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Phytochemical Analysis of the Essential Oils From the Rhizomes of Three Vietnamese *Curcuma* Species and Their Antimicrobial Activity

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Abstract

Objective/Background: The essential oils (EOs) of *Curcuma* species contain various volatile compounds with bioactivity. However, the phytochemical profile of *Curcuma thorelii* and the antimicrobial activities of *Curcuma rhabdota,* and *Curcuma petiolata* have received limited attention. This study aims to characterize and compare the major compounds and the antimicrobial activities of EOs extracted from the rhizomes of *C. rhabdota, C. thorelii, and C. petiolata* collected in Vietnam. **Methods:** EOs were obtained by hydrodistillation of the rhizomes of three *Curcuma* species. The chemical profiles were determined using gas chromatography-mass spectrometry (GC-MS). The antimicrobial activities against bacteria and a pathogenic fungus were determined through the broth dilution method. **Results:** The volatile profiles of *C. rhabdota, C. thorelii,* and *C. petiolata* EOs included 63 (97.1%), 47 (98.0%), and 50 (95.6%) compounds, respectively. The major compound in the EO of *C. rhabdota* rhizomes was 3-carene (16.6%), followed by camphene (9.8%), α-copaene (7.4%), γ-terpinene (7.3%), camphor (5.9%), and β-curcumene (5.7%). The predominant compounds of the EO extracted from *C. thorelii* rhizome were xanthorrhizol (40.7%), β-curcumene (20.7%), and α-curcumene (8.9%), while camphene (17.0%), *(E)*-β-elemenone (16.8%), *(E)*-β-farnesene (13.6%), germacrone (8.9%), 1,8-cineole (7.2%), and camphor (6.0%) were the most abundant components in *C. petiolata* rhizomes. Except for *Pseudomonas aeruginosa*, which was less susceptible to the EOs with a minimum inhibitory concentration (MIC) value of 128 μg/mL, the three oil samples exhibited potent antimicrobial activities against all investigated strains with MIC values in the range of 2-32 μg/mL. Especially, the EO of *C. thorelii* rhizomes showed intense activity against *Enterococcus faecalis*, *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli,* and *Candida albicans* with a MIC value of 2 μg/mL. **Conclusion:** The results showed the chemical variability of EOs from three *Curcuma* species and the prepared EO samples showed potent antimicrobial activities against several microbial strains, indicating a high potential application as a food preservative and in the pharmaceutical industry.

Keywords

curcuma, essential oil, monoterpene, sesquiterpene, antimicrobial activity

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Introduction

Curcuma is a large genus of the Zingiberaceae family with approximately 130 species growing in South and Southeast Asia.[1] Among them, there are currently more than 27 species of *Curcuma* widely distributed from the northern to southern provinces in Vietnam.[2,3] In the traditional medicine of many countries, *Curcuma* species have long been used medicinally for treating pneumonia, hormonal disorders, bronchial complaints, leucorrhea, diarrhea, dysentery, and parasitosis, among other conditions.[4–6] *Curcuma* species have been considered a rich source of essential oils (EOs), which are responsible for their pleasant aroma, as well as a valuable source of medicinal

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substances, such as curcumin, xanthorhizol, curdione, curcuzedoalide, isoprocurcumenol, and turmeronols,[7,8] which contribute to their various pharmacological properties.[9] Several studies on *Curcuma* EOs identified sesquiterpenoids and monoterpenoids as the major components.[10] Various EOs from *Curcuma* species have been reported to possess strong antioxidant activity.[11–13] Other bioactivities of these EOs also have been described such as antibacterial,[11] anti-inflammatory,[14] antimicrobial,[15] antitumor,[16] insecticidal,[17,18] antifungal,[19] and cytotoxic activities.[20] Furthermore, curcuminoid compounds are the major constituents of *Curcuma* species, which are generally regarded as the most active constituents, with a diverse range of bioactivities such as antitumor, anti-inflammatory, and neuro-protective, for treatment of a wide range of ailments,[21] and efficient inhibition of the enzyme tyrosinase.[22] Although studies on the phytochemistry and bioactivities of *Curcuma* EOs are abundant in the literature, there is no report describing the antimicrobial activity of *Curcuma rhabdota* Sirirugsa & M.F.Newman and *Curcuma petiolata* Roxb. Besides, there has been no phytochemical and pharmacological information on *Curcuma thorelii* Gagnep. Therefore, the present study was conducted to clarify the chemical compositions of EOs prepared from *C. thorelii*, *C. rhabdota*, and *C. petiolata* rhizomes and their antimicrobial activities.

Results and Discussion

EO Composition

Hydrodistillation of the rhizomes of the three *Curcuma* species all produced pale-yellow oils. The yields of the obtained EOs from *C. rhabdota*, *C. thorelii*, and *C. petiolata* were 0.19%, 0.22%, and 0.17% (w/w), respectively, calculated on a fresh weight basis. The chemical compositions of these EOs are given in Table 1.

In general, the *C. rhabdota* rhizome EO was rich in monoterpene (50.4%) and sesquiterpene (29.3%) hydrocarbons, the *C. thorelii* rhizome EO was rich in oxygenated sesquiterpenes (44.0%) and sesquiterpene hydrocarbons (37.8%), while the rhizome EO of *C. petiolata* showed no significant difference between the compound groups.

The analytical results showed the identification of 63, 47, and 50 principal constituents, making a total of 97.1%, 98.0%, and 95.6% of the EOs of *C. rhabdota*, *C. thorelii*, and *C. petiolata*, respectively (Table 1). 3-Carene (16.6%), camphene (9.8%), α-copaene (7.4%), γ-terpinene (7.3%), camphor (5.9%), and β-curcumene (5.7%) were the main components of *C. rhabdota* rhizome EO. Xanthorrhizol (40.7%), β-curcumene (20.7%), and α-curcumene (8.9%) were the principal compounds of the EO of *C. thorelii* rhizomes, and camphene (17.0%), (*E*)-β-elemenone (16.8%), (*E*)-β-farnesene (13.6%), germacrone (8.9%), 1,8-cineole (7.2%), and camphor (6.0%) were identified as the major constituents of the EO of *C. petiolata* rhizome. Remarkably, the EOs of *C. rhabdota* and *C. petiolata* had camphene and camphor as the same major components, while β-curcumene was found as the major component in both *C. rhabdota* and *C. thorelii* EOs.

A comparison of these results with those in the literature showed that there are some differences among the *C. rhabdota* EOs that have been studied. Specifically, three main constituents of the EO of this plant from Bangkok, Thailand were germacrone (24.4%), butanoic acid butyl ester (14.2%), and butanoic acid-1-methylpropyl ester (8.8%).[24] In another study, 3-carene and copaene were identified as two major compounds in the rhizome EO of this plant from Ubon Ratchathani, Thailand.[25] For *C. petiolata*, previous results showed marked differences in the quality and quantity of chemical compositions in which β-farnesene (74.8%) and 2-methyl-5-pentanol (84.0%) were revealed to be dominant.[26,27] In particular, xanthorrhizol in *C. xanthorrhiza* rhizomes[28] was found in *C. thorelii* rhizomes, but was absent from the rhizomes of *C. rhabdota* and *C. petiolata*. Additionally, α-curcumene and β-curcumene were found in *C. rhabdota* and *C. thorelii*, which is similar to the reported data for other *Curcuma* species (eg *Curcuma amada* and *Curcuma aromatica*[29,30]). However, these two compounds were not found in the EO of *C. petiolata*. These results showed that the variability in the chemical constituents of the EOs of *Curcuma* species depends on different species, different geographical locations, and different extraction methods leading to the variability of EO analytical results.

Antimicrobial Activity Evaluation

The results of the study of the antimicrobial activity of the EOs of the rhizomes of *C. rhabdota*, *C. thorelii*, and *C. petiolata* are presented in Table 2.

In general, the results showed that *C. thorelii* rhizome EO showed higher potential antimicrobial activities than those of *C. petiolata* and *C. rhabdota* EO against all investigated strains, except for *Pseudomonas aeruginosa*. Specifically, the rhizome EO of *C. thorelii* showed strong antibacterial activities against Gram-positive bacteria (*Enterococcus faecalis*, *Staphylococcus aureus*, and *Bacillus cereus*) with MIC values of 2 μg/mL and Gram-negative bacteria (*Escherichia coli* and *Salmonella enterica*), with MIC values of 2-8 μg/mL. The potential antibacterial activity of *C. petiolata* rhizome EO against *E. faecalis* was observed with a MIC value of 8 μg/mL, while the values against *B. cereus*, *S. aureus*, *S. enterica*, and *E.* coli were only 16 μg/mL. Similarly, *C. rhabdota* rhizome EO was only shown to possess moderate activity against the same bacterial strains with MIC values in the range of 16-32 μg/mL. Compared with the inhibitory effects of the positive controls on those bacteria, *C. thorelii* showed significantly stronger activity than kanamycin (MIC values of 4-128 μg/mL) and tetracycline (MIC values of 4-64 μg/mL), while *C. petiolata* and *C. rhabdota* possessed comparable antimicrobial activities to these antibiotics. Considering *P. aeruginosa*, all EOs tested exhibited weak antibacterial activity with a MIC value of 128 μg/mL, whereas kanamycin still effectively inhibited this strain, with a MIC of 64 μg/mL. Compared with some previous studies, the antimicrobial

Table 1. Chemical Compositions of EOs From the Rhizomes of Three Curcuma Species.

$RI_{(Exp.)}$	$RI_{(Lit.)}$	Constituents	*Curcuma rhabdota*	*Curcuma thorelii*	*Curcuma petiolata*
899	901	2-Heptanol	0.1	-	-
928	925	Tricyclene	0.2	0.1	1.5
932	929	α-Thujene	1.4	-	0.1
940	937	α-Pinene	3.4	1.2	1.2
955	952	Camphene	**9.8**	4.1	**17.0**
978	974	Sabinene	0.3	-	0.3
982	979	β-Pinene	1.1	1.0	0.6
993	991	β-Myrcene	0.6	0.3	2.4
1003	1001	2-Carene	0.1	-	-
1007	1005	α-Phellandrene	0.5	0.1	0.4
1015	1011	3-Carene	**16.6**	0.4	0.1
1021	1017	α-Terpinene	0.2	-	0.1
1029	1025	*p*-Cymene	4.1	0.1	0.6
1033	1030	Limonene	1.7	0.5	2.0
1037	1032	1,8-Cineole	0.1	0.1	**7.2**
1042	1038	*(Z)*-β-Ocimene	1.2	0.1	0.8
1052	1049	*(E)*-β-Ocimene	1.0	-	0.1
1064	1060	γ-Terpinene	**7.3**	0.1	0.1
1071	1070	*cis*-Sabinene hydrate	0.1	-	-
1091	1088	Terpinolene	0.4	-	0.1
1092	1096	Fenchone	-	0.2	-
1094	1092	2-Nonanone	0.1	-	-
1100	1099	Linalool	0.3	0.1	0.2
1133	1131	*neo-allo*-Ocimene	0.5	-	0.2
1140	1144	*trans*-Verbenol	0.3	-	-
1150	1145	Camphor	**5.9**	1.6	**6.0**
1153	1148	Camphene hydrate	-	-	0.8
1161	1157	Isoborneol	0.1	0.4	0.1
1170	1167	*endo*-Borneol	0.2	4.7	0.6
1181	1177	Terpinen-4-ol	0.4	0.1	0.3
1193	1189	α-Terpineol	0.1	-	0.3
1198	1195	Myrtenol	-	0.1	-
1224	1223	Fenchyl acetate	0.1	-	-
1245	1240	*cis*-Citral	0.1	-	-
1248	1242	Carvone	-	-	0.1
1274	1270	*trans*-Citral	0.1	-	-
1289	1285	Bornyl acetate	0.2	0.4	0.1
1302	1299	Carvacrol	0.1	-	-
1334	1327	Myrtenyl acetate	-	0.5	-
1342	1338	δ-Elemene	-	-	0.5
1354	1351	α-Cubebene	0.1	-	-
1371	1368	Cyclosativene	0.2	-	-
1380	1376	α-Copaene	**7.4**	-	0.1
1392	1391	7-*epi*-Sesquithujene	-	0.3	-
1393	1389	β-Cubebene	0.1	-	-
1394	1391	β-Elemene	0.1	0.1	3.5
1402	1399	Cyperene	-	0.1	-
1408	1402	Sesquithujene	0.1	1.2	-
1418	1415	*cis*-α-Bergamotene	0.1	0.7	-
1424	1419	*(E)*-β-Caryophyllene	4.5	1.2	0.8
1433	1432	β-Copaene	-	-	0.1
1438	1433	γ-Elemene	-	-	1.8
1440	1435	*trans*-α-Bergamotene	0.1	0.1	-
1448	1447	Selina-5,11-diene	-	0.1	-
1453	1440	Aromandendrene	-	-	0.1
1459	1454	α-Humulene	2.9	-	-
1460	1457	*(E)*-β-Farnesene	-	2.3	**13.6**
1466	1461	Aromadendrene	3.4	-	0.1

(Continued)

Table 1. Continued.

$RI_{(Exp.)}$	$RI_{(Lit.)}$	Constituents	*Curcuma rhabdota*	*Curcuma thorelii*	*Curcuma petiolata*
1480	1477	γ-Muurolene	1.3	-	0.1
1483	1480	γ-Curcumene	-	1.0	-
1485	1481	Germacrene D	-	-	1.3
1486	1483	α-Curcumene	2.0	**8.9**	-
1490	1486	β-Eudesmene	0.1	-	0.2
1496	1495	α-Zingiberene	-	0.6	-
1497	1493	*epi*-Cubebol	0.7	-	-
1498	1494	α-Selinene	-	-	0.4
1503	1499	α-Muurolene	0.1	-	-
1511	1509	β-Bisabolene	0.1	0.2	-
1516	1514	β-Curcumene	**5.7**	**20.7**	-
1519	1515	Cubebol	1.3	-	-
1527	1524	β-Sesquiphellandrene	-	0.3	-
1528	1524	Cadina-1(10),4-diene	0.9	-	0.1
1534	1527	α-Panasinsen	-	-	0.1
1537	1532	Cubenene	0.1	-	-
1547	1543	*cis*-Sesquisabinene hydrate	-	0.1	-
1554	1549	Elemol	0.1	-	-
1562	1557	Germacrene B	-	-	0.2
1567	1564	*(E)*-Nerolidol	-	0.1	-
1588	1581	Caryophyllene oxide	3.1	0.6	0.1
1591	1585	*epi*-Globulol	-	-	0.3
1603	1593	(*Z*)-β-Elemenone	-	-	1.6
1609	1597	*(E)*-β-Elemenone	-	0.4	**16.8**
1614	1606	Humulene epoxide II	2.8	-	-
1633	1631	Ledene oxide-(II)	-	-	1.0
1641	1637	Caryophylladienol II	-	0.1	-
1646	1642	τ-Cadinol	0.2	-	-
1651	1645	δ-Cadinol	0.1	-	-
1658	1653	α-Eudesmol	0.1	-	-
1667	1675	Ylangenal	0.6	-	-
1673	1671	β-Bisabolol	-	1.4	-
1687	1684	α-Bisabolol	-	0.3	-
1689	1695	Germacra-4(15),5,10(14)-trien-1β-ol	0.1	-	-
1699	1693	Germacrone	-	0.1	**8.9**
1759	1753	Xanthorrhizol	-	**40.7**	-
1804	1809	Ambrial	-	0.1	-
1844	1844	Curcumenone	-	0.1	0.6
		Monoterpene hydrocarbons	50.4	8.0	27.6
		Oxygenated monoterpenes	8.1	8.2	15.7
		Sesquiterpene hydrocarbons	29.3	37.8	23.0
		Oxygenated sesquiterpenes	9.1	44.0	29.3
		Others	0.2	-	-
		Total	97.1	98.0	95.6

Abbreviations. RI(Exp.): retention indices on HP-5MS ultra inert column; RI(Lit.): retention indices in literature (NIST 17 and Adams[23]); content (%) in "Bold" denotes major compounds (> 5%); EO: essential oil.

activities of *C. thorelii, C. petiolata*, and *C. rhabdota* were markedly pronounced. The MIC value of the EO from *Euphorbia helioscopia* against *S. aureus, E. faecalis,* and *E. coli* was 31.25 μg/mL.[31] In another study, the EO from *Meistera sudae* Šída f. & Škorničk leaf, a Vietnamese Zingiberaceae species, inhibited *Bacillus subtilis* and *S. aureus*, with the same MIC value of 25 μg/mL.[32] In recent research, EOs from the leaves of *Fokienia hodginsii* and *Amentotaxus argotaenia* strongly inhibited *E. faecalis* and *B. cereus*, with MIC values ranging from 32 to 64 μg/mL.[33]

For anti-yeast activity, the EO samples also showed moderate to strong effects against *Candida albicans*. Specifically, the strongest yeast inhibitory effect was found for *C. thorelii* rhizome EO (MIC = 2 μg/mL), followed by *C. petiolata* and *C. rhabdota* rhizome EOs, with a MIC value of 16 μg/mL.

This finding might be valuable because many EOs are known to inhibit significantly the cell wall of only Gram-positive bacteria.[34] Akarchariya et al demonstrated that EOs from other *Curcuma* rhizomes, such as *Curcuma aeruginosa,*

Table 2. Antimicrobial Activity of EOs From the Rhizomes of Three Curcuma Species.

Microbial strains		Minimum inhibitory concentration (MIC: μg/mL)					
		Curcuma rhabdota	*Curcuma thorelii*	*Curcuma petiolata*	Kanamycin	Tetracycline	Cycloheximide
Gram (+)	*Enterococcus faecalis* ATCC29212	16	2	8	128	4	-
	Staphylococcus aureus ATCC25923	16	2	16	4	16	-
	Bacillus cereus ATCC14579	16	2	16	8	64	-
Gram (-)	*Escherichia coli* ATCC25922	32	2	16	128	8	-
	Pseudomonas aeruginosa ATCC27853	128	128	128	64	256	-
	Salmonella enterica ATCC13076	32	8	16	16	64	-
Yeast	*Candida albicans* ATCC10231	16	2	16	-	-	32

Abbreviation. EO: essential oil.

Curcuma glans, and *Curcuma* cf. *xanthorrhiza*, also exhibited good antibacterial activities.[35] The antimicrobial and other bioactivities of the *Curcuma* genus have been summarized recently.[9]

In a previous study, β-curcumene was identified as a characteristic chemical component of the EOs of the *Curcuma* genus, along with other sesquiterpenes, such as *ar*-turmerone, α-curcumene, and xanthorrhizol.[9] To date, there have been limited studies on the bioactivities of β-curcumene. However, the EO of *C. thorelii* rhizomes displayed potential antimicrobial activities and β-curcumene formed 20.7% of the total content, which suggested that the olefinic sesquiterpene might possess promising antimicrobial activities. Xanthorrhizol, a bisabolene-type aromatic sesquiterpene, is the most abundant compound in the EO of *C. xanthorrhiza*. Recently, xanthorrhizol has become a compound of interest in the pharmacological field, in terms of anti-cancer and antimicrobial activities. The aromatic sesquiterpene exhibited strong antimicrobial effects against *S. aureus*, *E. coli*, and *Propionibacterium acnes*, which explained the strong antimicrobial effects of *C. thorelii* rhizome EO, which contained more than 40% of xanthorrhizol.[36] Xanthorrhizol was also shown to have potential anticancer properties with inhibitory effects on various cancer cells. Xanthorrhizol also exhibited synergistic effects with curcumin and tamoxifen on cancer cell growth inhibition.[37,38] 3-Carene is a bicyclic monoterpene, which can be commonly found in *Pinus* and pepper volatile oils. The compound had strong antibacterial activity against *Brochothrix thermosphacta* and *Pseudomonas fluorescens* by damaging cellular membranes, disrupting DNA structure, and interfering with cellular functions.[39] Camphene is a volatile compound commonly found in various aromatic plants, including *Thymus*, *Origanum*, and *Salvia* genera. Camphene was found to exhibit antimicrobial activities against various bacterial and fungal strains. This bicyclic monoterpene was also studied for other pharmacological activities, including antiviral, anti-leishmanial, anti-inflammatory, anti-diabetic, hypolipidemic, and anti-cancer activities.[40] In particular, previous studies demonstrated that 1,8-cineole has antinociceptive, vasodilator, bronchodilator, anti-inflammatory, hepatoprotective, gastroprotective, antibacterial, antimycotic, and antitumorigenic activities.[41] Camphor can be a promising agent for potential antibacterial, antifungal, analgesic, anti-inflammatory, and antioxidant activities.[42] Currently, further studies are needed on these herbs because of their antimicrobial and other biological effects. Based on that scientific basis, the orientation continues for the rational exploitation and use as well as the development of new functional foods and new drugs.

Materials and Methods

Plant Materials

The fresh rhizomes of *C. rhabdota* Sirirugsa & M.F.Newman and *C. petiolata* Roxb were collected from Phuoc Vinh Forest, Chau Thanh District, Tay Ninh Province, Vietnam in July 2021, while the fresh rhizomes of *C. thorelii* Gagnep were taken from Suoi Kiet Commune, Tanh Linh District, Binh Thuan Province, Vietnam in August 2022. The plants were identified by Dr Dang Van-Son (Institute of Tropical Biology, Vietnam Academy of Science and Technology) and Dr Nguyen Danh-Duc (Institute of Applied Technology, Thu Dau Mot University). Voucher specimens HC-008 (*C. rhabdota*), HC-009 (*C. petiolata*), and NDD-236 (*C. thorelii*) were deposited at the herbarium of the Institute of Applied Technology, Thu Dau Mot University, Binh Duong Province, Vietnam.

Isolation of the EOs

Five hundred grams of each sample was washed, pulverized, and distilled using a Clevenger apparatus until the amount of obtained EO was constant. After that, anhydrous sodium sulfate (Na_2SO_4) was used to completely remove all traces of

water. Experiments were performed in triplicate. Finally, the EOs were stored in a refrigerator at 4°C for later analysis of chemical composition and biological activity.

Chemical Characterization of the EOs

GC-MS analysis was performed on an Agilent 7890B GC System equipped with a 5977B MSD model. The GC column was an HP-5MS Ultral Inert (30 m × 0.25 mm, thin film of 0.25 μm). The injection volume (dissolved with a ratio of 1/100, v/v, *n*-hexane, Merck) was 1 μL using a splitting mode (1:25). The carrier gas was helium with a flow rate of 2.0 mL/min and a column head pressure of 8.2 psi. The inlet-F temperature was 300°C, the MS Quad temperature 50°C, the Aux-2 temperature 300°C, and the MS source 230°C. The GC oven temperature was kept at 60°C for 1 min and increased to 240°C at a rate of 4°C/min and kept constant at 240°C for 4 min. The MS scanned were obtained by electronic impact at 70 eV with automatic scanning in the range of 50-550 amu at 2 scans per second. The volatile constituents were identified by comparison of their mass spectra and retention indices (RI) with the literature (NIST 17 and Adams).[23] MassHunter Workstation Software was used to handle mass spectra and chromatography analysis. Finally, the content of each compound was quantified by dividing their respective peak areas by the sum of all the EO components' peak areas and multiplying the result by 100.

Antimicrobial Activity Assay

The rhizome EOs of *C. rhabdota*, *C. thorelii*, and *C. petiolata* were analyzed for antimicrobial activity using Gram-positive bacteria namely, *E. faecalis* ATCC29212, *S. aureus* ATCC2592, and *B. cereus* ATCC14579; Gram-negative bacteria, namely *E. coli* ATCC25922, *P. aeruginosa* ATCC27853, and *S. enterica* ATCC13076; and a yeast strain, namely *C. albicans* ATCC10231. All of them were purchased from the National Institute for Food Control (Hanoi, Vietnam).

The rhizome EOs of *C. rhabdota*, *C. thorelii*, and *C. petiolata* were dissolved in 10% DMSO (dimethyl sulfoxide) in a decreasing concentration range (μg/mL): 256, 128, 64, 32, 16, 8, 4, and 2; the experiment was conducted in triplicate. Fifty microliter of microbial culture, standardized at a concentration of 2×10^5 CFU/mL, was shaken at 120 r/min, and then incubated at 37 °C for 24 h. MIC values were determined as the lowest concentration of each of the EOs which completely inhibited (97%-100%) the growth of the microorganisms and were accurately determined based on turbidity measurement using a BioTek Epoch spectrophotometer (USA) and RawData software. Kanamycin, tetracycline, and cycloheximide were used as the antibacterial and antifungal standards.[43]

Conclusions

For the first time, the antimicrobial activity of rhizome EOs of *C. rhabdota* and *C. petiolata*, as well as the chemical constituents and antimicrobial activity of the rhizome EO extracted from *C. thorelii* were reported. The analysis results showed that *C. rhabdota* consisted mainly of monoterpenes while *C. thorelii* and *C. petiolata* were composed of sesquiterpenes. All three EOs showed strong antimicrobial activity against the investigated strains. Therefore, the results of this investigation may hold promise for food, pharmaceutical, and other industrial applications. Finally, the isolation and identification of nonvolatile compounds and their bioactivities from these species could be carried out in the near future.

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Supplemental Material

Supplemental material for this article is available online.

References

1. Leong-Škorničková J, Newman M. *Gingers of Cambodia, Laos & Vietnam*. Singapore Botanic Gardens, National Parks Board Singapore; 2015.
2. Leong-Škorničková J, Lý N-S, Nguyễn QB. *Curcuma arida* and *C. sahuynhensis*, two new species from subgenus *Ecomata* (Zingiberaceae) from Vietnam. *Phytotaxa*. 2015;192(3):181-189. doi: 10.11646/phytotaxa.192.3.4
3. Cuong NM, Van DT, Son NT, et al. Inhibitory effects of novel diarylheptanoids and other constituents of the rhizomes of *Curcuma singularis* on the catalytic activity of soluble epoxide hydrolase. *Bull Korean Chem Soc*. 2017;38(1):112-115. doi: 10.1002/bkcs.11033
4. Chuakul W, Boonpleng A. Ethnomedical uses of Thai Zingiberaceous plant (1). *Thai J Phytopharm*. 2003;10(1):33-39.
5. Basak S, Sarma GC, Rangan L. Ethnomedical uses of Zingiberaceous plants of Northeast India. *J Ethnopharmacol*. 2010;132(1):286-296. doi: 10.1016/j.jep.2010.08.032
6. Haddad M, Sauvain M, Deharo E. *Curcuma* as a parasiticidal agent: a review. *Planta Med*. 2011;77(06):672-678. doi: 10.1055/s-0030-1250549
7. Rajkumari S, Sanatombi K. Nutritional value, phytochemical composition, and biological activities of edible *Curcuma* species: a

review. *Int J Food Prop*. 2017;20(suppl3):S2668-S2687. doi: 10.1080/10942912.2017.1387556

8. Yuandani JI, Rohani AS, Sumantri IB. Immunomodulatory effects and mechanisms of *Curcuma* species and their bioactive compounds: a review. *Front Pharmacol*. 2021;12:643119. doi: 10.3389/fphar.2021.643119
9. Dosoky NS, Setzer WN. Chemical composition and biological activities of essential oils of *Curcuma* species. *Nutrients*. 2018;10(9):1196. doi: 10.3390/nu10091196
10. Itokawa H, Shi Q, Akiyama T, Morris-Natschke SL, Lee K-H. Recent advances in the investigation of curcuminoids. *Chin Med*. 2008;3(1):1-13. doi: 10.1186/1749-8546-3-11
11. George M, Britto SJ, Arulappan MT, Marandi R, Kindo I. Phytochemical, antioxidant and antibacterial studies on the essential oil of the rhizome of *Curcuma amada* Roxb. *Int J Curr Res*. 2015;7(7):18098-18104.
12. Gounder DK, Lingamallu J. Comparison of chemical composition and antioxidant potential of volatile oil from fresh, dried and cured turmeric (*Curcuma longa*) rhizomes. *Ind Crops Prod*. 2012;38:124-131. doi: 10.1016/j.indcrop.2012.01.014
13. George M, Britto SJ. Phytochemical and antioxidant studies on the essential oil of the rhizome of *Curcuma aeruginosa* Roxb. *Int Res J Pharm*. 2015;6(8):573-579. doi: 10.7897/2230-8407.068113
14. Liju VB, Jeena K, Kuttan R. An evaluation of antioxidant, anti-inflammatory, and antinociceptive activities of essential oil from *Curcuma longa*. L. *Indian J Pharmacol*. 2011;43(5):526. doi: 10.4103/0253-7613.84961
15. Sam LN, Huong LT, Minh PN, et al. *JJoEOBP*. Chemical composition and antimicrobial activity of the rhizome essential oil of *Curcuma sahuynhensis* from Vietnam. *J Essent Oil-Bear Plants*. 2020;23(4):803-809. doi: 10.1080/0972060X.2020.1821789
16. Xiang H, Zhang L, Yang Z, Chen F, Zheng X, Liu X. Chemical compositions, antioxidative, antimicrobial, anti-inflammatory and antitumor activities of *Curcuma aromatica* Salisb. essential oils. *Ind Crops Prod*. 2017;108:6-16. doi: 10.1016/j.indcrop.2017.05.058
17. Choochote W, Chaiyasit D, Kanjanapothi D, et al. Chemical composition and anti-mosquito potential of rhizome extract and volatile oil derived from *Curcuma aromatica* against *Aedes aegypti* (Diptera: culicidae). *J Vector Ecol*. 2005;30(2):302.
18. Liu ZL, Zhao NN, Liu CM, Zhou L, Du SS. Identification of insecticidal constituents of the essential oil of *Curcuma wenyujin* rhizomes active against *Liposcelis bostrychophila* Badonnel. *Molecules*. 2012;17(10):12049-12060. doi: 10.3390/molecules171012049
19. Singh G, Maurya S, Catalan CAN, Perotti ME. Chemical, antifungal, insecticidal and antioxidant studies on *Curcuma longa* essential oil and its oleoresin. *Indian Perfumer*. 2005;49(4):441-451.
20. Essien EE, Newby JS, Walker TM, Setzer WN, Ekundayo O. Chemotaxonomic characterization and *in-vitro* antimicrobial and cytotoxic activities of the leaf essential oil of *Curcuma longa* grown in southern Nigeria. *Medicines*. 2015;2(4):340-349. doi: 10.3390/medicines2040340
21. Ammon HP, Wahl MA. Pharmacology of *Curcuma longa*. *Planta Med*. 1991;57(1):1-7. doi: 10.1055/s-2006-960004
22. Prakash L, Satyan KS, Majeed S. Multifunctional ingredients: the novel face of natural. *Cosmetics & Toiletries*. 2003;118(11):41-47.
23. Adams RP. *Identification of essential oil components by gas chromatography/quadrupolemass spectrometry*. Allured Publishing; 2007.
24. Theanphong O, Jenjittikul T, Mingvanish W. The rhizome oil of *Curcuma rhabdota* Sirirugsa & MF Newman from Thailand. In Plant science: International proceedings; The 2nd international conference on advanced pharmaceutical research strategies and innovation in pharmaceutical research: Safety, efficacy and quality; March 2015; Thailand.
25. Theanphong O, Jenjittikul T, Mingvanish W. Essential oils composition of nine *Curcuma* species from Thailand: a chemotaxonomic approach. *Gard Bull*. 2019;71(2):499-518.
26. Theanphong O, Mingvanish W, Jenjittiku T. In vitro antioxidant activity of essential oil from *Curcuma petiolata* Roxb. rhizomes. *Interprof J Health Sci*. 2021;19(1):9-15.
27. Thakam A, Saewan N. Chemical composition of essential oil and antioxidant activities of *Curcuma petiolata* Roxb. rhizomes. *Adv Mater Res*. 2012;506:393-396. doi: 10.4028/www.scientific.net/AMR.506.393
28. Mary HPA, Susheela GK, Jayasree S, Nizzy AM, Rajagopal B, Jeeva S. Phytochemical characterization and antimicrobial activity of *Curcuma xanthorrhiza* Roxb. *Asian Pac J Trop Biomed*. 2012;2(2, Supplement):S637-S640. doi: 10.1016/S2221-1691(12)60288-3
29. Dosoky NS, Satyal P, Setzer WN. Variations in the volatile compositions of *Curcuma* species. *Foods*. 2019;8(2):53. doi: 10.3390/foods8020053
30. Srivastava AK, Srivastava SK, Shah NC. Constituents of the rhizome essential oil of *Curcuma amada* Roxb. from India. *J Essent Oil Res*. 2001;13(1):63-64. doi: 10.1080/10412905.2001.9699608
31. Zhu Q, Jiang M-L, Shao F, Ma G-Q, Shi Q, Liu R-H. Chemical composition and antimicrobial activity of the essential oil from *Euphorbia helioscopia* L. *Nat Prod Commun*. 2020;15(9):1934578X-20953249. doi: 10.1177/1934578X20953249
32. Huong LT, Son T, Sam N, et al. Chemical compositions and antimicrobial activity of essential oils from the leaves of 4 Vietnamese Zingiberaceae species. *Nat Prod Commun*. 2022;17(12):1934578X-221145917. doi: 10.1177/1934578X221145917
33. Thanh NT, Xuyen DT, Thuy LT, Huong LT, Dai DN, Ogunwande IA. Essential oils from the leaves of *Fokienia hodginsii* (Dunn) A. Henry & H. H. Thomas and *Amentotaxus argotaenia* (Hance) Pilg. and their antimicrobial activity. *J Essent Oil-Bear Plants*. 2023:1-9. doi: 10.1080/0972060X.2022.2159543
34. Chouhan S, Sharma K, Guleria S. Antimicrobial activity of some essential oils—present status and future perspectives. *Medicines*. 2017;4(3):58. doi: 10.3390/medicines4030058
35. Akarchariya N, Sirilun S, Julsrigival J, Chansakaowa S. Chemical profiling and antimicrobial activity of essential oil from *Curcuma aeruginosa* Roxb., *Curcuma glans* K. Larsen & J. Mood and *Curcuma cf. xanthorrhiza* Roxb. collected in Thailand. *Asian Pac J Trop Biomed*. 2017;7(10):881-885. doi: 10.1016/j.apjtb.2017.09.009
36. Oon SF, Nallappan M, Tee TT, et al. Xanthorrhizol: a review of its pharmacological activities and anticancer properties. *Cancer Cell Int*. 2015;15:100. doi: 10.1186/s12935-015-0255-4
37. Noomhorm N, Chang CJ, Wen CS, et al. *In vitro* and *in vivo* effects of xanthorrhizol on human breast cancer MCF-7 cells treated with

tamoxifen. *J Pharmacol Sci*. 2014;125(4):375-385. doi: 10.1254/jphs.14024fp

38. Cheah YH, Nordin FJ, Sarip R, et al. Combined xanthorrhizol-curcumin exhibits synergistic growth inhibitory activity via apoptosis induction in human breast cancer cells MDA-MB-231. *Cancer Cell Int*. 2009;9(1):1. doi: 10.1186/1475-2867-9-1
39. Shu H, Chen H, Wang X, et al. Antimicrobial activity and proposed action mechanism of 3-carene against *Brochothrix thermosphacta* and *Pseudomonas fluorescens*. *Molecules*. 2019;24(18):3246. doi: 10.3390/molecules24183246
40. Hachlafi NEL, Aanniz T, Menyiy NE, et al. *In vitro* and *in vivo* biological investigations of camphene and its mechanism insights: a review. *Food Rev Int*. 2021:1-28. doi: 10.1080/87559129.2021.1936007
41. Patra JK, Das G, Bose S, et al. Star anise (*Illicium verum*): chemical compounds, antiviral properties, and clinical relevance. *Phytother Res*. 2020;34(6):1248-1267. doi: 10.1002/ptr.6614
42. Chaturvedi T, Kumar A, Kumar A, et al. Chemical composition, genetic diversity, antibacterial, antifungal and antioxidant activities of camphor-basil (*Ocimum kilimandscharicum* guerke). *Ind Crops Prod*. 2018;118:246-258. doi: 10.1016/j.indcrop.2018.03.050
43. Hadacek F, Greger H. Testing of antifungal natural products: methodologies, comparability of results and assay choice. *Phytochem Anal*. 2000;11(3):137-147. doi: 10.1002/(SICI)1099-1565(200005/06)11:3<137::AID-PCA514>3.0.CO;2-I