A Systematic Review on Volatile Components and Therapeutic Properties of the Genus *Alpinia* (Zingiberaceae)

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Received: July 5, 2025
Accepted: September 12, 2025

The genus *Alpinia* (Zingiberaceae) is a prolific source of aromatic and medicinal compounds, particularly through its essential oils, which are rich in monoterpenes, sesquiterpenes, and other bioactive volatiles. This systematic review consolidates current knowledge on the chemical composition, biological activities, and ethnopharmacological relevance of *Alpinia* essential oils. Following PRISMA guidelines, a comprehensive literature search was conducted across Scopus, PubMed, and Google Scholar. The essential oils of 37 *Alpinia* species primarily from Vietnam, India, and China were chemically characterized, with dominant compounds including β-pinene, 1,8-cineole, α-pinene, and γ-terpinene. Malaysian species were highlighted for their phytochemical richness and high oil yields. Pharmacologically, *Alpinia* essential oils exhibit a wide range of bioactivities, notably antioxidant, anti-inflammatory, antibacterial, antifungal, anticancer, and antidiabetic effects, aligning with their extensive traditional use in treating digestive, inflammatory, and infectious diseases. Despite growing interest, gaps remain in understanding the mechanisms of action, toxicity profiles, and clinical relevance of these oils. This review underscores the therapeutic promise of *Alpinia* essential oils and calls for further in vivo, mechanistic, and clinical studies to support their development as standardized phytotherapeutic agents.

Keywords: Zingiberaceae, *Alpinia*, essential oil, bioactive compounds, monoterpenes, antioxidant

1. INTRODUCTION

Essential oils, produced as secondary metabolites by aromatic plants, are complex mixtures of low-molecular-weight compounds that exhibit significant biological activities, including antioxidant, antimicrobial, antiviral, and anticancer properties [1]. These oils are predominantly composed of terpenoid compounds, primarily monoterpenes and sesquiterpenes, alongside various alcohols, aldehydes, ketones, ethers, esters, and phenols. These constituents not only contribute to the distinctive aroma and scent of essential oils but also play a vital role in the fragrance of spices and condiments. Moreover, essential oils are widely used for their repellent properties in the development of natural insecticides and herbicides [2]. Among the diverse plant families that produce essential oils, the Zingiberaceae family stands out as a rich source of bioactive constituents. Essential oils derived from different parts of Zingiberaceae species have been shown to possess a broad spectrum of pharmacological activities.

The Zingiberaceae family, commonly referred to as the ginger family, comprises over 50 genera and more than 1,600 species of perennial herbaceous plants characterized by creeping horizontal or tuberous rhizomes [3]. These plants are predominantly distributed across tropical regions of Asia, Africa, and the Americas, with Southeast Asia serving as a major center of diversity. Within this region, the Malaysian floristic zone, which includes Brunei, Indonesia, Papua New Guinea, Peninsular Malaysia, the Philippines, and Singapore, hosts the highest concentration of Zingiberaceae genera and species [4]. Among the countries in this zone, Malaysia records the greatest richness, with at least 150 species across 21 genera, followed by Indonesia (113 species, 24 genera), Thailand (30 species, 11 genera), and Vietnam (26 species, 8 genera) [5]. Members of this family hold considerable economic and cultural significance. They are widely used as ornamental plants and culinary spices, most notably ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*), as well as in various traditional medicinal systems (Kress, 2008). Notable genera with established ethnopharmacological relevance include *Alpinia*, *Amomum*, *Curcuma*, *Elettaria*, *Hedychium*, *Kaempferia*, and *Zingiber*, which are frequently investigated for their therapeutic properties [6].

The genus *Alpinia* represents the largest and most extensively distributed genus within the Zingiberaceae family, comprising approximately 230 species [7]. Species within this tribe are evergreen herbs characterized by the absence of an abscission layer between the rhizome and the leafy shoots. The leaves are positioned in a plane that is transverse to the direction of rhizome growth. The flowers generally possess very small lateral staminodes, which may appear as slight swellings at the base of the labellum or be completely absent. Extrafloral nectaries are lacking, and the fruits are typically fleshy, spherical, and indehiscent. The natural range of this genus extends from Sri Lanka and the Western Ghats of India to regions such as China, Japan, Southeast Asia, and across the Pacific Islands, reaching as far as Fiji, Samoa, and the Caroline Islands, as well as northern New South Wales in Australia [8]. Among the numerous species within the Zingiberaceae family, several well-known examples include bitter ginger (*Zingiber zerumbet*), galangal (*Alpinia galanga*), ginger (*Zingiber officinal*), patumma or Siam tulip (*Curcuma alismatifolia*), and turmeric (*Curcuma longa*) [9].

Traditionally, species of *Alpini*a have been widely used in the treatment of various ailments, including bronchitis, eczema, colitis, ulcers, digestive disorders, and cholera, as well as for their antioxidant properties [10]. The traditional applications of various well-known *Alpinia* species vary significantly across regions. *A. galanga* is particularly renowned in Southeast Asian countries such as Indonesia, Thailand, and Malaysia. *A. zerumbet* has a long-standing history of use in the Ayurvedic medicinal system in India. In contrast, *A. oxyphylla* is prominently utilized in traditional Chinese medicine. Additionally, species such as *A. officinarum*, *A. calcarata* and *A. purpurata* are commonly employed in traditional practices across diverse regions, including Asia, Africa, and Latin America [11]. Due to their remarkably rich phytochemical composition, *Alpinia* species are consistently and extensively valued for their potent medicinal and diverse biological activities, primarily attributed to their highly aromatic and therapeutically significant essential oils.

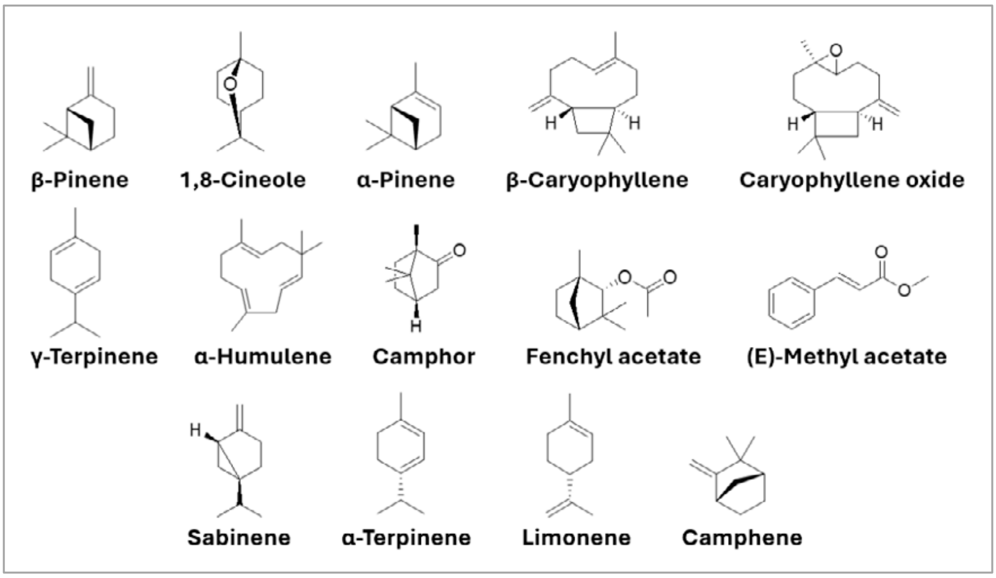

Figure 1. Chemical structures of major constituents found in *Alpinia* essential oils

Recently, essential oils and other aromatic compounds derived from plants have gained increasing attention for their potential use in alternative medicine. Therefore, a review on *Alpinia* essential oils is necessary to consolidate and simplify the available information. Relevant data were gathered through electronic searches of scientific databases, including Scopus, PubMed, and Google Scholar. This review aims to provide a comprehensive overview of published findings on the chemical composition, biological activities, and medicinal applications of essential oils extracted from various *Alpinia* species. While this review provides a global perspective, special attention is given to Malaysian species. Malaysia lies within the floristic center of Zingiberaceae diversity, yet many of its *Alpinia* species remain comparatively underexplored relative to those from Vietnam, India, and China. Highlighting the Malaysian representatives therefore adds regional significance, addresses a gap in the literature, and underscores their potential for both chemotaxonomic and pharmacological investigations.

2. SEARCH STRATEGY

The protocol for performing this study was developed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) [12]: (a) the first step was to exclude duplicate articles, (b) titles and abstracts were then read and the inclusion and exclusion criteria were applied, (c) all articles resulting from this stage were read in full, and the inclusion and exclusion criteria were applied again. Following this step, we reached the articles chosen for the present study. This systematic review was conducted through searches using Scopus, PubMed, and Google Scholar. The keywords used were '*Alpinia*', 'essential oil', and 'biological activity' articles over the period from the beginning of the database until June 2025. In addition, as a second search strategy, we included studies obtained by a manual search of the reference lists of the included studies. Articles on the genus of *Alpinia* that reported traditional uses, essential oils, and their biological activities were included. The inclusion of articles considered the following criteria: (1) type of publication - original journal articles, (2) only articles in English (3), articles must present the chemical composition of essential oils, (4) articles must discuss the biological activity of the essential oils. The following were used as the exclusion criteria: (1) articles that did not show the search terms in the title and in the abstract; (2) review articles (3) full-text articles not found, (4) articles without one of the keywords, and (5) articles that did not show the composition of the essential oils.

3. MEDICINAL USES OF GENUS *ALPINIA*

The traditional medicinal applications of *Alpinia* species are deeply rooted in various ethnobotanical practices across Asia. Table I shows the medicinal uses of *Alpinia* species across different geographical regions, illustrating the genus's widespread ethnopharmacological significance. China emerges as the most frequently mentioned country. Several species such as *A. blepharocalyx*, *A. oxyphylla*, *A. katsumadai* and *A. kwangsiensis* are commonly used in Chinese traditional medicine for treating digestive ailments, urinary issues, oxidative stress, and kidney-related conditions [13-16]. Vietnam also holds a significant place, where species like *A. breviligulata*, *A. globosa*, *A. oxymitra*, and *A. tonkinensis* are traditionally used to relieve abdominal pain, nausea, indigestion, arthritis, and inflammation [17-19]. India demonstrates consistent use of *A. galanga* in Ayurvedic medicine, targeting eczema, bronchitis, gastrointestinal disturbances, and skin infections [20]. Other countries with notable ethnomedicinal practices involving *Alpinia* include Malaysia (*A. pahangensis*) [21], Indonesia (*A. malaccensis*) [22], Japan (*A. intermedia*) [23] and Taiwan (*A. japonica*, *A. nantoensis*) [24, 25].
Among the wide range of medicinal claims, the most consistently reported traditional use is for treating digestive-related disorders. Species such as *A. allughas*, *A. globosa*, *A. breviligulata*, *A. mutica*, *A. oxyphylla*, *A. suishaensis*, and *A. vietnamica* are frequently cited for their effectiveness in managing indigestion, stomach discomfort, vomiting, flatulence, and diarrhea [26, 27]. Inflammatory conditions and rheumatic pain are also commonly addressed using species like *A. jianganfeng* and *A. nantoensis* [25, 28]. Notably, the rhizome stands out as the most widely used plant part, featured in nearly every species documented. Rhizomes are traditionally employed to alleviate a broad spectrum of conditions, including digestive issues (*A. globosa*), respiratory ailments (*A. smithiae*), pain and inflammation (*A. chinensis*), and infections (*A. macroura*), likely due to their rich content of volatile oils and bioactive compounds.
In terms of historical documentation, the traditional uses of *Alpinia* species have been reported over a wide time span, reflecting both enduring traditional knowledge and growing modern scientific interest. Early records such as those of *A. chinensis* and *A. jianganfeng* date back to 1997 and 2002 respectively [29], while recent studies on species like *A. breviligulata* and *A. oxyphylla* [17, 30] indicate a resurgence of interest in these plants within the context of essential oil research and phytotherapy. Collectively, this ethnopharmacological diversity and the widespread use of *Alpinia* rhizomes reinforce their value as promising candidates for further investigation into their essential oil composition and bioactivity.

Table I - Medicinal uses of *Alpinia* species

Species	Part	Medicinal Uses
A. allughas	Rhizome	Traditionally used for the treatment of gout, colic, rheumatism, bronchial inflammation, digestive disorders, and respiratory issues, particularly in children [26]
A. blepharocalyx	Seed	Traditionally used in Chinese medicine to treat stomach disorders [13]
	Rhizome	Traditionally utilized to treat skin conditions [31]
A. blongifolia	Rhizome	Used to stimulate digestion and treat abdominal pain caused by cold, stomach aches, cough, respiratory inflammation, arthritis, and muscle pain [18]
A. breviligulata	Rhizome	Used in traditional Vietnamese medicine to treat abdominal pain by either drinking water infused with it or applying it topically to the abdomen [17]
A. calcarata	Rhizome	It is commonly used to treat cough, respiratory conditions, bronchitis, asthma, arthritis, and diabetes [32]
A. chinensis	Rhizome	Traditionally used asthma-relieving and analgesic (pain-relieving) properties [29]
A. conchigera	Rhizome	Traditionally utilized for post-partum care, managing fungal and skin infections [33]
A. elegans	Rhizome	Traditionally used to treat musculoskeletal diseases, haemoptysis (coughing up blood), headaches, stomach aches, and to prevent relapse in women [34]
A. galanga	Rhizome	Traditionally utilized in Ayurveda medicine for treating eczema, bronchitis, colds, measles, pityriasis versicolor, ear infections, gastritis, ulcers, and cholera [20]
A. globosa	Rhizome	Used in Vietnam as anti-nausea [18]
	Fruit	Used to treat stomach aches, indigestion, dysentery, abdominal pain, cholera, vomiting, and premature ejaculation [18]
A. hainanensis	Rhizome	Nutritional and dietary supplement for managing ulcerative colitis [35]
A. hankei	Rhizome	Traditionally used to treat fever and gastrointestinal discomfort [27]
A. intermedia	Rhizome	Traditionally used to relieve the symptoms of physical exhaustion, upper respiratory infection and other illnesses [36]
A. japonica	Root	Traditionally employed to dispel dampness, reduce swelling, pain relief, and improve blood circulation to clear meridian blockages. It has been used in treating dyspepsia, rheumatoid arthritis and traumatic injuries [24]
A. jianganfeng	Rhizome	Used in traditional Chinese medicine to treat rheumatism [28]
A. katsumadai	Seed	Markedly reducing oxidative stress and enhancing retinal function, it is also utilized in Chinese medicine to aid digestion, prevent nausea, soothe skin irritation, and treat gastric disorders [15]
A. kwangsiensis	Rhizome	In Chinese traditional medicine, it is used to treat abdominal pain, stomach cold-induced vomiting, and traumatic injuries [16]
A. latilabris	Rhizome	Traditionally used as a folk remedy for treating gastrointestinal diseases [37]
A. macroura	Rhizome	Used to treat wounds, reduce fever, and manage intestinal infections [38]
A. malaccensis	Fruit	Historically utilized to prevent nausea and vomiting [22]
	Leaf	Acts to freshen mouth and prevent vomiting [22]
	Rhizome	Used as hair oil and massage oil [22]
A. monopleura	Rhizome	Utilize to reduce body aches [39]
A. mutica	Rhizome	Traditionally utilized by locals to alleviate stomach gas issues [40]
	Fruit	Utilized to minimize inflammation [40]
A. nantoensis	Rhizome	Traditionally employed to ease pain, treat rheumatoid arthritis, support bruise healing, reduce toothache discomfort, and soothe stomach issues [25]
	Flower	Traditionally used to aid digestion, relieve gastric disorders, and counteract the effects of food or drug poisoning [25]
	Fruit	Traditionally used to dispel dampness, reduce vomiting, relieve diarrhea and nausea, and enhance appetite [25]
A. nigra	Root	Traditionally mixed with rice whisky and applied to the skin to treat fungal infections such as ringworm and melasma, it is also used in traditional medicine to manage gastric ulcers and jaundice [20]
	Rhizome	Used to treat obesity [41]
A. nutans	Rhizome	Widely used in folk medicine, primarily for treating indigestion, intestinal disorders, and high blood pressure [42]
A. officinarum	Rhizome	Involved in regulating nociception, respiratory defense mechanisms and gastrointestinal protection, it is also used for treating arthritis and microbial infections [43]
A. oxymitra	Flower	Used to treat arthritis [18]
	Rhizome	Traditionally used as a carminative and a remedy for diarrhoea [44]
A. oxyphylla	Rhizome	Helps enhance the effectiveness of nootkatone in preventing acute kidney injury [30]
	Fruit	Traditionally used to treat kidney deficiency, urinary issues, gonorrhea, digestive disorders, and excessive saliva production, it is also used for healing ulcers and managing dementia [14]
A. pahangensis	Rhizome	Used to treat flatulence [21]
A. pinnanensis	Rhizome	Used to treat coughs, fever, abdominal pain, flatulence, and stomach aches [38]
A. pricei	Rhizome	Possesses the ability to reduce and prevent hypercholesterolemia and is also used to alleviate abdominal discomfort, stimulate stomach secretions, and promote peristalsis [25]

Table I - Continues

A. purpurata	Inflorescence	It is consumed to relieve cough symptoms [45]
	Rhizome	Used to treat headaches, rheumatism, sore throat, and kidney infections [45]
A. rafflesiana	Rhizome	Utilized to treat nausea, vomiting, ulcers, and bacterial infections [46]
A. rugosa	Rhizome	Used to treat stomach ailments and nausea [27]
A. smithiae	Rhizome	Used in folk medicine for treating respiratory infections [27]
A. suishaensis	Rhizome	Used to help with digestive issues, improve circulation, and ailments related to wind or cold in traditional herbal formulation [28]
A. tonkinensis	Rhizome	Used to treat stomach aches, indigestion, and arthritis [18]
A. tonrokuensis	Rhizome	Used to treat fevers, muscle spasms, intestinal gas, and inflammation [27]
A. velutina	Rhizome	Used to treat digestive issues, respiratory conditions, and infections [27]
A. villosum	Rhizome	Protective substances for the digestive system [13]
A. vietnamica	Rhizome	The essential oil used for traditional, food, and medicinal purposes [27]
A. vitellina	Rhizome	Traditionally used to relieve stomach pain and indigestion [27]
A. zerumbet	Rhizome	Traditionally used in medicine to treat colds, flu, fever, flatulence, stomach issues, indigestion, cardiovascular diseases, high blood pressure, and inflammation, it also serves as an antispasmodic agent and plays a role in preventing atherosclerosis [47]

4. CHEMICAL COMPOSITION OF *ALPINIA* ESSENTIAL OILS

A comprehensive overview of the chemical compositions identified from the essential oils of 37 unique *Alpinia* species is provided in Table II, highlighting the genus's rich phytochemical diversity and the global interest in its bioactive constituents [48-96]. These species have been investigated across 11 countries, with Vietnam reporting the highest number (18 species), followed by India (8 species) and China (6 species). Additional studies have emerged from Indonesia and Brazil (3 species each), Taiwan (2 species), and one species each from Japan, Thailand, Sri Lanka, Egypt, and France. While certain species such as *A. galanga* and *A. zerumbet* were examined in multiple countries, each was counted only once in the total. This distribution underscores Southeast and South Asia, particularly Vietnam, India, and China, as key hotspots for *Alpinia* essential oil research, reflecting both regional biodiversity and longstanding ethnomedicinal significance.

The essential oil compositions are classified into six major chemical groups, which are monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, esters, and others. Among these, monoterpene hydrocarbons were the most frequently dominant across the *Alpinia* species.

The most frequently reported compounds across the *Alpinia* species are dominated by monoterpene hydrocarbons and oxygenated monoterpenes. β-Pinene, a monoterpene hydrocarbon, was among the most common constituents and was found in *A. allughas* [48], *A. maclurei* [72], and *A. breviligulata* [17]. Another widely detected compound was 1,8-cineole, an oxygenated monoterpene, which occurred in multiple species including *A. nelumboides*, *A. vietnamica*, and *A. zerumbet* [78, 89, 91]. α-Pinene, also a monoterpene hydrocarbon, was reported in the oils of *A. breviligulata* and *A. macroura* [38], while limonene, from the same group, was detected in *A. napoensis* and *A. macroura* [38, 77]. Additionally, γ-terpinene, another frequently reported monoterpene hydrocarbon, was found in *A. napoensis*, *A. strobiliformis*, and *A. zerumbet* [31, 77, 93].

In terms of chemical richness, the rhizome essential oil of *A. officinarum* collected from China had the highest number of identified components, with 75 compounds accounting for 93.1% of its essential oil [81]. This was followed by the leaf essential oil of *A. nelumboides* from Vietnam, which contained 74 components comprising 88.1% of the oil [78] and the leaf essential oil of *A. nigra* from India, which consisted of 52 components with a concentration of 96.4% [79]. Regarding essential oil yield, the rhizome of *A. malaccensis* from Indonesia showed the highest yield at 1.22%, followed by the fruit of *A. monopleura* from Indonesia at 1.34%, and the fruit of *A. mutica* from India at 0.9% [22, 74, 75]. These findings highlight the commercial and therapeutic potential of selected *Alpinia* species, especially those with both high yield and diverse chemical constituents.

5. ANALYTICAL METHODS AND RELIABILITY

Volatile components were identified primarily by gas chromatography-mass spectrometry (GC-MS), using electron-impact spectra matched to commercial libraries (e.g., NIST/Wiley) in conjunction with calculated linear (Kovats) retention indices (RIs); where available, identities were confirmed by co-injection of authentic standards. GC-MS therefore served as the main qualitative tool and is regarded as the most widely used and reliable approach for volatile profiling in *Alpinia* oils summarized here. Relative abundances were typically obtained by GC-FID with peak-area normalization (semi-quantitative), which is appropriate for comparisons within a study but can vary across studies due to differing response factors. These practices underlie the species-level composition summaries and tables compiled in this review.

Table II - Major components identified from *Alpinia* essential oils

Species	Locality (Part)	Total (%)[a]	Yield (%)	Group (%)[b]	Major components (%)
A. allughas	India (Rhizome)	16, 90.0	NM	MH, 68.5	β-Pinene (55.3%), α-pinene (9.7%) [48]
	India (Leaf)	18, 90.0	NM	MH, 32.1	β-Pinene (25.5%), α-pinene (5.4%) [48]
	India (Rhizome)	22, 85.2	NM	MH, 68.5	β-Pinene (55.3%), α-pinene (9.7%), 7-*epi*-α-eudesmol (4.1%) [49]
	India (Leaf)	42, 88.0	NM	MH, 31.3	β-Pinene (25.5%), 1,8-cineole (23.3%), α-humulene (9.7%) [49]
A. brephrocalyx	Vietnam (Leaf)	41, 93.3	0.15	SH, 49.3	β-Pinene (12.0%), τ-muurolol (4.0%), α-cadinol (3.0%) [31]
	Vietnam (Pseudostem)	38, 99.6	0.11	SH, 58.2	β-Pinene (10.4%), τ-muurolol (9.5%), α-cadinol (9.5%) [31]
	Vietnam (Rhizome)	37, 98.4	0.15	OS, 27.5	β-Pinene (9.5%), τ-muurolol (11.2%), α-cadinol (11.2%) [31]
A. breviligulata	Vietnam (Flower)	35, 87.9	0.30	MH, 68.2	α-Pinene (12.7%), β-pinene (20.2%), β-caryophyllene (14.0%) [50]
	Vietnam (Leaf)	NM, 92.4	0.31	OS, 31.9	α-Pinene (19.4%), caryophyllene oxide (15.1%), α-copaene (8.5%) [17]
	Vietnam (Stem)	NM, 97.4	0.12	OS, 62.4	Caryophyllene oxide (27.7%), humulene epoxide II (6.4%), α-copaene (5.4%) [17]
	Vietnam (Rhizome)	NM, 98.3	0.10	MH, 46.6	α-Pinene (5.5%), camphene (10.3%), limonene (4.5%) [17]
	Vietnam (Root)	NM, 89.6	0.11	MH, 29.3	α-Humulene (12.3%), camphene (10.3%), *endo*-fenchyl acetate (9.4%), β-caryophyllene (7.0%), α-pinene (5.5%) [17]
	Vietnam (Leaf)	40, 97.2	0.25	NM	Caryophyllene oxide (23.1%), α-pinene (17.7%) [50]
	Vietnam (Rhizome)	35, NM	0.08	NM	β-Pinene (11.1%), caryophyllene oxide (10.5%), β-caryophyllene (8.0%), α-humulene (7.9%), borneol (7.0%) [51]
	Vietnam (Root)	35, NM	0.05	NM	Caryophyllene oxide (13.0%), α-humulene (10.8%), fenchyl acetate (8.8%), β-caryophyllene (7.5%), 1,8-cineole (6.0%), borneol (5.5%) [51]
A. calcarata	India (Rhizome)	15, 83.1	0.48	NM	1,8-Cineole (25.7%), ethyl *iso*-allocholate (16.0%), fenchyl acetate (15.1%) [52]
	India (Root)	69, 98.3	0.88	OM, 66.9	Fenchyl acetate (49.8%) [53]
A. chinensis	Vietnam (Flower)	30, 99.0	0.86	S, 95	(*E,E*)-α-farnesene (26.5%), α-humulene (22.3%), β-bisabolene (17.1%), β-caryophyllene (13.1%) [54]
	Vietnam (Leaf)	40, 98.9	0.08	S, 69.7	β-bisabolene (47.9%), (*E,E*)-farnesyl acetate (6.6%), *trans*-β-farnesene (6.6%), β-pinene (5.1%) [55]
	Vietnam (Root)	19, 99.4	0.06	S, 51.2	Caryophyllene oxide (13.2%), β-bisabolene (10.4%), γ-selinene (8.6%), α-humulene (6.2%), β-caryophyllene (5.2%), valencene (5.2%), juniper camphor (4.4%) [56]
A. coriandriodora	China (Rhizome)	32, 92.0	NM	NM	β-Pinene (27.9%), 1,8-cineole (17.3%), *p*-Cymene (13.5%), camphene (7.3%), myrcene (5.4%) [57]
A. gagnepainii	Vietnam (Leaf)	46, 95.8	0.02	MH, 72.8	β-Pinene (27.0%), α-pinene (17.6%), limonene (6.8%) [58]
	Vietnam (Rhizome)	49, 98.3	0.01	MH, 54.2	β-Pinene (20.4%), α-pinene (13.6%), fenchone (13.0%) [58]
A. galanga	China (Flower)	57, 96.0	0.11	SH, 69.6	α-Farnesene (64.3%), farnesyl acetate (3.6%), eugenol acetate (3.2%), eugenol (3.1%), *E*-nerolidol (2.9%) [59]
	Vietnam (Leaf)	NM	0.11	NM	(*E,E*)-Farnesyl acetate (39.6%), β-caryophyllene (15.8%), caryophyllene oxide (7.4%), β-elemene (5.6%), (*E*)-phytol (4.5%) [60]
	Vietnam (Leaf)	NM	0.12	NM	(*E,E*)-Farnesyl acetate (33.1%), β-caryophyllene (20.0%), β-elemene (8.6%), germacrene D (5.6%), caryophyllene oxide (5.3%) [60]
	Vietnam (Rhizome)	NM	0.26	NM	1,8-Cineole (42.5%), indan-5-ol (20.2%), α-pinene (4.7%) [60]
	Vietnam (Root)	NM	0.13	NM	Caryophyllene oxide (20.3%), β-pinene (9.0%), 7-*epi*-α-selinene (7.2%), β-caryophyllene (5.7%), selin-11-en-4α-ol (4.7%) [60]

Table II - Continues

A. galanga	Thailand (Leaf)	25, 95.7	0.25	NM, 80.4	β-Caryophyllene (28.7%), aciphyllene (18.3%), α-bisabolene (10.7%) [61]
	Thailand (Rhizome)	27, 98.7	NM	NM, 94.8	*cis*-Ethyl cinnamate (47.3%), safrole (19.8%), *p*-vinylphenylisothiocyanate (11.5%) [61]
	India (Rhizome)	12, NM	0.30	NM	Myrcene (94.5%), β-ocimene (2.0%) [62]
	India (Leaf)	12, NM	0.12	NM	Myrcene (52.3%), β-ocimene (17.0%), α-pinene (9.0%) [62]
	India (Rhizome)	10, 98.5	0.04	OM, 73.7	1,8-Cineole (57.0%), geranyl acetate (10.2%), β-caryophyllene (5.4%), *n*-tricosanol (5.2%) [63]
	India (Rhizome)	53, NM	0.1	NM	Carotol (26.7%), 1,8-cineole (10.8%), β-caryophyllene (5.8%), fenchyl acetate (4.8%) [64]
	India (Root)	39, NM	0.08	NM	Fenchol (30.5%), cubenol (5.7%) [64]
	Sri Lanka (Rhizome)	16, 87.0	0.56	S, 50.8	Zerumbone (44.8%), *p*-cymene (6.5%), camphene (6.4%), 1,8-cineole (6.3%) [65]
A. globosa	Vietnam (Leaf)	70, 95.8	0.16	MH, 31.0	β-Pinene (12.1%), α-gurjunene (10.5%), (*Z*)-13-docosenamide (9.0%) [19]
A. guilinensis	China (Fruit)	14, 99.6	0.04	NM	β-Phellandrene (26.7%), 1,8-cineole (25.8%), β-pinene (15.7%), (*E*)-methyl cinnamate (10.4%), α-pinene (10.2%) [66]
	China (Leaf)	15, 99.8	0.06	NM	β-Pinene (49.7%), α-pinene (20.1%), β-phellandrene (19.9%) [66]
	China (Stem)	18, 93.3	0.03	NM	β-Pinene (34.2%), β-phellandrene (27.0%), α-pinene (13.4%) [66]
A. guinanensis	China (Leaf)	27, 97.4	0.04	MH, 47.9	1,8-Cineole (43.1%), α-phellandrene (17.1%), β-pinene (14.5%) [67]
A. hainanensis	China (Leaf)	34 93.6	0.14	NM	α-Ocimene (27.4%), β-pinene (10.1%), 9-octadecenoic acid (6.5%), *n*-hexadecanoic acid (5.8%), 9,12-octadecadienoic acid (5.4%) [68]
	China (Leaf)	34, 93.6	0.14	NM	α-Ocimene (27.4%), β-pinene (10.1%), 9-octadecenoic acid (6.5%), *n*-hexadecanoic acid (5.8%), 9,12-octadecadienoic acid (5.4%) [68]
	China (Flower)	36, 98.7	0.08	NM	α-Ocimene (39.8%), β-pinene (17.7%), α-terpinene (5.5%), terpinene-4-ol (4.9%), β-caryophyllene (4.9%) [68]
A. hongiaoensis	Vietnam (Leaf)	36, 89.9	0.25	M, 40.1	β-Pinene (32.8%), (*E*)-methyl cinnamate (15.8%), *cis*-eudesma-6,11-diene (4.5%) [69]
A. katsumadai	China (Seed)	14, 97.3	0.03	E, 64.2	(*E*)-Methyl cinnamate (64.2%), *cis*-4-decen-1-ol (7.3%), 2H-Inden-2-one, octahydro-, cis- (6.7%) [70]
	China (Leaf)	44, 96.8	0.11	NM	*p*-Menth-1-en-ol (22.0%), α-terpinene (19.0%), 4-carene (9.1%), 1,8-cineole (8.3%), camphor (5.6%) [68]
	China (Flower)	36, 98.5	0.10	NM	*p*-Menth-1-en-ol (21.3%), 1,8-cineole (20.2%), α-terpinene (12.6%), α-phellandrene (7.0%), 4-carene (6.4%) [68]
	Vietnam (Leaf)	27, 99.9	0.50	NM	Geraniol (25.0%), guaiol (23.0%), 1,8-cineole (14.4%), α-pinene (7.9%), α-phellandrene (6.8%) [71]
	Vietnam (Stem)	27, 89.7	0.05	NM	Fenchone (25.1%), geraniol (13.5%), 1,8-cineole (13.4%), β-pinene (11.6%) [71]
	Vietnam (Seed)	27, 95.3	0.19	NM	Geraniol (31.2%), linalool (11.4%), citronellol (10.5%), geranyl acetate (8.0%), decanol (6.8%) [71]
A. kwangsiensis	China (Rhizome)	31 92.4	0.16	M, 82.8	Camphor (17.5%), 1,8-cineole (15.1%), β-pinene (11.1%), α-pinene (10.5%), α-terpineol (7.2%), camphene (6.8%) limonene (5.2%) [16]
A. maclurei	Vietnam (Leaf)	30, 90.0	0.25	MH, 75.1	β-Pinene (53.0%), α-pinene (13.9%) [72]
	Vietnam (Stem)	42, 90.8	0.23	MH, 60.1	β-Pinene (47.1%), α-pinene (5.75%), caryophyllene oxide (5.7%), β-caryophyllene (5.5%) [72]
	Vietnam (Root)	46, 90.7	0.19	MH, 46.9	β-Pinene (22.1%), β-phellandrene (12.0%), fenchyl acetate (6.7%), bornyl acetate (6.0%) [72]
A. macroura	Vietnam (Leaf)	33, 95.2	0.21	MH 59.9	1,8-Cineole (17.7%), γ-terpinene (13.3%), β-pinene (11.4%), α-phellandrene (8.5%), α-pinene (7.8%), α-terpinene (6.4%) [39]
	Vietnam (Stem)	32, 93.6	0.15	MH, 71.9	γ-Terpinene (16.9%), β-pinene (16.4%), 1,8-cineole (11.2%), α-terpinene (9.4%), α-pinene (8.4%), α-phellandrene (5.9%) [39]
	Vietnam (Root)	46, 92.0	0.24	MH, 56.3	γ-Terpinene (13.9%), β-pinene (12.5%), 1,8-cineole (8.7%), α-terpinene (8.5%), fenchyl acetate (7.8%), α-pinene (6.5%) [39]

Table II - Continues

A. macroura	Vietnam (Fruit)	42, 93.5	0.18	MH, 35.9	β-Caryophyllene (18.1%), β-pinene (11.1%), 1,8-cineole (11.1%), caryophyllene oxide (7.1%), γ-terpinene (5.9%), α-pinene (5.8%), bornyl acetate (5.0%) [39]
	Vietnam (Flower)	35, 97.7	0.30	MH, 44.8	β-Caryophyllene (12.6%), sabinene (9.0%), β-pinene (8.8%), γ-terpinene (7.9%), bornyl acetate (7.2%) [39]
A. malaccencis	Indonesia (Rhizome)	16, NM	1.22	NM	(*E*)-Methyl cinnamate (64.4%), α-pinene (14.8%), β-pinene (13.5%), 1,8-cineol (10.4%), camphor (6.3%), α-terpineol (6.3%) [22]
	Indonesia (Stem)	16, NM	0.25	NM	(*E*)-Methyl cinnamate (30.2%), 1,8-cineole (16.6%), β-pinene (12.4%), α-pinene (13.1%), α-terpineol (6.2%), nerol (5.5%) [22]
	Indonesia (Leaf)	18, NM	0.70	NM	α-Pinene (30.6%), 1,8-cineole (21.4%), β-pinene (11.4%) [22]
A. manghaiensis	Vietnam (Rhizome)	23, 90.2	0.18	MH, 84.6	β-Pinene (46.5%), β-phellandrene (25.7%), α-pinene (8.5%) [73]
A. monopleura	Indonesia (Leaf)	19, 93.3	1.16	NM	Caryophyllene oxide (22.6%), β-caryophyllene (16.5%), α-pinene (14.7%), limonene (13.4%), β-pinene (10.2%), α-humulene (7.2%) [74]
	Indonesia (Fruit)	22, 96.4	1.34	NM	Caryophyllene oxide (24.1%), β-caryophyllene (18.3%), β-pinene (12.9%), limonene (11.5%), α-pinene (10.4%), α-humulene (7.6%) [74]
A. mutica	India (Rhizome)	47, 92.8	0.3	MH, 43.3	β-Pinene (20.2%), camphor (13.3%), 1,8-cineole (8.9%), camphene (7.9%), α-pinene (6.2%) [75]
	India (Fruit)	69, 97.8	0.9	OM, 36.7	1,8-Cineole (14.8%), camphor (11.7%), β-pinene (7.6%), camphene (4.8%) [75]
A. nantoensis	Taiwan (Leaf)	14, 77.9	0.11	NM	Camphor (21.3%), camphene (11.4%), β-pinene (8.2%), *p*-cymene (5.2%), α-pinene (4.4%), D-limonene (2.5%) [42]
	Taiwan (Rhizome)	15, 70.8	0.20	NM	Camphor (29.5%), camphene (10.4%), β-pinene (9.1%), α-pinene (4.2%), *p*-cymene (3.2%), D-limonene (2.4%) [42]
A. napoensis	Vietnam (Rhizome)	32, 95.8	0.26	MH, 49.8	1,8-Cineole (18.2%), γ-terpinene (12.5%), terpinene-4-ol (9.6%), β-pinene (9.2%), fenchyl acetate (7.7%) [76]
	Vietnam (Leaf)	25, 99.3	0.21	MH, 62.1	γ-Terpinene (23.2%), 1,8-cineole (21.8%), α-terpinene (11.7%), terpinen-4-ol (10.8%), o-cymene (9.1%) [77]
	Vietnam (Stem)	25, 94.5	0.17	MH, 61.4	γ-Terpinene (20.5%), 1,8-cineole (17.6%), α-terpinene (12.5%), o-cymene (8.4%), terpinen-4-ol (8.2%), β-pinene (5.3%), α-terpinolene (5.3%) [77]
	Vietnam (Root)	28, 94.3	0.25	MH, 64.6	γ-Terpinene (19.3%), α-terpinene (13.2%),1,8-cineole (10.7%), β-pinene (6.2%), α-terpinolene (5.1%) [77]
A. nelumboides	Vietnam (Rhizome)	14, 99.7	0.20	NM	1,8-Cineole (71.23%), geranial (6.45%), β-pinene (5.34%) [78]
	Vietnam (Leaf)	74, 88.1	0.22	NM	1,8-Cineole (32.8%), α-terpineol (8.1%), α-Pinene (4.2%) [78]
A. nigra	India (Seed)	44, 98.2	0.76	NM	β-Caryophyllene (49.0%), β-pinene (13.7%), α-humulene (7.8%), α-pinene (6.3%), caryophyllene oxide (4.5%) [79]
	India (Flower)	45, 98.3	0.06	NM	β-Caryophyllene (48.6%), β-pinene (14.4%), α-humulene (7.7%), α-pinene (6.6%), caryophyllene oxide (4.4%) [79]
	India (Leaf)	52, 96.4	0.23	NM	β-Caryophyllene (47.7%), β-pinene (13.8%), α-humulene (7.5%), α-pinene (6.4%), caryophyllene oxide (4.3%) [79]
	India (Rhizome)	46, 97.9	0.18	NM	β-Caryophyllene (48.7%), β-pinene (14.1%), α-humulene (7.7%), α-pinene (6.5%), caryophyllene oxide (4.4%) [79]
A. nutans	India (Aerial)	42, 97.1	0.76	MH, 27.8	Sabinene (27.8%), 1,8-cineole (17.4%), terpinen-4-ol (14.9%), *p*-cymene (5.2%), γ-terpinene (5.1%), *cis*-sabinene hydrate (3.3%) [44]
	India (Flower)	23, 88.9	0.51	OM, 41.5	Terpinen-4-ol (25.1%), γ-terpinene (19.4%), sabinene (14.2%), 1,8-cineole (10.8%) [44]
A. oblongfolia	Vietnam (Leaf)	38 99.1	0.18	MH 63.2	β-Pinene (17.9%), α-phellandrene (3.5%), limonene (11.1%), (*E*)-methyl cinnamate (16.7%), *p*-cymene (9.6%), camphene (9.3%) [80]
	Vietnam (Rhizome)	52, 98.1	0.12	MH, 80.7	β-Pinene (26.2%), α-phellandrene (11.7%), limonene (14.5%), (*E*)-methyl cinnamate (4.1%) [80]
A. officinarum	China (Rhizome)	75, 93.1	0.60	OM, 40.3	1,8-Cineol (22.0%), α-terpineol (11.8%), γ-cadinene (8.6%) [81]
A. oxyphylla	China (Fruit)	74, 83.9	0.9	SH, 56.2	Valencene (19.0%), calamenene (10.1%), β-caryophyllene (5.5%), α-panasinsen (4.8%), α-selinene (4.0%) [82]
A. pinnanensis	Vietnam (Leaf)	NM, 97.9	0.41	OM, 31.6	1,8-Cineole (20.5%), 4-phenyl-2-butanol (19.5%), α-phellandrene (10.8%), β-pinene (5.5%) [39]
	Vietnam (Stem)	NM, 96.0	0.11	SH, 42.3	1,8-Cineole (10.0%), β-elemene (8.7%), α-gurjunene (7.6%), β-pinene (7.3%), (*E,E*)-farnesol (7.2%) [39]

Table II - Continues

A. pinnanensis	Vietnam (Root)	NM, 89.0	0.15	SH, 27.3	(*E,E*)-Farnesol (8.4%), α-gurjunene (6.2%), camphene (5.6%), fenchyl acetate (5.4%), linalool (4.6%), β-pinene (4.6%) [126]
	Vietnam (Fruit)	NM, 96.1	0.23	OS, 37.9	α-Cadinol (18.1%), β-caryophyllene (11.4%), (*E,E*)-farnesol (6.3%), β-pinene (6.1%), β-elemene (5.6%) [39]
A. purpurata	Brazil (Flower)	42, 97.6	0.05	SH, 41.5	β-Caryophyllene (18.2%), β-pinene (13.9%), linalool (9.6%), 7-*epi*-α-selinene (8.2%), α-pinene (6.2%) [83]
	Brazil (Leaf)	30, 98.9	0.44	MH, 49.7	β-pinene (34.7%), α-pinene (11.8%), *trans*- β-guaiene (6.0%) [84]
A. speciosa	India (Leaf)	24, 90.6	NM	OM, 59.3	Terpinen-4-ol (28.4%), 1,8-cineole (19.2%), sabinene (8.2%), *p*-cymene (8.0%), γ-terpinene (5.7%) [50]
	India (Flower)	25, 86.2	NM	OM, 68.9	Terpinen-4-ol (26.0%), 1,8-cineole (24.4%), linalool (6.1%), sabinene (11.3%) [50]
	India (Rhizome)	66, 96.0	0.69	MH, 61.2	Terpinen-4-ol (15.4%), 1,8-cineole (11.1%) [85]
	Taiwan (Seed)	38, 97.0	0.33	NM, 58.3	Camphor (19.3%), sabinene (15.1%), β-ocimene (7.9%), 1,8-cineole (5.6%), terpinen-4-ol (5.3%), α-pinene (5.1%) [86]
	Taiwan (Leaf)	39, 98.7	0.14	NM, 61.1	Camphor (31.6%), sabinene (9.4%), γ-terpinene (8.0%), terpinen-4-ol (6.6%), α-terpineol (5.5%) [86]
	Egypt (Leaf)	33, 93.7	0.12	M, 87.1	Sabinene (10.2%), γ-terpinene (11.1%), *p*-cymene (5.9%) [87]
	Egypt (Rhizome)	33, 93.0	0.10	M, 86.2	Sabinene (9.8%), γ-terpinene (9.3%) [87]
	Egypt (Stem)	33, 87.1	0.05	M, 75.2	Sabinene (7.5%), γ-terpinene (8.2%) [87]
	Brazil (Leaf)	17, 79.4	0.25	S, NM	Terpinen-4-ol (20.4%), 1,8-cineole (14.8), γ-terpinene (9.4%), *p*-cymene (9.3%), α-thujene (4.5%) [88]
A. strobiliformis	Vietnam (Leaf)	39, 94.9	0.18	MH, 47.2	1,8-Cineole (25.5%), β-pinene (10.7%), γ-terpinene (12.5%) [31]
	Vietnam (Pseudostem)	47, 96.1	0.13	MH, 55.8	1,8-Cineole (14.1%), β-pinene (15.0%), γ-terpinene (11.0%) [31]
	Vietnam (Rhizome)	34, 98.1	0.20	MH, 56.9	1,8-Cineole (16.5%), β-pinene (12.5%), γ-terpinene (13.6%) [31]
A. tonkinesis	Vietnam (Leaf)	51, 97.4	0.21	MH, 74.8	β-Pinene (33.5%), β-ocimene (9.6%), γ-terpinene (9.2%), α-pinene (8.4%) [19]
A. vietnamica	Vietnam (Rhizome)	36, 98.0	NM	MH, 62.5	1,8-Cineole (29.0%), geraniol (15.2%), β-pinene (12.8%), α-pinene (7.5%) [89]
	Vietnam (Leaf)	45, 95.3	NM	MH, 60.4	1,8-Cineole (25.7%), β-pinene (21.3%), geraniol (9.0%), α-pinene (6.1%) [89]
A. vittata	Brazil (Leaf)	20, NM	NM	MH	β-Pinene (35.3%), α-pinene (10.1%), *epi*-cubenol (5.0%) [90]
A. zerumbet	Japan (Leaf)	NM	0.07	NM	1,8-Cineole (18.8%), camphor (11.9%), (*E*)-methyl cinnamate (7.5%), cryptone (6.6%) [91]
	Brazil (Leaf)	16, 96.5	0.17	OM, 69.4	Terpinene-4-ol (32.9%), 1,8-cineole (21.4%), γ-terpinene (10.0%), sabinene (7.1%) [92]
	France (Flower)	71, 97.8	0.25	M, 51.5	1,8-Cineole (17.4%), terpinen-4-ol (14.7%), sabinene (7.0%), γ-terpinene (6.9%) [93]
	Japan (Leaf)	17, 100	0.07	NM	*p*-Cymene (28.0%), 1,8-cineole (17.9%), terpinen-4-ol (11.9%), limonene (6.3%), camphor (5.2%) [94]
	Brazil (Leaf)	14, 100	NM	NM	Terpinen-4-ol (37.4%), caryophyllene oxide (7.5%), *trans*-sabinene hydrate (6.6%), 1,8-cineol (4.2%) [95]
	Brazil (Leaf)	13, 89.1	0.44	OM, 52.5	Terpinen-4-ol (43.6%), bornyl acetate (13.8%), caryophyllene oxide (11.3%), α-humulene (10.7%) [96]

[a]Total components identified in the oil and their percentage
[b]Major group components identified in the oil and their percentage
NM-not mentioned; MH-monoterpene hydrocarbon; SH-sesquiterpene hydrocarbon; OS-oxygenated sesquiterpene; OM-oxygenated monoterpene; AM-aromatic monoterpene; E-ester; S-sesquiterpene; M-monoterpene

Table III - Major components identified from Malaysian *Alpinia* essential oils

Species	Locality (Part)	Total (%)[a]	Yield (%)	Group (%)[b]	Major components (%)
A. aquatica	Malaysia (Rhizome)	49, 79.2	0.10	MH, 34.7	β-Pinene (11.7%), α-humulene (8.9%), aromadendrene (8.7%), sabinene (7.7%) [97]
	Malaysia (Leaf)	36, 83.6	0.09	MH, 40.5	Germacrene D (21.3%), β-pinene (15.6%), sabinene (12.1%) [97]
	Malaysia (Pseudostem)	37, 80.4	0.02	SH, 60.8	α-Humulene (19.8%), germacrene D (15.2%), β-caryophyllene (8.7%) [97]
A. conchigera	Malaysia (Leaf)	40 63.6	0.30	S 36.2	β-Bisabolene (15.3%), β-pinene (8.2%), β-sesquiphellandrene (7.6%), chavicol (7.5%), β-elemene (6.0%) [98]
	Malaysia (Pseudostem)	33, 66.1	0.04	S, 51.1	β-Bisabolene (19.9%), β-sesquiphellandrene (11.3%), β-caryophyllene (8.8%), β-elemene (4.7%) [98]
	Malaysia (Rhizome)	39, 65.1	0.32	S, 31.8	1,8-Cineole (17.9%), β-bisabolene (13.9%), β-sesquiphellan-drene (6.8%), β-elemene (4.0%) [98]
A. galanga	Malaysia (Rhizome)	40, 88.2	0.15	M, NM	α-Pinene (10.2%), *trans*-β-farnesene (18.2%), β-bisabolene (16.2%), α-bergamotene (10.7%)**,** 1,8- cineole (5.5%), geranyl acetate (5.1%) [99]
A. latilabris	Malaysia (Fruit)	44, 97.7	0.05	M, 92.1	1,8-Cineole (35.9%), β-pinene (19.0%), α-pinene (8.8%), camphor (8.8%), camphene (5.8%) [100]
A. ligulata	Malaysia (Rhizome)	9, NM	0.80	AM, 67.5	(*E*)-Methyl cinnamate (36.4%), α-humulene (5.8%) [101]
A. murdochii	Malaysia (Rhizome)	37, 71.0	0.48	SH, 26.8	γ-Selinene (15.5%), (*E,E*)-farnesyl acetate (6.5%), terpinene-4-ol (5.5%), α-terpineol (5.0%) [102]
	Malaysia (Leaf)	40, 94.3	0.09	MH, 72.5	β-Pinene (23.8%), sabinene (23.7%), terpinene-4-ol (10.4%) [102]
A. nieuwenhuizii	Malaysia (Rhizome)	9, NM	0.90	AM, 81.2	(*E*)-Methyl cinnamate (67.8%), β-pinene (3.1%) [101]
A. pahangensis	Malaysia (Leaf)	38, 86.9	0.18	M, 90.5	β-Pinene (36.6%), α-pinene (7.5%), limonene (4.8%) [103]
	Malaysia (Rhizome)	38, 75.2	0.09	M, 28.1	(*E,E*)-Farnesyl acetate (8.6%), α-terpineol (6.3%) [103]
A. rafflesiana	Malaysia (Leaf)	47, 97.3	0.03	SH, 44.0	*β*-caryophyllene (32.6%), caryophyllene oxide (8.6%), (2*E*,6*Z*)-farnesol (4.9%), α-terpineol (4.2%) [104]
	Malaysia (Pseudostem)	40, 99.2	0.01	OM, 46.8	1,8-Cineole (32.2%), myrcene (13.6%), β-caryophyllene (9.8%) [104]
	Malaysia (Rhizome)	30, 97.9	0.05	OS, 38.3	Tetracosane (42.6%), τ-cadinol (7.4%), α-terpineol (6.7%) [104]
	Malaysia (Fruit)	37, 95.0	0.07	OS, 47.9	Tetracosane (13.3%), caryophyllene oxide (8.0%), 1,8-cineole (4.6%) [104]
A. scabra	Malaysia (Rhizome)	41, 70.9	0.16	NM	γ-Selinene (33.4%), α-selinene (3.6%), α-terpineol (3.5%) [102]
	Malaysia (Leaf)	40, 86.6	0.02	NM, 73.0	β-Pinene (63.3%), α-pinene (6.5%) [102]
	Vietnam (Pseudostem)	47, 96.1	0.13	MH, 55.8	1,8-Cineole (14.1%), β-pinene (15.0%), γ-terpinene (11.0%) [31]
	Vietnam (Rhizome)	34, 98.1	0.20	MH, 56.9	1,8-Cineole (16.5%), β-pinene (12.5%), γ-terpinene (13.6%) [31]
A. zerumbet	Malaysia (Fruit)	48, 97.0	0.30	S, 77.4	(*E,E*)-Farnesol (51.2%), α-farnesene (8.0%) [105]

[a]Total components identified in the oil and their percentage
[b]Major group components identified in the oil and their percentage
NM-not mentioned; MH-monoterpene hydrocarbon; SH-sesquiterpene hydrocarbon; OS-oxygenated sesquiterpene; OM-oxygenated monoterpene; AM-aromatic monoterpene; E-ester; S-sesquiterpene; M-monoterpene

6. EXTRACTION METHODS AND SOURCES OF VARIABILITY

Essential oils in the included studies were most often obtained by hydrodistillation or steam distillation (Clevenger-type), with yields reported where available alongside composition. Beyond the extraction route, between-study variation in identities and relative abundances can arise from plant factors (species/chemotype, organ, phenology), geography/season, and analytical conditions (stationary phase/column length, carrier-gas flow, oven program, peak deconvolution and normalization). Accordingly, we anchor identifications in GC–MS with retention indices (RI) and, where available, authentic standards, and we report relative percentages exactly as provided in the source studies rather than meta-normalizing across datasets.

7. CHEMICAL COMPOSITIONS OF MALAYSIAN *ALPINIA* ESSENTIAL OILS: A REGIONAL PERSPECTIVE

A detailed account of the major components identified from the essential oils of 12 *Alpinia* species collected in Malaysia is presented in Table III [97-105]. The analysis covered various plant parts, including rhizomes, leaves, pseudostems, and fruits, with rhizomes and leaves being the most frequently examined. Notably, species such as *A. aquatica*, *A. conchigera*, *A. murdochii*, *A. rafflesiana*, and *A. scabra* were studied for more than one plant part, offering deeper insights into intra-species chemical variation. The inclusion of multiple anatomical parts underscores the diverse phytochemical potential of Malaysian *Alpinia* species. The essential oil constituents were classified into eight major chemical groups, with monoterpene hydrocarbons being the most frequently dominant, particularly in the leaf and rhizome oils of *A. aquatica*, *A. murdochii*, and *A. scabra*. The highest number of identified components was observed in *A. rafflesiana* pseudostem oil, with 47 compounds accounting for 99.2% of the total oil [104]. Other species with high component richness include *A. zerumbet*, *A. latilabris*, and *A. aquatica*. In terms of essential oil yield, the highest was recorded in the rhizome of *A. nieuwenhuizii* (0.90%), followed by *A. ligulata* (0.80%) and *A. murdochii* (0.48%) [101, 102]. Among the most frequently reported compounds, β-pinene (monoterpene hydrocarbon) was consistently identified in *A. aquatica*, *A. murdochii*, *A. scabra*, *A. latilabris*, and *A. pahangensis* [97, 100, 102, 103]. 1,8-Cineole, an oxygenated monoterpene, was dominant in *A. latilabris*, *A. rafflesiana*, and *A. conchigera* [100, 104]. Other commonly detected compounds include α-pinene, γ-terpinene, caryophyllene oxide, β-caryophyllene, and β-bisabolene, highlighting consistent chemical signatures across species.

8. BIOLOGICAL ACTIVITIES OF *ALPINIA* ESSENTIAL OIL

The essential oils of *Alpinia* species have been extensively investigated for their diverse biological activities [105-125]. A summary of these activities for several *Alpinia* essential oils is presented in Table IV. Among the most frequently investigated properties is antioxidant activity. For instance, *A. gagnepainii* leaf and rhizome oils exhibited significant antioxidant effects, with IC_{50} values of 2446 and 1519 μg/mL in the ABTS assay, respectively [58]. Additionally, *A. katsumadai* seed oil showed remarkable antioxidant potential with IC_{50} values of 1.6 μg/mL in the DPPH assay [106]. Similarly, *A. malaccensis* leaf oil demonstrated IC_{50} values of 18 μg/mL and 20 μg/mL in the DPPH and ABTS assays, respectively [108]. In addition to antioxidant properties, *Alpinia* essential oils have also shown significant anti-inflammatory effects. For example, *A. oxyphylla* fruit oil inhibited nitric oxide (NO) production, with an IC_{50} value of 10 μg/mL [14]. Furthermore, *A. galanga* flower oil exhibited notable anti-inflammatory activity through the inhibition of tyrosinase and other enzymes, with IC_{50} values of 2.3 μg/mL [112].

The antibacterial properties of *Alpinia* essential oils have also been extensively studied, revealing significant effects against both Gram-positive and Gram-negative bacteria. *A. oxyphylla* fruit oil demonstrated strong antibacterial activity against *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, with MIC values of 0.295 mg/mL, 1.18 mg/mL, and 1.18 mg/mL, respectively [14]. Additionally, *A. katsumadai* seed oil showed significant antibacterial effects, particularly against *Campylobacter jejuni* and *Campylobacter coli*, with MIC values ranging from 0.256 to 4.103 mg/mL [106]. Moreover, *A. galanga* flower oil exhibited antibacterial activity against *S. aureus*, *Bacillus subtilis*, *P. aeruginosa*, and *P. vulgaris* with MIC values of 3.13 mg/mL [59].

Cytotoxicity studies have demonstrated that *Alpinia* essential oils possess significant anticancer potential. *A. coriandriodora* rhizome essential oil shows in-vitro anticancer activity in A549 lung carcinoma cells, comparable to an elemene-injection positive control, via G1 arrest and mitochondrial-pathway apoptosis and with reduced migration/invasion [126].

The antifungal properties of *Alpinia* oils have also been explored. For example, *A. zerumbet* essential oil showed activity against *Acremonium brasiliensis* with an MIC value of 0.4 μg/mL [115]. Similarly, *A. galanga* oil demonstrated inhibition of *Malassezia*, with inhibition zones ranging from 16 mm to 34 mm [117]. In

Table IV - Biological activities of several *Alpinia* essential oils

Bioactivities	Essential oils	Description
Antioxidant	*A. gagnepainii*	The leaf and rhizome oil showed IC_{50} value of 2446 and 1519 µg/mL in ABTS assay [58]
		The leaf and rhizome oil showed IC_{50} value of 107 and 295 µg/mL in DPPH assay [58]
	A. oxyphylla	The fruit oil showed IC_{50} value of 188.9 µg/mL in DPPH assay [14]
		The fruit oil showed IC_{50} value of 40.1 µg/mL in ABTS assay [14]
	A. katsumadai	The seed oil showed IC_{50} value of 1.6 µg/mL in DPPH assay [106]
		The seeds oil showed IC_{50} value of 10.4 µg/mL in DPPH assay [106]
	A. officinarum	The rhizome oil showed IC_{50} value of 58 µg/mL in DPPH assay [107]
		The rhizome oil showed radical scavenging activity towards hydrogen peroxide with IC_{50} value of 4.5 µg/mL [107]
	A. coriandriodora	The rhizome oil showed inhibition percentage of 85% in DPPH assay 85% [57]
	A. malaccenis	The leaf oil showed IC_{50} value of 18 µg/mL (DPPH) and 20 µg/mL (ABTS) assays [108]
Anti-inflammatory	*A. oxyphylla*	The fruit oil showed activity against NO production and β-hexosaminidase with IC_{50} value of 10 and 141 µg/mL, respectively [14]
		The fruit oil showed activity against NO production and β-hexosaminidase with IC_{50} value of 5.5 and 158 µg/mL, respectively [14]
		The fruit oil inhibited the release of PGE2 with IC_{50} value of 90 µM [23]
		The fruit oil inhibited COX-1, COX-2 enzyme and 5-LOX activity with IC_{50} values of 299, 199, and 170 µg/mL, respectively [109]
		The fruit oil strongly reduced the IL-6 and TNF-α levels in the range of 87.2 to 94.1% and 37.8 to 37.9%, respectively [110]
	A. zerumbet	The rhizome oil showed inhibitory activity against NO production with IC_{50} ranging from 3.62 to 8.33 µM [111]
		The seed oil showed the highest inhibitory activity against tyrosinase, pancreatic lipase (PL), 15-lipoxygenase (15-LOX), and LDL oxidation, with IC_{50} values of 2.3, 5.0, 1.2, and 15.4 µg/mL, respectively [112]
	A. japonica	The seeds oil inhibited NO production with IC_{50} value of 10 µM [23]
Antibacterial	*A. oxyphylla*	The fruit oil showed activity against *S. aureus* with MIC value of 0.295 mg/mL [14]
		The fruit oil showed activity against *E. coli* with MIC value of 1.18 mg/mL [14]
		The fruit oil showed activity against *P. aeruginosa* with MIC value of 1.18 mg/mL [14]
	A. officinarum	The rhizome oil showed strong activity against *M. tuberculosis* and *M. bovis* with IC_{50} values of 4.2 and 4.7 µg/mL, respectively [23]
		The rhizome oil showed activity against *B. cereus*, *B. subtilis*, and *S. aureus* with MIC ranging from 16 to 32 µg/mL [23]
		The rhizome oil caused cell death in *E. coli* and *S. paratyphi* with MIC value of 50 µg/mL [23]
	A. katsumadai	The seeds oil showed strong effect against *C. jejuni* and *C. coli* with MIC ranging from 0.256 to 4.103 mg/mL [106]
		The seeds oil showed effects on *M. smegmatis* with MIC less than 64 mg/L [106]
		The seed oil demonstrated inhibitory effects on *S. aureus, S. epidermidis*, and *E. coli*, with MIC values ranging from 0.12 to 2.55 mg/mL [106]
	A. galanga	The flower oil exhibit strong activity against *S. aureus*, *B. subtilis*, *P. aeruginosa*, and *P. vulgaris* with MIC values of 3.13 mg/mL [59]
		The rhizome oil showed strong activity against *B. subtilis*, *S. aureus*, and *S. typhimurium* with MIC (0.04 to 1.28 mg/mL) and MBC (0.08 to 2.56 mg/mL) [113]
	A. guilinensis	The fruit oil showed strong activity *S. aureus*, *B. subtilis*, and *E. coli* with MIC value of 1.25 to 2.5 mg/mL [66]
		The leaves oil has strong inhibitory effect on *E. coli* with MIC value of 2.5 mg/mL [66]
		The stem oil showed moderate activity against *S. aureus*, *B. subtilis*, *P. aeruginosa*, and *E. coli* with MIC value of 2.5 to 5 mg/mL [66]
	A. latilabris	The fruit oil showed activity against *E. coli* with MIC value of 5.0 mg/mL [100]
		The fruit oil showed activity against *S. aureus* and *B. subtilis* with MIC value between 2.50 to 5.0 mg/mL [100]
	A. mutica	The fruit oil showed activity against *S. aureus* and *B. subtilis* with MIC value 2.50 mg/mL [100]
	A. pahangensis	The rhizome oil exhibits activity against *S. aureus* with MIC value <1.0 µg/µL [103]
	A. malaccensis	The root oil showed activity against *E. aerogenes*, *E. coli*, *P. aeruginosa*, and *S. dysenteriae* with MIC value of 60 µM [23]

Table IV Continues

Cytotoxicity	*A. officinarum*	The rhizome oil inhibited the growth of gastric carcinoma (SGC-7901), human breast cancer (MCF-7), and cervical carcinoma (CaSki) with IC_{50} value of 11, 15, and 15 μM, respectively [23]
	A. mutica	The rhizome oil inhibited the UCK2 enzyme and reduced the proliferation of HT-29 cells with IC_{50} values of 28and 44 μM, respectively [23]
	A. katsumadai	The rhizome oil suppressed the proliferation of human gastric cancer cells (MGC803) with IC_{50} value of 16 μM [23]
	A. nelumboides	The rhizome oil showed activity on NCI-H460 and HepG2 with IC_{50} value of 98.2 and 189.8 μg/mL, respectively [78]
Antidiabetic	*A. galanga*	The rhizome oil enhanced the viability of human umbilical vein endothelial cells impaired by high glucose by 83% [23]
		The flower oil displayed significant α-glucosidase activity with IC_{50} value of 0.16 mg/mL [59]
	A. nelumboides	The leaves oil inhibited α-glucosidase with IC_{50} value of 2.42 mg/mL [78]
	A. pahangensis	The rhizome oil showed inhibitory activity against α-amylase and α-glucosidase with IC_{50} values of 114.8 and 153.8 μM, respectively [114]
Antifungal	*A. zerumbet*	The essential oil showed activity against *A. brasiliensis* with MIC value of 0.4 μg/mL [115]
	A. purpurata	The essential oil inhibits the growth of *Candida krusei* by 7.33 to 11.0 mm inhibition zone diameter [116]
	A. galanga	The essential oil showed activity against *Malassezia* with inhibition zone ranged from 16 mm to 34 mm [117]
	A. conchigera	The rhizome oil showed activity against *C. albicans, M. canis,* and *T. rubrum* with MIC values of 62.5, 156, and 156 μg/mL, respectively [118]
Anticancer	*A. oxyphylla*	The rhizome oil suppresses the growth of HepG2, A549, and NCI-H460 cells with IC_{50} values of 52, 48, and 44 μM, respectively [14]
		The seeds oil exhibits activity against HL-60 leukemia cells and A549 cells with IC_{50} values of 58.4 and 4.27 μM, respectively [14]
		The seed oil suppresses the proliferation of SCC25 and A431 cells with IC_{50} values of 18.8 and 13.3 μM, respectively [14]
	A. galanga	The flower oil showed significant activities against A549, PC-3, NCI-H1299, L929 cells with IC_{50} values ranging from 41.5 to 127.3 μg/mL [59]
		The rhizome oil reduced the viability of A549 lung cancer cells, CRL2522 fibroblasts, and MCF-12A breast cancer cells, exhibiting IC_{50} values of 100 μg/mL [119]
		The rhizome oil suppresses the melanogenesis process by inhibiting tyrosinase activity, with an IC_{50} value of 7.3 μg/mL [120]
Antiproliferative	*A. katsumadai*	The seeds oil exhibited significant effects on NCI-H460, HeLa, SMMC-7721, and HCT-116 cell lines with IC_{50} values ranging from 12.7 to 42.2 μM [106]
		The seeds oil showed significant inhibition of SMMC-7721 cells with IC_{50} values of 4.8 μM [106]
	A. galanga	The rhizome oil showed IC_{50} value of 170 μg/mL against MCF-7 [121]
Antiviral	*A. katsumadai*	The seeds oil inhibited rotavirus infection with EC_{50} values of 8.4 μg/mL [106]
		The seeds oil showed inhibitory activity against porcine rotavirus, G5P with EC_{50} values ranging from 0.7 to 33.7 μg/mL [122]
Insecticidal	*A. oxyphylla*	The fruit oil showed activity against *D. melanogaster* with LC_{50} value of 11.50 μmol/mL [14]
	A. galanga	The rhizome oil showed activity against *H. longicornis* nymphs by inhibiting the AChE with IC_{50} value of 60 μg/cm^2 [23]
Tyrosinase	*A. pahangensis*	The flower oil exhibited a moderate effect with IC_{50} value of 0.62 mg/mL [59]
Antiangiogenic	*A. oxyphylla*	The fruit oil showed inhibitory activity against blood vessel formation by 31% [123]
Antidiarrhoea	*A. oxyphylla*	The fruit oil showed effect on carbachol-induced contraction by reducing 25.5% [124]
Anticholinesterase	*A. galanga*	The flower oil exhibited activity against AChE and BChE with IC_{50} values of 2.49 and 10.14 mg/mL, respectively [59]
Toxicity	*A. calcarata*	The rhizome oil showed LC_{50} value of 9.64 mg/cm^2 against *T. castaneum* [54]
		The rhizome oil showed LC_{50} value of 0.86 mg/cm^2 against *L. serricorne* [54]
		The rhizome oil showed LC_{90} value of 1.19 mg/cm^2 against *C. chinensis* [54]
	A. galanga	The rhizome oil showed activity against *C. gestroi* with LD_{50} value 5407 mg/kg [125]
		The rhizome oil showed activity against *C. curvignathus* with LD_{50} value 3456 mg/kg [125]

addition to the bioactivities discussed above, *Alpinia* oils have been reported to exhibit several other beneficial effects, such as anticancer [14], antiproliferative [106], antiviral [122] and insecticidal activities [23]. Furthermore, these oils have shown antiangiogenic [123] and antidiarrheal effects [124], making them suitable for a diverse range of applications in both medicinal and industrial contexts.

9. BIOACTIVITY MECHANISMS AND SYNERGISM

Across the included studies, whole *Alpinia* essential oils (EOs) exert their effects through well-described mechanisms, which include antioxidant activity via hydrogen-atom/electron transfer radical scavenging; anti-inflammatory effects through suppression of NO/iNOS and down-modulation of NF-κB/MAPK signaling; antibacterial/antifungal actions, primarily via membrane permeabilization, ion leakage, and biofilm inhibition; and cytotoxicity through cell-cycle arrest and mitochondrial apoptosis ($\Delta\psi m$ loss, Bax/Bcl-2 shift, caspase-9/-3 activation, PARP cleavage). Notably, *A. coriandriodora* rhizome EO induces G1 arrest and mitochondrial apoptosis in A549 cells, illustrating these pathways in a whole-oil context [14, 59, 106, 126]. Given that EOs are mixtures of terpenes and oxygenated terpenes, synergism among major and minor constituents is likely and may explain why whole oils can outperform single compounds at isoeffective doses; accordingly, we report EO activities in μg/mL or mg/mL and avoid extrapolating μM data from isolated constituents.

10. CONCLUSION

This review highlights the considerable phytochemical diversity and bioactivity of essential oils obtained from *Alpinia* species. Rich in monoterpenes, sesquiterpenes, and other volatile constituents, these oils demonstrate a wide spectrum of biological activities, including antioxidant, antibacterial, antifungal, anti-inflammatory, cytotoxic, and antidiabetic effects. Such findings corroborate the extensive traditional uses of *Alpinia* in ethnomedicine across Asia and other regions. Notably, variations in chemical composition associated with species differences, plant parts, environmental conditions, and geographic origin underscore the importance of standardization in future research and potential therapeutic applications. The Malaysian *Alpinia* species have emerged as promising sources of bioactive compounds with significant chemotaxonomic and pharmacological relevance. Despite the growing body of evidence supporting the medicinal potential of *Alpinia* essential oils, further studies are necessary to clarify their mechanisms of action, evaluate their safety and efficacy through rigorous in vivo and clinical investigations, and assess their feasibility for development into standardized natural products. Addressing these gaps will be critical to fully realize the therapeutic and commercial potential of *Alpinia* essential oils in modern phytotherapy and pharmaceutical applications.

ACKNOWLEDGEMENT

This research was supported by the Geran Penyelidikan Universiti (Kecemerlangan@UPSI) under grant number 2025-0012-103-01, funded by Universiti Pendidikan Sultan Idris.

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