

## Chemical composition of rhizome essential oil of Ginger Lily (*Hedychium*) from the Western Ghats, India

Sinjumol Thomas<sup>1</sup> and Bince Mani<sup>2\*</sup>

<sup>1</sup>Department of Botany, Carmel College (*Autonomous*), Mala, Thrissur 680732, Affiliated to University of Calicut, Kerala, India

<sup>2</sup>Department of Botany, St. Thomas College, Palai, Kottayam 686574, Affiliated to Mahatma Gandhi University, Kerala, India

Received 20 July 2022; revised received 21 September 2023; accepted 12 October 2023

*Hedychium* species are perennial rhizomatous herbs with high-quality terpenoids. In the present study, the essential oil yield and composition from dried rhizomes of *Hedychium* taxa collected from the Western Ghats of India were evaluated. Essential oils were obtained by hydro-distillation, and the yield varied from 0.4–3.96% (v/w). The components were identified by gas chromatography, flame ionisation detector, and gas chromatography-mass spectrometry. A total of 73 components were identified among the eight taxa, and a maximum of 90.20% (31 compounds) and a minimum of 66.41% (36 compounds) of the oil constituents were identified from *Hedychium matthewii* and *Hedychium forrestii* var. *forrestii*, respectively.  $\beta$ -linalool was the major constituent in the oils of *Hedychium coronarium* (17.72%), *H. forrestii* (25.38%), *H. flavescens* (18.64%), and *H. matthewii* (48.41%).  $\beta$ -pinene was the major constituent in the oils of *H. forrestii* var. *paliense* (18.31%) and *H. flavum* (20.17%), whereas 1,8-cineole was the dominant component in *H. venustum* (25.81%) and  $\alpha$ -cadinol in *H. spicatum* (18.59). The results showed that geographic factors greatly influence the essential oil composition in *Hedychium*. Essential oil composition in *H. coronarium* and *H. spicatum* from the Western Ghats significantly differs from other geographical regions of origin. Hence, *H. coronarium* and *H. spicatum* from the Western Ghats are two chemotypes for rhizome essential oils.

**Keywords:** *Hedychium flavum*, *Hedychium forrestii*, *Hedychium spicatum*, *Hedychium coronarium*, Monoterpenes, Sesquiterpenes, Terpenoids

**IPC code; Int. cl. (2021.01)**– A61K 36/00, A61K 36/906, A61K 125/00

### Introduction

Essential oils are assemblages of volatile compounds, having a characteristic odour and density, produced by plants<sup>1-2</sup>. These molecules are derived mostly from three biosynthetic pathways, namely, the mevalonate pathway (sesquiterpenes), the methylerythritol-pathway (mono- and diterpenes), and the shikimic acid pathway (phenylpropenes). Essential oils are found in different parts of the plants, such as flowers, leaves, rhizomes, roots, seeds, fruits, wood and bark<sup>2</sup>, and several of these compounds have diverse ecological functions<sup>1</sup>. Essential oils constitute many compounds, which show tremendous variation in their composition<sup>1</sup>. They have characteristic odour, antimicrobial activity, antioxidant potential, anti-inflammatory activity, cancer chemoprotective activity, cytotoxicity, allelopathic activity, repellent and insecticidal activity, etc. Therefore, they are extensively used in perfumery, pharmaceutical and medicinal applications, health and wellness, veterinary

medicines, agriculture applications, aromatherapy, and the cosmetics industry<sup>2</sup>. Those plant species possessing an essential oil of commercial interest may be referred to as “Essential oil plants”, and they have growing demand<sup>3</sup>. Qualitative and quantitative differences in essential oil composition are often found among the populations of a species. This may be either due to genetic differences or due to environmental influences. In general, the differences due to genetic variations are often higher than those of environmental conditions. At the same time, essential oil formation greatly depends on climatic conditions, particularly irradiance, temperature, day length, water supply, and biotic factors such as symbiosis<sup>4-5</sup>.

Zingiberaceae, one of the key plant families, is a principal source of raw materials for food, medicines, spices, perfume, dyes, and aesthetics<sup>6</sup>. *Alpinia*, *Amomum*, *Costus*, *Curcuma*, *Elettaria*, *Hedychium*, *Kaempferia*, and *Zingiber* are the major economically and medicinally important genera of Zingiberaceae, which are characterised by the presence of essential oils and oleoresins<sup>7</sup>. The genus *Hedychium* comprises

\*Correspondent author  
Email: binsnm@gmail.com

more than 80 species mainly distributed in India, China, and southeast Asia<sup>8-9</sup>. As a key member of the Zingiberaceae family, it is widely used in the perfume industry, and the starch found in its rhizomes and aerial stems serves as a raw material for paper<sup>10-11</sup>. Moreover, *Hedychium* species are popular among ornamental plants because of their diverse and showy flowers, sweet fragrance, and attractive foliage<sup>12</sup>.

*Hedychium* species are one of the principal sources of various essential oil components having pharmaceutical and other industrial applications<sup>13</sup>. Essential oils extracted from *Hedychium aurantiacum*, *H. coronarium*, *H. ellipticum*, *H. forrestii* var. *palaniense* and *H. matthewii*, *H. spicatum* displayed good antimicrobial and antioxidant activity<sup>14-18</sup>. The growth of *Staphylococcus aureus* and *S. epidermidis* was inhibited by the essential oil obtained from the flower and leaf of *H. gardnerianum* *in vitro*<sup>19</sup>. Rhizome oils of *H. larsenii* inhibited the growth of Gram-positive and Gram-negative bacteria<sup>20</sup>. In a comprehensive study, Rajasekaran *et al.*<sup>21</sup> reported the antifungal activity of seventeen species of *Hedychium* volatile oils against *Aspergillus flavus* and *Fusarium verticillioides*. Miranda *et al.*,<sup>22</sup> demonstrated the inhibitory potential of leaves and rhizome oils of *H. coronarium* against the coagulant and fibrinolytic activities induced by snake venoms. Moreover, insecticidal activities of essential oils from different *Hedychium* species were analysed by Sakhanokho *et al.*<sup>13</sup>. At the same time, isolated essential oil constituents are also reported to possess various biological properties.  $\alpha$ -pinene and  $\beta$ -pinene are reported to have properties such as antidiabetic, antimicrobial, anti-acetylcholinesterase, anti-allergic, anti-inflammatory, anticoagulant, antitumor, antimalarial, antioxidant, and cytotoxicity. Linalool has various activities, including anticancer, antioxidant, antibacterial, anti-inflammatory, and insect-repellent properties. 1,8-cineole has antimicrobial, mucolytic, broncholytic, anti-inflammatory, antigenotoxic, antifungal against *Candida albicans*, and insecticidal

against *Rhodnius prolixus*. Terpinen-4-ol, T-muurolol, and limonene exhibit antibacterial and antifungal properties.  $\alpha$ -terpineol shows pharmacological effects such as anti-inflammatory, antihypertensive, antiproliferative, and cytotoxic activities, while  $\alpha$ -humulene possesses properties such as analgesic, anti-inflammatory, and antineoplastic activities<sup>23-24</sup>. Considering all the above-mentioned facts, *Hedychium* species are potential sources of natural alternatives to synthetic antibiotics, antifungals, and insecticides<sup>12</sup>.

Essential oils isolated from different populations of *Hedychium* from diverse geographical origins show variation in their essential oils composition<sup>12</sup>. As an important source of valuable essential oils, it is important to study the qualitative and quantitative variations in essential oil composition of *Hedychium* species/accessions across different geographical regions. A comprehensive study on the essential oil profiling of Western Ghats' *Hedychium* is unavailable. Earlier, there was little consensus on the number of species of *Hedychium* in the Western Ghats of India as either three or four. However, recent studies revealed the exact diversity of *Hedychium* in the Western Ghats and the number of taxa is found to be eight<sup>9,25-27</sup>. Based on these considerations, the present study examined the essential oil profile of *Hedychium* species growing in the Western Ghats of India.

## Materials and Methods

### Plant material

The rhizomes of all taxa were collected from their natural habitats in the Western Ghats during October and November 2017 (Table 1). The taxonomic identification of the species and varieties (Fig. 1) was done by the authors (Dr. Bince Mani, Department of Botany, St. Thomas College, Palai, Kottayam, Kerala and Dr. Sinjumol Thomas, Department of Botany, Carmel College, Mala, Thrissur, Kerala) and the voucher specimens (Table 1) of all the taxa are deposited at Rapinat Herbarium (RHT), St. Joseph's

Table 1 — The oil yield percentage from dried rhizomes of *Hedychium* taxa

S. No.	Name	Collection locality	Voucher No.	Average oil yield (% v/w)
1	<i>H. coronarium</i>	Munnar, Kerala	RHT65120	0.43
2	<i>H. forrestii</i> var. <i>forrestii</i>	Idukki, Kerala	RHT65146	0.76
3	<i>H. forrestii</i> var. <i>palaniense</i>	Kodaikanal, Tamilnadu	RHT65200	1.23
4	<i>H. flavescens</i>	Munnar, Kerala	RHT65134	0.40
5	<i>H. flavum</i>	Nilgiri, Tamilnadu	RHT66466	0.86
6	<i>H. venustum</i>	Vagamon, Kerala	RHT65495	3.96
7	<i>H. spicatum</i>	Munnar, Kerala	RHT65122	2.46
8	<i>H. matthewii</i>	Idukki, Kerala	RHT65615	1.63



Fig. 1 — *Hedychium* taxa present in the Western Ghats of India collected for the study. a) *H. coronarium*; b) *H. forrestii* var. *forrestii*; c) *H. forrestii* var. *palaniense*; d) *H. flavescens*; e) *H. flavum*; f) *H. venustum*; g) *H. spicatum*; and h) *H. matthewii*.

College, Tiruchirappalli, Tamil Nadu. The materials were washed thoroughly to remove adhering soil particles. The rhizomes were dried at room temperature after being cut into small pieces.

#### Essential oil extraction

The coarse powder of the dried rhizomes (25 g) was hydrodistilled for 3 hours using Clevenger apparatus. The extraction of essential oil was performed three times. Anhydrous sodium sulphate was used for removing traces of water molecules and

kept at 4°C for essential oil profiling. The essential oil yield was determined as a percentage on the dry weight basis of each sample. The weight of the sample is the most influential factor in the oil extraction process. A larger sample size facilitates higher oil recovery because more sample molecules can dissolve in the solvent, leading to a more efficient extraction process. Furthermore, drying and grinding the samples into a powder can help achieve complete oil release, resulting in enhanced oil recovery with increased sample weight<sup>28</sup>.

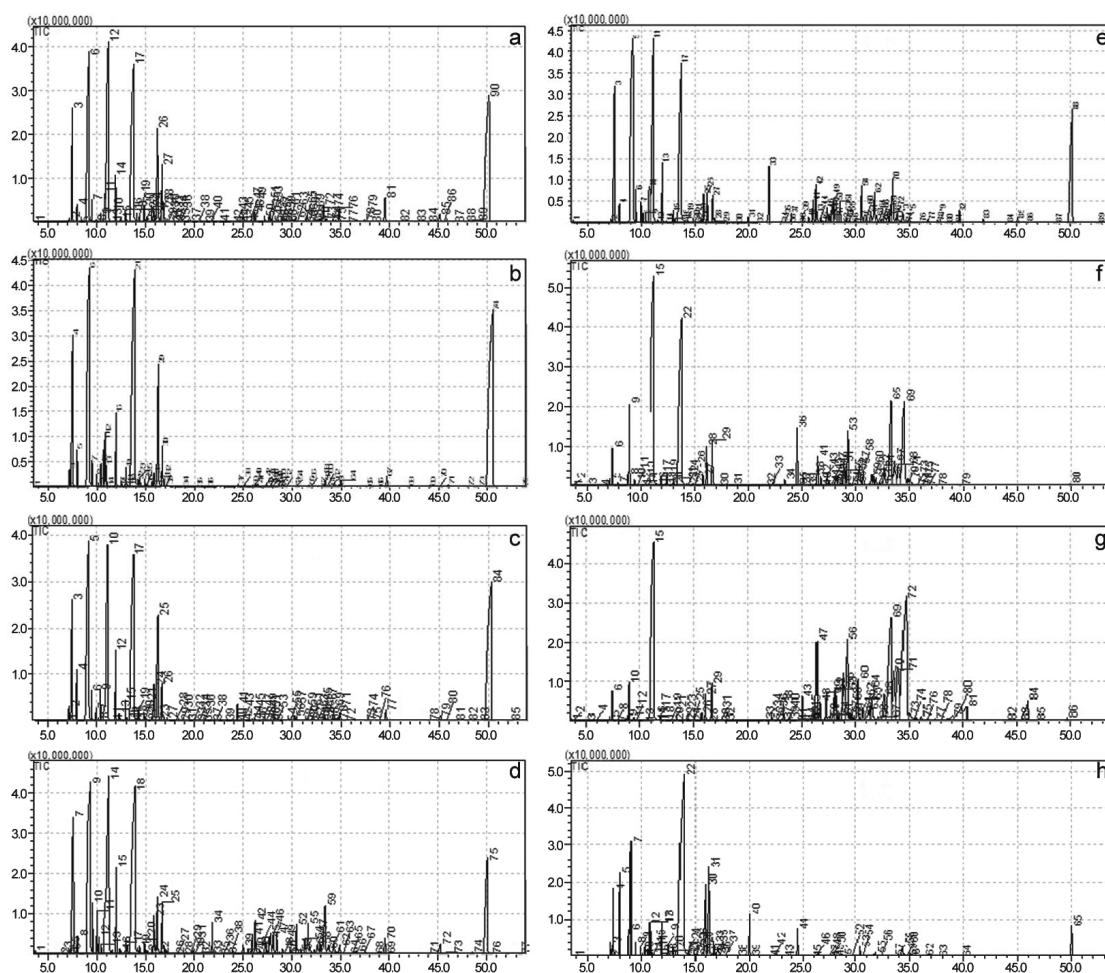


Fig. 2 — GC-MS chromatogram of essential oil, a) *H. coronarium*; b) *H. forrestii* var. *forrestii*; c) *H. forrestii* var. *palaniense*; d) *H. flavescens*; e) *H. flavum*; f) *H. venustum*; g) *H. spicatum*; and h) *H. matthewii*.

#### Characterisation and identification of essential oil constituents

GC/MS analyses were performed using Shimadzu GC-2010 gas chromatograph-flame ionisation detector (GC-FID) equipped with DB-5 column and QP 2010 mass spectrometer (MS). Approximately 0.1  $\mu$ L of essential oil sample, carried by Helium at a flow rate of 1 mL/min, was injected into gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS) analysis. Individual constituents were identified by matching their mass spectra and linear retention indices (LRI) with the library (NIST and Wiley) provided by the instrument software, online databases (<http://webbook.nist.gov/chemistry>; <http://www.flavornet.org>) and published literature<sup>29</sup>.

#### Results

The isolated essential oils were pale yellow to yellow, and the yield ranged from 0.4 to 3.96%. The highest yield was obtained from the rhizome of

*Hedychium venustum* (Table 1). Essential oils obtained from each taxon were relatively complex mixtures and recorded more than 60 area peaks per sample (Fig. 2). The oils were chiefly mixtures of monoterpenes, and sesquiterpenes and a total of 73 compounds were identified, which are given in Table 2. A large number of unknown compounds with moderately high to low percentages of occurrence were also noticed.

Among the 73 compounds identified, thirty-nine compounds were monoterpenes and thirty-four sesquiterpene compounds and accounted for 53.42 and 46.58%, respectively. The hydrocarbon and oxygenated terpene composition was 60.27 and 39.73%, respectively. However, it is remarkable that there was great variability in the composition of hydrocarbon and oxygenated terpenoids among monoterpenoids and sesquiterpenoids. The oxygenated compounds (22) accounted for the major part of the monoterpene class,

Table 2 — Chemical composition of rhizome essential oils from *Hedychium* taxa

No Compounds	RI	Molecular formula	Chemical class	Peak area %								
				<i>H. coronarium</i>	<i>H. forrestii</i>	<i>H. forrestii</i> var. <i>flavescens</i>	<i>H. flavum</i>	<i>H. venustum</i>	<i>H. spicatum</i>	<i>H. matthewii</i>		
1 $\alpha$ -thujene	924	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.14	0.52	0.49	0.14	0.16	0.17	0.07	0.53	
2 $\alpha$ -pinene	932	C <sub>10</sub> H <sub>16</sub>	Monoterpene	4.4	6.37	4.93	7.03	6.8	0.94	0.58	2.89	
3 Camphene	946	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.51	0.88	1.44	0.55	0.61	0.09	0.01	3.97	
4 $\beta$ -myrcene	958	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.47	0.48	0.62	0.94	0.72	0.18	0.11	0.45	
5 (+) Sabinene	969	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.01	—	—	—	—	0.37	0.13	1.59	
6 $\beta$ -pinene	974	C <sub>10</sub> H <sub>16</sub>	Monoterpene	16.64	19.89	18.31	18.59	20.17	2.53	0.81	7.01	
7 $\alpha$ -phellandrene	1002	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.06	0.23	0.26	0.79	0.46	—	—	0.34	
8 3-carene	1008	C <sub>10</sub> H <sub>16</sub>	Monoterpene	—	0.07	0.06	0.31	0.19	—	—	0.13	
9 $\alpha$ -terpinene	1014	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.28	—	0.77	0.28	0.25	—	—	—	
10 4-carene	1014	C <sub>10</sub> H <sub>16</sub>	Monoterpene	—	0.45	—	—	—	0.08	0.02	0.41	
11 p-Cymene	1020	C <sub>10</sub> H <sub>14</sub>	Monoterpene	0.42	1.09	—	—	2.48	0.04	—	1.33	
12 Limonene	1024	C <sub>10</sub> H <sub>16</sub>	Monoterpene	—	—	—	—	—	—	—	1.27	
13 1,8-cineole	1026	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	14.83	0.39	12.04	16.42	12.66	25.81	17.91	0.16	
14 (Z)- $\beta$ -ocimene	1032	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.01	0.01	0.05	—	0.08	0.01	—	0.03	
15 (E)- $\beta$ -ocimene	1044	C <sub>10</sub> H <sub>16</sub>	Monoterpene	—	0.01	—	—	—	—	—	0.11	
16 $\gamma$ -terpinene	1054	C <sub>10</sub> H <sub>16</sub>	Monoterpene	1.16	1.77	1.94	2.18	1.51	0.22	0.08	1.32	
17 4- thujanol	1065	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	0.13	0.03	0.24	0.24	0.04	—	0.03	0.17	
18 Linalool oxide	1067	C <sub>10</sub> H <sub>18</sub> O <sub>2</sub>	Tetrahydrofurans	—	0.12	—	—	—	0.36	—	1	
19 $\alpha$ -terpinolene	1086	C <sub>10</sub> H <sub>16</sub>	Monoterpene	0.44	0.38	0.48	0.64	0.27	—	0.02	—	
20 $\beta$ -linalool	1095	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	17.72	25.38	17.75	18.64	15.87	20.7	0.11	48.41	
21 Fenchol	1114	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	0.27	0.08	0.04	—	0.03	—	—	0.02	
22 $\alpha$ -campholenal	1122	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	0.36	—	—	—	—	—	—	—	
23 p-menth-2-en-1-ol	1118	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	—	0.22	0.28	—	—	0.04	0.22	0.27	
24 L-pinocarveol	1135	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	0.54	—	—	0.14	—	—	—	—	
25 Verbenol	1137	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	—	—	—	—	—	—	—	—	
26 L-camphor	1141	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	0.08	0.04	0.09	—	0.05	0.03	0.02	0.14	
27 Pinocarvone	1160	C <sub>10</sub> H <sub>14</sub> O	Monoterpenoid	0.46	0.12	0.08	—	0.07	—	—	0.1	
28 Borneol	1165	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	0.71	0.42	1.62	1.33	0.91	—	—	7.53	
29 L-4-terpineol	1174	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	4.68	5.41	5.45	1.74	0.95	1.4	0.65	6.67	
30 $\alpha$ - terpineol	1186	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	2.29	1.17	1.58	2.22	0.9	2.1	1.17	0.79	
31 Myrtenal	1195	C <sub>10</sub> H <sub>14</sub> O	Monoterpenoid	1.17	—	—	—	0.2	—	—	—	
32 (E) Piperitol	1207	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	—	—	—	—	—	—	—	0.27	
33 $\beta$ -citronellol	1223	C <sub>10</sub> H <sub>20</sub> O	Monoterpenoid	—	—	—	—	—	0.04	0.03	—	
34 (Z) carveol	1226	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	0.05	—	—	—	—	—	—	—	
35 Nerol	1227	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	—	0.04	—	—	0.03	—	—	—	
36 Bornyl acetate	1287	C <sub>12</sub> H <sub>20</sub> O <sub>2</sub>	Monoterpenoid	—	—	0.03	0.11	—	—	—	2.00	
37 Thymol	1289	C <sub>10</sub> H <sub>14</sub> O	Monoterpenoid	—	—	—	0.12	—	—	—	0.11	
38 Perillol	1295	C <sub>10</sub> H <sub>16</sub> O	Monoterpenoid	—	0.02	—	—	—	—	—	—	
39 $\delta$ -elemene	1335	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.07	—	0.04	0.78	2.06	—	—	—	
40 $\alpha$ -cubebene	1345	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	0.04	—	0.09	0.19	—	
41 $\alpha$ -terpineol	1346	C <sub>10</sub> H <sub>18</sub> O	Monoterpenoid	0.22	—	0.19	—	—	—	—	0.79	
42 Copaene	1374	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	0.06	0.05	0.21	0.46	—	
43 $\beta$ -cubene	1387	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	0.23	—	0.04	—	
44 $\beta$ -elemene	1389	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.02	—	—	0.36	0.3	0.1	0.11	—	
45 $\alpha$ -gurjunene	1409	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	0.79	1.35	—	—	—	
46 $\alpha$ -cedrene	1410	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	0.17	—	—	—	—	0.1	
47 $\beta$ -caryophyllene	1417	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.11	0.13	—	—	0.48	0.74	—	
48 $\gamma$ -elemene	1434	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.02	—	—	—	1.49	—	—	—	
49 Alloaromadendrene	1458	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.08	—	0.23	0.17	0.43	0.69	—	
50 Aromadendrene	1439	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.06	—	—	—	—	—	—	

(Contd.)

Table 2 — Chemical composition of rhizome essential oils from *Hedychium* taxa

No Compounds	RI	Molecular formula	Chemical class	Peak area	No Compounds			RI	Molecular formula	Chemical class	Peak area	No
				%	<i>H. coronarium</i>	<i>H. forrestii</i>	<i>H. forrestii</i> var. <i>palaniense</i>	<i>H. flavescens</i>	<i>H. flavum</i>	<i>H. venustum</i>	<i>H. spicatum</i>	<i>H. matthewii</i>
51 β-farnesene	1440	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	—	—	—	3.43	—
52 α-caryophyllene	1452	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.14	—	—	—	—	1.37	—	—
53 Epi – bicyclo-sesquiphellandrene	1465	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	—	—	0.14	—	—
54 γ-muuroleone	1478	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.03	—	—	—	—	0.59	1.06	—
55 Germacrene D	1484	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	0.17	—	—	0.32	—	—	—
56 β-selinene	1489	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.22	—	—	—	—	0.69	0.1	—	—
57 Valencene	1496	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	—	0.05	—	—	—
58 α-selinene	1498	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.27	0.05	—	—	—	—	—	—	—
59 α-muuroleone	1500	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	—	—	0.52	1	—
60 β-Bisabolene	1505	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.05	0.04	—	—	—	—	—	—
61 γ-cadinene	1513	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.01	—	—	—	—	—	1.05	—	—
62 β-sesquiphellandrene	1521	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	0.1	—	—	—	—	—	0.29
63 δ-cadinene	1522	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	0.04	0.08	—	0.63	0.81	2.82	4.82	—	—
64 α-cadinene	1526	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	—	—	—	0.8	0.2	—	—	—
65 Germacrene B	1532	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.05	—	1.16	0.18	—	—	—	—
66 β-cadinene	1536	C <sub>15</sub> H <sub>24</sub>	Sesquiterpene	—	0.09	—	—	—	—	—	—	—
67 (E) Nerolidol	1561	C <sub>15</sub> H <sub>26</sub> O	Sesquiterpenoid	—	—	—	—	—	0.84	0.61	—	—
68 Germacrene D-4-ol	1574	C <sub>15</sub> H <sub>26</sub> O	Sesquiterpenoid	—	—	—	—	—	—	0.82	—	—
69 Spathulenol	1577	C <sub>15</sub> H <sub>24</sub> O	Sesquiterpenoid	—	—	—	0.59	0.44	0.84	0.65	—	—
70 Caryophyllene oxide	1582	C <sub>15</sub> H <sub>24</sub> O	Sesquiterpenoid	—	—	0.05	—	—	0.55	1.14	—	—
71 Ledol	1602	C <sub>15</sub> H <sub>26</sub> O	Sesquiterpenoid	—	—	—	—	0.16	—	—	—	—
72 10-epi-γ-eudesmol	1622	C <sub>15</sub> H <sub>26</sub> O	Sesquiterpenoid	—	—	—	—	—	7.21	0.26	—	—
73 α-cadinol	1652	C <sub>15</sub> H <sub>26</sub> O	Sesquiterpenoid	—	—	—	0.62	—	—	18.59	—	—
Total number of compounds				90	75	85	77	90	80	86	65	
Number of compounds identified				33 (68.70%)	36 (66.41%)	30 (69.44%)	29 (77.67%)	40 (74.74%)	37 (72.65%)	34 (56.58%)	31 (90.20%)	
Monoterpene hydrocarbons (%)				39.39	38.88	40	34.48	32.50	27.03	26.47	48.39	
Oxygenated monoterpenes (%)				39.39	33.33	36.67	31.03	25	24.32	23.53	45.16	
Sesquiterpene hydrocarbons (%)				21.22	27.79	20	27.59	35	37.84	26.47	6.45	
Oxygenated sesquiterpenes (%)				0	0	3.33	6.90	7.50	10.81	23.53	0	

whereas hydrocarbon terpenes were the major constituents (27) in sesquiterpenes. The essential oil components of the highest concentration were monoterpenes such as α-pinene, β-pinene, 1, 8-cineole, and β-linalool. Sesquiterpenes such as 10-epi-γ-eudesmol and α-cadinol were present in considerable amounts in the essential oils of a few taxa.

## Discussion

The essential oil yield was found to be high in *Hedychium* taxa from the Western Ghats of India as compared to previous studies in *Hedychium* using both

fresh and dried rhizomes<sup>18,21,30</sup>. The essential oils of *Hedychium coronarium*, a widely distributed species, contain major compounds such as β-linalool, β-pinene, and 1, 8-cineole in approximately equal percentages. The present study is in agreement with the previous studies on the rhizome essential oil profile of *H. coronarium* collected from Western Ghats<sup>30,31</sup>. However, the concentration of major compounds differs quantitatively. In contrast, various other studies reported that the composition of rhizome oils of *H. coronarium* from other geographical regions differs both qualitatively and quantitatively<sup>12,18,22,32-39</sup>.

Essential oils of *H. forrestii* var. *forrestii* contain  $\beta$ -linalool (25.38%) and  $\beta$ -pinene (19.89%) as major constituents. Previous studies stated linalool as the major compound in *H. forrestii*<sup>13</sup>. On the other hand, essential oils of *H. forrestii* var. *palaniense* were dominated by  $\beta$ -pinene (18.31%),  $\beta$ -linalool (17.75%) and 1, 8-cineole (12.04%). Conversely, the latter compound was found in least quantity (0.39%) in *H. forrestii* var. *forrestii*. An ample quantity of  $\alpha$ -pinene and L-4-terpineneol was also noted in both taxa (Table 2).

$\beta$ -pinene,  $\beta$ -linalool, and 1, 8-cineole were the major constituents in the EOs of *H. flavescens* and *H. flavum*. Similar results were reported in *H. flavescens* collected from Western Ghats<sup>30</sup>, Mauritius<sup>34</sup> and Thailand<sup>40</sup> and *H. flavum* collected from Vietnam<sup>39</sup>.

$\beta$ -linalool, Borneol,  $\beta$ -pinene, and L-4-terpineneol were the components in the essential oils of *H. matthewii*, another endemic species of the Western Ghats. Components such as  $\alpha$ -pinene, camphene, and bornyl acetate were also in sufficient quantities. The essential oil composition of rhizome oil and its biological properties were reported recently<sup>17</sup>.

Terpenoids such as 1,8-cineole,  $\beta$ -linalool and 10-epi- $\gamma$ - eudesmol were the major constituents in the rhizome oil of *H. venustum*, a Western Ghats endemic.  $\beta$ -pinene,  $\alpha$ - terpineol and  $\delta$ -cadinene were also present in notable quantities. The results of the present study are comparable to those of the earlier work<sup>30</sup>.  $\alpha$ -cadinol was the major constituent in the EO of *H. spicatum*, followed by 1, 8-cineole. Prakash *et al.*<sup>36</sup>, reported that 1, 8-cineole and  $\alpha$ -eudesmol were the major constituents in the rhizome oils of *H. spicatum* collected from Nainital. Several other works also reported 1, 8-cineole as the major constituents in the rhizome oils of *H. spicatum* collected from different parts of the Himalayan range. Comparing the results of the present study with that of the latter shows that both qualitative and quantitative differences are detected in the EO composition in the rhizome oil of *H. spicatum* in the Western Ghats and Himalaya<sup>15,32,41-42</sup>.

The present study conducted research on the chemical composition of rhizome essential oils in various species of *Hedychium*, a flowering plant. The findings of the study revealed significant differences in the chemical composition of these essential oils among different species of *Hedychium*, as well as among similar species that were growing in different parts of the world.

One of the key findings of the study was that the essential oils extracted from the rhizomes of

*H. coronarium* and *H. spicatum* from various regions around the world had distinct variations in their main components, both in terms of quality and quantity. This suggests that the geographical location and environmental conditions have a significant impact on the chemical makeup of these essential oils. Interestingly, the study also identified new chemotypic forms of *H. coronarium* and *H. spicatum* in the Western Ghats of India, highlighting the diversity within these species. Furthermore, the study noted similarities in the volatile fractions of rhizome essential oils among *H. flavescens*, *H. flavum*, and *H. forrestii* var. *forrestii* collected from the Western Ghats compared to other geographical regions. This suggests that some species or varieties of *Hedychium* may maintain consistent chemical profiles across different locations. One intriguing finding was the difference in the volatile fraction composition of *H. forrestii* var. *palaniense* compared to *H. forrestii* var. *forrestii*. This distinction raises questions about the factors contributing to these variations, such as genetic differences or environmental influences. Additionally, the study provided insight into the essential oil composition of endemic species found in the Western Ghats, including *H. forrestii* var. *palaniense*, *H. venustum*, and *H. matthewii*. This information is valuable for conservation efforts and potential applications in various industries. Lastly, the study highlighted that the essential oil yields obtained from natural populations of *Hedychium* species analysed in the research were more promising than previous studies, indicating the potential for these plants as a valuable source of essential oils.

## Conclusion

The study on the chemical composition of rhizome essential oils in various species of *Hedychium* from the Western Ghats revealed significant differences among different species and variations in essential oil components within similar species across different regions. Geographical location and environmental conditions were found to have a significant impact on the chemical makeup of these essential oils. The study also provided valuable information about previously undiscovered chemotypic forms of *H. coronarium* and *H. spicatum* were identified in the Western Ghats of India, showcasing the diversity within these species. Additionally, the research provided insights into the essential oil composition of endemic species in the Western Ghats, which can be valuable for conservation and potential industrial applications.

Lastly, the study indicated that the essential oil yields from natural populations of *Hedychium* species were promising, suggesting their potential as a valuable source of essential oils with ethnobotanical, commercial and ecological significance.

### Acknowledgement

The authors are thankful to the Indian Institute of Spices Research (IISR), Calicut, India, for providing facilities for GC/MS analysis. We are indebted to the Department of Science & Technology (WISE-KIRAN Division), Government of India, for granting financial assistance (DST/CURIE-PG/2022/44 G).

### Conflict of interest

The authors declare that we have no conflicts of interest.

### References

- Harrewijn P, van Oosten A M and Piron P G M, *Natural Terpenoids as Messengers* (Springer, Dordrecht: Kluwer Academic Publishers), 2001, 1–9.
- Hanif M A, Nisar S, Khan G S, Mushtaq Z and Zubair M, Essential Oils, in *Essential Oil Research: Trends in Biosynthesis, Analytics, Industrial Applications and Biotechnological Production*, edited by S Malik, (Springer Nature, Switzerland AG), 2019, 3–18.
- Franz C and Novak J, Sources of Essential Oils, in *Handbook of Essential Oils Science, Technology, and Applications*, edited by K H Can Başer & G Buchbauer, (CRC Press, Boca Raton), 2010, 39–81.
- Figueiredo A C, Barroso J G, Pedro L G and Scheffer J J C, Physiological aspects of essential oil production, in *Essential Oils: Basic and Applied Research*, edited by C Franz, A Máthé & G Buchbauer, (Allured Publishing, Carol Stream), 1997, 95–107.
- Salamon I, Effect of the internal and external factors on yield and qualitative–quantitative characteristics of chamomile essential oil, *Acta Hort*, 2007, **749**, 45–64, doi: org/10.17660/ActaHortic.2007.749.3.
- Jantan I B, Yassin M S M, Chin C B, Chen L L and Sim N L, Antifungal activity of the essential oils of nine Zingiberaceae species, *Pharm Biol*, 2003, **4**, 392–397, doi: org/10.1076/phbi.41.5.392.15941.
- Verma P and Kundu R, The ginger prophecy; A review of the underexplored genus, *Hedychium* against Cancer, *Indian J Pharm Sci*, 2019, **82**, 11–20, doi: org/10.36468/pharmaceutical-sciences.618.
- Sirirugsa P and Larsen K, The genus *Hedychium* (Zingiberaceae) in Thailand, *Nordic J Bot*, 1995, **15**, 301–304, doi: org/10.1111/j.1756-1051.1995.tb00156.x.
- Thomas S, Mani B and Britto S J, A new species of *Hedychium* (Zingiberaceae) from the southern Western Ghats, India, *Webbia*, 2015, **70**, 221–225, doi: org/10.1080/00837792.2015.1082270.
- Mukherjee I, Chromosome studies of some species of *Hedychium*, *Bot Mag Tokyo*, 1970, **83**, 237–241.
- Wood T, Ginger lilies, *American Gardener*, 1999, **78**, 40–45.
- Sakhanokho H F and Rajasekaran K, *Hedychium* Essential oils: Composition and uses, in *Essential Oil Research: Trends in Biosynthesis, Analytics, Industrial Applications and Biotechnological Production*, edited by S Malik, (Springer Nature, Switzerland AG), 2019, 49–60.
- Sakhanokho H F, Sampson B J, Tabanca N, Wedge D E, Demirci B, *et al.*, Chemical composition, antifungal and insecticidal activities of *Hedychium* essential oils, *Molecules*, 2013, **18**, 4308–4327, doi: org/10.3390/molecules18044308.
- Bisht G S, Awasthi A K and Dhole T N, Antimicrobial activity of *Hedychium spicatum*, *Fitoterapia*, 2006, **77**, 240, doi: org/10.1016/j.fitote.2006.02.004.
- Joshi S, Chanotiya C S, Agarwal G, Prakash O, Pant A K, *et al.*, Terpenoid compositions anti-oxidant and antimicrobial properties of the rhizome essential oils of different *Hedychium* species, *Chem Biodivers*, 2008, **5**, 299–309, doi: org/10.1002/cbdv.200890027.
- Thomas S and Mani B, Chemical composition, antibacterial and antioxidant properties of essential oil from rhizomes of *Hedychium forrestii* var. *planiense* Sanj and M. Sabu, *Ind J Pharm Sci*, 2016, **78**, 452–457, doi: org/10.4172/pharmaceutical-sciences.1000139.
- Thomas S and Mani B, Composition, antibacterial and anti-oxidant potentials of the essential oil of *Hedychium matthewii*, *Bangladesh J Pharmacol*, 2017, **12**, 173–179, doi: org/10.3329/bjp.v12i2.29339.
- Ray A, Jena S, Dash B, Kar B, Halder T, *et al.*, Chemical diversity, antioxidant and antimicrobial activities of the essential oils from Indian populations of *Hedychium coronarium* Koen, *Ind Crop Prod*, 2018, **112**, 353–362, doi: org/10.1016/j.indcrop.2017.12.033.
- Medeiros J R, Campos L B, Mendonca S C, Davin L B and Lewis N G, Composition and antimicrobial activity of the essential oils from invasive species of the Azores, *Hedychium gardenarium* and *Pittosporum undulatum*, *Phytochemistry*, 2003, **64**, 561–65, doi: org/10.1016/s0031-9422(03)00338-8.
- Raj G, Dan M, Shihuraj S, Sethuraman M G and George V, Chemical composition and antibacterial activity of the rhizome oil of *Hedychium larsenii*, *Acta Pharma*, 2005, **55**, 315–320.
- Rajasekaran K, Sakhanokho H F and Tabanca N, Antifungal activities of *Hedychium* essential oils and plant extracts against mycotoxigenic fungi, *J Crop Improv*, 2012, **26**, 389–396, doi: org/10.1080/15427528.2011.649395.
- Miranda C A S F, Cardoso M G, Mansanares M E, Gomes M S and Marcussi S, Preliminary assessment of *Hedychium coronarium* essential oil on fibrinogenolytic and coagulant activity induced by Bothrops and Lachesis snake venoms, *J Venom Anim Toxins Incl Trop Dis*, 2014, **20**, 39, doi: org/10.1186/1678-9199-20-39.
- Binimol K J, Vani S, Thomas S and Mani B, Chemical principles, bioactivity, and pharmacology of two ginger lilies *Hedychium forrestii* diels and *Hedychium venustum* wight (Family: Zingiberaceae), in *Bioactives and pharmacology of medicinal plants*, edited by T Pullaiah, (Apple Academic Press, USA), 2022, 25–38.
- Mani B and Thomas S, Chemical principles, bioactivity, and pharmacology of two yellow ginger lily *Hedychium flavescens* Carey ex Roscoe and *H. flavum* Roxb. (Family:

- Zingiberaceae), in *Biomolecules and pharmacology of medicinal plants*, edited by T Pullaiah, (Apple Academic Press, USA), 2023, 49–62.
- 25 Sanoj E, Sabu M and Rajesh Kumar T, *Hedychium forrestii* (Zingiberaceae) with a new synonymy and a variety from India, *J Bot Res Inst Texas*, 2010, **4**, 633–639.
  - 26 Thomas S, *Classical and molecular taxonomy and systematics in Hedychium from the Western Ghats*, Ph D Thesis, Bharathidasan University, Tiruchirappalli, 2016.
  - 27 Thomas S, Britto S J and Mani B, First records of two Ginger Lilies *Hedychium* (Zingiberaceae) species from the Western Ghats, India, *J Threat Taxa*, 2017, **9**, 10914–10919, doi: org/10.11609/jott.3117.9.11.10914-10919.
  - 28 Mohammed H H, Laftah W A, Ibrahim A N and Yunus M A C, Extraction of essential oil from *Zingiber officinale* and statistical optimization of process parameters, *RSC Adv*, 2022, **12**, 4843, doi: org/10.1039/d1ra06711g.
  - 29 Adams R P, *Identification of essential oil components by gas chromatography/ mass spectrometry*, 4<sup>th</sup> edn, (IL, Allured Business Media), 2009.
  - 30 Sabulal B, George V, Dan M and Pradeep N S, Chemical composition and antimicrobial activities of the essential oils from the rhizomes of four *Hedychium* species from South India, *J Essent Oil Res*, 2007, **19**, 93–97, doi.org/10.1080/10412905.2007.9699237.
  - 31 Joy B, Rajan A and Abraham E, Antimicrobial activity and chemical composition of essential oil from *Hedychium coronarium*, *Phytother Res*, 2007, **21**, 439–443.
  - 32 Dixit V K, Varma K C and Vashisht V N, Studies on essential oils of rhizomes of *Hedychium spicatum* Koenig and *Hedychium coronarium* Koenig, *Ind J Pharm Sci*, 1977, **39**, 58–60.
  - 33 Lechat-Vahirua I, François P, Menut C, Lamaty G and Bessiere J-M, Aromatic plants of French Polynesia I. Constituents of the essential oils of rhizomes of three Zingiberaceae: *Zingiber zerumbet* Smith, *Hedychium coronarium* Koenig and *Etlingera cevuga* Smith, *J Essent Oil Res*, 1993, **5**, 55–59, doi: org/10.1080/10412905.1993.9698170.
  - 34 Gurib-Fakim A, Maudarbaccus N, Leach D, Doimo L and Vohlmuth H, Essential oil composition of *Zingiberaceae* species from Mauritius, *J Essent Oil Res*, 2002, **14**, 271–273, doi: org/10.1080/10412905.2002.9699850.
  - 35 dos Santos B C B, Barata, L E S, Marques F A, Baroni A C M, Kanos B A C, *et al.*, Composition of leaf and rhizome essential oils of *Hedychium coronarium* Koen. from Brazil, *J Essent Oil Res*, 2010, **22**, 305–306, doi: org/10.1080/10412905.2010.9700331.
  - 36 Prakash O, Rajput M, Kumar M and Pant A K, Chemical composition and antibacterial activity of rhizome oils from *Hedychium coronarium* Koenig and *Hedychium spicatum* Buch-Ham, *J Essent Oil Bear Plants*, 2010, **13**, 250–259, doi: org/10.1080/0972060X.2010.10643819.
  - 37 Ho J-C, Antimicrobial, mosquito larvicidal and antioxidant properties of the leaf and rhizome of *Hedychium coronarium*, *J Chin Chem Soc*, 2011, **58**, 563–567, doi: org/10.1002/jccs.201190021.
  - 38 Rodrigues D F, Velasquez A M A, Cavaleiro C, Salgueiro L, Martins G Z, *et al.*, Chemical composition and trypanocidal activity of the essential oils from *Hedychium coronarium* J. Koenig (Zingiberaceae), *ISRN Infect Dis*, 2013, **2013**, 1–6.
  - 39 Van Thanh B, Dai D N, Thang T D, Binh N Q, Anh L D N, *et al.*, Composition of essential oils of four *Hedychium* species from Vietnam, *Chem Cent J*, 2014, **8**, 54, doi: org/10.1186/s13065-014-0054-3.
  - 40 Suksathan R, Sookkhee S, Anuntalabhochai S and Chansakaow S, Chemical composition and antibacterial activity of rhizome oils from five *Hedychium* species, *Nat Prod Commun*, 2013, **8**, 519–522, doi: org/10.1177/1934578X1300800429.
  - 41 Garg S N, Shawl A S and Gulati B C, Essential oil of *Hedychium spicatum* var. *acuminatum*, *Indian Perfum*, 1977, **21**, 79–82.
  - 42 Bottini A T, Garfagnoli D J, Delgado L S, Dev V, Duong S T, *et al.*, Sesquiterpene alcohols from *Hedychium spicatum* var. *acuminatum*, *J Nat Prod*, 1987, **50**, 732–734, doi: org/10.1021/np50052a027