Journal of Essential Oil & Plant Composition

JEOPC, 4(1), 42-50, 2026
https://doi.org/10.58985/jeopc.2026.v04i01.80
ISSN (Print): 2958-9630

Short Communication

Curcuma longa (Zingiberaceae) and *Piper nigrum* (Piperaceae): A novel technique for extracting curcuminoids and piperine from plant materials

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Article Information
Received: 20 March 2026
Revised: 11 April 2026
Accepted: 14 April 2026
Published: 17 April 2026

Academic Editor
Prof. Dr. Radosław Kowalski

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Keywords
Black pepper, curcuminoids, DeepSpectra®, gas chromatography, liquid chromatography, mass spectrometry, piperine, turmeric.

Abstract

Turmeric (*Curcuma longa*) and black pepper (*Piper nigrum*) have a long history of cultivation and economic value. Both plants have been celebrated for their culinary and medicinal properties. The current study investigated the use of a novel patented extraction technique (DeepSpectra®) that employs turmeric essential oil (EO) as a natural solvent for extracting medicinally important non-volatile compounds from turmeric rhizomes (curcuminoids) and black pepper berries (piperine). GC/MS and UPLC-PDA were employed to evaluate the volatile and non-volatile characteristics of the resulting extracts, respectively. The volatile profile was largely composed of γ-curcumene (8.6%), α-zingiberene (5.3%), AR-turmerone (42.1%), and α-turmerone (8.3%). The non-volatile profile contained curcumin (5.30 mg/mL), demethoxycurcumin (2.94 mg/mL), bisdemethoxycurcumin (3.59 mg/mL), and piperine (1.56 mg/mL). These findings suggest that turmeric EO is a reliable, natural solvent for extracting non-volatile compounds from raw plant materials.

1. Introduction

Curcuma longa L. (turmeric) is a plant species belonging to the Zingiberaceae family [1]. Turmeric has a long history of cultivation, largely for the harvest of aromatic rhizomes for medicinal, culinary, and textile (dye) uses [2]. Modern research has demonstrated that three primary curcuminoids (curcumin, demethoxycurcumin, and bisdemethoxy-curcumin) are responsible for the medicinal properties of rhizomes [3]. In recent years, considerable research has been conducted on the distillation of turmeric rhizomes for the production of EO. Studies have shown that turmeric EO demonstrates antioxidant, antimicrobial, anti-inflammatory, antinociceptive, and herbicidal properties [4-7]. The EO of turmeric (specifically *C. longa*) is largely composed of sesquiterpenoids [3], with prominent compounds being AR-turmerone, α-turmerone, and β-turmerone [5-9].

Piper nigrum L. (black pepper) is a plant species in the Piperaceae family [10] with historical importance in

commerce, particularly in the spice trade [2]. Significant research has been conducted on the therapeutic value of the non-volatile alkaloid piperine, which is present in black pepper berries. Both piperine and black pepper EO have been attributed with anti-inflammatory, antimicrobial, antioxidant, and analgesic properties [11-16]. Black pepper EO is largely composed of (*E*)-caryophyllene, α-pinene, β-pinene, δ-3-carene, limonene, and sabinene [14-17].

The current study employs a novel, patented extraction technique (DeepSpectra®) [18,19] that uses steam distilled turmeric EO as a natural solvent to extract non-volatile compounds from a mixture of both ground turmeric and black pepper plant materials. This approach eliminates the use of harsh chemical solvents (DCM, methanol, etc.) and provides a means to obtain additional biologically active and beneficial compounds [20, 21] that are otherwise not detectable in either turmeric or black pepper EO. The chemical profiles of turmeric EO and secondarily extracted (aka, DeepSpectra® extraction) samples were established using GC/MS and UPLC-PDA analyses. This is the first study to investigate a novel patented extraction technique for turmeric and black pepper. Future research will further expand the identification of additional non-volatile compounds present in DeepSpectra® samples.

2. Materials and methods

2.1. Raw materials and extraction methods

Turmeric (*C. longa*) EO, dried turmeric rhizomes, and dried black pepper (*P. nigrum*) berries were procured from Greenleaf Extractions Pvt. Ltd. (Greenleaf, Kochi, India). Both turmeric and black pepper plant materials were procured in a pre-ground condition. The black pepper EO, used as a reference sample, was procured from Young Living Essential Oils (Young Living, Lehi, UT, USA).

Secondary extraction DeepSpectra® samples (n = 3) were produced as follows: pre-ground plant materials of turmeric and black pepper were accurately weighed and added to turmeric EO in an approximate ratio of 24:11:1 (oil-to-turmeric-to-peppercorn), mixed in a beaker at 250 rpm for 2 h, and filtered using a 0.22 µm PVDF Luer lock filter (Restek Corporation, Bellefonte, PA, USA) (Fig. 1). Exact DeepSpectra® sample extraction details can be found in Table 1.

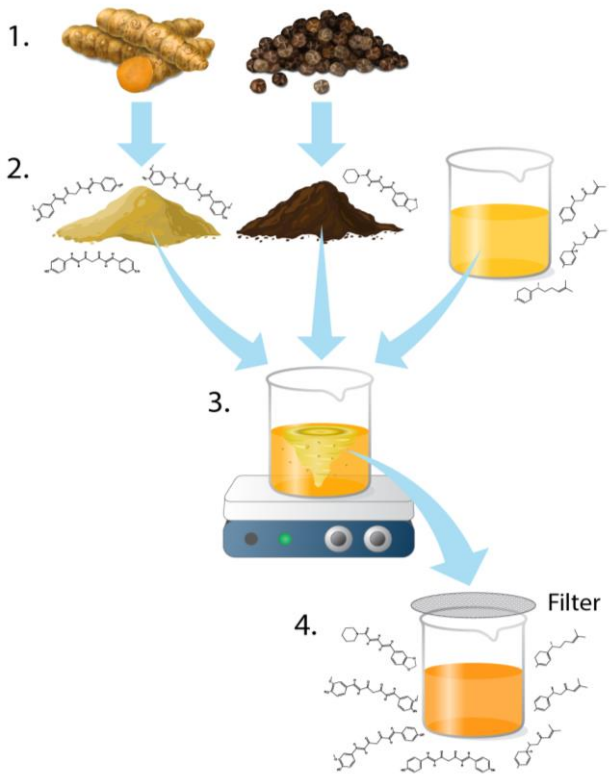

Figure 1. Illustration of the DeepSpectra® extraction process. (1) Dried turmeric rhizome and black pepper berries are ground into powder, (2) turmeric essential oil, turmeric powder, and black pepper powder are added together in a specific ratio, (3) solution is mixed, (4) and the resulting solution (DeepSpectra® extraction) is filtered. Illustrated by Rick Simonson, Science Lab Studios, Inc. (Kearney, NE, USA).

2.2. Analysis methods

To determine volatile compound profiles, EO and DeepSpectra® samples were analyzed, and compounds were identified and quantified by GC/MS using an Agilent 7890B GC/5977B MSD (Agilent Technologies, Santa Clara, CA, USA) and Agilent J&W DB-5, 60 m × 0.25 mm, 0.25 µm film thickness, fused silica capillary column. Operating conditions: 0.1 µL of sample (20% soln. for EO in ethanol), 100:1 split ratio, initial oven temp. of 40 °C with an initial hold time of 5 min, and oven ramp rate of 4.5 °C per min to 310 °C with a hold time of 5 min. The electron ionization energy was 70 eV, scan range was 35–650 amu, scan rate was 2.4 scans per s, source temperature 230 °C, and quadrupole temp. 150 °C. The compounds were identified using the Adams volatile oil library

Table 1. DeepSpectra® (DS) extraction details, including raw material mass (g) and essential oil mass (g) used for production of each sample.

Raw Materials	DS Sample A	DS Sample B	DS Sample C
Turmeric Essential Oil	24.06 g	24.00 g	23.99 g
Turmeric Rhizome Powder	11.03 g	11.04 g	11.00 g
Black Pepper Berry Powder	1.01 g	1.05 g	1.00 g

[22] and a Chemstation library search in conjunction with retention indices.

To determine the curcuminoid and piperine content, EO and DeepSpectra® samples were analyzed by UPLC-PDA. Analysis was performed using a Waters ACQUITY UPLC H-Class PLUS system coupled to a Waters Photodiode Array detector (Waters Corporation, Milford, Massachusetts, USA). Analyte separation was achieved using a CORTECS UPLC Shield RP18 (1.6 µm, 2.1 mm X 100 mm) column with a CORTECS Shield RP18 Pre-column (1.6 µm, 2.1 mm X 5 mm).

The chromatographic conditions were as follows: mobile phase A was 0.1% Citric Acid (VWR, ACS grade, item 0529) in ultra-pure water (Milli-Q IQ 7000, 0.22 µm Millipak filter) and mobile phase B was Acetonitrile (J.T. Baker, LC-MS grade, Avantor item 9829-02), and the column temperature was 35 °C. Positive identification was achieved by comparing the retention time and UV-Vis absorbance spectra obtained from the PDA detector. For curcuminoid analysis, 2.0 µL of the sample was injected onto the column and subjected to the mobile phase composition and flow rate described in Table 2.

Table 2. Mobile phase details for curcuminoids (method time, flow rate, concentrations of mobile phases A and B).

Number	Time (min)	Flow (mL/min)	A (%)	B (%)	Curve
1	Initial	0.3	55	45	Initial
2	10.0	0.3	55	45	6

For piperine analysis, 2.0 µL of the sample was injected onto the column and subjected to the mobile phase composition and flow rate described in Table 3.

The PDA detector conditions for curcuminoid analysis was a UV-channel set at 420 nm. For the curcuminoid analysis (Curcumin, Demethoxy-curcumin, and Bisdemethoxycurcumin), EO and DeepSpectra® samples were prepared for analysis by

Table 3. Mobile phase gradient details for piperine (method time, flow rate, concentrations of mobile phases A and B).

Number	Time (min)	Flow (mL/min)	A (%)	B (%)	Curve
1	Initial	0.3	98	2	Initial
2	1.5	0.3	98	2	6
3	8.0	0.3	20	80	6
4	10.0	0.3	1	99	6
5	10.1	0.3	98	2	6
6	15.0	0.3	98	2	6

adding 100 µL of sample to 9.90 mL of HPLC-MS grade Methanol (BDH, VWR item BDH85800) with a calibrated pipette in a 15 mL light sensitive centrifuge tube. The samples were inverted several times to mix, sonicated at room temperature for 10 min, and then centrifuged at 6000 RPM for 10 min. Each sample was then filtered (Restek syringe filter, PVDF, 0.22 µm x 30 mm) into an amber HPLC vial. Quantitation of the analytes was achieved by comparing the peak area responses to an established calibration curve (linear regression, minimum R^2 value of 0.995) with a range of 10 to 100 µg/mL (ppm). Calibration curves, retention times, and UV-Vis spectra were established by certified reference materials (Cayman Chemical Company, Curcumin, item 81025; Bisdemethoxy-curcumin, item 10960; Demethoxycurcumin, item 10961).

The PDA detector conditions for piperine analysis was a UV-channel set at 340 nm. For piperine analysis, EO and DeepSpectra® samples were prepared by adding 300 µL of the sample to 9.7 mL of acetonitrile (J.T. Baker, LC-MS grade, Avantor item 9829-02) with a calibrated pipette to a 15 mL light sensitive centrifuge tube. The samples were inverted several times to mix, vortexed for 1 min, and sonicated at room temperature for 10 min. The samples were centrifuged at 6000 RPM for 10 min, and then 100 µL of supernatant was transferred to 9.9 mL of acetonitrile (J.T.Baker, LC-MS grade, Avantor item

9829-02) in a second 15 mL light sensitive centrifuge tube with a calibrated pipette and inverted to mix. Each sample was then filtered (Restek syringe filter, PVDF, 0.22 µm x 30 mm) into an amber HPLC vial. Quantitation of the analytes was achieved by comparing the peak area responses to an established calibration curve (linear regression, minimum R^2 value of 0.995) in the range of 0.1 to 1 µg/mL. Calibration curves, retention times, and UV-Vis spectra were established by a certified reference material (Sigma-Aldrich, Piperine, item P49007).

3. Results

The volatile profiles of turmeric EO, black pepper EO, and DeepSpectra® samples (n = 3) are provided in Table 4. DeepSpectra® samples were produced through a novel, patented extraction process that used turmeric EO as a solvent to extract non-volatile compounds from a mixture of turmeric rhizome and black pepper berry plant materials. Prominent compounds (≥5.0%) in the turmeric EO and DeepSpectra® samples included γ-curcumene (7.1%, 8.6%), α-zingiberene (4.1%, 5.3%), AR-turmerone (46.6%, 42.1%), and α-turmerone (8.5%, 8.3%). The prominent compounds in the black pepper EO were α-pinene (11.6%), sabinene (9.4%), β-pinene (9.5%), δ-3-carene (7.8%), limonene (13.0%), and (E)-caryophyllene (27.6%).

Several non-volatile compounds were identified in the DeepSpectra® samples; however, these same non-volatile compounds were either possibly detected (but below the limit of quantitation) or not detected in either EO sample (turmeric or black pepper). The non-volatile compounds detected in DeepSpectra® samples were characteristic of turmeric (curcumin, demethoxycurcumin, and bisdemethoxycurcumin) and black pepper (piperine). A summary of the UPLC-PDA findings is provided in Table 5.

4. Discussion

The turmeric EO was a light-orange color. Upon extracting compounds from both turmeric rhizome and black pepper berries, the resulting liquid solution was dark, amber-orange color. This initial finding suggests that the turmeric EO is a suitable solvent for extracting additional compounds from both plant materials.

GC/MS analysis resulted in similar volatile profiles for both turmeric EO and DeepSpectra® samples (n = 3); however, there were subtle differences. The average relative abundance of monoterpenoids (10-carbon backbone) and sesquiterpenoids (15-carbon backbone) in the EO samples differed from that in the DeepSpectra samples. Monoterpenoids comprised 5.3% of the turmeric EO and 8.2% of the DeepSpectra® samples. Sesquiterpenoids comprised an average of 89.4% of the turmeric EO and 87.3% of the DeepSpectra® samples. These data suggest that the DeepSpectra® process increases the efficiency of monoterpenoid recovery from plant material samples when extracting compounds from fresh raw materials.

UPLC-PDA analysis of the DeepSpectra® samples resulted in the detection of several curcuminoids and piperine (Fig. 1). However, these same non-volatile compounds were either possibly detected (but below the limit of quantitation) or not detected in either turmeric or black pepper EO samples. The detected curcuminoids in the DeepSpectra® samples included curcumin (aka diferuloylmethane), demethoxy-curcumin, and bisdemethoxycurcumin. Additionally, other non-volatile compounds were expected to be co-extracted through DeepSpectra® extraction (Fig. 2), as found in previous studies [20, 21]. However, additional reference standards and resources are required for their identification. These data suggest that the turmeric EO used in the DeepSpectra® process, which is employed as a natural solvent for extracting non-volatile compounds from raw plant materials, is a suitable solvent. Previous reports on the essential oil profile of turmeric [5-9] did not report the presence of any curcuminoids. However, it should be noted that these same analyses were only conducted using gas chromatography, which is typically reserved for analyzing volatile compounds with relatively low molecular weights (i.e., not curcuminoids). DeepSpectra® samples are unique in their chemical composition, which comprises a range of compounds, including monoterpenoids, sesquiterpenoids, curcuminoids, and alkaloids.

The DeepSpectra® extraction employed herein (co-extraction of turmeric and black pepper plant materials simultaneously) was based on research

Table 4. Volatile compounds detected in essential oil (EO) or DeepSpectra® (DS) samples.

Compound name	KI	Turmeric EO	DeepSpectra® sample	Black Pepper EO
α-Thujene	924	nd	nd	1.1
α-Pinene	932	0.1	0.1	11.6
Camphene	946	0.1	0.1	0.3
Sabinene	969	tr	tr	9.4
β-Pinene	974	nd	nd	9.5
Myrcene	988	nd	nd	0.8
α-Phellandrene	1002	1.2	1.9	0.7
δ-3-Carene	1008	tr	0.1	7.8
α-Terpinene	1014	0.1	0.2	0.1
p-Cymene	1020	1.2	1.8	0.8
Limonene	1024	0.3	0.4	13.0
1,8-Cineole	1026	1.2	1.9	nd
(*E*)-β-Ocimene	1044	nd	nd	tr
γ-Terpinene	1054	0.1	0.1	0.1
(*Z*)-Sabinene hydrate	1065	nd	nd	0.1
p-Mentha-2,4(8)-diene	1085	nd	nd	0.1
Terpinolene	1086	1.0	1.5	0.2
Linalool	1095	nd	nd	0.2
(*E*)-Sabinene hydrate	1098	nd	nd	0.1
Terpinen-4-ol	1174	tr	tr	0.4
p-Cymen-8-ol	1179	tr	tr	nd
Dill Ether	1184	tr	tr	nd
α-Terpineol	1186	tr	tr	tr
Thymol	1289	tr	tr	nd
δ-Elemene	1335	nd	nd	2.2
α-Cubebene	1348	nd	nd	0.2
Cyclosativene	1369	nd	nd	0.1
unknown compound 1	*1371	3.1	3.5	nd
α-Copaene	1374	nd	nd	4.2
β-cubebene	1387	nd	nd	0.8
α-Gurjunene	1409	nd	nd	0.1
α-Cedrene	1410	0.2	0.4	nd
(*E*)-Caryophyllene	1417	0.8	1.1	27.6
β-Ylangene	1419	nd	nd	0.2
α-Guaiene	1437	nd	nd	0.1
(*Z*)-β-Farnesene	1440	nd	nd	tr
unknown compound 2	*1444	0.7	0.8	nd
(*Z*)-Muurola-3,5-diene	1448	nd	nd	tr
Amorpha-4,11-diene	1449	0.9	1.1	nd
α-Humulene	1452	nd	nd	1.4
(*Z*)-Cadina-1(6),4-diene	1461	nd	nd	tr
γ-Muurolene	1478	nd	nd	0.1
AR-Curcumene	1479	2.5	3.1	nd
Germacrene D	1480	nd	nd	0.2
γ-Curcumene	1481	7.1	8.6	nd
β-Selinene	1489	nd	nd	0.3
α-Zingiberene	1493	4.1	5.3	nd
α-Muurolene	1500	nd	nd	1.0
β-Bisabolene	1505	1.0	1.3	1.5

Table 4. (Continued)

Compound name	KI	Turmeric EO	DeepSpectra® Sample	Black Pepper EO
Cubebol	1514	nd	nd	0.2
β-Curcumene	1514	0.3	0.4	nd
β-Sesquiphellandrene	1521	1.7	2.0	nd
δ-Cadinene	1522	nd	nd	1.7
(*E*)-γ-Bisabolene	1529	0.3	0.3	nd
Spathulenol	1577	nd	nd	tr
Caryophyllene oxide	1582	nd	nd	1.1
Dihydro-AR-turmerone	1595	3.5	2.9	nd
unknown compound 3	*1609	1.0	1.0	nd
α-Muurolol	1644	nd	nd	0.2
unknown compound 4	*1648	0.9	0.7	nd
AR-Turmerone	1668	46.6	42.1	nd
α-Turmerone	*1672	8.5	8.3	nd
(*Z*)-γ-Atlantone	1694	0.7	0.5	nd
β-Turmerone	*1701	2.7	2.4	nd
(*E*)-γ-Atlantone	1706	0.9	0.7	nd
(6R,7R)-Bisabolene	1740	0.5	0.3	nd
(*E*)-α-Atlantone	1777	1.3	0.8	nd

The compound name, KI, and relative area % are reported. KI is the Kovat's Index value and was previously calculated by Robert Adams using a linear calculation on a DB-5 column [22]. Values for turmeric and black pepper EO samples resulted from the analysis of single samples. Values for the DS sample are an average value from three samples (n = 3).
*Either unknown compound or compound not found in the Adams Library [22]. KI manually calculated.

Table 5. Non-volatile compounds detected in DeepSpectra® samples (average).

Compound Name	Value (mg/mL)
Curcumin	5.30
Demethoxycurcumin	2.94
Bisdemethoxycurcumin	3.59
Piperine	1.56

reports that the co-administration of curcuminoids and piperine increases absorption and sustained bioavailability in both animal and human models [23, 24]. Initial research was conducted to achieve approximately a 10:1 ratio of total curcuminoids to piperine in the DeepSpectra® sample. The DeepSpectra® extract, with an approximate 10:1 ratio of curcuminoids to piperine, as well as additional ratios of turmeric and black pepper plant materials, will be produced and evaluated in the future to determine their extraction efficiency and biological activities. Regardless, the current study is the first to establish the use of turmeric EO as a natural and reliable solvent for extracting non-volatile compounds from both turmeric rhizomes and black pepper berries.

5. Conclusions

A novel patented extraction technique (DeepSpectra®) was employed using turmeric EO as a natural solvent for extracting medicinally important non-volatile compounds from turmeric rhizome (curcuminoids) and black pepper berries (piperine). GC/MS and UPLC-PDA were employed to evaluate the volatile and non-volatile characteristics of the resulting extracts, respectively. The volatile profiles of the DeepSpectra® samples was largely composed of γ-curcumene (8.6%), α-zingiberene (5.3%), AR-turmerone (42.1%), and α-turmerone (8.3%). The non-volatile profiles of the DeepSpectra® samples contained curcumin (5.30 mg/mL), demethoxycurcumin (2.94 mg/mL), bisdemethoxycurcumin (3.59 mg/mL), and piperine (1.56 mg/mL). These same non-volatile compounds were either possibly detected (but below the limit of quantitation) or not detected in either turmeric or black pepper EO samples. These findings suggest that turmeric EO is a reliable natural solvent for extracting non-volatile compounds from raw plant materials.

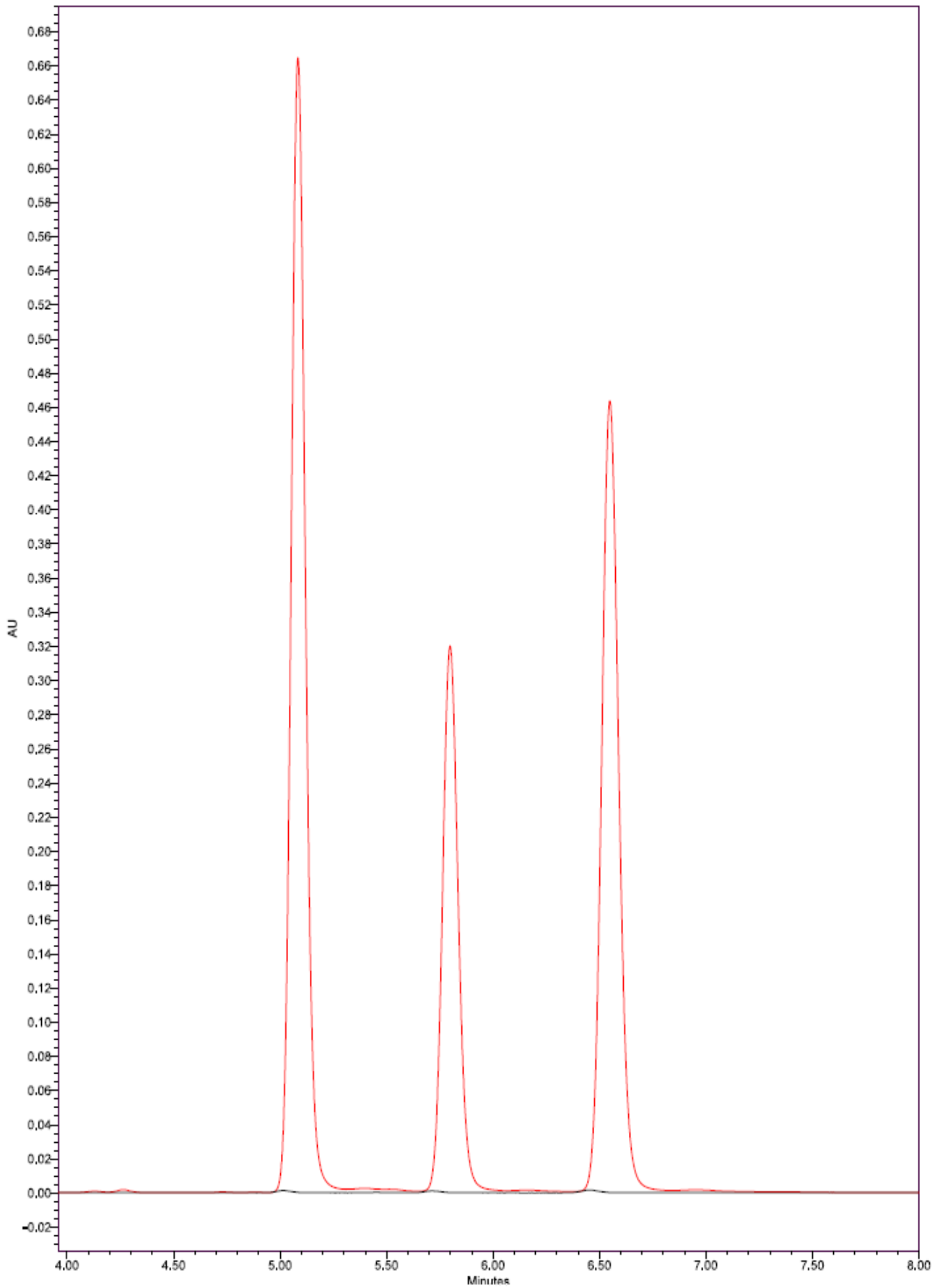

Figure 2. UPLC-PDA chromatographic overlay of turmeric essential oil (black) and the DeepSpectra® extraction (red).

https://doi.org/10.58985/jeopc.2026.v04i01.80

Patents

United States Patent Number: US 12,559,697 B2. Date of Patent: 24 February 2026. Publication Title: METHODS AND SYSTEMS FOR EXTRACTING ADDITIONAL BENEFICIAL LIPID-SOLUBLE COMPOUNDS FROM PLANT MATERIALS IN ENVIRONEMENTIALLY SUSTAINABLE WAYS.

United States Patent Number: US 12,540,293 B2. Date of Patent: 3 February 2026. Publication Title: METHODS AND SYSTEMS FOR EXTRACTING ADDITIONAL BENEFICIAL LIPID-SOLUBLE COMPOUNDS FROM PLANT MATERIALS IN ENVIRONEMENTIALLY SUSTAINABLE WAYS.

Abbreviations

The following abbreviations are used in this manuscript: EO (Essential Oil); DCM (Dichloromethane); DS (DeepSpectra®); GC/MS (Gas Chromatography/Mass Spectrometry); UPLC-PDA (Ultra-Performance Liquid Chromatography – Photodiode Array Detector).

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization, M.C.J., H.K.L., T.M.W.; sample procurement and production, M.C.J., H.K.L., T.M.W.; methodology, M.C.J., T.M.W.; software, M.C.J., T.M.W.; validation, C.R.B.; formal analysis, M.C.J., T.M.W.; data curation, M.C.J., T.M.W.; writing—original draft preparation, T.M.W.; writing—review and editing, M.C.J., H.K.L., C.R.B., T.M.W.; funding acquisition, C.R.B.

Acknowledgements

The authors wish to thank Rick Simonson (Science Lab Studios, Inc.) for the botanical illustration.

Funding

This research was funded by Young Living Essential Oils.

Availability of data and materials

All data are presented within the current manuscript.

Conflicts of interest

The authors declare no conflicts of interest. While the funders (Young Living Essential Oils) hold the patent for DeepSpectra® technology, the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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