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

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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* had 42 components each, accounting for 94.10% and 92.63% of their respective compositions. The predominant components in *H. coronarium*, *A. calcarata*, and *H. spicatum* were β-pinene (24.62%) 1, 8-cineole (27.48%), and β-pinene (13.93%), respectively. In summary, the three plants of the Zingiberaceae family had high oil yields, and the major components present in all these samples are widely used in industries such as pharmaceuticals and perfumery.

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

1. Introduction

The Zingiberaceae family is well recognized worldwide for its use as a spice and as traditional medicine. The family includes several 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 the attention of researchers. Rhizomes from this family are widely utilised 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 tranquillizing potential [2].

A rhizomatous herb, *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 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 tumours. 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, derived from its leaves, flowers, and rhizome, has strong inhibitory, antibacterial, anti-inflammatory, and analgesic properties. 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]. The use of these herbal medicines offers both health and financial benefits to 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 depending on the genetic profile of the medicinal plant, its altitude, sunlight incidence, culture conditions, and 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 may provide new insights into the use 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).

(a) **(b)** **(c)**

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

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
Hedychium coronarium J. Konig. (Ac. 44221) (HCLJ)	29˚32'N, 79˚50'E	345	Jeolikote (J)	October
Alpinia calcarata Haw. Roscoe (Ac. 17141) (ACLB)	29˚55'N, 79˚38'E	765	Betalghat (B)	May
Hedychium spicatum Buch. Ham. (Ac. 41538) (HSLN)	29˚ 40'N, 79˚ 45'E	2240	Nainital (N)	August

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 analyzed for flavor on a Shimadzu 2010 oil chromatograph equipped with a capillary column (30 m × 0.25 mm × 0.25 µm) and a 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_9-C_{33} 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. The predominant components of the extracted oil were *β*-pinene (24.62%), *α*-pinene (12.34%), *α*-eudesmol (11.08%), *β*-caryophyllene (9.45%), elemol (8.18%), and 1,8-cineole (6.11%). However, *γ*-10-*epi*-eudesmol (3.99%), *γ*-eudesmol (3.94%), *γ*-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%.

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

Sr. No.	RT (min)	Compound	HCLJ	ACLB	HSLN
1.	8.42	*α*-thujene	0.27	ND	ND
2.	8.70	*α*-pinene	**12.34[c] ±0.03**	**2.83[b] ±0.02**	**1.99[a] ±0.01**
3.	9.34	Camphene	0.07	2.80	0.56
4.	10.28	Sabinene	ND	0.19	2.38
5.	10.52	*β*-pinene	**24.62 [b] ±0.04**	**12.74[a] ±0.03**	**13.93 [a] ±0.04**
6.	10.98	Myrcene	0.45	1.13	0.14
7.	11.69	*α*-phellandrene	ND	0.11	ND
8.	12.53	*p*- cymene	0.13	0.22	0.13
9.	12.74	Limonene	ND	3.68	0.77
10.	12.98	1,8-cineole	**6.11[a] ±0.02**	**27.48[c] ±0.05**	**8.99[b] ±0.02**
11.	13.53	*β*-(*E*)-ocimene	0.06	0.88	ND
12.	14.05	*γ*- terpinene	0.04	0.41	ND
13.	14.64	*cis*-sabinene hydrate	0.15	ND	0.25
14.	14.68	*β*-(*E*)-terpineol	0.02	0.11	ND
15.	15.79	6-camphenone	ND	0.10	ND
16.	16.1	Linalool	1.04	0.40	1.29
17.	17.23	*α*-campholenal	0.03	ND	ND
18.	16.46	Verbenol	ND	ND	0.18
19.	18.29	Camphor	ND	**12.20±0.03**	ND
20.	18.61	Camphene hydrate	ND	0.20	ND
21.	18.92	Pinocarveol	0.09	ND	1.64
22.	18.18	*trans*- verbenol	ND	ND	0.30
23.	18.89	Pinocarvone	0.05	0.09	0.34
24.	19.47	Borneol	0.05	1.13	0.70
25.	19.81	Terpinene-4-ol	0.21	0.72	0.37
26.	20.25	Myrtenal	ND	0.06	0.40
27.	20.59	*α*-terpineol	0.89	3.67	ND
28.	22.67	*z*-citral	ND	0.22	0.09
29.	23.84	Geranial	ND	ND	0.09
30.	23.85	2-decenal	ND	0.20	ND
31.	24.51	Bornyl acetate	ND	1.30	ND
32.	27.28	*α*-terpinyl acetate	ND	0.22	ND
33.	28.82	*β*-bourbonene	0.13	ND	ND
34.	29.09	*β*-elemene	0.13	ND	0.41
35.	29.1	Methyl cinnamate	ND	4.01	ND
36.	29.84	*α*-gurjunene	0.07	ND	ND
37.	30.36	*β*-caryophyllene	**9.45[c] ±0.03**	**0.40[a]**	**2.08[b] ±0.02**
38.	30.8	*cis*-*β*-copaene	0.04	ND	ND
39.	30.8	*β*-gurjunene	ND	ND	0.29
40.	30.95	*α*-trans bergamotene	ND	0.21	ND
41.	31.79	*β*-(*E*)-farnesene	ND	0.84	ND
42.	31.86	*α*-humulene	**1.22[a] ±0.01**	ND	**8.78[b] ±0.04**
43.	32.04	9-*epi*-(*E*)-caryophyllene	1.94	ND	0.32
44.	32.97	*γ*-amorphene	2.17	ND	ND
45.	33.24	*β*-selinene	ND	ND	1.62
46.	33.26	*γ*-gurjunene	0.09	ND	ND
47.	32.54	Dauca-5,8-diene	ND	0.21	ND
48.	33.54	*α*-selinene	ND	0.11	1.42
49.	33.58	Bicyclogermacrene	2.19	ND	ND
50.	34.24	*γ*-cadinene	0.04	ND	0.18
51.	34.03	Cubebol	ND	0.58	0.47
52.	34.25	*δ*-cadinene	0.3	0.31	ND

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

RT = Retention time, ND = Not detected

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

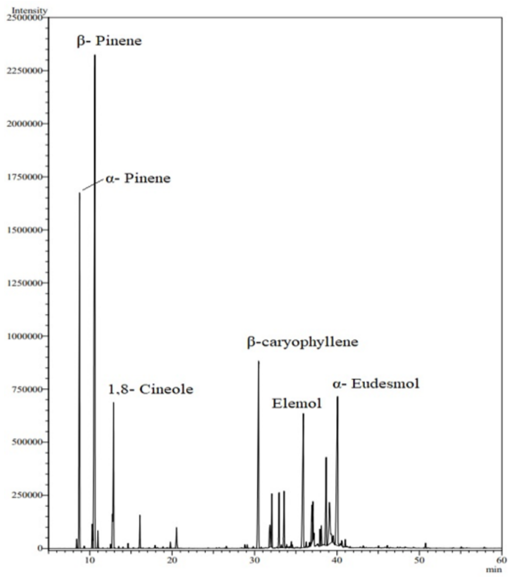

Figure 2. GC chromatogram of HCLJ essential oil.

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 94.10% of the composition. *A. calcarata* essential oil had an ample amount of 1,8-cineole (27.48%), *β*-pinene (12.74%), camphor (12.20%), and carotol (9.08%). Methyl cinnamate (4.01%), limonene (3.68%), *α*-terpineol (3.67%), camphene (2.79%), and *β*-eudesmol (2.73%) were found as minor constituents (Figure 3 and Table 2). The oil content of the leaves was 0.16%.

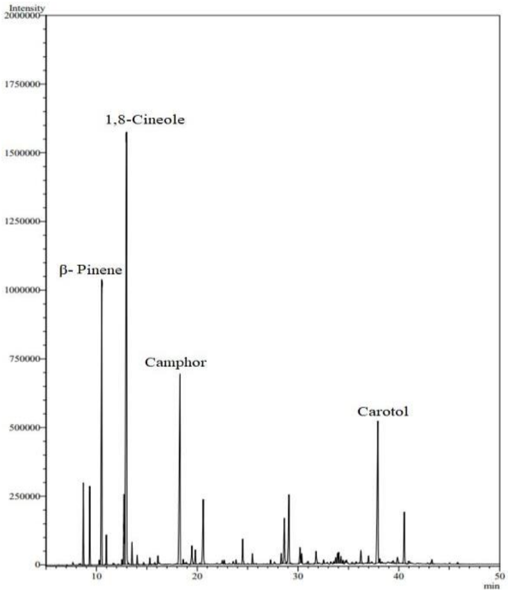

Figure 3. GC chromatogram of ACLB essential oil.

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

The analysis identified forty-two compounds representing 92.63% of the composition. The leaf oil had a yield of 0.20% (v/w). *β*-Pinene (13.93%), elemol (12.90%), 1,8-cineole (8.99%), *α*-humulene (8.78%), *α*-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%), γ-10-epi-eudesmol (2.64%), sabinene (2.38%), maaliol (2.13%), β-caryophyllene (2.08%), and α-pinene (1.99%) (Figure 4 and Table 2).

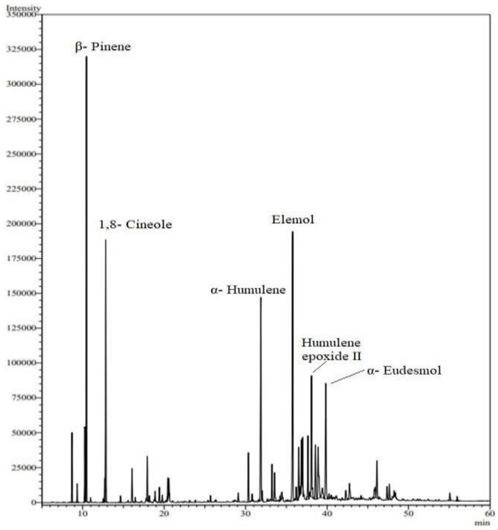

Figure 4. GC chromatogram of HSLN essential oil.

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 *β*-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 *β*-pinene followed the order: *H. coronarium* >*H. spicatum* >*A. calcarata*. The major components, camphor and carotol, were present only in *A. calcarata*, while *α*-humulene and *α*-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 *γ*-eudesmol (2.93%), bicyclogermacrene (2.19%), *γ*-amorphene (2.17%), 5-*epi*-7-*epi*-*α*-eudesmol (0.82%), globulol(0.73%), agarospirol (0.37%), *α*-thujene (0.27%), *β*-bourbonene (0.13%), *γ*-gurjunene (0.09%), *α*-gurjunene (0.07%), *cis*-*β*-copaene (0.04%) and *α*-campholenal (0.03%) were present only in *H. coronarium*. Six minor components, including limonene, sabinene, *α*-selinene, cubebol, *z*-citral, and myrtenal, were absent in *H. coronarium*. Sixteen minor components such as methyl cinnamate (4.01%), *β*-eudesmol (2.73%), bornyl acetate (1.30%), *β*-(*E*)-farnesene (0.84%), cadinol (0.48%), *β*-caryophyllene (0.43%), cedroxyde (0.28%), *α*-*epi*-muurolol (0.26%), *α*-terpinyl acetate (0.22%), *α*-*trans*-bergamotene (0.21%), *α*-*epi*-bisabolol (0.21%), dauca-5,8-diene (0.21%), camphene hydrate (0.20%), 2-decenal (0.20%), *α*-phellandrene (0.11%) and 6-camphenone (0.10%) were present only in *A. calcarata*. Seven minor compounds, namely 10-*epi*-*γ*-eudesmol, spathulenol, 9-*epi*-(*E*)-caryophyllene, pinocarveol, *cis*-sabinene hydrate, *β*-elemene, and *γ*-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%), *β*-selinene (1.62%), *Ʈ*-muurolol (0.96%), oplopanone (0.94%), *trans*-verbenol (0.30%), *β*-gurjunene (0.29%), 7-*epi*-*α*-eudesmol (0.24%), verbenol (0.18%) and geranial (0.09%) were found to be present only in *H. spicatum* while five components namely *β*-(*E*)-Ocimene, *γ*-terpinene, *β*-(*E*)-terpineol, *α*-terpineol, and*δ*-cadinene were absent in *H. spicatum*.

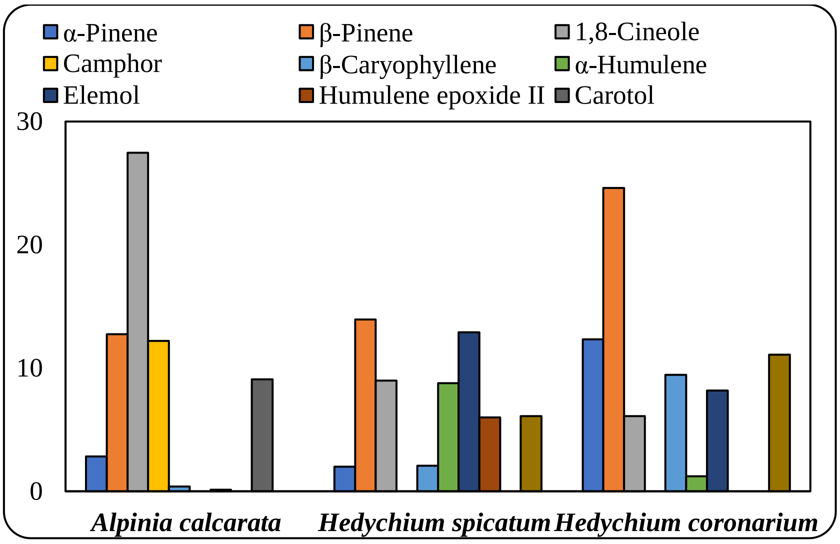

Figure 5. Variation in the major components in the selected species.

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).

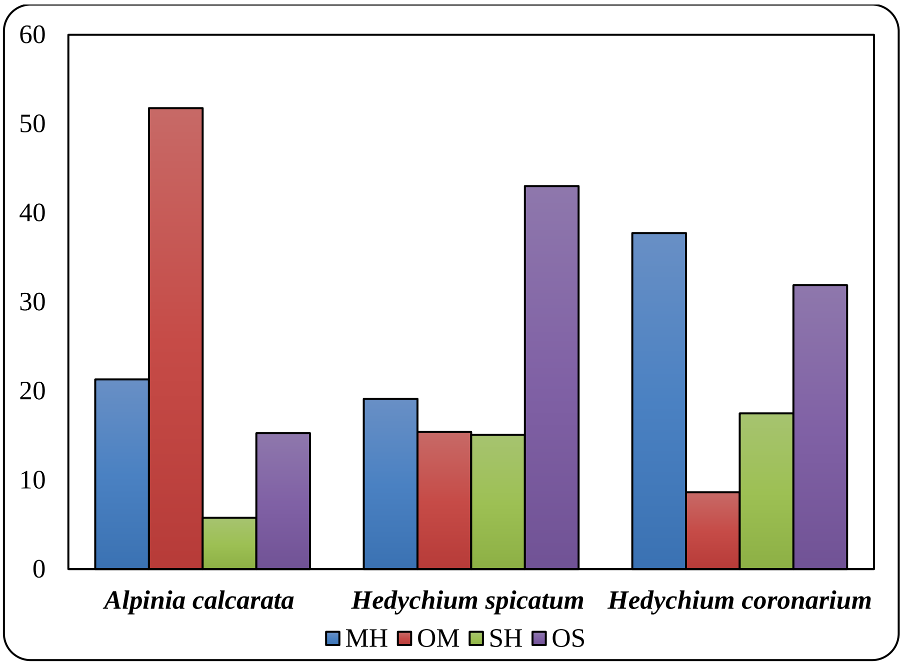

Figure 6. Variation in the class of compounds among the species.

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: *β*-Pinene (13.93-24.62%), elemol (8.18-12.9%), 1,8-cineole (6.11-8.99%), *α*-eudesmol (6.10-11.08%), *β*-caryophyllene (2.08-9.45%), *α*-humulene (1.22-8.78%)

Cluster 2: 1,8-Cineole (27.48%), *β*-pinene (12.74%), camphor (12.20%), carotol (9.08%).

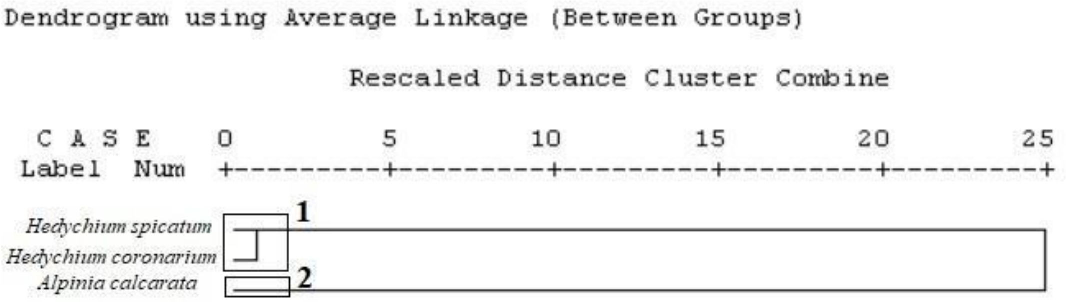

Figure 7. Cluster analysis of the oils.

4. Discussion

In the present investigation, the volatile profile of HCLJ was characterized by six main compounds: β-pinene, α-pinene, α-eudesmol, β-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 β-caryophyllene, caryophyllene oxide, and β-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]. Chemical compounds such as β-pinene, linalool, 1,8-cineole, α-pinene, and α-terpineol were identified in the leaf essential oil of *H. coronarium* grown in Vietnam [14]. A study conducted in Uttarakhand, India, revealed that β-pinene (44.1%), α-pinene (23.0%), β-caryophyllene (13.4%), sabinene (6.1%), and 1,8-cineole (5.1%) were the predominant chemicals in the oil of H. coronarium leaves [15]. In another study, the main flavor compounds were 1,8-cineole (2.68%), *β*-pinene (14.78%), caryophyllene (12.95%), and *β*-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 *α*-pinene (5.13%) as the compounds with percentages 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, *α*-farnesene, *α*-pinene, spathulenol, and *β*-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, β-pinene and (*E*)-caryophyllene were recorded as the most abundant components of leaf oil [19]. Further, in a report from Thailand, eucalyptol was found to be the predominant compound in the rhizome oil, and (E)-caryophyllene was the primary compound in the leaf essential oil of *H. coronarium* [20]. Additionally, β-pinene, α-pinene, and β-caryophyllene were present in plentiful amounts in the leaves' essential oil of *H. yunnanense* [21]. β-Pinene, borneol, α-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, β-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 β-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, *α*-eudesmol and elemol (8.18%) were recorded as the predominant chemicals in *H. coronarium* leaf oil.

Research on *Alpinia calcarata* Rosc. essential oils have yielded diverse compositional profiles. Leaf oil analyses of *A. calcarata* Rosc. cultivated at Bhubneshwar have consistently identified 1,8-cineole and β-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 β-pinene as major bioactive compounds, comprising up to 24.7% and 20.5%, respectively [27]. Furthermore,1,8-cineole, camphor, methyl cinnamate, carotol, and *β*-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 identified 1,8-cineole, *α*-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 δ-cadinene, *γ*-cadinene, 1,8-cineole, cubenol, *α*-eudesmol, 10-*epi*-*γ*-eudismol, and germacrene D-4-ol [2]. Verma and Padalia suggested that *β*-pinene, 1,8-

cineole, and *α*-pinene were present in a significant amount (>9%) in *H. spicatum* leaf essential oil [9]. However, in the present study, *β*-pinene (13.93%), elemol (12.89%), 1,8-cineole (8.99%), *α*-humulene (8.78%), and *α*-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, ß-pinene, myrcene, and α-phellandrene [32]. According to Ray *et al*., *β*-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 *the chloroform extract of H. spicatum rhizome and reported curcumenone and coronarin as the most abundant components* [34].

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

High *β*-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. 1,8-Cineole, β-pinene, camphor, and carotol were the main components and indicate the aromatic and bioactive properties of *A. calcarata*. On the other hand, the *H. coronarium* and *H. spicatum* essential oils were reported to have β-pinene, 1, 8 cineole elemol, and *α*-eudesmol as the major compounds. This comparative study of the three species highlights the diversity and similarities in chemical characteristics within the family, indicating that these plants could be useful as a natural source of phytoconstituents. Sesquiterpenes predominated in *H. spicatum* and *H. coronarium*, whereas monoterpenes were abundant in *A. calcarata*. Notably, 1,8-cineole and β-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, A.G., G.T. and C.P.; methodology, A.G.; software, G.T., and A.G.; B.K. 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.; N.N.; visualization, A.G.; G.C. K.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.

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Data Availability Statement

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

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Conflicts of Interest

The authors declare no conflict of interest.

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