

# Diversity in the Flavor Constituents of the Leaves of Three Zingiberaceae Family Plants

Aabha Gangwar<sup>1</sup> , Geeta Tewari<sup>1,\*</sup> , Chitra Pande<sup>1</sup> , Bhawana Kanyal<sup>1</sup> , Neeta Negi<sup>1</sup> ,  
Manisha Joshi<sup>1</sup> , Girish C. Kharkwal<sup>1</sup> 

<sup>1</sup> Department of Chemistry, D.S.B. Campus, Kumaun University, Nainital, Uttarakhand, India; aabhangangwar3@gmail.com (A.G.); geeta\_k@rediffmail.com (G.T.); chitrapande2861@gmail.com (C.P.); bhawanakanyal42@gmail.com (B.K.); neetanegi67@gmail.com (N.N.); mjoshidsb@gmail.com (M.B.); gckharkwal@gmail.com (G.C.K.);

\* Correspondence: geeta\_k@rediffmail.com;

Received: 4.06.2024; Accepted: 1.01.2025; Published: 6.09.2025

**Abstract:** India has a rich variety of medicinal plants containing a variety of active ingredients that promote good health. Zingiberaceae is the order's largest family with 56 genera and more than 1,300 species. The present work investigated the volatile constituents of three Zingiberaceae plants (*Hedychium coronarium* Konig, *Alpinia calcarata* Roscoe, and *Hedychium spicatum* Buch. Ham) through GC and GC/MS. *Hedychium coronarium* was found to contain 47 compounds, accounting for 95.99% of its composition. Meanwhile, both *A. calcarata* and *H. spicatum* were found to have 42 components each, representing 94.09% and 92.63% of their respective compositions. The predominant components in *H. coronarium*, *A. calcarata*, and *H. spicatum* were  $\beta$ -pinene (24.62%), 1, 8-cineole (27.48%), and elemol (12.90%), respectively. It can be summarized that the three plants of the Zingiberaceae family had good oil yield, and the major components present in all these samples were widely used in industries like pharmaceutical and perfumery.

**Keywords:** *Hedychium coronarium*; *Hedychium spicatum*; *Alpinia calcarata*; essential oil; gas chromatography.

© 2025 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The authors retain copyright of their work, and no permission is required from the authors or the publisher to reuse or distribute this article, as long as proper attribution is given to the original source.

## 1. Introduction

The Zingiberaceae family is well recognized around the world for its use as a spice and a traditional medicine. The family consists of some significant spices such as *Curcuma longa*, *Elettaria cardamomum*, *Zingiber officinale*, *Hedychium spicatum*, *Alpinia calcarata*, and *Hedychium coronarium* [1]. The therapeutic potential of the Zingiberaceae family has drawn researchers' attention. Rhizomes from this family are widely utilized as food seasonings and flavours around the world, especially in Southeast Asia. Traditional uses for the rhizomes of *H. coronarium* J. Konig and *H. spicatum* Buch. Ham. include parasite control, fungal resistance, pain relief, anti-inflammatory effects, and tranquilizing potential [2].

A rhizomatous herb known as *Alpinia calcarata* Rosc., which flourishes luxuriantly in dense forests at high altitudes, is said to have originated in India. Additionally, the species is found in New Guinea, Indonesia, Thailand, and Burma [3]. *Alpinia calcarata* has been a valuable resource in traditional medicine, where it is employed to alleviate various health issues, including rheumatism, diabetes, fever, and stomach problems [4]. Further, research into <https://nanobioletters.com/>

the plant's properties revealed that the essential oil of *A. calcarata* is primarily composed of oxygenated monoterpenoids, as identified by Parthasarathy et al. in their 2008 study [5].

The *Charaka Samhita*, *Sushruta Samhita*, and *Ayurveda* describe the curative advantages of *H. spicatum*. Although the functions of this plant vary by region, all portions are used in medicine and for other daily purposes. It is also used as a medicine to treat tonsillitis, infected nostrils, and tumors. Traditional Chinese medicine has long valued this plant for its ability to relieve rheumatism, soothe sharp pains, reduce bruising, and headaches [6]. This plant's essential oil, which is derived from its leaves, flowers, and rhizome, has strong inhibitory, antibacterial, anti-inflammatory, and analgesic qualities. In situations where snakebite is present, a rhizome paste is applied externally. Various parts of this fragrant rhizomatous plant, *H. coronarium*, are used in both conventional and modern medicine due to their significant therapeutic characteristics [1]. Although *H. coronarium* originated in the Himalayas, this plant is also native to Brazil, Japan, and Nepal. Notably, its leaf essential oil contains caryophyllene, a compound with potent anti-inflammatory properties. This remarkable plant's therapeutic potential holds promise for enhancing stroke treatment and recovery [7]. Utilization of these herbal medicines has both health and financial advantages for the people [8].

It is found in subtropical regions at elevations between 1000 and 3000 meters above sea level in the Indian Himalayan Region and the Western Ghats. This plant grows abundantly in Bhutan, China, India, Japan, Madagascar, Mauritius, Myanmar, Nepal, Pakistan, Seychelles, and Thailand [9]. The therapeutic potential of a plant species is directly linked to its wealth of bioactive compounds, which can vary considerably according to the genetic profile of the particular medicinal plant's altitude where it is located, incidence of sunlight, culture conditions, and some other factors [10].

The leaf essential oil compounds of *H. coronarium*, *A. calcarata*, and *H. spicatum* have not been compared in any study so far; hence, this study aimed to bridge this knowledge gap by analyzing and identifying the chemical compounds present in the leaf essential oils of three members that belonged to the Zingiberaceae family, i.e., *H. coronarium*, *A. calcarata*, and *H. spicatum*, using GC and GC/MS analytical methods. The analytical results of this study might have some potential to give new insight into the utilization of these species in the perfume and fragrance industries.

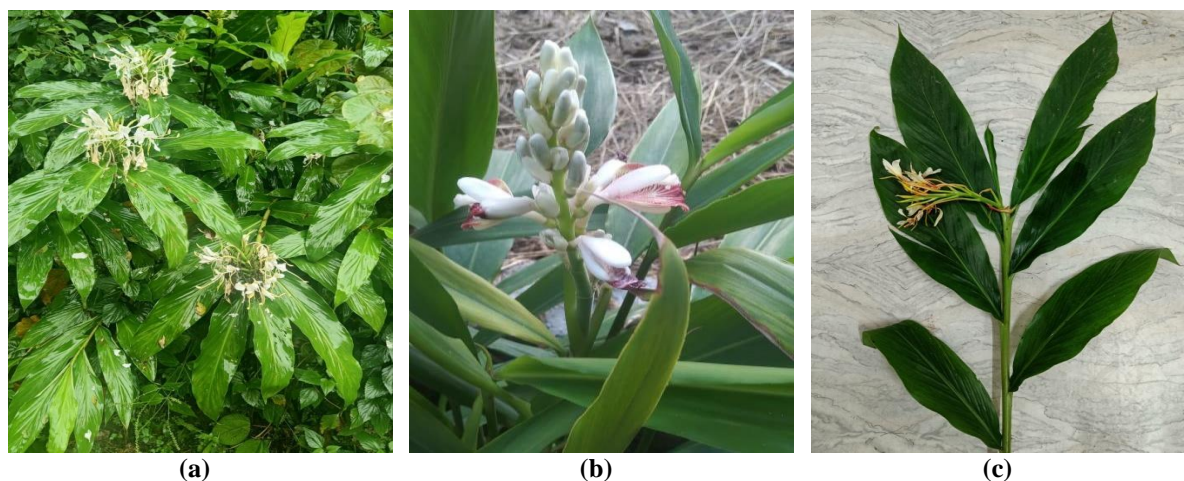
## 2. Materials and Methods

### 2.1. Collection of leaves of *H. coronarium*, *A. calcarata*, and *H. spicatum*.

The leaves of the three plants were collected from the Nainital District of Uttarakhand State, India (Figure 1 and Table 1).

**Table 1.** Details of the collection of the leaves (L) of Zingiberaceae plants.

Plant species	Geographical coordinates	Altitude (m)	Collection site	The month of the collection of plants
<i>Hedychium coronarium</i> J. Konig. (Ac. 44221) (HCLJ)	29°32'N, 79°50'E	345	Jeolikote (J)	October
<i>Alpinia calcarata</i> Haw. Roscoe (Ac. 17141) (ACLB)	29°55'N, 79°38'E	765	Betalghat (B)	May
<i>Hedychium spicatum</i> Buch. Ham. (Ac. 41538) (HSLN)	29° 40'N, 79° 45'E	2240	Nainital (N)	August



**Figure 1.** Morphology of (a) *H. coronarium*; (b) *A. Calcarata*; (c) *H. spicatum*.

### 2.2. Extraction of oil.

Five hundred grams of the leaves of each species were subjected to essential oil extraction in a glass apparatus (Clevenger) for 4 hours, and the process of extraction was replicated three times for reliable results.

### 2.3. Oil analysis.

All the oil samples were taken for flavor analysis on a Shimadzu 2010 oil chromatograph supplied with a capillary column (30 m × 0.25 mm × 0.25 μm) and flame ionization detector (FID). The analysis protocol involved a multi-step temperature program: initially set at 50°C for 2 minutes, then ramped to 210°C at 3°C/min (held for 2 minutes), followed by a further increase to 280°C at 8°C/min (held for 9 minutes). The carrier gas, nitrogen, flowed at 1.21 mL/min. The detector port temperature and split ratio were fixed at 280°C and 1:10, respectively. For each analysis, 0.2 μL of neat oil was injected. Mass spectrometry conditions were optimized as follows: the ion source temperature was set to 220°C, interface temperature to 270°C, and split ratio to 1:100. The mass scanning range was fixed between 40-600 (m/z).

### 2.4. Identification and quantification of the compounds.

To determine the components present in the three oils, the retention index (RI) was computed based on the n-alkane C<sub>9</sub>-C<sub>33</sub> series under similar investigational conditions. The mass spectrometer was matched with libraries from NIST (version 4.1) and WILEY (7th edition). Without the use of a response factor, the identification of each compound was finalized by comparing its fragmentation pattern to those documented in the literature [11].

### 2.5. Statistical analysis.

SPSS 16.0 software was used to perform cluster analysis and one-way analysis of variance to evaluate the variation of different data for all three essential oils. The results were calculated using MS-Excel 2019 and were presented as standard deviation.

### 3. Results and Discussion

#### 3.1. Flavour constituents of the leaves of *Hedychium coronarium* (HCLJ).

Forty-seven compounds were identified, representing 95.99% of the composition in the oil of *H. coronarium* leaves.

**Table 2.** Comparative percentage of the flavour components present in the leaves of Zingiberaceae plants.

Sr. No.	RT (min)	Compound	ACLB	HSLN	HCLJ
1.	8.42	$\alpha$ -thujene	ND	ND	0.27
2.	8.70	$\alpha$ -pinene	<b>2.83<sup>b</sup> ±0.02</b>	<b>1.99<sup>a</sup> ±0.01</b>	<b>12.34<sup>c</sup> ±0.03</b>
3.	9.34	Camphene	2.80	0.56	0.07
4.	10.28	Sabinene	0.19	2.38	ND
5.	10.52	$\beta$ -pinene	<b>12.74<sup>a</sup> ±0.03</b>	<b>13.93<sup>a</sup> ±0.04</b>	<b>24.62<sup>b</sup> ±0.04</b>
6.	10.98	Myrcene	1.13	0.14	0.45
7.	11.69	$\alpha$ -phellandrene	0.11	ND	ND
8.	12.53	<i>p</i> -cymene	0.22	0.13	0.13
9.	12.74	Limonene	3.68	0.77	ND
10.	12.98	1,8-cineole	<b>27.48<sup>c</sup> ±0.05</b>	<b>8.99<sup>b</sup> ±0.02</b>	<b>6.11<sup>a</sup> ±0.02</b>
11.	13.53	$\beta$ -( <i>E</i> )-ocimene	0.88	ND	0.06
12.	14.05	$\gamma$ -terpinene	0.41	ND	0.04
13.	14.64	<i>cis</i> -sabinene hydrate	ND	0.25	0.15
14.	14.68	$\beta$ -( <i>E</i> )-terpineol	0.11	ND	0.02
15.	15.79	6-camphenone	0.10	ND	ND
16.	16.1	Linalool	0.40	1.29	1.04
17.	17.23	$\alpha$ -campholenal	ND	ND	0.03
18.	16.46	Verbenol	ND	0.18	ND
19.	18.29	Camphor	<b>12.20±0.03</b>	ND	ND
20.	18.61	Camphene hydrate	0.20	ND	ND
21.	18.92	Pinocarveol	ND	1.64	0.09
22.	18.18	<i>trans</i> - verbenol	ND	0.30	ND
23.	18.89	Pinocarvone	0.09	0.34	0.05
24.	19.47	Borneol	1.13	0.70	0.05
25.	19.81	Terpinene-4-ol	0.72	0.37	0.21
26.	20.25	Myrtenal	0.06	0.40	ND
27.	20.59	$\alpha$ -terpineol	3.67	ND	0.89
28.	22.67	$\alpha$ -citral	0.22	0.09	ND
29.	23.84	Geranial	ND	0.09	ND
30.	23.85	2-decenal	0.20	ND	ND
31.	24.51	Bornyl acetate	1.30	ND	ND
32.	27.28	$\alpha$ -terpinyl acetate	0.22	ND	ND
33.	28.82	$\beta$ -bourbonene	ND	ND	0.13
34.	29.09	$\beta$ -elemene	ND	0.41	0.13
35.	29.1	Methyl cinnamate	4.01	ND	ND
36.	29.84	$\alpha$ -gurjunene	ND	ND	0.07
37.	30.36	$\beta$ -caryophyllene	<b>0.40<sup>a</sup></b>	<b>2.08<sup>b</sup> ±0.02</b>	<b>9.45<sup>c</sup> ±0.03</b>
38.	30.8	<i>cis</i> - $\beta$ -copaene	ND	ND	0.04
39.	30.8	$\beta$ -gurjunene	ND	0.29	ND
40.	30.95	$\alpha$ -trans bergamotene	0.21	ND	ND
41.	31.79	$\beta$ -( <i>E</i> )-farnesene	0.84	ND	ND
42.	31.86	$\alpha$ -humulene	ND	<b>8.78<sup>b</sup> ±0.04</b>	<b>1.22<sup>a</sup> ±0.01</b>
43.	32.04	9- <i>epi</i> -( <i>E</i> )- caryophyllene	ND	0.32	1.94
44.	32.97	$\gamma$ -amorphene	ND	ND	2.17
45.	33.24	$\beta$ -selinene	ND	1.62	ND
46.	33.26	$\gamma$ -gurjunene	ND	ND	0.09
47.	32.54	Dauca-5,8-diene	0.21	ND	ND
48.	33.54	$\alpha$ -selinene	0.11	1.42	ND
49.	33.58	Bicyclogermacrene	ND	ND	2.19

Sr. No.	RT (min)	Compound	ACLB	HSLN	HCLJ
50.	34.24	$\gamma$ -cadinene	ND	0.18	0.04
51.	34.03	Cubebol	0.58	0.47	ND
52.	34.25	$\delta$ -cadinene	0.31	ND	0.3
53.	35.37	Elemol	<b>0.13<sup>a</sup></b>	<b>12.9<sup>c</sup> ± 0.02</b>	<b>8.18<sup>b</sup> ± 0.03</b>
54.	36.24	( <i>E</i> )-nerolidol	0.77	0.60	0.20
55.	36.51	Maaliol	ND	2.13	ND
56.	36.85	Spathulenol	ND	1.72	1.98
57.	36.99	Caryophyllene oxide	ND	1.71	ND
58.	37.65	Humulene epoxide I	ND	2.82	ND
59.	37.93	Globulol	ND	ND	0.73
60.	38.08	Humulene epoxideII	ND	<b>5.99 ± 0.03</b>	ND
61.	38.1	Eudesmol-5- <i>epi</i> -7- <i>epi</i> - $\alpha$	ND	ND	0.82
62.	38.57	Eudesmol-10- <i>epi</i> - $\gamma$	ND	2.64	3.99
63.	36.99	$\beta$ -caryophyllene	0.43	ND	ND
64.	37.91	Carotol	<b>9.08 ± 0.03</b>	ND	ND
65.	38.9	Cadin-4-en-1-ol	ND	3.6	ND
66.	39.08	$\gamma$ - eudesmol	ND	ND	3.94
67.	39.43	$\zeta$ -muurolol	ND	0.96	ND
68.	39.44	$\alpha$ - <i>epi</i> -muurolol	0.26	ND	ND
69.	39.54	Agarospirol	ND	ND	0.37
70.	39.83	$\alpha$ - eudesmol	<b>ND</b>	<b>6.10<sup>a</sup> ± 0.01</b>	<b>11.08<sup>b</sup> ± 0.02</b>
71.	39.87	Cadinol	0.48	ND	ND
72.	40.23	Eudesmol-7- <i>epi</i> - $\alpha$	ND	0.24	ND
73.	40.5	Eudesma-4(15),7-dien-1 $\beta$ -ol	ND	0.18	0.30
74.	40.54	$\beta$ - eudesmol	2.73	ND	ND
75.	40.97	$\alpha$ - <i>epi</i> - bisabolol	0.21	ND	ND
76.	42.75	Oplopanone	ND	0.94	ND
77.	43.27	Cedroxide	0.28	ND	ND
Monoterpene hydrocarbons			21.3	19.12	37.73
Oxygenated monoterpene hydrocarbons			51.76	15.41	8.63
Sesquiterpene hydrocarbon			5.77	15.09	17.49
Oxygenated Sesquiterpene hydrocarbon			15.26	43.01	31.87
Total			94.10	92.63	95.99

RT = Retention time; ND = Not detected

The percentage denoted by bold font specifies the major flavour compounds of the oils. The mean percentage, followed by mismatched small alphabets in their superscript for a row, is significantly non-identical at a probability level of 0.05.

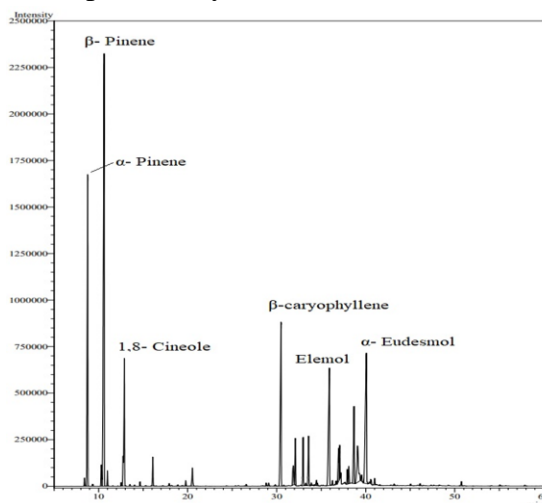
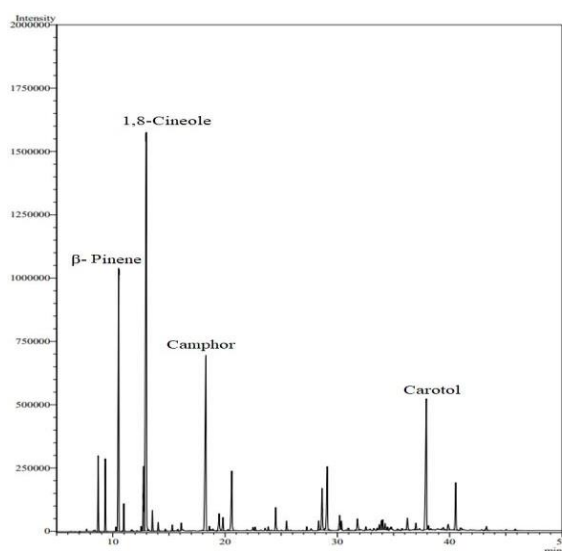


Figure 2. GC chromatogram of HCLJ essential oil.

The predominant components of the extracted oil were  $\beta$ -pinene (24.62%),  $\alpha$ -pinene (12.34%),  $\alpha$ -eudesmol (11.08%),  $\beta$ -caryophyllene (9.45%), elemol (8.18%), and 1,8-cineole (6.11%). However,  $\gamma$ -10-*epi*-eudesmol (3.99%),  $\gamma$ -eudesmol (3.94%),  $\gamma$ -amorphene (2.17%), bicyclo germacrene (2.19%), spathulenol (1.97%), and 9-*epi*-(*E*)-caryophyllene (1.94%) were present as minor constituents (Figure 2 and Table 2). The oil yield was 0.20%.

### 3.2. Flavour constituents in the leaves of *Alpinia calcarata* (ACLB).

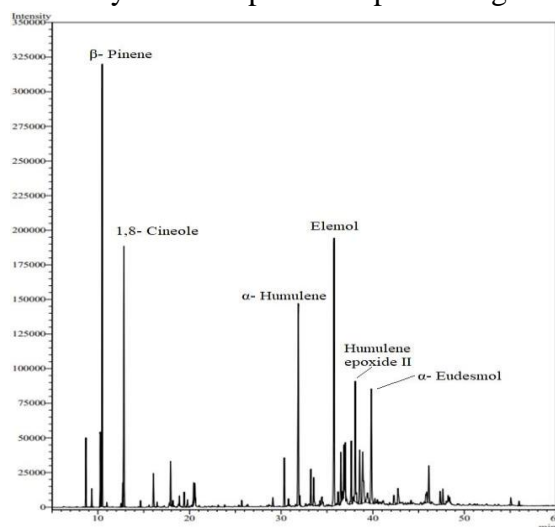
GC and GC/MS results showed that 42 of the 53 compounds were identified, accounting for 94.09% of the composition. *A. calcarata* essential oil had an ample amount of 1,8-cineole (27.48%),  $\beta$ -pinene (12.74%), camphor (12.20%), and carotol (9.08%). Methyl cinnamate (4.01%), limonene (3.68%),  $\alpha$ -terpineol (3.67%), camphene (2.79%), and  $\beta$ -eudesmol (2.73%) were found as minor constituents (Figure 3 and Table 2). The oil content of the leaves was 0.16%.



**Figure 3.** GC chromatogram of ACLB essential oil.

### 3.3. Flavour constituents in the leaves of *Hedychium spicatum* (HSLN).

The analysis identified forty-two compounds representing 92.63% of the composition.



**Figure 4.** GC chromatogram of HSLN essential oil.

The leaf oil had a yield of 0.20% (v/w).  $\beta$ -Pinene (13.93%), elemol (12.90%), 1,8-cineole (8.99%),  $\alpha$ -humulene (8.78%),  $\alpha$ -eudesmol (6.09%), and humulene epoxide II (5.99%)

were noted as the major compounds in the oil of *H. spicatum*. Further analysis revealed a range of minor compounds in the oil, including cadin-4-en-1-ol (3.60%), humulene epoxide I (2.82%),  $\gamma$ -10-epi-eudesmol (2.64%), sabinene (2.38%), maaliol (2.13%),  $\beta$ -caryophyllene (2.08%), and  $\alpha$ -pinene (1.99%) (Figure 4 and Table 2).

### 3.4. Variation in the major and minor compounds among the three species.

The common compounds of all three oils were 1,8-cineole (6.11-27.48%) and  $\beta$ -pinene (12.74-24.62%). The percentage of 1,8-cineole was highest in *A. calcarata* leaf oil, followed by *H. spicatum* and *H. coronarium* (Figure 5 and Table 2). The content of  $\beta$ -pinene followed the order: *H. coronarium* > *H. spicatum* > *A. calcarata*. The major components, camphor and carotol, were present only in *A. calcarata*, while  $\alpha$ -humulene and  $\alpha$ -eudesmol, which were the predominant components of *H. coronarium* and *H. spicatum*, were found to be absent in *A. calcarata*. Twelve minor components such as  $\gamma$ -eudesmol (2.93%), bicyclogermacrene (2.19%),  $\gamma$ -amorphene (2.17%), 5-*epi*-7-*epi*- $\alpha$ -eudesmol (0.82%), globulol (0.73%), agarospirol (0.37%),  $\alpha$ -thujene (0.27%),  $\beta$ -bourbonene (0.13%),  $\gamma$ -gurjunene (0.09%),  $\alpha$ -gurjunene (0.07%), *cis*- $\beta$ -copaene (0.04%) and  $\alpha$ -campholenal (0.03%) were present only in *H. coronarium*.

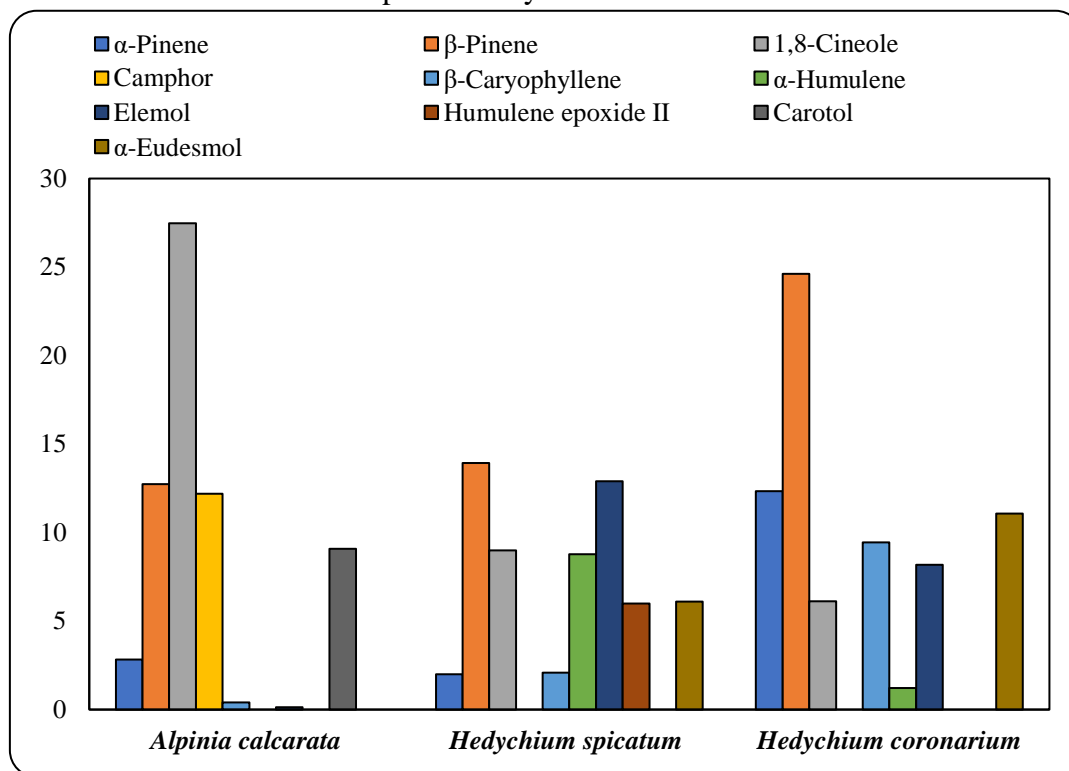


Figure 5. Variation in the major components in the selected species.

Six minor components, including limonene, sabinene,  $\alpha$ -selinene, cubebol,  $z$ -citral, and myrtenal, were absent in *H. coronarium*. Sixteen minor components such as methyl cinnamate (4.01%),  $\beta$ -eudesmol (2.73%), bornyl acetate (1.30%),  $\beta$ -(*E*)-farnesene (0.84%), cadinol (0.48%),  $\beta$ -caryophyllene (0.43%), cedroxyde (0.28%),  $\alpha$ -*epi*-muurolol (0.26%),  $\alpha$ -terpinyl acetate (0.22%),  $\alpha$ -*trans*-bergamotene (0.21%),  $\alpha$ -*epi*-bisabolol (0.21%), dauca-5,8-diene (0.21%), camphene hydrate (0.20%), 2-decenal (0.20%),  $\alpha$ -phellandrene (0.11%) and 6-camphenone (0.10%) were present only in *A. calcarata*. Seven minor compounds, namely 10-*epi*- $\gamma$ -eudesmol, spathulenol, 9-*epi*-(*E*)-caryophyllene, pinocarveol, *cis*-sabinene hydrate,  $\beta$ -elemene, and  $\gamma$ -cadinene, were observed to be absent in *A. calcarata*.

Humulene epoxide II (5.99%), cadin-4-en-1-ol (3.60%), humulene epoxide I (2.82%), caryophyllene oxide (1.71%),  $\beta$ -selinene (1.62%),  $\gamma$ -muurolol (0.96%), oplopanone (0.94%), *trans*-verbenol (0.30%),  $\beta$ -gurjunene (0.29%), 7-*epi*- $\alpha$ -eudesmol (0.24%), verbenol (0.18%) and geranial (0.09%) were found to be present only in *H. spicatum* while five components namely  $\beta$ -(*E*)-Ocimene,  $\gamma$ -terpinene,  $\beta$ -(*E*)-terpineol,  $\alpha$ -terpineol, and  $\delta$ -cadinene were absent in *H. spicatum*.

### 3.5. Class of compounds.

The essential oil of *H. coronarium* was observed to be dominant in monoterpene hydrocarbons (MH) (37.73%), followed by oxygenated sesquiterpenes (OS) (31.87%), sesquiterpene hydrocarbons (SH) (17.49%), and oxygenated monoterpenes (OM) (8.63%). Oxygenated monoterpene (51.76%) was the major class of compound in *A. calcarata*, followed by monoterpene hydrocarbons (21.30%), oxygenated sesquiterpenes (15.26%), and sesquiterpene hydrocarbons (5.77%). Oxygenated sesquiterpenes (43.01%) were present in the highest amount in *H. spicatum* leaf oil, followed by MH (19.12%, OS (15.41%), and SH (15.09%) (Figure 6 and Table 2).

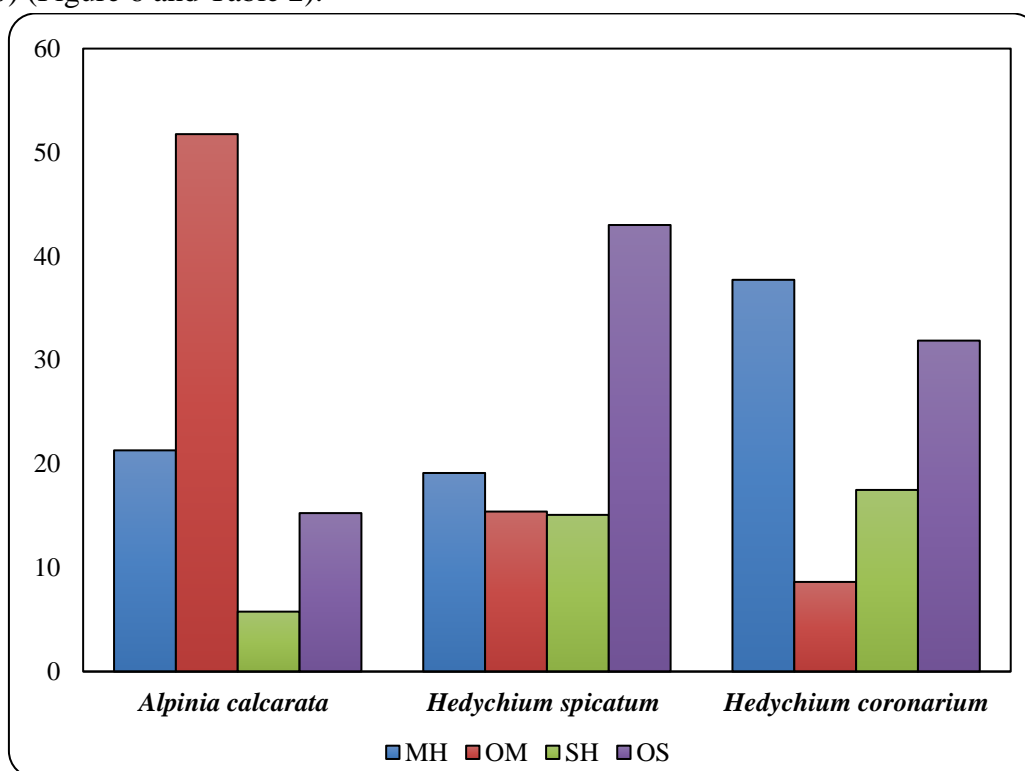


Figure 6. Variation in the class of compounds among the species.

### 3.6. Cluster study.

The cluster study of the extracted oils showed the presence of two clusters. Cluster 1 contained *H. spicatum* and *H. coronarium*, which were rich in sesquiterpenes, and Cluster 2 included *A. calcarata*, which was observed to be rich in monoterpenes (Figure 7).

Cluster 1:  $\beta$ -Pinene (13.93-24.62%), elemol (8.18-12.9%), 1,8-cineole (6.11-8.99%),  $\alpha$ -eudesmol (6.10-11.08%),  $\beta$ -caryophyllene (2.08-9.45%),  $\alpha$ -humulene (1.22-8.78%)

Cluster 2: 1,8-Cineole (27.48%),  $\beta$ -pinene (12.74%), camphor (12.20%), carotol (9.08%).

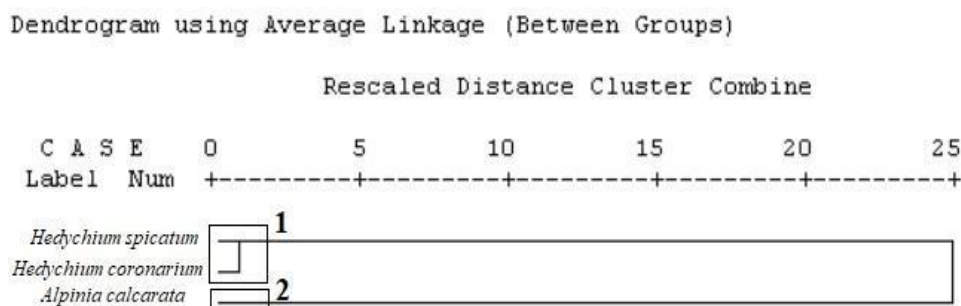


Figure 7. Cluster analysis of the oils.

#### 4. Discussion

In the present investigation, the volatile profile of HCLJ was characterized by the presence of six main compounds:  $\beta$ -pinene,  $\alpha$ -pinene,  $\alpha$ -eudesmol,  $\beta$ -caryophyllene, elemol, and 1,8-cineole. According to research conducted by Santos et al. in Brazil, the leaf essential oil of *H. coronarium* was predominantly composed of  $\beta$ -caryophyllene, caryophyllene oxide, and  $\beta$ -pinene [12]. Another study from the United States showed that sesquiterpenoids, especially caryophyllene oxide and (*E*)-caryophyllene, were the important flavour constituents of *H. coronarium* [13]. The chemical compounds such as  $\beta$ -pinene, linalool, 1,8-cineole,  $\alpha$ -pinene, and  $\alpha$ -terpineol were found in the leaf essential oil of *H. coronarium* grown in Vietnam [14]. From a study conducted in Uttarakhand, India, it was revealed that  $\beta$ -pinene (44.1%),  $\alpha$ -pinene (23.0%),  $\beta$ -caryophyllene (13.4%), sabinene (6.1%), and 1,8-cineole (5.1%) were the predominant chemicals of the oil of leaves of *H. coronarium* [15]. In another study, the main flavor compounds were 1,8-cineole (2.68%),  $\beta$ -pinene (14.78%), caryophyllene (12.95%), and  $\beta$ -terpineol (7.90%) [16]. However, Parida et al. showed the presence of caryophyllene (33.60%), eucalyptol (24.21%), eugenol (12.84%), caryophyllene oxide (9.20%), terpinene-4-ol (7.70%), and  $\alpha$ -pinene (5.13%) as the compounds with a percentage greater than 5% in *H. coronarium* essential oil [17]. Arya et al. identified sesquiterpenes as the main component group in *H. coronarium* aerial part oil, including 7-hydroxyfarnesen,  $\alpha$ -farnesene,  $\alpha$ -pinene, spathulenol, and  $\beta$ -pinene [18]. In a recent study from Brazil, the predominant bioactive compound in the essential oil derived from the roots and rhizomes of *H. coronarium* was observed to be 1,8-cineole. On the other hand,  $\beta$ -pinene and (*E*)-caryophyllene were recorded as the most abundant components of leaf oil [19]. Further, in a report from Thailand, eucalyptol was found as the predominant compound in the rhizome oil, and (*E*)-caryophyllene as the primary compound in the leaf essential oil of *H. coronarium* [20]. Additionally,  $\beta$ -pinene,  $\alpha$ -pinene, and  $\beta$ -caryophyllene were present in plentiful amounts in the leaves' essential oil of *H. yunnanense* [21].  $\beta$ -Pinene, borneol,  $\alpha$ -pinene, and myrtenal were the predominant constituents of the oils extracted from rhizomes and leaves of *Zingiber monophyllum*, an important Zingiberaceae plant [22]. The predominant compounds in *Z. officinale* oil were camphene, geranial, geraniol, geranyl acetate, neral,  $\beta$ -phellandrene, and zingiberene [23]. In a comprehensive study from Kerala, Thomas and Mani analyzed four *Hedychium* species (*H. coronarium*, *H. forrestii*, *H. flavescens*, and *H. matthewii*) and discovered  $\beta$ -linalool as the major constituent of all essential oils [24]. In the present investigation, sesquiterpene (49.36%) was the key group of compounds. Monoterpenes and sesquiterpenes are the classes of terpenoids that give the ginger plant a special scent [25]. For the first time,  $\alpha$ -eudesmol and elemol (8.18%) were recorded as the predominant chemicals in *H. coronarium* leaf oil.

Research on *Alpinia calcarata* Rosc. essential oil has yielded diverse compositional profiles. Leaf oil analyses of *A. calcarata* Rosc. cultivated at Bhubneshwar have consistently identified 1,8-cineole and  $\beta$ -pinene as significant components, with camphor also present in notable quantities [26]. A study by Arambewela et al. in Sri Lanka reported 1,8-cineole and  $\beta$ -pinene as major bioactive compounds, comprising up to 24.7% and 20.5%, respectively [27]. Furthermore, 1,8-cineole, camphor, methyl cinnamate, carotol, and  $\beta$ -pinene were abundant in the leaf essential oil of *A. calcarata*, and the oil yield was found to be 0.14% [28]. Another report from South India suggested the presence of 1,8-cineole,  $\alpha$ -terpineol, and camphor as the major components of the leaf oil [29]. Shibila et al. reported eucalyptol as the primary chemical in the aroma fraction of rhizomes of *A. calcarata* collected from Kerala [30]. In the rhizome oil of another species of *Alpinia* (*Alpinia coriandriodora*), (*E*)-2-decenal and (*E*)-2-decenyl acetate were detected as the major components in China [31]. The present study is the first report from Uttarakhand, India, on *A. calcarata* leaf essential oil.

A study from Uttarakhand by Prakash et al. showed that the dominant compounds of *H. spicatum* rhizome's oil were  $\delta$ -cadinene,  $\gamma$ -cadinene, 1,8-cineole, cubenol,  $\alpha$ -eudesmol, 10-*epi*- $\gamma$ -eudismol, and germacrene D-4-ol [2]. Verma and Padalia suggested that  $\beta$ -pinene, 1,8-cineole, and  $\alpha$ -pinene were present in a significant amount (>9%) in *H. spicatum* leaf essential oil [9]. However, in the present study,  $\beta$ -pinene (13.93%), elemol (12.89%), 1,8-cineole (8.99%),  $\alpha$ -humulene (8.78%), and  $\alpha$ -eudesmol (6.09%) were also found as the major components. They also derived monoterpenes (monoterpene hydrocarbons; 54.4% and oxygenated monoterpenes; 13.2%) as the important category of volatile phytochemicals in the leaves of *H. spicatum* [9]. In contrast, in the present investigation, sesquiterpenes (58.10%) formed the important group of aroma components of the *H. spicatum* leaves. According to Mittal et al., terpenoids found in the *H. spicatum* rhizome are monoterpenoids, sesquiterpenoids, and diterpenoids, with the main ingredients being 1, 8-cineole, camphene, sabinene,  $\beta$ -pinene, myrcene, and  $\alpha$ -phellandrene [32]. According to Ray et al.,  $\beta$ -pinene, eucalyptol, sabinene, and *trans*-isolimonene were detected as the major phytochemicals in the rhizomes of *H. spicatum* collected from Kalimpong, India [33]. Rawat et al. investigated the composition of *H. spicatum* rhizome chloroform extract and reported curcumenone and coronarin as the most abundant components of the extract [34].

In a previous investigation,  $\alpha$ -phellandrene,  $\alpha$ -terpinolene, p-cymene, and eucalyptol were noted as the most bountiful phytochemicals in *Curcuma longa* leaf essential oil [35]. However, the volatile oil of *H. villosum* leaves had a plentiful amount of  $\beta$ -pinene,  $\beta$ -caryophyllene, and 1,8-cineole, while *A. hongiaoensis* leaf oil contains  $\beta$ -pinene and (*E*)-methyl cinnamate [36]. *Curcuma longa* (LEO) leaves' essential oils mostly contain  $\alpha$ -phellandrene, 2-carene, and eucalyptol [37].

High  $\beta$ -pinene percent in all three plants could be responsible for the biological properties, including antimicrobial, cytotoxic, antibacterial, and depressive effects [38]. Carotol may be engaged in allelopathic interactions and exhibit antifungal, herbicidal, and insecticidal activities [39].

## 5. Conclusion

The present research work concluded that three Zingiberaceae family plants possess significant oil yields. The key compounds identified were: (i) *Alpinia calcarata*: 1,8-cineole,  $\beta$ -pinene, camphor, and carotol; (ii) *Hedychium coronarium* and *Hedychium spicatum*:  $\alpha$ -pinene,  $\beta$ -pinene, and 1,8-cineole. Sesquiterpenes predominated in *H. spicatum* and *H.*

*coronarum*, whereas monoterpenes were abundant in *A. calcarata*. Notably, 1,8-cineole and  $\beta$ -pinene, present in all samples, hold great value in pharmaceutical and perfumery applications. The bioactive constituents in these plants make them promising sources of herbal medicines. Future research can investigate their potential therapeutic properties, such as antioxidant, anti-inflammatory, anticancer, antifungal, etc. This study emphasizes the potential of these Zingiberaceae plants as esteemed resources for developing natural remedies.

### Author Contributions

Conceptualization, G.T. and C.P.; methodology, A.G.; software, G.T., and A.G.; validation, A.G.; formal analysis, A.G., B.K., N.N., M.J., G.C.K.; investigation, A.G. resources, G.T., and C.P.; data curation, A.G.; writing—original draft preparation, A.G.; writing—review and editing, G.T., M.J. and A.G.; visualization, A.G.; supervision, G.T., and C.P.; project administration, A.G.; funding acquisition, A.G. All authors have read and agreed to the published version of the manuscript.

### Institutional Review Board Statement

Not applicable.

### Informed Consent Statement

Not applicable.

### Data Availability Statement

Data supporting the findings of this study are available upon reasonable request from the corresponding author.

### Funding

Department of Science and Technology, Government of India, has funded this research through DST-WISE-PhD fellowship with reference number (DST/WISE-PhD/CS/2023/13).

### Acknowledgments

The authors are thankful to the Head of the Chemistry Department, D. S. B. Campus, Kumaun University, Nainital, for the laboratory facilities and to DST, New Delhi, for financial support in the form of a DSTWISE-PhD fellowship.

### Conflicts of Interest

The authors declare no conflict of interest.

### References

1. Warriar, P.K. Indian medicinal plants: a compendium of 500 species. Orient Blackswan, Hyderabad, India, 1993; Volume 5.
2. Prakash, O.; Rajput, M.; Kumar, M.; Pant, A.K. Chemical composition and antibacterial activity of rhizome oils from *Hedychium coronarium* Koenig and *Hedychium spicatum* Buch-Ham. *Journal of Essential Oil Bearing Plants* **2010**, *13*, 250-259, <https://doi.org/10.1080/0972060X.2010.10643819>.

3. Rahman, M.A.; Islam, M.S. *Alpinia calcarata* Roscoe: A potential phytopharmacological source of natural medicine. *Pharmacognosy Reviews* **2015**, *9*, 55, <https://doi.org/10.4103/0973-7847.156350>.
4. Van, H.T.; Thang, T.D.; Luu T.N.; Doan, V.D. An overview of the chemical composition and biological activities of essential oils from *Alpinia* genus (Zingiberaceae). *RSC advances* **2021**, *11*, 37767-37783, <https://doi.org/10.1039/D1RA07370B>.
5. Parthasarathy, V.A.; Chempakam, B.; Zachariah, T.J. Chemistry of Spices. CABI, **2008**.
6. Mishra, T.; Pal, M.; Meena, S.; Datta, D.; Dixit, P.; Kumar, A.; Meena, B.; Rana, T.S.; Upreti, D.K. Composition and in vitro cytotoxic activities of essential oil of *Hedychium spicatum* from different geographical regions of western Himalaya by principal components analysis. *Natural Product Research* **2016**, *30*, 1224-1227, <https://doi.org/10.1080/14786419.2015.1049176>.
7. Parida, R.; Mohanty, S.; Nayak, S. Chemical composition of essential oil from leaf and rhizome of micropropagated and conventionally grown *Hedychium coronarium* Koen. from Eastern India. *Journal of Essential Oil Bearing Plants* **2015**, *18*, 161-167, <https://doi.org/10.1080/0972060X.2014.960268>.
8. Aftab, T.; Hakeem, K. R. Medicinal and Aromatic Plants. Expanding their Horizons through Omics, 1<sup>st</sup> Edition; Aftab, T., Hakeem, K.R., Eds.; Academic Press: **2020**.
9. Verma, R.S.; Padalia, R.C. Comparative essential oil composition of different vegetative parts of *Hedychium spicatum* Smith. from Uttarakhand, India. *International Journal of Green Pharmacy* **2010**, *4*, 292-295.
10. Jain, R.; Tiwari, R.; Kumar, S.; Shukla, A.K.; Kumar, M.; Shukla, A.K. Description of Medicinal Herb, Perfume Ginger: *Hedychium spicatum* (Zingiberales: Zingiberaceae). *The Scientific Temper* **2022**, *13*, 133-140, <https://doi.org/10.58414/SCIENTIFICTEMPER.2022.13.2.19>.
11. Adams, R.P. Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry, 4<sup>th</sup> Edition; Allured Publishing, Carol Stream, IL: **2007**.
12. Santos, B.C.B.; Barata, L.E.S.; Marques, F.A.; Baroni, A.C.M.; Karnos, B.A.C.; Oliveria P.R.; Guerrero, P.G. Composition of leaf and rhizome essential oils of *Hedychium coronarium* Koen. from Brazil. *Journal of Essential Oil Research* **2020**, *22*, 305-306, <https://doi.org/10.1080/10412905.2010.9700331>.
13. Rodrigues, D.F.; Arenas Velásquez, A.M.; Cavaleiro, C.; Salgueiro, L.; Martins, G.Z.; Magalhães, N.O.; Martins, M.B.; Cicarelli, R.M.; Moreira, R.R. Chemical composition and trypanocidal activity of the essential oils from *Hedychium coronarium* J. Koenig (Zingiberaceae). *International Scholarly Research Notices* **2013**, *2013*, 639275, <https://doi.org/10.5402/2013/639275>.
14. Thanh, B.V.; Dai, D.N.; Thang, T.D.; Binh, N.Q.; Anh, L.D.N.; Ogunwande, I.A. Composition of essential oils of four *Hedychium* species from Vietnam. *Chemistry Central Journal* **2014**, *54*, <https://doi.org/10.1186/s13065-014-0054-3>.
15. Shanmugam, P.V.; Yadav, A.; Chanotiya, C.S. Enantiomer differentiation of key volatile constituents from leaves, stems, rhizome and flowers of cultivated *Hedychium coronarium* Koenig from India. *Journal of Essential Oil Research* **2015**, *27*, 101-106, <https://doi.org/10.1080/10412905.2014.987929>.
16. Guzmán, L.; Nerio, L.S.; Venturini, W.; Macias, J.P.J.; Donoso, W.; Doria, O.F. Antiplatelet and antibacterial activities of essential oils obtained from rhizomes and leaves of *Hedychium coronarium* J. Koenig. *Anais da Academia Brasileira de Ciências* **2020**, *92*, e20190615, <https://doi.org/10.1590/0001-3765202020190615>.
17. Parida, R.; Nayak, S. Quantitative and qualitative evaluation of leaf essential oil in micropropagated *Hedychium coronarium* - an endangered medicinal plant. *Research Journal of Pharmacy and Technology* **2022**, *15*, <https://doi.org/10.52711/0974-360X.2022.00648>.
18. Arya, S.; Kumar, R.; Prakash, O.; Kumar, S.; Mahawer, S.K.; Chamoli, S.; Kumar, P.; Srivastava R.M.; de Oliveira, M.S. Chemical composition and biological activities of *Hedychium coccineum* Buch.-Ham. ex Sm. essential oils from Kumaun Hills of Uttarakhand. *Molecules* **2023**, *27*, 4833, <https://doi.org/10.3390/molecules27154833>.
19. Cruz, J.N.; Oliveira, M.S.D.; Cascaes, M.; Mali, S.N.; Tambe, S.; Santos, C.B.R.D.; Zoghbi, M.D.G.B.; Andrade, E.H.D.A. Variation in the chemical composition of endemic specimens of *Hedychium coronarium* J. Koenig from the Amazon and in silico investigation of the ADME/Tox properties of the major compounds. *Plants* **2023**, *12*, 2626, <https://doi.org/10.3390/plants12142626>.
20. Tammasorn, P.; Charoensup, W.; Bunrod, A.; Kanjanakawinkul, W.; Chaiyana, W. Promising anti-wrinkle applications of aromatic extracts of *Hedychium coronarium* J. Koenig via antioxidation and collagenase inhibition. *Pharmaceuticals* **2023**, *16*, 1738, <https://doi.org/10.3390/ph16121738>.
21. Giang, L.D.; Tran-Trung, H.; Chung, N.T.; An, N.T.G.; Van Trung, H.; Van Son, D.; Nguyen, D.K.; Thang, T.D.; Nguyen, T.H.; and Duc, D.X. Chemical composition and antimicrobial activity of essential oils from

- the leaves and rhizomes of *Hedychium yunnanense* Gagnep. (Zingiberaceae) collected in Vietnam. *Journal of Essential Oil Bearing Plants* **2023**, *26*, 1151-1160, <https://doi.org/10.1080/0972060X.2023.2259947>.
22. Tuan, D.Q.; Dinh, D.; Tran, T.N.; Pham, T.V.; Ho, D.V.; Le, N.T.; Le, A.T.; Nguyen, H.T. Chemical composition of essential oil from the *Zingiber monophyllum* (Zingiberaceae) from Vietnam. *Journal of Essential Oil Bearing Plants* **2022**, *25*, 987-993, <https://doi.org/10.1080/0972060X.2022.2132835>.
  23. Aabha, Tewari, G.; Pande, C.; Kanyal, B.; Rana, L.; Singh, S. Impact of drying methods on the chemical profile of *Zingiber officinale* Rosc. rhizome essential oil, *Journal of Essential Oil Bearing Plants* **2022**, *25*, 1-19, <http://doi.org/10.1080/0972060X.2022.2152739>.
  24. Thomas, S.; Bince, M. Chemical composition of rhizome essential oil of Ginger Lily (*Hedychium*) from the Western Ghats, India. *Indian Journal of Natural Products and Resources* **2024**, *14*, <https://doi.org/10.56042/ijnpr.v14i4.5735>.
  25. Deng, M.; Yun, X.; Ren, S.; Qing, Z.; Luo, F. Plants of the genus *Zingiber*: A review of their ethnomedicine, phytochemistry and pharmacology. *Molecules* **2022**, *27*, 2826, <https://doi.org/10.3390/molecules27092826>.
  26. Rout, P.K.; Sahoo, S.; Rath, S.P.; Rao, Y.R. Analysis of the leaf, rhizome and root oils of two accessions of *Alpinia calcarata* Rosc. cultivated at Bhubaneswar. *Journal of Essential Oil Research* **2005**, *17*, 398-400, <https://doi.org/10.1080/10412905.2005.9698941>.
  27. Arambewela, L.S.R.; Kumaratunge, A.; Arawwawela, M.; Owen N. L.; Du, L. Volatile oils of *Alpinia calcarata* Rosc. grown in Sri Lanka. *Journal of Essential Oil Research* **2005**, *17*, 124-125, <https://doi.org/10.1080/10412905.2005.9698850>.
  28. Bhuiyan, N.I.; Begum, J.; Nandi, N.C. Volatile constituents of essential oils isolated from different parts of *Alpinia calcarata* Rosc. *African Journal of Plant Science* **2011**, *5*, 349-352, <https://doi.org/10.5897/AJPS10.109>.
  29. Chandrakanthan, M.; Handunnetti, S.M.; Premakumara, G.S.A.; Kathirgamanathar, S. Topical anti-inflammatory activity of essential oils of *Alpinia calcarata* Rosc., its main constituents, and possible mechanism of action. *Evidence-Based Complementary and Alternative Medicine* **2020**, *7*, 1-19, <https://doi.org/10.1155/2020/2035671>.
  30. Shibila, K.; Aneesha, A.K.; Suma, A.; Anitha, P.; Rashmi, C.R. Morphological and biochemical characterization of *Alpinia calcarata* rhizomes. *Journal of Spices & Aromatic Crops* **2023**, *32*, <https://doi.org/10.25081/josac.2023.v32.i2.8876>.
  31. Wu, X.; Wei, F.; Ding, F.; Yang, N.; Niu, J.; Ran, Y.; Tian, M. Phytochemical analysis, antioxidant, antimicrobial, and anti-enzymatic properties of *Alpinia coriandriodora* (sweet ginger) rhizome. *Frontiers in Plant Science* **2023**, *14*, 1284931, <https://doi.org/10.3389/fpls.2023.1284931>.
  32. Mittal, R.; Goel, P.; Kushwah, A.S.; Ranga, G. Perfumed ginger (*Hedychium spicatum* Sm): An essential oil-bearing plant. *Research Journal of Pharmacognosy and Phytochemistry* **2022**, *14*, 77-88, <https://doi.org/10.52711/0975-4385.2022.00016>.
  33. Ray, A.; Gadnayak, A.; Jena, S.; Sahoo, A.; Patnaik, J.; Panda, P.C.; Nayak, S. *Hedychium spicatum* rhizome essential oil induces apoptosis in human prostate adenocarcinoma PC-3 cells via mitochondrial stress and caspase activation. *Heliyon* **2023**, *9*, e13807, <https://doi.org/10.1016/j.heliyon.2023.e13807>.
  34. Rawat, A.; Kholiya, S.; Chauhan, A.; Kumar, D.; Venkatesha, K. T.; Upadhyay, R. K.; Padalia, R. C. Chemical composition of the essential oil from different plant parts of *Zingiber zerumbet* Sm. grown in the foothills of Uttarakhand. *Biochemical Systematics and Ecology* **2023**, *108*, 104627, <https://doi.org/10.1016/j.bse.2023.104627>.
  35. Sotiboldieva, D.; Mahkamov, T. Component composition of essential oils *Curcuma longa* L. (Zingiberaceae) introduced in Uzbekistan. *American Journal of Plant Sciences* **2020**, *11*, 1247-53, <https://doi.org/10.4236/ajps.2020.118088>.
  36. Huong, L.Y.; Son, N.T.; Sam, L.N.; Phan, N.M.; Luyen, N.D.; Hao N.T.; Dai, D.N. Chemical compositions and antimicrobial activity of essential oils from the leaves of 4 Vietnamese Zingiberaceae species. *Natural Product Communications* **2022**, *17*, 1-6, <https://doi.org/10.1177/1934578X22114591>.
  37. Albaqami, J.J.; Hamdi, H.; Narayanankutty, A.; Visakh, N.U.; Sasidharan, A.; Kuttithodi, A.M.; Famurewa, A.C.; Pathrose, B. Chemical composition and biological activities of the leaf essential oils of *Curcuma longa*, *Curcuma aromatica* and *Curcuma angustifolia*. *Antibiotics* **2022**, *11*, 1547, <https://doi.org/10.3390/antibiotics11111547>.
  38. Das A.; Banik, B.K. Dipole moment in medicinal research: Green and sustainable approach. In: *Green Approaches in Medicinal Chemistry for Sustainable Drug Design* **2020**, *26*, 921-964, <https://doi.org/10.1016/B978-0-12-817592-7.00021-6>.

39. Jasicka-Misiak, I.; Lipok, J.; Nowakowska-Bogdan, E.; Wieczorek, P.P.; Młynarz, P.; Kafarski, P. Antifungal activity of the carrot seed oil and its major sesquiterpene compounds. *Zeitschrift für Naturforschung C* **2004**, *59*, 791-796, <https://doi.org/10.1515/znc-2004-11-1205>.

### **Publisher's Note & Disclaimer**

The statements, opinions, and data presented in this publication are solely those of the individual author(s) and contributor(s) and do not necessarily reflect the views of the publisher and/or the editor(s). The publisher and/or the editor(s) disclaim any responsibility for the accuracy, completeness, or reliability of the content. Neither the publisher nor the editor(s) assume any legal liability for any errors, omissions, or consequences arising from the use of the information presented in this publication. Furthermore, the publisher and/or the editor(s) disclaim any liability for any injury, damage, or loss to persons or property that may result from the use of any ideas, methods, instructions, or products mentioned in the content. Readers are encouraged to independently verify any information before relying on it, and the publisher assumes no responsibility for any consequences arising from the use of materials contained in this publication.