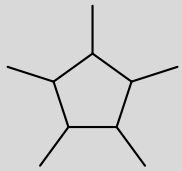
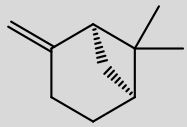
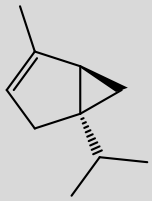
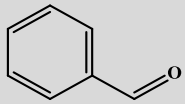
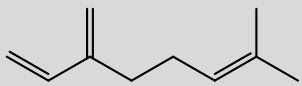
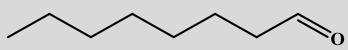
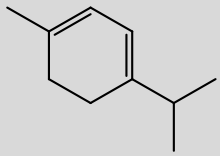
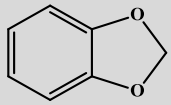
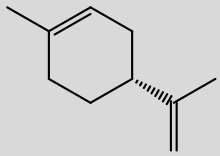
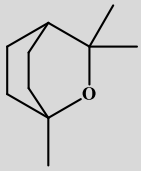
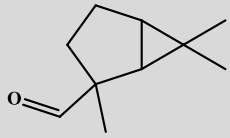
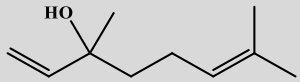
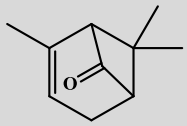
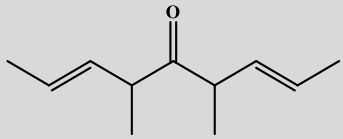
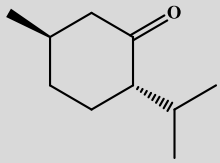
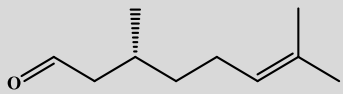
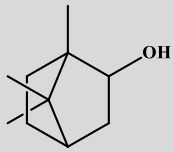
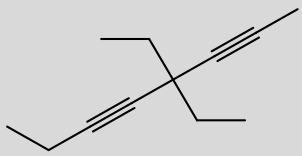
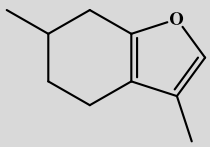
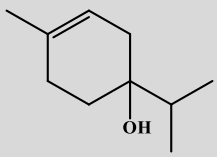
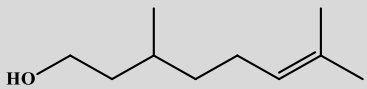
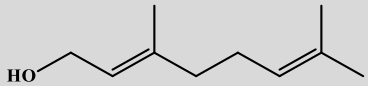
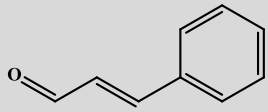
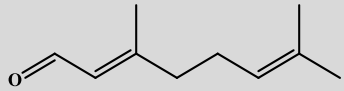
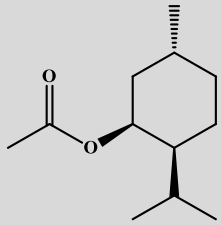
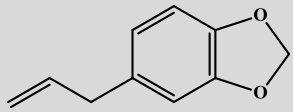
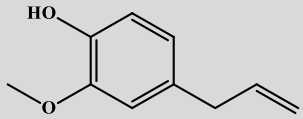
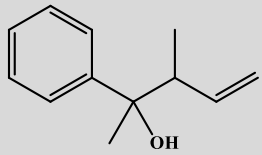
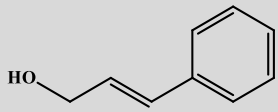
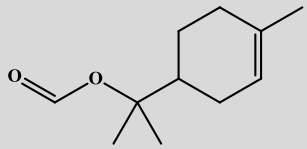
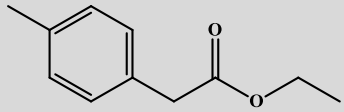
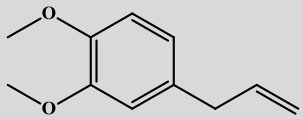
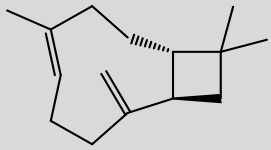
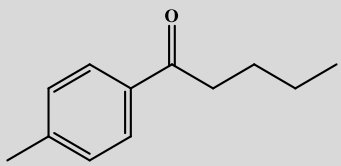


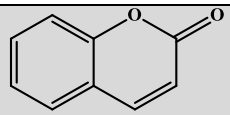
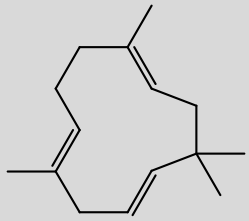
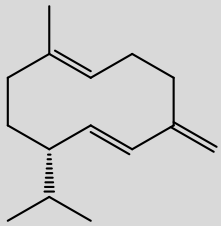
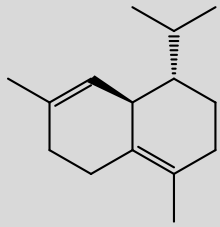
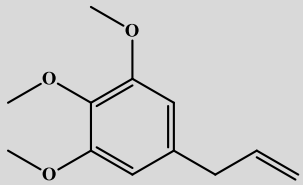
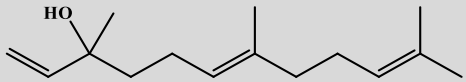
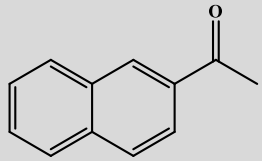
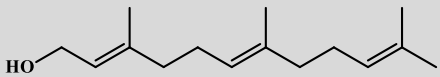
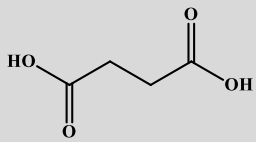
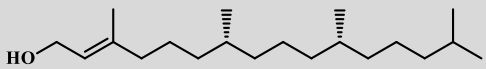
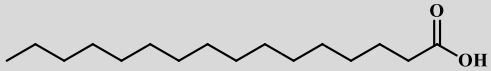
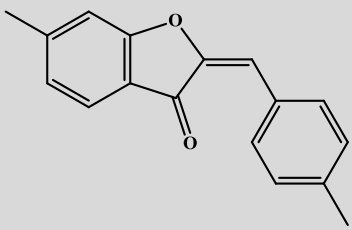
Fig. 1. GC-MS total ion chromatogram of *L. adscendens* essential oil

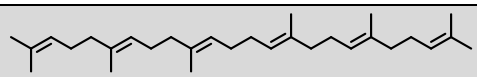
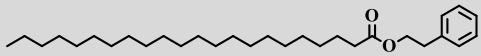
TABLE-1
CHEMICAL COMPOSITIONS FROM THE ESSENTIAL OIL OF *L. adscendens*

Peak	RT (min)	Compound Name	Formula	Library RI	Structure	Area (%)
1	3.13	Methyl alcohol	CH_4O	354	–OH	0.42
2	4.81	Acetophenone	C_8H_8O	548		0.04
3	6.47	3-Methyl-1,5-hexadiene	C_7H_{12}	633		0.42
4	7.30	*n*-Propyl acetate	$C_5H_{10}O_2$	712		0.18
5	7.55	2-Ethyl-5-methylfuran	$C_7H_{10}O$	802		0.02
6	7.67	3-Hexene-2,5-dione	$C_6H_8O_2$	898		0.08
7	8.39	Pentamethyl-cyclopentane	$C_{10}H_{20}$	905		0.02
8	8.44	(-)-β-Pinene	$C_{10}H_{16}$	943		3.67
9	8.46	(-)-α-Thujene	$C_{10}H_{16}$	964		9.49
10	8.50	Benzaldehyde	C_7H_6O	965		2.64
11	8.53	β-Myrcene	$C_{10}H_{16}$	991		5.97
12	8.63	Caprylaldehyde	$C_8H_{16}O$	1003		0.36
13	9.15	α-Terpinene	$C_{10}H_{16}$	1017		11.20
14	9.28	1,3-Benzodioxole	$C_7H_6O_2$	1025		0.12

15	9.32	D-Limonene	$C_{10}H_{16}$	1031		8.04
16	9.47	Eucalyptol	$C_{10}H_{18}O$	1033		0.02
17	11.07	*cis*-1,3,3-trimethylbicyclo[3.1.0]hexane-1-carboxaldehyde	$C_{10}H_{16}O$	1079		1.41
18	13.20	Linalool	$C_{10}H_{18}O$	1103		0.93
19	13.54	Chrysanthenone	$C_{10}H_{16}O$	1131		0.26
20	13.63	4,6-Dimethyl-2,7-nonadien-5-one	$C_{11}H_{18}O$	1138		0.14
21	13.63	*trans*-Menthone	$C_{10}H_{18}O$	1148		0.71
22	13.64	(R)-3,7-Dimethyloct-6-enal	$C_{10}H_{18}O$	1153		0.14
23	13.95	Borneol	$C_{10}H_{18}O$	1154		2.24
24	14.12	4,4-Diethylocta-2,5-diyne	$C_{12}H_{18}$	1164		0.04
25	14.70	Menthofuran	$C_{10}H_{14}O$	1165		0.18
26	14.96	Terpinen-4-ol	$C_{10}H_{18}O$	1177		0.06
27	14.99	Citronellol	$C_{10}H_{20}O$	1232		0.04

28	15.64	Geraniol	$C_{10}H_{18}O$	1253		0.04
29	15.64	Cinnamaldehyde	$C_9H_{10}O$	1270		0.12
30	15.64	Citral	$C_{10}H_{16}O$	1273		0.06
31	15.88	(+)-Neomenthyl acetate	$C_{12}H_{22}O_2$	1277		0.16
32	16.28	Safrole	$C_{10}H_{10}O_2$	1287		0.40
33	16.81	Eugenol	$C_{11}H_{14}O_2$	1287		0.04
34	16.85	3-Methyl-2-phenylpent-4-en-2-ol	$C_{12}H_{16}O$	1308		0.02
35	17.45	(E)-3-Phenylprop-2-en-1-ol	$C_9H_{10}O$	1310		0.12
36	17.46	Terpinyl formate	$C_{11}H_{18}O_2$	1330		0.61
37	17.46	Ethyl-*p*-tolylacetate	$C_{11}H_{14}O_2$	1372		0.12
38	18.06	Methyleugenol	$C_{11}H_{14}O_2$	1403		16.54
39	18.86	β-Caryophyllene	$C_{15}H_{24}$	1422		23.52
40	21.45	4-Methyl-1-pentanoylbenzene	$C_{12}H_{16}O$	1440		0.04

41	22.83	Chromen-2-one	$C_9H_6O_2$	1440		0.06
42	23.41	α-Humulene	$C_{15}H_{24}$	1455		1.23
43	23.67	Germacrene D	$C_{15}H_{24}$	1483		0.61
44	23.92	(+)-δ-Cadinene	$C_{15}H_{24}$	1525		0.10
45	24.23	Elemicin	$C_{12}H_{16}O_3$	1554		0.10
46	24.82	(E)-Nerolidol	$C_{15}H_{26}O$	1563		0.02
47	25.26	2-Acetylnaphthalene	$C_{12}H_{10}O$	1620		0.02
48	25.92	Farnesol	$C_{15}H_{26}O$	1718		0.02
49	28.02	Tetradecanoic acid	$C_{14}H_{28}O_2$	1772		0.28
50	28.61	Phytol	$C_{20}H_{40}O$	1945		0.10
51	29.75	Hexadecanoic acid	$C_{16}H_{32}O_2$	1968		1.92
52	33.40	3',6-Dimethoxyaurone	$C_{17}H_{14}O_4$	2343		0.26

53	37.61	Squalene	$C_{30}H_{50}$	2822		0.02
54	55.14	2-Phenylethyl docosanoate	$C_{30}H_{52}O_2$	3324		0.31
		Monoterpene hydrocarbons			5 (38.37%)	
		Oxygenated monoterpenes			14 (6.86%)	
		Sesquiterpene hydrocarbons			4 (25.46%)	
		Oxygenated sesquiterpenes			2 (0.04%)	
		Derivatives of benzene (benzenoids)			15 (20.83%)	
		Other			14 (4.12%)	
		Total			54 (95.68%)	

The application of MAE significantly influenced the volatile composition of *L. adscendens* by improving extraction efficiency while preserving thermolabile constituents. The characteristic volatile profile obtained through MAE can be attributed to the interaction between microwave energy and intracellular moisture within the plant matrix. Highly volatile monoterpenes such as α-terpinene, (-)-α-thujene, D-limonene and β-myrcene are generally prone to oxidation, hydrolysis and structural rearrangement during prolonged conventional hydrodistillation. However, the shorter extraction duration achieved by MAE (42 min) minimized thermal exposure and reduced degradation of these low molecular weight compounds, resulting in their enhanced preservation. In addition, microwave-induced volumetric heating generated localized internal pressure within glandular trichomes and vascular tissues, leading to rapid rupture of cell walls and efficient release of volatile constituents. This mechanism particularly facilitated the extraction of heavier and less volatile sesquiterpenes such as β-caryophyllene (23.52%), which are otherwise difficult to recover efficiently through conventional heating methods.

The higher recovery of benzenoid compounds, especially methyleugenol (16.54%), further demonstrated the selective extraction capability of MAE. Microwave heating operates through dipole rotation and ionic conduction, allowing compounds containing polar functional groups to interact strongly with the electromagnetic field. The presence of methoxy groups in methyleugenol enhanced localized heating, thereby increasing its diffusion and extraction efficiency from plant tissues. Consequently, the synergistic effects of rapid heating, efficient cellular disruption and reduced thermal degradation enabled MAE to produce a chemically enriched extract containing balanced proportions of monoterpenes, sesquiterpenes and benzenoid compounds. Such preservation of structurally diverse bioactive constituents may contribute to the enhanced pharmacological potential of the *L. adscendens* volatile extract.

Antibacterial activity: The antibacterial efficacy of the *L. adscendens* volatile extract against *E. coli* (ATCC 25922) was evaluated using the agar disc diffusion method. The results demonstrated a dose-dependent inhibitory effect. At the lowest active concentration of 0.75 mg/mL, the volatile extract exhibited an inhibition rate of 7.24% with an inhibition zone diameter (IZD) of 3 mm. As the concentration increased to 2.00 mg/mL, the antibacterial activity surged significantly, achieving an 86.94% inhibition rate and a large IZD of 28 mm, which is highly comparable to the positive control ciprofloxacin (IZD = 34 mm) (Table-2).

The antibacterial activity against *E. coli* might be correlated with the presence of the lipophilic constituents of the extract. However, further bioactivity-guided fractionation is necessary to identify the specific active principles. β-Caryophyllene, the most abundant bicyclic sesquiterpene in the extract, is highly lipophilic and can effectively partition into the lipid bilayer of the bacterial cell membrane, thereby altering its permeability. Concurrently, monoterpenes like α-terpinene and D-limonene further disrupt the membrane structure. The presence of methyleugenol also plays a synergistic role; its ether groups interact with membrane proteins, leading to the leakage of intracellular constituents, disruption of cellular respiration and ultimately, bacterial cell death.

Antioxidant activity: The antioxidant capacity was determined using the DPPH free radical scavenging assay. The *L.*

TABLE-2
ANTIBACTERIAL ACTIVITY OF *L. adscendens* VOLATILE COMPOUNDS AGAINST *E. coli*

Bacterial density	Volatile compounds (mg/mL)	IZD (mm)			Resistance (%)
		1	2	3	
10^6 CFU	2.00	28	28.5	27.0	86.94
10^6 CFU	1.75	23	22.5	22.0	69.71
10^6 CFU	1.50	17	17.5	17.5	55.61
10^6 CFU	1.25	12	12.5	12.5	38.15
10^6 CFU	1.00	9	8.5	8.5	26.00
10^6 CFU	0.75	3	3.0	3.0	7.24
10^6 CFU	0.50	0	0	0	0.00
Ciprofloxacin	1.00	34	34.0	34.0	100

Ciprofloxacin: Positive control for antibacterial activity.

adscendens volatile extract exhibited concentration-dependent antioxidant properties. As the concentration increased from 0.625 mg/mL to 10 mg/mL, the DPPH scavenging capacity escalated from 36.19% to 99.17%. Notably, the calculated IC_{50} value of the volatile extract was 2.46 mg/mL, indicating a moderate antioxidant activity. Although the IC_{50} value (2.46 mg/mL) is relatively high compared to highly purified standard antioxidants which typically operate in the μg/mL range, it showed better scavenging capacity than the BHT control under these specific assay conditions (IC_{50} = 6.10 mg/mL) (Table-3).

TABLE-3
ANTIOXIDANT ACTIVITY OF *L. adscendens* VOLATILE COMPOUNDS

Volatile compounds (mg/mL)	Inhibition (%)			IC_{50} (mg/mL)
	1	2	3	
10	96.31	98.43	99.17	
5.0	74.83	75.28	75.46	
2.5	56.01	53.97	51.15	2.46 ± 0.2
1.25	47.32	42.05	43.79	
0.625	36.19	36.41	36.73	
BHT (Positive control for antioxidant activity)				6.10 ± 0.1

The strong radical scavenging activity of the extract may be attributed to the presence of methyleugenol and highly unsaturated terpenoid constituents. Methyleugenol, a phenylpropene derivative, contains an electron-rich aromatic system capable of donating electrons or hydrogen atoms to stabilize DPPH free radicals [28]. Similarly, monoterpenes such as α-terpinene and β-myrcene possess conjugated double-bond systems that readily interact with reactive radical species, thereby contributing to antioxidant activity [29]. The enhanced antioxidant potential of the extract may also be associated with the MAE process, which minimizes thermal degradation and preserves the structural integrity of these thermolabile unsaturated compounds [30]. Consequently, the retained bioactive volatile constituents likely contributed to the superior radical scavenging performance of the extract compared with the synthetic antioxidant BHT.

α-Glucosidase inhibitory activity: The potential of the *L. adscendens* volatile extract to manage postprandial hyperglycemia was evaluated using the α-glucosidase inhibition assay. The extract exhibited dose-dependent inhibition, with rates increasing from 32.64% to 95.51% as the concentration rose from 1.25 to 20 mg/mL. The IC_{50} value was determined to be 4.81 mg/mL (Table-4).

The volatile extract exhibited measurable α-glucosidase inhibitory activity; however, its potency was considerably lower than that of the standard drug acarbose (IC_{50} = 0.013 mg/mL). This comparatively weaker inhibition can be explained by the chemical composition of the extract. Strong α-glucosidase inhibitors generally contain multiple hydroxyl (-OH) groups, as observed in flavonoids, tannins and carbohydrate-based inhibitors, which facilitate strong hydrogen-bond interactions with amino acid residues at the enzyme active site. In contrast, MAE predominantly enriches non-polar to moderately polar volatile constituents, mainly hydrocarbons and simple oxygenated terpenes, which possess limited polyhydroxyl functionality and therefore exhibit lower binding affinity toward the enzyme. Consequently, the volatile extract showed relatively weak *in vitro* antidiabetic activity with an IC_{50} value of 4.81 mg/mL compared with acarbose.

TABLE-4
α-GLUCOSIDASE INHIBITORY ACTIVITY OF *L. adscendens* VOLATILE COMPOUNDS

Volatile compounds (mg/mL)	Inhibiting (%)			IC_{50} (mg/mL)
	1	2	3	
20	93.84	95.51	95.32	
10	66.47	65.72	66.15	
5	54.22	53.48	52.84	4.81 ± 0.43
2.5	39.55	38.49	38.92	
1.25	33.78	32.64	33.21	
Acarbose				0.013 ± 0.01

Acarbose: Positive control for anti-α-glucosidase activity.

Conclusion

This study presents the first investigation of volatile compounds from *L. adscendens* collected in Dak Lak, Vietnam using microwave-assisted extraction (MAE). GC-MS analysis identified 54 compounds representing 95.68% of the total extract, with β-caryophyllene (23.52%), methyleugenol (16.54%) and α-terpinene (11.20%) as the major constituents. The MAE process enabled efficient recovery of volatile constituents while minimizing thermal degradation of sensitive monoterpenes and preserving bioactive sesquiterpenes and benzenoid compounds. The biological evaluations demonstrated moderate antioxidant, antibacterial and α-glucosidase inhibitory activities of the volatile extract, indicating the contribution of terpenoid and phenylpropanoid constituents to the observed bioactivity.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

DECLARATION OF AI-ASSISTED TECHNOLOGIES

During the preparation of this manuscript, the authors used an AI-assisted tool(s) to improve the language. The authors reviewed and edited the content and take full responsibility for the published work.

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